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Modeling recession and low flow characteristics of Iowa streams

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of Iowa streams

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Dedicated

To the Memory of My Parents

Marziah and Asghar

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ABSTRACT

Available mean daily streamflow data from 143 gaging stations were initially analyzed to characterize recessions and low flows of Iowa streams. The period of record varies between 10 and 115 years for different stations. A computerized mathematical model was used to derive two master recession curves (MRC's)—one for winter and the other for summer—and to calculate the median storage delay factor (K_{med}) for each individual station. These factors were used to estimate the diffusivity of the aquifer(s) contributing base flow to each stream.

The MRC's can be used to forecast the general behavior of streams during a period of low flow. The calculated K_{med} factors were also used as indicators of the overall effect of basin geology to develop predictive statistical-based models for estimation of low flow indices at ungaged sites on Iowa streams.

Two calculated low flow indices which were selected as dependent variables for establishment of multiple regression models are (1) the Iowa regulated protected low flow defined as the flow rate on the duration curve which is equaled or exceeded 84% of the time ($Q_{84\%}$) and (2) the minimum average of seven consecutive daily discharges that is expected once a decade ($Q_{7,10}$).

Four explanatory variables were initially chosen as potential independent variables. They are (1) drainage area, (2) datum elevation at the gage, (3) mean annual streamflow as a substitute for annual precipitation,

and (4) average storage delay factor, which was calculated in the first phase of this research. Multivariate regression techniques with different screening procedures were applied to formulate the models. Advanced diagnostic methods were utilized to improve performance of the models, and a complete residual analysis was conducted to check their adequacy.

About 10% of the data were deliberately left out to be used later as a new set to evaluate the models in terms of validity and predictive ability.

CHAPTER 1. INTRODUCTION

Allocation of streamflow among different users, making decisions regarding possible interbasin transfer of water (Vogel and Kroll, 1990), and maintenance of a proper balance between instream and offstream uses (McCormick, 1984) all require an in-depth knowledge of magnitude, duration, and frequency of low flows.

Low flow is a broadly-used term (Miller and Wenzel, 1985) referring to flows that are considerably below normal. In a more precise sense, however, it is characterized by certain measures and indices, collectively called low flow characteristics.

Low flow constitutes the most critical variable in design and management of reservoirs that should maintain adequate throughflow to satisfy hydropower requirements, irrigation supplements, and municipal supplies. Furthermore, in unregulated streams that receive effluent from wastewater treatment facilities, the reaeration capability (Riggs, 1980), the natural purification capacity, and the corresponding required degree of treatment is dependent upon characteristics of streamflow during dry weather conditions. There is also the concept of *regulated protected flow* that necessitates a required minimum instream flow to maintain an acceptable water quality standard for supporting fish and wildlife. This criterion ties low flow characteristics to instream water quality and justifies detailed low flow investigations.

Although in cold regions such as Alaska there may be periods of even zero streamflow due to prolonged subzero temperatures, low flows in general occur during warm periods, when evapotranspiration is high and precipitation is insignificant. At the same time, the demand for water use is high. In such periods of deficiency streamflow is sustained exclusively by base flow, which is the contribution of groundwater (Mull, 1986). This is another facet of low flow, which relates aquifer characteristics to streamflow. It is a step toward integration of surface water and groundwater studies.

Description of the studied area

Iowa is one of the glaciated prairie states situated in the upper Mississippi valley. It is bounded on the east by the Mississippi River and on the west by the Missouri and Big Sioux Rivers, which drain the entire state.

The Missouri basin is separated from the Mississippi basin by a natural divide lying roughly along a northwest to southeast line. This line separates the western third of the state (17,379 sq. miles) from the remainder (38,860 sq. miles) (Larimer, 1957). Streams west of the divide follow a northeast to southwest direction discharging into the Missouri River, while those in the east have a northwest to southeast orientation discharging into the Mississippi River (Figure 1.1). This arrangement gives Iowa a unique drainage pattern scheme. The interior streams act as a network of natural secondary drains, carrying the surface runoff into the border rivers. The two major river systems, the Des Moines and the Iowa, are located in the eastern part of the divide. In general, drainage basins are long and narrow with parallel lateral boundaries (Figure 1.2).

On the basis of physiography, Lara (1974) established two hydrologic regions in Iowa that agree with the glacial geology of the state (Figure 1.3). Region I covers about 70% of the state and is characterized by the presence of a well-developed drainage network. Region II covers most of the area known as

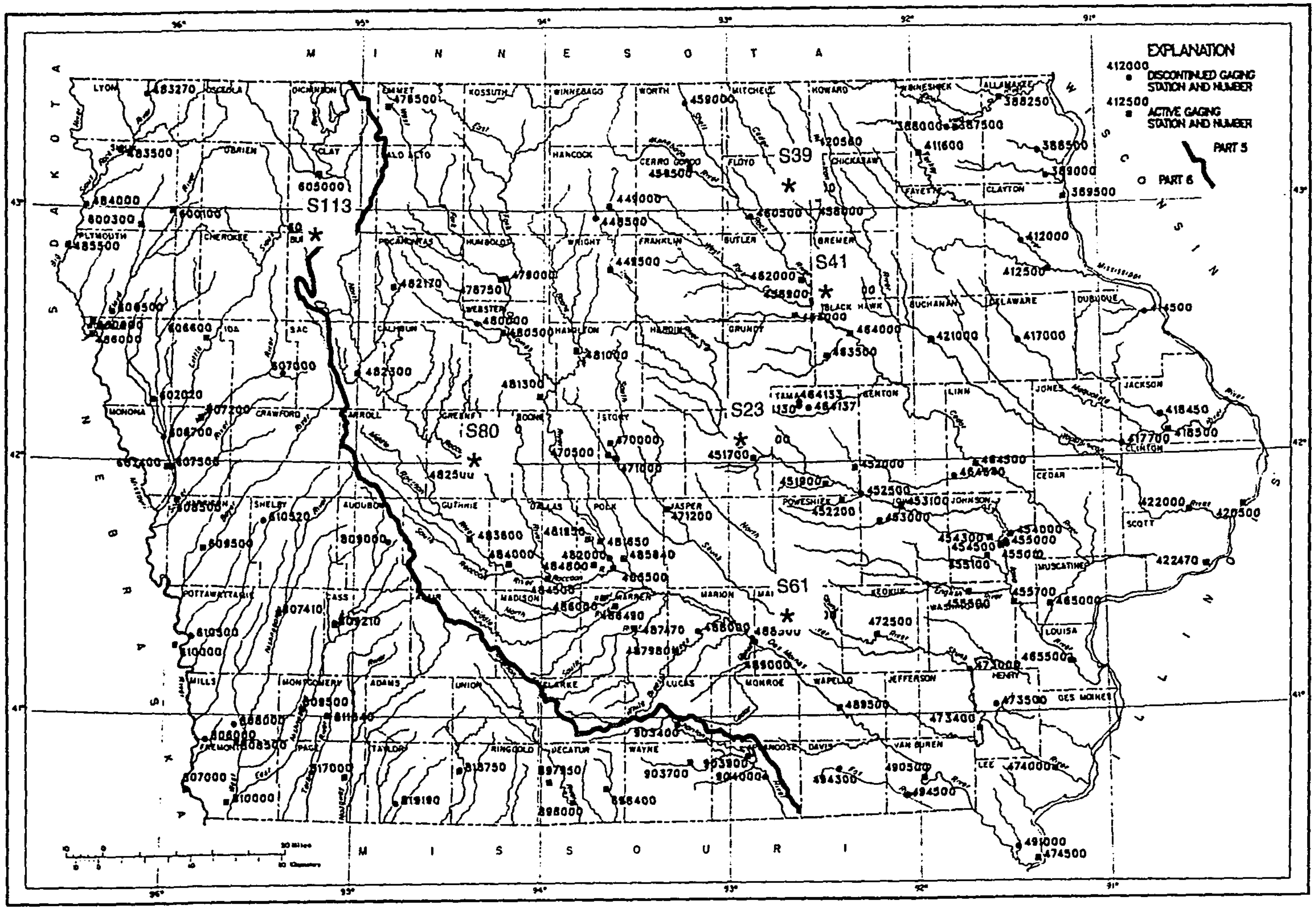

Figure 1.1. Orientation of streams and location of gaging stations in Iowa (Fischer et al., 1990).

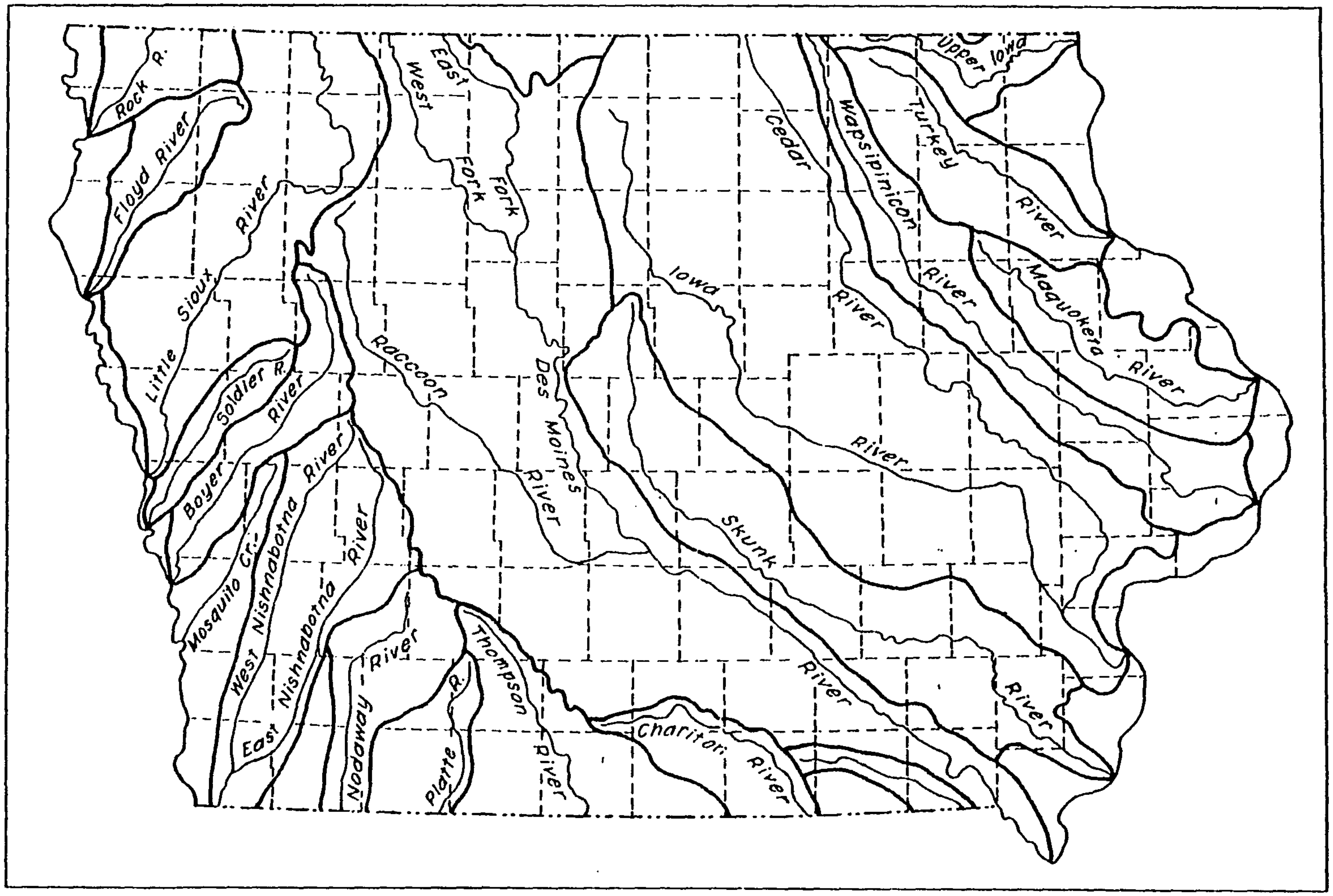

Figure 1.2. Major drainage basins of Iowa (Larimer, 1957).

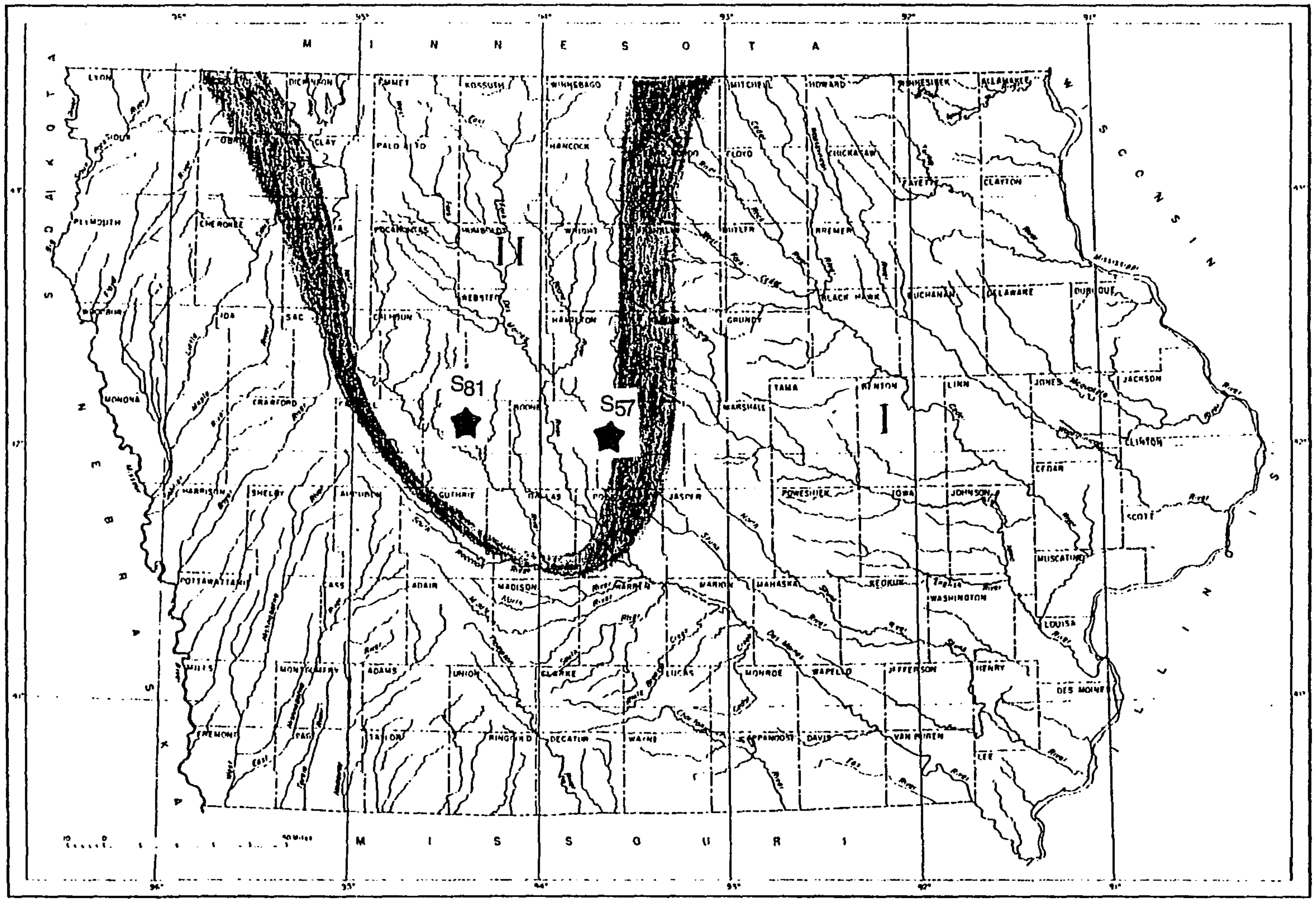

Figure 1.3. Hydrologic regions of Iowa (Lara, 1974).

the Des Moines lobe (Ruhe, 1969). Flat topography, poorly-developed drainage patterns, and the existence of small ponds in shallow depressions (potholes) are the main features of this region.

The topography of the state is closely related to glacial history. During the glaciation ages, the entire state was covered several times by glaciers (Figure 1.4). Later depositions by receding glaciers, together with wind-blown deposits (loess) and continuous erosion, are responsible for the rolling geomorphology, and soils of the state. Land forms range from the flat plains of north central Iowa to the narrow valleys of northeastern regions (Schwob 1958). The lack of mountains, which has hydrologic significance in terms of natural storage and climate, is a unique characteristic of the state. The highest point in Iowa is in Osceola County (elev. 1675 feet), and the lowest point near Keokuk (elev. 480 feet) (Larimer, 1957).

Climate

Iowa has a temperate, humid climate subject to a variety of weather conditions (Kunkle, 1968). The state is the crossroad of different air masses and fronts. Therefore, the weather exhibits rapid and frequent changes (Shaw and Waite, 1964).

During the summer, thunderstorms and showers account for most of the rainfall and for the highly variable streamflow. Heavy snow and rain are typical in the winter. The mean annual precipitation varies from 26 inches in the northwest to more than 34 inches in the southeast corner, with a statewide average of 32 inches.

The normal annual temperature ranges from 45°F in the north to 51°F in the south, with an average of about 49°F for the state.

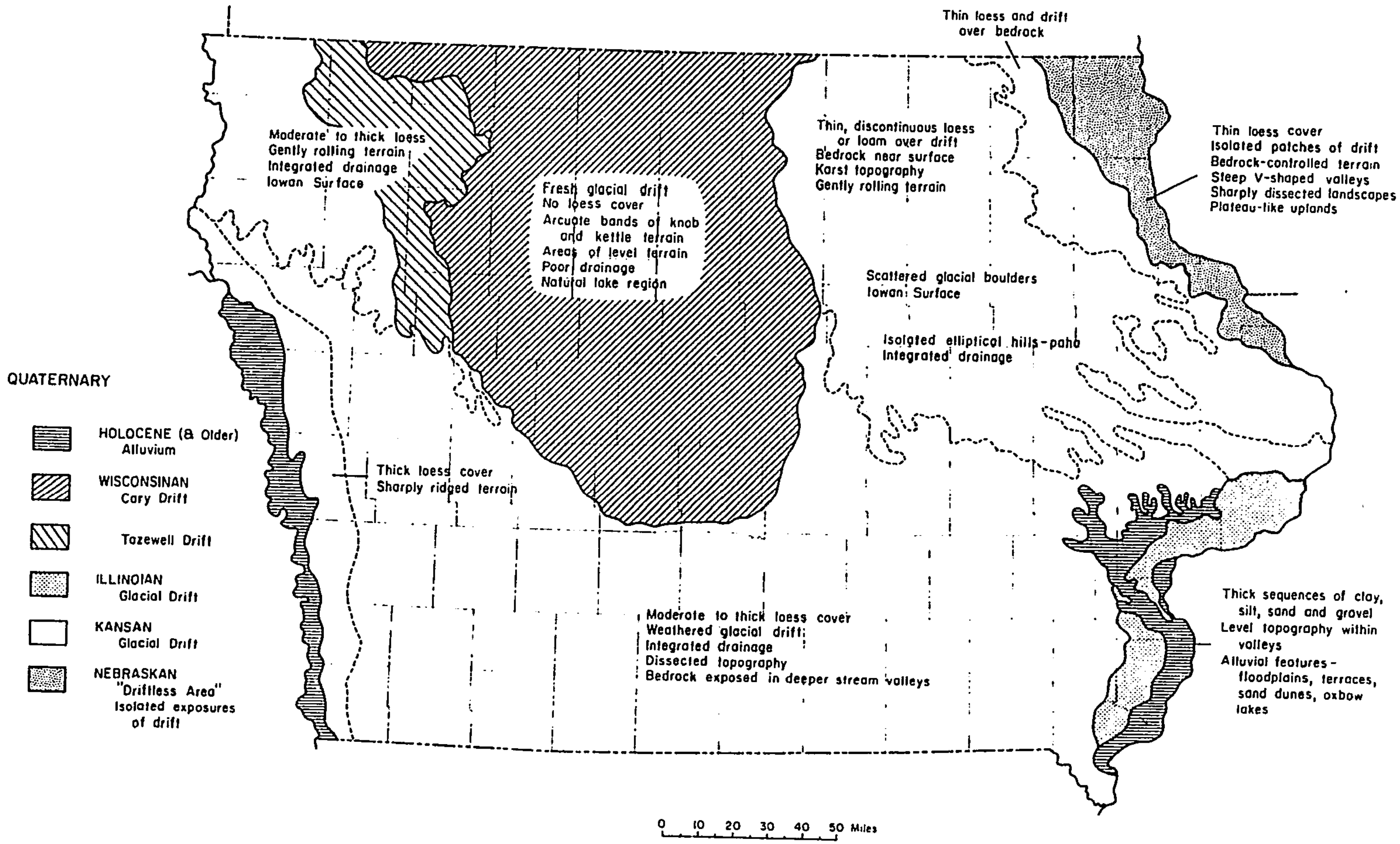

Figure 1.4. Glacial geology map of Iowa (Prior, 1976).

Background

In response to the increasing demand for analysis of low flows in Iowa, Schwob (1958) analyzed the available data for the standard base period of 1934-1953 on interior Iowa streams. He summarized the results of his analysis in the form of tables and graphs for 84 gaging stations. This analysis was updated by Heinitz (1970) and Lara (1979), with a similar format but of course an increased number of stations and longer periods of record. The last updated statistical summaries of Iowa streamflow data including low flow statistics based on the data up to 1988 has been recently published by U.S. Geological Survey (Fischer et al., 1990).

In addition to the above-mentioned activities by the U.S. Geological Survey, there have been some academic studies on the subject. Taiganides (1960) studied the frequency of low flows in 14 streams in north central and western Iowa. Howe (1966 and 1968) studied recession characteristics of 76 stations and obtained a recession constant, k (defined in equation 2.2A), for each month of the growing season (May through September). The k was found to range from 0.75 to 0.99 for different months and stations. Saboe (1966) tabulated base flow recession curves for the summer months (June through September) for 94 gaging stations having at least five years of record. However, in the work of both Saboe and Howe, it appears that for each station only a few recession segments that receded linearly in a semi-logarithmic plot have been chosen, and the rest of the data have been ignored. Dougal (1969) studied variability of low flows in central Iowa.

Objectives

The objectives of this study are:

1. To generate Master Recession Curves (MRC's) for each gaging station in Iowa using all available data.
2. To calculate a *median storage delay factor* for each gaging station. This factor will be used to represent the overall effect of basin geology on low flow characteristics.
3. To develop predictive models for estimation of low flow at ungaged sites.

CHAPTER 2. LITERATURE REVIEW

That part of the hydrologic cycle pertaining to stream regime during dry weather conditions is the primary concern of this study. Such a regime can be described by various statistics collectively referred to as low flow characteristics. Therefore, this literature review is concerned with the analysis and interpretation of streamflow variability in low flow periods. A brief review of the available literature on theoretical concepts and applied methods currently used in low flow analysis follows. Attempts are made to bridge the gap from introductory hydrology to the basic existing literature of this area.

Low streamflow refers to the flow that is maintained during the dry-weather season. It is supplied by groundwater storage, which is known as base flow. Base flow provides a permanent supply to the perennial streams and, therefore, is the most reliable part of the streamflow.

The study of base flow is one of the complicated problems in the hydrologic cycle. The complexity stems from the fact that the movement of groundwater toward the stream, from a hydraulic standpoint, is unsteady and the governing differential equation for this type of flow is nonlinear. A further complication is that hydraulic conductivity and effective porosity of the contributing aquifer(s) show substantial spatial variability.

Significance of low flow studies

Under the Federal Water Pollution Control Act (1972), the Environmental Protection Agency (EPA) is required to mandate the maintenance of a minimum water quality standard in streams, especially those receiving effluent from industrial or municipal waste water treatment facilities. They have also identified the protection of fishery resources and wildlife habitats as one of the goals of sustaining instream flow. Since stream water quality degrades as its quantity declines (given a constant input of pollutants), low flow evaluation has become increasingly important for qualitative purposes. A better understanding of mechanisms involved in low flow generation and its behavior can help in making estimation of water supply, required storage for maintenance of adequate flow for waste dilution, and in controlling withdrawals for irrigation, cooling, and other uses during low flow periods.

Interest in low flow studies can be traced back to at least 90 years ago, when the fundamental concepts of base flow were developed and its basic mathematics were derived. Hall (1968) prepared a comprehensive historical perspective of studies on base flow recession, some dating back to even the mid-19th century.

Comparison of peak flow and low flow

A literature survey indicates that in flood studies the primary concern is only magnitude. An annual flood is defined as the highest peak discharge during a year (Riggs, 1985). In low flow analysis, however, the annual low flow (annual minimum flow) has been only used in frequency analysis. In most studies low flow is considered as a two-dimensional variable and characterized by magnitude and duration. In effect, a low flow period is viewed as a short drought. The duration term allows removal of diurnal variation and minor upstream disturbances.

Low flow indices

It is difficult to determine who first suggested the definition of a low flow index as the lowest average of n-consecutive daily flows, but in practice this definition is well accepted and commonly used. Generally, low flow indices for 1, 3, 7, 14, 30, 60, 90, 120, and 183 consecutive days are extracted from a streamflow record. The most widely used index of low flow in effluent dilution in the United States is seven-day ten-year low flow ($Q_{7,10}$) defined as the smallest average of seven consecutive daily discharge that is expected to occur once in a ten-year period (Riggs, 1980).

Weisman (1978) proposed a new idea that the period of time during which streamflow falls below a specified threshold flow (Q_{Th}) being substituted for the conventional n-day low flow. This index may be applicable in situations where duration of flow below a critical value is an important factor.

Linkage between water quality and low flow

Studies indicate that instream water quality is intimately related to the flow magnitude. Investigators have shown an inverse relation between stream discharge and the concentration of total dissolved solids (TDS) (Toler, 1965a; Kunkle, 1965). Therefore, during low flow conditions, the TDS content of surface water tends to rise significantly.

Kunkle (1965) reported that the minimum specific conductance of the streamflow, which is directly proportional to the TDS, coincided with the peak discharge; it increased continuously following the falling limb of hydrograph. Furthermore, lower discharges are more vulnerable to temperature fluctuation. Hence, during dry-weather conditions, not only the flow magnitude is of concern, but the quality of available water is also deteriorated.

Methods of studying low flow characteristics

Several techniques have been devised to study and present the results of low flow analysis. These include the use of streamflow regime, base flow recession curves, flow duration curves, and frequency curves.

Streamflow regime

When long-term streamflow data are available, flow regime can be plotted as the graph of streamflow versus time. The time scale may be months or years. If the line of mean flow is plotted on the same coordinate system, the curve can be used to evaluate hydrologic droughts. Droughts are considered to have three components--duration, magnitude (average water deficiency), and severity (cumulative water deficiency) (Hudson and Hazen, 1964; Dracup et al., 1980A and 1980B). Flow regimes may also be considered as a time-series and be used to inspect trends, oscillatory patterns, and periodicities by utilizing moving average and other techniques (Spiegel, 1961; Yevjevich, 1972; McMahon and Diaz Arenas, 1982).

Considerable information regarding basin permeability can be extracted from the flow regime. Figure 2.1 illustrates streamflow regimes of two streams of Indiana: Wildcat Creek with 277 square kilometers and Tippecanoe River with 201 square kilometers drainage area. Their drainage basins are only 80 kilometers apart and annual runoffs are about the same but their regimes are entirely different. The greater variability, and sharp response of Wildcat Creek to the runoff is attributed to the low permeability of its basin, which is floored with clayey till, as opposed to sandy, gravelly glacial outwash for Tippecanoe River (McGuinness, 1963).

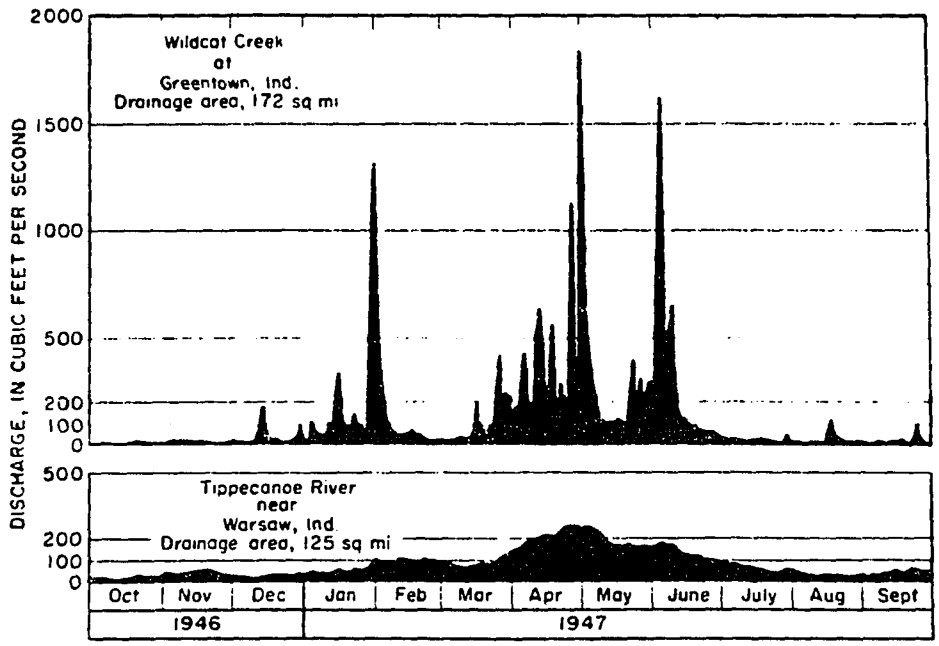

Figure 2.1. Contrast in streamflow regime of two adjacent streams draining basins with different permeability (McGuinness, 1963).

Storm hydrograph

A hydrograph is a plot of streamflow or stream elevation versus time at a given cross-section of the stream. The time scale is generally hours or days. It reflects the combined effects of basin characteristics, climate, and vegetation. It also represents the integrated response of different flow pathways. Yet it gives no indication of the origin of each individual pathway. Freeze and Cherry (1979) stated:

> Hydrograph reflects two very different types of contributions from the watershed. The peak delivered by overland flow and interflow and the base flow which is the result of a slow response to long-term changes in the regional groundwater system.

Hydrograph components

Once a sufficient prolonged rainfall occurs, three major components with different lag times contribute discharge to the stream: (1) overland flow; (2) interflow; and (3) base flow. Sometimes two more components are also significant: (4) throughflow and (5) channel precipitation. The magnitude of different components has a stochastic nature.

Overland flow is the main mode of water movement in arid climates, impervious or low permeable sites, and urban areas. It starts from the moment that rainfall intensity exceeds infiltration capacity. It may also be originated from snowmelt. Once it reaches a stream channel, it is called surface runoff (Stanley and DeWiest, 1966).

Interflow or storm seepage is defined as the flow which infiltrates to the soil and moves laterally toward the stream before it reaches the water table. It is a prevalent mode in permeable basins underlain by a hardpan layer, which encourages lateral movement of infiltrated water, or in well-drained forested basins (Brooks et al., 1991).

Base flow comes from groundwater storage in a sufficient prolonged dry period. It is the last component of flow to diminish.

Throughflow (or return flow) is the part that infiltrates into the soil on a slope and later seeps out downslope, joining the overland flow.

Channel precipitation is the portion that falls directly on the stream channel. It may be significant in basins with high drainage density or numerous lakes. The Lake Michigan basin receives one-third of its precipitation directly on the body of water (Fetter, 1980).

The above discrete characterization of the modes of water movement to streams is, of course, a gross simplification of a more complex natural process (Eagleson, 1977).

Hydrograph separation

In derivation of unit hydrograph and in aquifer recharge studies (Meyboom, 1961; Vecchioli et al., 1991), it is required to separate the hydrograph, in terms of time response, into two main components, namely direct surface runoff and base flow (Hursh and Brater, 1941). There is no universal method available. The adopted empirical procedures are somewhat arbitrary and not to be used blindly except for the sake of comparison.

One commonly used method is to find the onset of base flow recession on the hydrograph using the empirical relation

$$N = A^n \tag{2.1}$$

where N is the number of days it takes for overland flow and interflow to recede, A is the basin area in square miles, and $n = 0.2$ (Viessman et al., 1977; Linsley et al., 1982). Ahmed (1987) recommended a value of 0.35 for n. When bank storage (discussed later) is significant, it would be difficult to quantify base flow.

Graphical separation of base flow is tedious and subject to personal judgment. Based on equation 2.1, White and Sloto (1990) used a computer program to separate the base flow in hydrographs of selected streams in Pennsylvania. They concluded that compared with the manual method, the program was fast and reduced subjectivity.

According to Freeze (1972), "hydrograph separation appears to be little more than a convenient fiction."

In addition to the conventional separation techniques, some researchers have used methods to relate the chemical composition of the solutions to the original pathways that water has taken to reach the stream channel (Kennedy et al., 1986; Robson and Neal, 1990). Pinder and Jones (1969) used the chemical hydrograph technique with a mass balance approach to determine base flow. O'Bien and Hendershot (1993) took the same approach using both reactive and conservative tracers.

Recession of hydrograph

Following a storm peak, the hydrograph starts to decline. The falling limb represents the recession of three main components: surface runoff, interflow, and base flow, with of course some overlapping. The lower part of the falling limb is dominated by base flow. Barnes (1939) pointed out that each component has exponential decay according to the relationship $Q_t = Q_0 k^t$, where k is the recession constant. The recession constant, however, differs markedly for different components. While k for surface runoff is about 0.1, it is around 0.99 for base flow (Nutbrown and Downing, 1976). That means the recession rate slows down progressively (James and Thompson, 1970). In other words, $1 > k_{\text{base flow}} > k_{\text{interflow}} > k_{\text{overland flow}} > 0$.

Stream categorization

In arid and semiarid regions, due to low precipitation, the water table is usually much lower than the stream bed. Therefore, as streams wind to lower elevations, they lose water through percolation and the discharge decreases accordingly. These streams are called influent or losing streams (Figure 2.2A) and are fed by snowmelt runoff or base flow only at high altitude tributaries. If the supply from upstream is not sufficient, an influent stream may go dry for some time (Farvolden, 1963).

In humid areas such as Iowa, streams are in hydraulic connection with the local groundwater. During recession periods, they receive base flow from the sloping water table. Streams of this type are called effluent and their discharge increases gradually as they move to downstream points (Figure 2.2B).

According to Naney et al. (1978) in most regions of the Great Plains, groundwater provides the entire streamflow for several months. Bjorklund and Brown (1957) reported that the South Platte River in Nebraska and Colorado is sustained by base flow for many months.

During a flood event, if the flood crest exceeds the water table elevation, the hydraulic gradient which was previously toward the stream becomes reversed. Therefore, a gaining stream may temporarily become a losing stream (Fetter, 1980). Figure 2.2C depicts this condition.

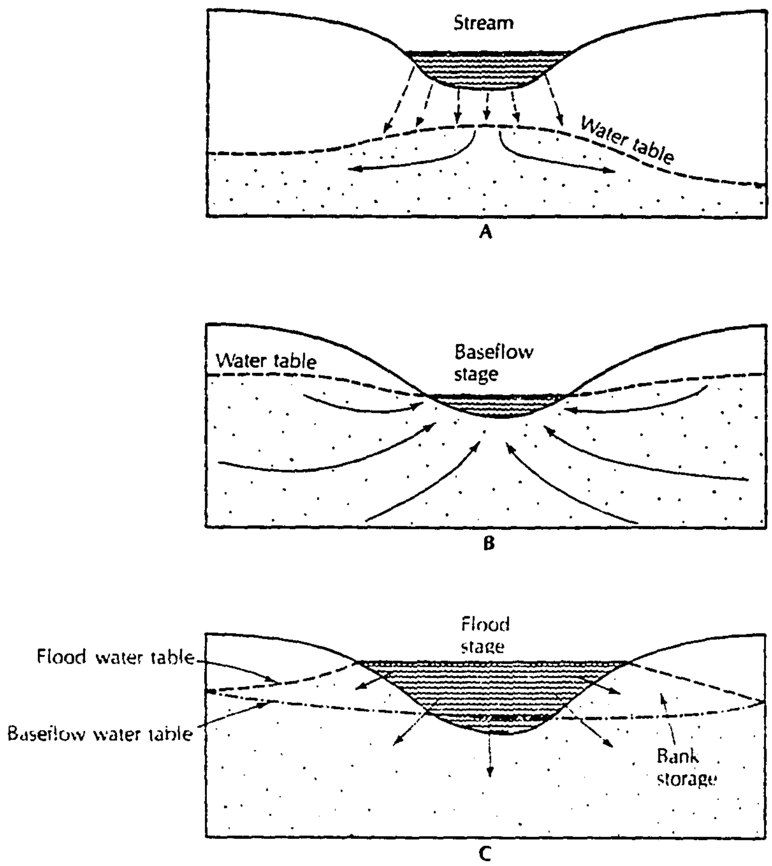

Figure 2.2. Cross sections of influent and effluent streams:
A. a losing stream;
B. a gaining stream;
C. a stream reach which is losing during flood stage and gaining during low flow periods (Fetter, 1980).

Base flow recession curve

This curve is the lower part of the falling limb of the hydrograph and represents the rate at which groundwater is discharged into the stream, in the absence of any replenishment. The shape and slope of recession curves are mainly controlled by geologic features of the basin, that is (1) the permeability and extent of the alluvium adjacent to the flood plain and in the vicinity of stream banks (Ewart and Brutsaert, 1972); (2) the dimension and type of contributing aquifer and its hydrogeologic characteristics (transmissivity and specific yield); and (3) the hydraulic gradient toward the streams at different times (i.e., the amount of water which is currently stored).

Hall (1968) prepared a comprehensive historical perspective of different aspects of base flow recession. Using base flow recession curves, Riggs (1953) proposed a methodology for predicting low flows. Riggs (1964) used base flow recessions to characterize the aquifers.

Base flow recession has been a subject of extensive mathematical modeling (Werner and Sundquist, 1951; Singh, 1969; Singh and Stall, 1971; Marino, 1973; Nutbrown and Downing, 1976; Rushton and Tomlinson, 1979; Dillon and Liggett, 1983). Based on idealized conditions of (1) homogeneous and isotropic water table aquifer that is hydraulically connected to the stream and overlies a horizontal, impervious layer; (2) Dupuit-Forchheimer assumption for horizontal flow; and (3) no recharge or abstraction by leakage and evapotranspiration, Singh (1969) and Singh and Stall (1971) developed mathematical models for recession curves in both partially (stream bed above impervious layer) and fully (stream bed at impervious layer) penetrated streams.

Since base flow recession curves contain valuable information about sustainable flow and the parameters governing groundwater system (Nutbrown and Downing, 1976), their parameters often need to be used in the modeling of complex operational problems dealing with multiple supply and demand sites (Beran and Gustard, 1977). Recession characteristics are also being used to estimate evapotranspiration from groundwater (Langbein, 1944; Daniel, 1976); diffusivity of aquifers (Rorabaugh, 1960); recharge of groundwater (Rorabaugh, 1964; Vecchioli et al., 1991); and comparative studies of basins from a geological viewpoint (Knisel, 1963). From the results of analysis of the base flow recession curves of a stream draining a chalk formation in Britain's lowlands, Foster (1974) concluded that the formation consisted of layers with different hydraulic characteristics.

Recession equations

Traditionally, the best-known equation for describing the recession curves is simple exponential. Perhaps due to its relative ease of application in graphing and modeling formulation, it has gained general acceptance.

According to this equation, during the period of no excess precipitation, base flow recedes exponentially with time. Therefore, at least part of the recession limb can be expressed by:

$$Q_t = Q_0 k^t \tag{2.2A}$$

or

$$Q_t = Q_0 e^{-at} \tag{2.2B}$$

where

Q_0 = initial discharge

Q_t = discharge at t time units later

k = recession constant ($\frac{Q_t}{Q_0}$ after one time unit)

a = recession factor

t = time elapse between Q_0 and Q_t (usually in days)

Equation 2.2A can be obtained from equation 2.2B by substituting k for e^{-a}. According to Toebes and Strang (1964), the first theoretical derivation and application of both equations is ascribed to Maillet (1905), although his extensive and practical work has not been sufficiently acknowledged by hydrologists (Appleby, 1970). Since then many investigators have used these equations for base flow analysis (Horton 1933; Barnes, 1939; Werner and Sundquist, 1951; Howe, 1966; Singh and Stall, 1971; Foster, 1974; Nutbrown and Downing, 1976; Boughton, 1986; Loganathan, et al., 1986).

According to the U.S. Army Corps of Engineers (1956), equation 2.2A also approximates the recession rate of streamflow generated by snowmelt.

James and Thompson (1970) proposed a method based on a least squares procedure to estimate recession constants for both base flow and interflow. He then successfully tested his model on over 20 streams in Kentucky.

Exponential decay implies that early decline is rapid while later decrease is slower. A plot of Q_t in equation 2.2A versus time on semi-logarithmic graph paper (Q_t in log axis), yields a straight line with the slope equal to log k. The application of exponential decaying functions to natural processes is common. They have been successfully used to model the decay of radioactive substances, infiltration, population decline of microorganisms, reduction of drug concentration in the blood, and so on.

The recession constant (k) is always less than one, and varies within a narrow range, usually 0.80 to 0.99 with a considerable "bunching" (Martin,

1973) when it approaches unity. Langbein (1940) indicated that k is a function of drainage density. The effect of evaporation on k was investigated by Weisman (1977). Experimenting on three basins, he showed that k declined inversely with pan evaporation according to a convex-upward curve.

The small range of k reduces its sensitivity to be used for modeling purposes. Nonetheless, k has been used by many researchers to characterize the base flow recessions (Brown, 1965; Howe, 1966). Knisel (1963) used the base flow recession constants of streams in the south-central United States to compare the geologic features of their basins.

There is an alternative to the recession constant k, however, called the *storage delay factor*. It is denoted by K, and defined as the time taken for discharge to recede by a factor of 10 (i.e. one log cycle) (Singh and Stall, 1971). This index has a wide range and can be more accurately evaluated from semi-log recession curves. It is also visually significant in that its magnitude is a measure of stability and sustainability of base flow.

Using the definition of K (i.e. $Q_t = 0.1 Q_0$ when $t = K$) together with equation 2.2A yields

$$0.1\, Q_0 = Q_0\, k^K$$

or $$k^K = 0.1 \Rightarrow k = 10^{\frac{-1}{K}} \qquad \text{or } K = -1/\log k \qquad (2.2C)$$

For example, if $k = 0.9$ then $K = -1/\log 0.9 = -1/-0.04576 = 21.85$ days.

Equation 2.2A can be written as

$$Q_t = Q_0\,(10)^{\frac{-t}{K}} \qquad (2.2D)$$

As will be seen later, K is also related to the most important aquifer parameter, namely *diffusivity,* which is defined as transmissivity divided by storage coefficient.

Martin (1973) introduced the concept of *half-flow period,* the time required for base flow to halve. It is exactly the same notion of half life as in nuclear physics and does not seem to offer more information than the storage delay factor.

Although a simple exponential equation has been widely used, it does not fit all practical recession cases encountered. Clausen (1992) examined equation 2.2A to characterize the base flow recession periods for two Danish streams. He concluded that the equation $Q_t = B + C\,k^t$ can explain the behavior of these streams much better. B and C are constants within each recession period. Petras (1986) pointed out that equation 2.2B represents the depletion from homogeneous aquifers. In heterogeneous cases, the recession curves could be defined by superposition of a number of simple exponential equations

$$Q_t = Q_{01}\,e^{-a_1 t} + Q_{02}\,e^{-a_2 t} + \cdots\cdots + Q_{0n}\,e^{-a_n t} \tag{2.3}$$

Foster (1974) showed that the recession of two streams could be split into three log-linear segments. Based on an investigation of many streams in Britain, Nutbrown and Downing (1976) noted that the semi-logarithmic plot of base flow recession, even for streams draining a homogeneous aquifer is not a single straight line, but rather a curve. This curve can be represented by superposition of several exponential terms as

$$Q_t = \sum_{i=1}^{\infty} A_i\,k_i^t \tag{2.4}$$

where k_i are the recession constants and A_i are coefficients dependent only upon the initial base flow value (Q_0), and the original distribution of piezometric head in the aquifer. In practice, only a few terms of the equation are required. Such a form can be used to fit empirically the observed base flow recession curve (Figure 2.3). In addition to cases that can be approximated by different exponential decay equations, there are more complex situations that need to be treated otherwise. A number of equations have been proposed accordingly, some empirical, but most of these equations are based on linear solution of the Boussinesq basic differential equation governing the dynamics of groundwater, under simplifying assumptions (Hall, 1968). Table 2.1 contains some of these equations.

In a thorough study of the streams of Japan, Ishihara and Takagi (1965) derived low flow equations mathematically. They concluded that the base flow is supplied by two distinct sources, namely confined and unconfined aquifers.

$$Q = Q_c + Q_u \tag{2.5}$$

The confined component was expressed by the exponential function

$$Q_c = Q_{0c}\, e^{-at} \tag{2.6}$$

and the unconfined component was calculated as a reciprocal function.

$$Q_u = \frac{Q_{u0}}{(1+ct)^2} \tag{2.7}$$

a and c are constants dependent upon aquifer characteristics.

They further showed that since Q_c recedes faster, low flow during a long period is mainly sustained by the unconfined aquifer. Ineson and Downing (1964) concluded that the nonlinear response of aquifers can be due to multiple sources, carry-over storage from a previous recharge period, spatial variations

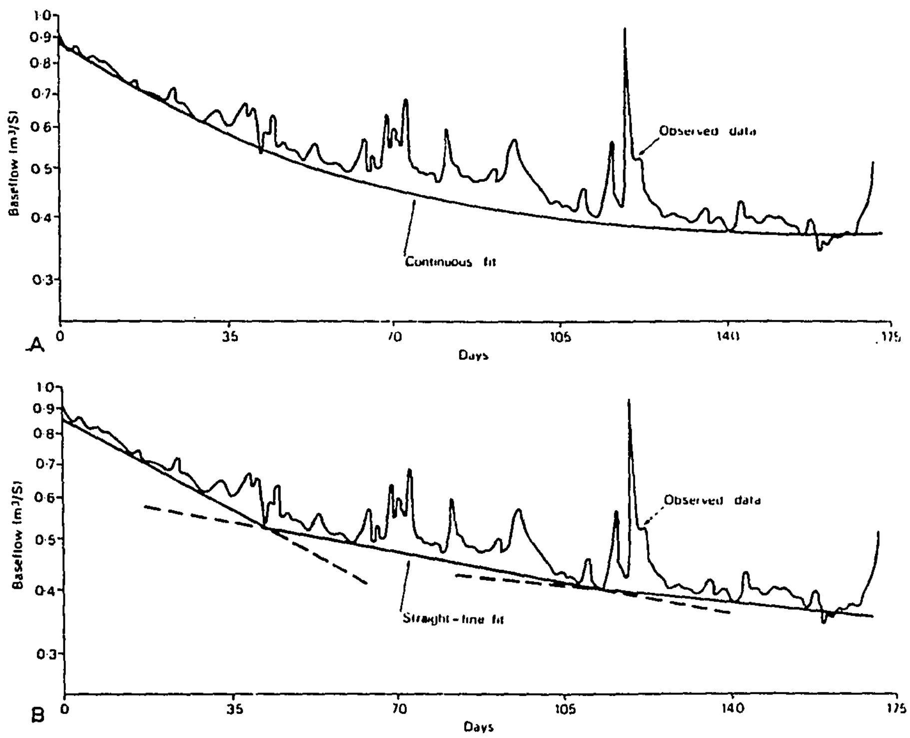

Figure 2.3 A. Empirical fit to recession of the River Wylye at Norton Bavant, U.K., in 1970, using superposition of three exponential terms.
B. Three-straight line fit to the same data (Nutbrown and Downing, 1976).

Table 2.1. Various proposed recession equations.

Equation	Description	Proposed/reported by
1. $Q_t = Q_0 e^{-at^n}$	Double exponential	Horton (1933)
2. $Q_t = \frac{Q_0}{(1+ct)^2}$	Hyperbola for spring discharge in Europe	Maillet (1905)
3. $Q_t = A + (Q_0 - A)e^{-at}$	Ice melt exponential	Wicht (1943)
4. $Q_t = \frac{a}{t^n} + b$	Ice melt hyperbola for stream fed by ice and snow	Toebes and Morrissey (1969)
5. $Q_t = \frac{(Q_0 - B)}{(1+ct)^2} + B$	Special version of Equation 2	Hall (1968)
6. $Q_t = Q_{01}e^{-a_1 t} + Q_{02}e^{-a_2 t}$	Based on principle of linear superposition	Hall (1968)
7. $Q_t = \frac{1}{at} + Q_0$	Empirical	Indri (1960)
8. $Q_t = B + Ct^k$	Empirical	Clausen (1992)

Q_t = streamflow after time t in cfs or m^3/s (1 cfs = 0.0283 m^3/s).

Q_0 = initial streamflow in cfs or m^3/s.

t = time interval between Q_0 and Q_t, usually in days.

e = natural logarithm base.

$a, n, c, A, b, B, a_1, a_2,$ and C are constants.

of evapotranspiration, and presence of storage in banks and flood plain. Riggs (1964) showed that the combination of two linear sources generates a nonlinear recession. Situations where the base flow is provided by discharge from two different aquifers have been reported by Kilpatrick, 1964; Toler, 1965b; Kunkle, 1968; and Riggs, 1985. Bingham (1982) reported that most streams in Alabama received water from two or more aquifers.

Storage volume

The storage volume which supplies base flow is the result of integration of the recession equation within the time period between zero and infinity (Boughton, 1986).

$$S_0 = Q_0 + Q_1 + Q_2 + Q_3 + \cdots$$

or $$S_0 = Q_0 + kQ_0 + k^2 Q_0 + k^3 Q_0 + \cdots$$

or $$S_0 = Q_0(1 + k + k^2 + k^3 + \cdots)$$

Since $k < 1 \Rightarrow \lim(1 + k + k^2 + k^3 + \cdots) = \frac{1}{1-k}$ therefore, $$S_0 = \frac{Q_0}{1-k} \qquad (2.8)$$

This equation relates discharge and storage in a linear fashion. Such an aquifer system can be regarded as *linear reservoir.* The linearity of the storage with respect to discharge is implicit in simple exponential model (Foster, 1974).

In general, the relationship between discharge and storage is non-linear (Langbein, 1938). One reason is that base flow discharge is composed of two components, bank- and basin-storage, although some authors regard bank-storage as a part of channel flow (Singh, 1968). Curvilinear reservoir is also typical under more heterogeneous, anisotropic conditions, or in cases where aquifers of different nature (artesian and water table) are contributing to discharge (Riggs, 1964), and in small and relatively wet basins (Boughton, 1986). According to Boughton (1986) the simplest nonlinear form of storage is

$$Q = aS^b \tag{2.9}$$

a and b are constants. He used this equation along with curved base flow recessions for a stream in Queensland, Australia, to quantify the storage. He concluded that relating base flow to the storage provides more information than relating base flow to flow on the previous times. Kunkle (1962) determined that the discharge from basin storage is largely controlled by the texture of surficial deposits.

Bank storage

Bank storage refers to the variable amount of water stored temporarily in the stream banks during rising flood stage (Todd, 1955). If the soil moisture is below field capacity, part of this water supplies the moisture deficiency of the soil.

During abatement of stream stage, the hydraulic gradient is reversed, and part of the water returns to the stream. This water is released relatively faster than basin outflow. If t_p denotes the time to peak of the flood hydrograph, a major portion of the bank storage is depleted within 1.5 t_p (Singh, 1968). In general, only small strips adjacent to the stream banks are involved in this exchange. There are situations, however, where a very pervious and extensive flood plain provides a large supply for base flow. The permeability of the soil-water interface at the banks and the porosity and width of the permeable deposits along the stream greatly influence the amount of bank storage.

The flow of water into and out of bank storage can be predicted. Cooper and Rorabaugh (1963a, b) derived equations to quantify inflow and outflow of bank storage for finite and semi-finite aquifers. Rorabaugh (1964) estimated the component of flow to and from bank storage from river fluctuation data.

A distinction between bank storage and basin storage can be made based on their origin. While the basin storage results from the groundwater recharge due to precipitation or snowmelt and infiltrability of surficial deposits, the bank storage is generated by rising stage.

During the recharge of bank storage, the normal base flow tends to pond up near the banks. This process reduces the basin storage gradient toward the stream. Therefore, the base flow decreases gradually and may even stop for some time.

Although the volume of bank storage at a certain time can be remarkably less than that of basin storage, the annual discharge from this source may equal or even exceed the share from basin storage due to frequent contribution and higher rate of discharge (Kunkle, 1962). The concept of bank storage has been discussed by Todd (1955).

In addition to its effect on the base flow hydrograph, bank storage has a pronounced influence on attenuation of floodwaves (Freeze and Cherry, 1979). It is also a source of delayed flow during the recession of ephemeral streams (Riggs, 1985).

Flow duration curves

Flow duration curve is a cumulative frequency curve, showing the percentage of time that a specified discharge was equaled or exceeded. Hickox and Wessenauer (1933) and Foster (1934) discussed its earliest application in hydroelectric studies. It was adopted by USGS for hydropower investigations around 1920 and soon after became a familiar and useful medium for other purposes, such as site selection for industrial units and treatment plants (Searcy, 1959), low flow and water supply investigations (Singh, 1971), and sediment transport computations. It may also be used as a convenient means to display graphically the comparative variability of the streamflows (Riggs, 1985), and the influence of any significant change such as impoundment or diversion on the basin. While the upper end of duration curve has been used for flood studies (Beard, 1943), the lower part can be used for low flow investigations (Cross, 1949). Flow duration curves are almost always plotted based on *mean daily discharge* for as many years as data are available. The longer the period of data, the more reliable interpretation can be made. If, instead of daily discharges, monthly or annual values are used, then different duration curves are obtained (Searcy, 1959; Figure 2.4), although the effect of varying time scale is not identical for different streams.

The slope of the lower end of the curve is indicative of variability of low flows and basin storage capacity. A steep slope indicates that low flows recede rapidly and so they are not dependable. A flat slope usually means a well-sustaining low flow stream, fed from sufficient storage to maintain a relatively high base flow during dry periods (Schwob, 1958; Searcy, 1959).

Common indices of low flow taken from a duration curve are: streamflows that are exceeded 50%, 84%, 90%, and 95% of the time ($Q_{50\%}$, $Q_{84\%}$, $Q_{90\%}$, $Q_{95\%}$). $Q_{90\%}$ or $Q_{95\%}$ from long-term duration curves are sometimes comparable to special points (such as $Q_{7,10}$) on the low flow frequency curve.

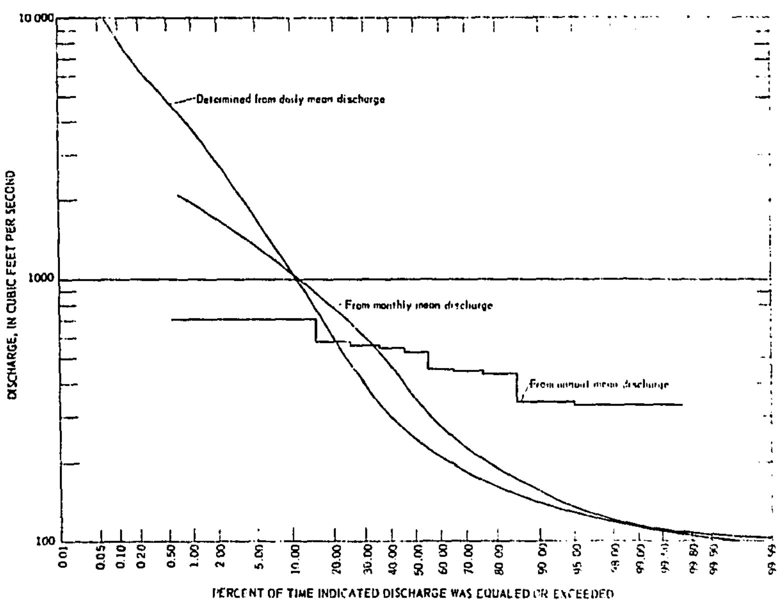

Figure 2.4. Flow duration curve for Bowie Creek near Hattiesburg, Miss., 1939-1948, using daily, monthly, and annual streamflow (Searcy, 1959).

To compare two or more streams in terms of low flow, the effect of basin size should be removed. Hence, indices can be standardized by basin area and expressed as discharge per unit area or depth per unit time (e.g. cfs per square mile or inches per day). Sometimes low flow data are transformed to dimensionless values by dividing each individual low flow by mean annual flow (Q_m).

Cross (1949) studied flow duration curves of 141 stations in Ohio and chose (Q_{90}/area) (in cfs per sq. mi.) as an index to represent the effect of geology. Based on the data from 120 gaging stations in Illinois, Singh (1971) proposed a simple model for estimation of flow duration at ungaged sites. His model, which relates the discharge to the basin area, is

$$Q_p = cA^n \tag{2.10}$$

where Q_p = the discharge which p percent of time is equaled or exceeded

A = basin area

and c and n are constants.

Kunkle (1962) utilized the concept of flow duration curve to establish a *base* flow duration curve for each of six basins within the state of Michigan. He also used these curves to compare the basins in terms of reliability of base flow. Furthermore, base flow duration curves allowed him to develop a method for partitioning the base flow into two distinct components, bank storage and basin storage.

Factors affecting duration curves

According to Todd (1957), climate and basin characteristics strongly influence the shape of duration curves. According to Singh (1971), physiography is the major factor influencing the general shape of duration curves, and within a relative homogeneous physiographic area, the size of the drainage basin is the chief determinant of the shape of the lower half of the curve.

Limitations

1. According to Riggs (1985) flow duration curve should not be regarded as a frequency curve for two reasons: (1) mean daily flows, based upon which the curve is drawn, follow a known pattern throughout the year (not random) and (2) they are serially correlated.
2. When daily streamflow data are arranged in descending order, the chronological sequence of the data is disturbed.
3. The effects of years with unusually high or low daily flows are obscured.

<u>Low flow frequency analysis</u>

Theoretical distributions

Frequency analysis involves the assumption of a theoretical probability distribution for the data; testing goodness of fit; and, if the fitness was satisfactory, using the distribution for estimating the probability of occurrence of large events, which is otherwise not directly possible from the data. Sometimes a confidence interval is calculated for the estimated low flow.

For flood frequency analysis, there is a recommended procedure. According to the U.S. Water Resources Council (1977), the log-Pearson type III distribution was recommended to be adopted by all federal agencies. For low flows, however, there is no single widely acceptable method. Some theoretical distributions have been fitted to the annual minimum flow. In a study of low flows of streams selected from all parts of the United States, Matalas (1963) investigated the suitability of four theoretical distributions for annual minimum flows. This study demonstrated that the minimum discharges can be represented equally well by either the Gumbel or Pearson type III distributions. Joseph (1970) concluded that the 3-parameter gamma distribution was the best of the five distributions used for frequency analysis of 14-day low flows of Missouri streams.

Tasker (1987) compared four distributions for estimating the 7-day, 10-year and 7-day, 20-year low flows for 20 long-term stations in Virginia, and showed that the log-Pearson type III and Weibull had lower mean square errors than Box-Cox or log-Boughton methods. A complete discussion of the mathematical properties of log-Pearson type III was given by Bobée (1975).

Gumbel (1958) discussed the extreme value type III distribution. Later, the technique was applied by Ewart and Brutsaert (1972) to study characteristics of drought low flow of the Mekong River. McCormick (1984) found that Gumbel type III and Weibull distributions are unacceptable for the analysis of low flows. He recommended the log-Boughton distribution for this purpose. Vogel and Kroll (1990) found that sequences of 3-, 5-, 7-, 14- and 30-day low flows in Massachusetts can be estimated quite well by a two-parameter log-normal distribution.

According to Loganathan et al. (1986) the major limitations of statistical distributions is that they do not take into account the physics of the hydrologic process.

Gottschalk and Perzyna (1989) combined the exponential recession function with Gumbel Extreme Value Type I to derive a so-called "physically based distribution function." They tested their model on six basins in southern Norway and concluded that the applicability of the model is generally limited to the minimum flow with higher return periods.

Graphical frequency curves

Hydrologists frequently use graphically-fitted low flow frequency curves, which are not bound to a particular form of the distribution. This seems appropriate especially in case of low flow, where basin characteristics has large influence on the shape of frequency curve (Riggs, 1968).

A frequency curve relates magnitude of low flow to frequency of occurrence. Given a streamflow record, the annual average minimum flow for various numbers of consecutive days (n) can be obtained by computer and then each group of n-day low flow data sets is ranked in ascending order. Graphical frequency curve will be prepared for each group separately. After ranking, each individual discharge is assigned a probability (or recurrence interval) by means of a plotting position formula

e.g., $$P = \frac{m}{n-1} \quad \text{or} \quad RI = \frac{n-1}{m} \tag{2.11}$$

where P = probability

RI = recurrence interval

n = number of data

m = the order number.

Then the magnitudes of low flows are plotted on the log axis versus probability, and the best smooth line is drawn to include plotted points. Figure 2.5 shows such a plot for the Des Moines River at Fort Dodge. The reliability of this method is determined by the length of record. Typically, low flow

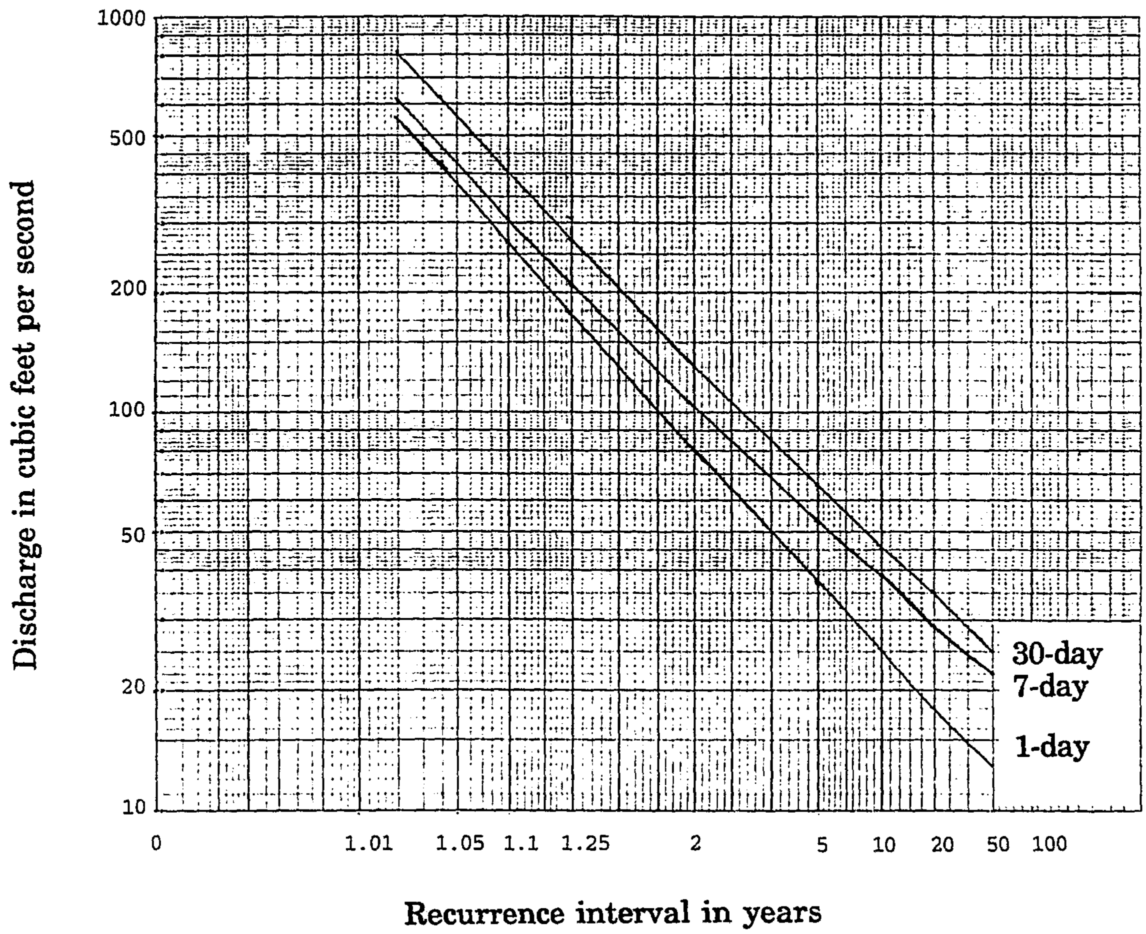

Figure 2.5. Frequency curves for Des Moines River at Fort Dodge, Iowa (1946-1988). Data used in this plot are taken from Fischer et al. (1990).

frequency curves are convex downward. There are cases, however, that frequency curves have distinct irregularity due to complex basin lithology, high evapotranspiration rate, or due to the existence of "several aquifers, not all of which contribute at all times" (Riggs, 1985).

Among the low flow indices which may be taken from a frequency curve is the seven-day ten-year low flow ($Q_{7,10}$), the lowest average discharge of seven consecutive days which is expected once in a decade. This index is widely used in effluent dilution computations.

Velz and Gannon (1960), in analysis of drought flow of 81 Michigan streams, used a *variability ratio* as an index of stability of the stream. This index is defined as the ratio of the 10-year low flow over the most probable value (taken as the average annual minimum). A higher ratio indicates a more stable stream.

Aquifer-stream interactions

Most aquifers are somehow connected with surface water in the form of seepage to or from streams, discharge as springs, and exchange with lakes and wetlands (Olmsted and Hely, 1962; Miles, 1985). A variety of mathematical models have been proposed for quality and quantity evaluation of interacting surface-subsurface water systems (Marino, 1973; Rushton and Tomlinson, 1979; Miles, 1985; and Guymon et al., 1992). Merriam (1948) correlated low flows with water levels in observation wells to make short-term forecasts of streamflow.

Rorabaugh (1960) derived an equation to relate the so-called hydraulic diffusivity of an aquifer (the ratio of transmissivity to the storage coefficient, T/S) to the water level declination in the observation well as follows.

$$\frac{T}{S}=\frac{4a^2\ln(h_1/h_2)}{\pi^2(t_2-t_1)}=\frac{0.933a^2\log(h_1/h_2)}{t_2-t_1} \tag{2.12}$$

where T = transmissivity of the aquifer (ft²/day)

S = storage coefficient

a = half width of the aquifer (ft)

h_1 = water level (ft) at time t_1 (days)

h_2 = water level (ft) at time t_2 (days)

and there are simplifying assumptions, as usual, underlying the derivation of equation 2.12.

Later, Rorabaugh (1964) introduced the concept of the critical time defined as the time required for the recession curve to become a straight line, and calculated by the following relationship.

$$t_c = 0.2a^2S/T \tag{2.13}$$

After the critical time $t_2 - t_1/\log(h_1/h_2)$ can be replaced by K, and equation 2.12 is written as (Bevans, 1986):

$$\frac{T}{S}=\frac{0.933a^2}{K} \tag{2.14}$$

where $K=\frac{\Delta t}{\text{log cycle}}$ = storage delay factor.

Due to difficulties in determining the accurate value for a, Bevans (1986) used T/a^2S (in day^{-1}) as a lumped parameter to characterize the stream-aquifer properties in 18 selected basins in Kansas. In this case there is no need to determine a. He also stated that if the base flow recession curve after critical time declines exponentially and is not affected by any factor other than aquifer properties, then the required assumptions in derivation of equation 2.12 hold true.

Equations 2.13 and 2.14 can be written respectively as

$$\frac{T}{a^2S} = \frac{0.933}{K} \tag{2.15}$$

$$t_c = \frac{0.2K}{0.933} \tag{2.16}$$

Dillon and Liggett (1983) studied the interaction between an ephemeral stream and an unconfined aquifer in southern Australia using the boundary integral method. Aron and Borrelli (1973) developed a model to predict base flow contribution to streamflow for a watershed in Pennsylvania. Their model was based on the analogy between drainage toward tile lines (Brooks, 1961) and seepage toward streams. Naney et al. (1978) improved the applicability of the model to be usable on ungaged sites by calculating the required model parameters from results of observation wells, pumping tests, and topographic maps.

Seasonal variability

During the summer periods, evaporation from the stream channel and aquifer, and evapotranspiration from riparian vegetation, may influence base flow by increasing the recession rate significantly. In winter, however, losses due to evapotranspiration are minor. Therefore, base flow recessions for winter represent more closely the discharge from groundwater. However, for many streams it is difficult to find sufficient long recession periods during the winter due to frequent precipitation or freezing. If possible it is common to define separate recession curves for summer and winter (Riggs, 1985) for the sake of comparison, although summer recessions are more critical because of their coincidence with the high demand period. Riggs (1964) described other factors that cause variability in recession rate.

Master base flow recession curves

Hydrographs of different peak magnitudes in a basin have different base flow recession curves because of variation in storage (Toebes and Strang, 1964). The individual recession segments can be synthesized into a full recession curve known as master base flow recession curve (MRC). In effect, an MRC, as an envelope to all recession segments, displays the general recession behavior of the basin. Five methods available for generating an MRC are:

Method 1. The linear MRC

In basins with alluvium surficial deposits and a single, uniform water table aquifer where the exponential decay can be assumed, individual recession segments are plotted on separate transparent sheets. They are ranked then according to discharge and replotted on a coordinate system by horizontal moving. A common straight line on semi-log plot can be drawn to be tangential to the lower ends of these segments. This line represents a linear master base flow recession (Wilson, 1974). Bevans (1986) used this method for Big Hill Creek near Cherryvale, Kansas (Figure 2.6).

Method 2. The matching strip method

This method involves plotting selected recession segments on tracing paper with the same coordinate scales as the hydrographs. By superposition, they are shifted horizontally until the main parts overlap (Toebes and Morrissey, 1969) and make a continuous alignment. A mean line connecting the overlapped parts represents the master recession curve. Riggs (1985) used this method for the James River, Virginia (Figure 2.7). Methods 1 and 2 can be computerized in order to minimize errors due to personal judgement.

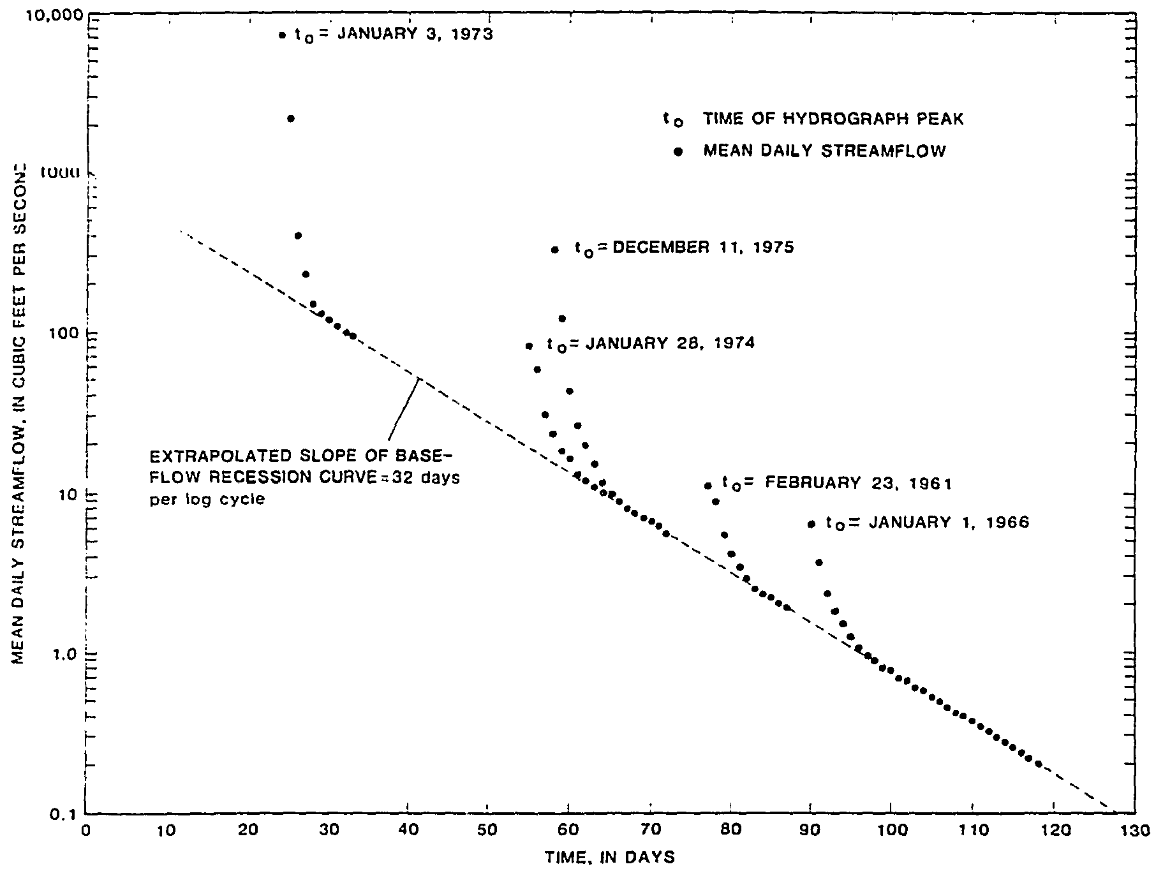

Figure 2.6. Linear master recession curve for Big Hill Creek near Cherryvale, Kansas (Bevans, 1986).

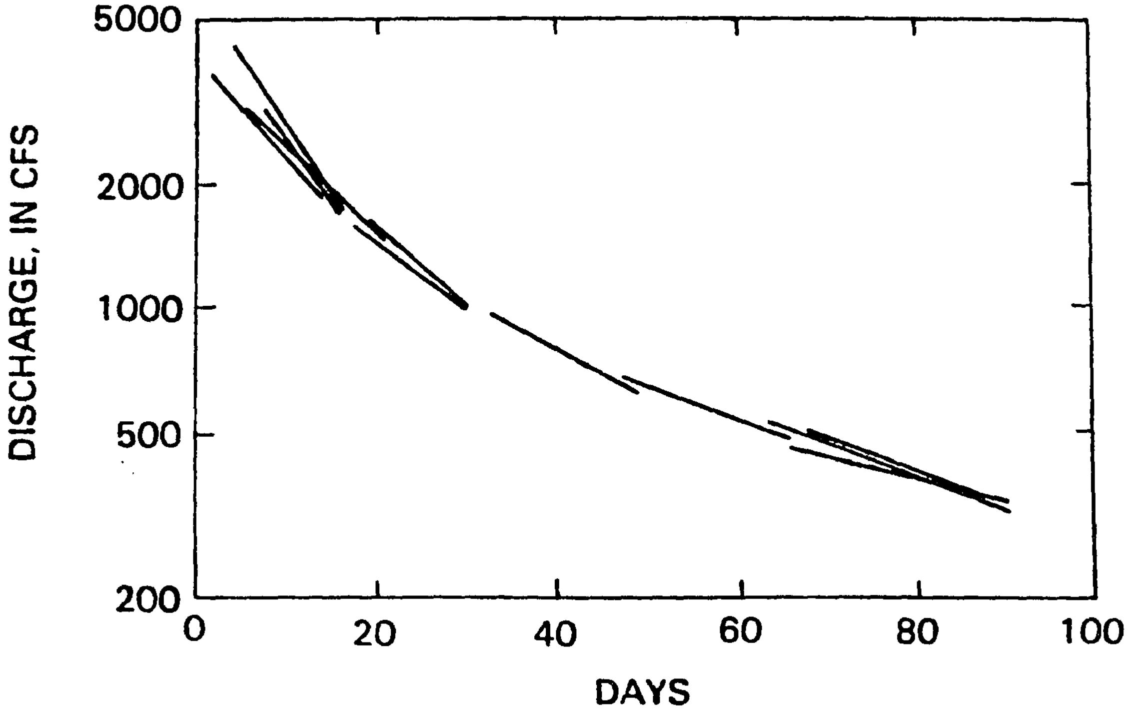

Figure 2.7. A master recession curve for James River, Virginia, obtained by the matching strip method (Riggs, 1985).

Method 3. The tabulation method

In this method, which in principle is the same as the strip method, the data for each recession segment are arranged in a vertical column. The columns are then adjusted vertically until the discharges in a horizontal line match approximately. The discharges on each row are averaged and used to plot a master recession curve. Johnson and Dils (1956) and Toebes and Strang (1964) described this method.

Method 4. The correlation method

Suggested by Langbein (1938), this method involves the plotting of Q_{t+n} versus Q_t on either natural or log scale and the regression line is drawn. This line is then transformed into a recession curve. Riggs (1985) used the method to synthesize a base flow recession curve for the Buffalo River, Tennessee (Figure 2.8). Saboe (1966) utilized this method to characterize summer base flow recessions for 94 streams in Iowa. The selection of appropriate value for n is usually based upon the length and variability of recession data. Table 2.2 shows different values that have been used for n.

Table 2.2. Different values for n that have been used in the correlation method.

Year	Investigator	n (days)
1938	Langbein	1
1963	Knisel, Jr.	1
1966	Stanley and DeWiest	1
1966	Saboe	10
1969	Toebes and Morrissey	5
1976	Beran and Gustard	2
1985	Riggs	10

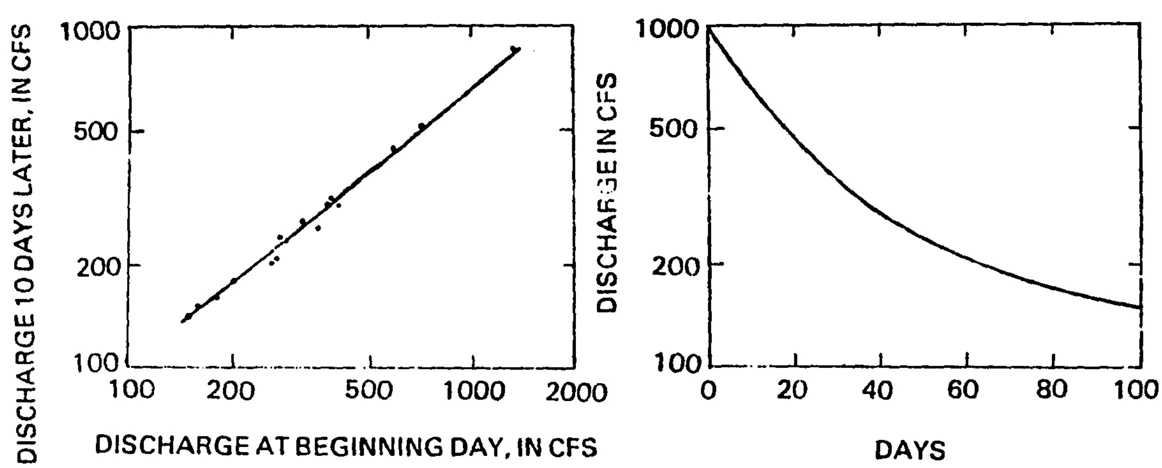

Figure 2.8. Master recession curve for Buffalo River near Lobelville, Tennessee, obtained by correlation method (Riggs, 1985).

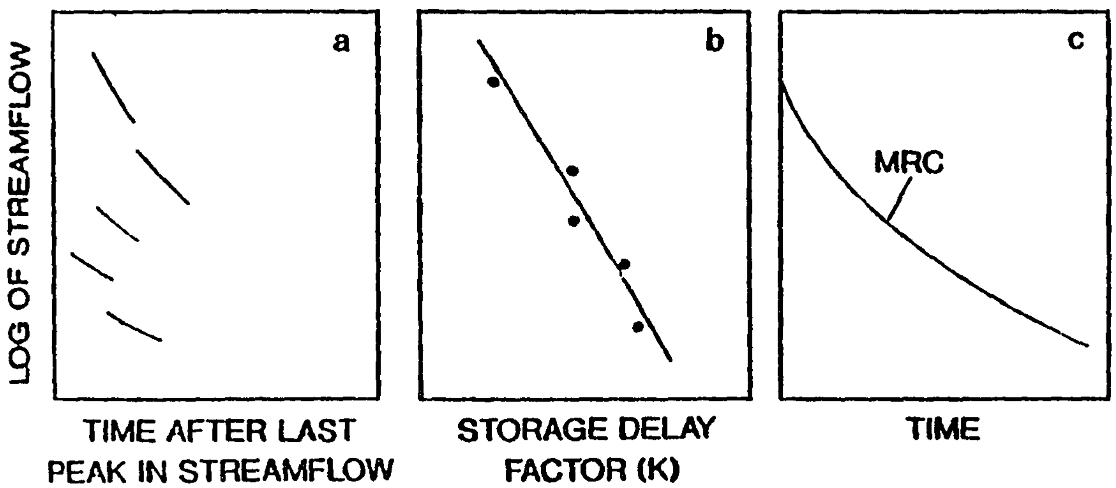

Figure 2.9. Schematic illustration of USGS method of generating a master recession curve:
(a) selected near -linear recession segments;
(b) plotting points corresponding to each segment;
(c) the MRC, calculated by integration of line in b (Rutledge, 1991).

Method 5. USGS method

This is an empirical, mathematics-based method with some similarity to the matching strip method, devised by the U.S. Geological Survey for regional aquifer system analysis program (Rutledge, 1991). It is established based upon the assumption that for each segment, the mean logarithms of streamflow data (log Q) varies in a linear fashion with the storage delay factor.

The method involves searching several linear or near-linear recession segments (Figure 2.9a) and for each selected segment, plotting a point with mean of log Q's as y and $K = \dfrac{-\Delta t}{\Delta(\log Q)}$ as x coordinates. Then a least-squares straight line is fitted to the points (Figure 2.9b). The equation of this line has the form

$$\frac{\Delta t}{\Delta(\log Q)} = a(\log Q) + b \tag{2.17}$$

Integration of equation 2.17 yields a second-order polynomial equation expressing time (t) as a function of log Q in the form of

$$t = \frac{a}{2}(\log Q)^2 + b(\log Q) + c \tag{2.18}$$

This equation represents a parabola, the lower part of which is regarded as a master recession curve (Figure 2.9c).

Since the above approach has been applied in this research endeavor, it will be described in more detail in the following chapter.

Factors affecting low flow

Several factors have an important effect on low flow rate and duration. In fact, low flow is a complex function of the interaction among (1) basin characteristics, (2) climate, (3) topography, (4) vegetative cover type, and (5) man-made influences.

Basin characteristics

Although it is not visible, basin geology is the most import factor affecting types of aquifer(s) and their features, such as transmissivity and storage coefficient. Extreme variations in lithology and structure may exist within a basin (Schneider, 1965). Moreover, the existence of faults and folds that interrupt the continuity and uniformity of rock types may convert a water table aquifer to a confined one at the center of synclines (Fetter, 1980) or may create springs of differing capacity.

In limestone and dolomite terrain, sinkholes and karst springs make a significant contribution to low flow. Generally, spring-fed streams have dependable low flows. However, not all springs flow uniformly, and their rate of discharge depends on the hydraulic conductivity, storage coefficient, and extent of the feeding aquifer. Some limestone aquifers drain rapidly because of their well-developed system of connected fractures and solution channels.

Sometimes two different types of aquifers (confined and unconfined) contribute to supply low flow, causing the low flow period to last longer. Riggs (1985) has discussed an example of this situation. In a hydrogeologic study of the Four Mile Creek in east central Iowa, Kunkle (1968) concluded that base flow in this creek is supplied by two interconnected aquifers. The upper is unconfined, composed of loess, which is underlain by a semi-artesian aquifer in alluvial sand, silt, and clay. In a comprehensive study, Beran and Gustard (1977), while discussing the low flow characteristics of British rivers, emphasized the need for incorporation of a geology index in the models developed for estimation of low flow on ungaged catchments. The effect of geology on low flow in Ohio has been discussed by Cross (1949), Cross and

Bernhagen (1949), and Schneider (1957). Johnston (1971) studied aquifer characteristics in the coastal plain of Delaware as indicated by base flows.

Surficial soils have a dominant influence in low flow generation and basin response. "They have the first opportunity to absorb, store, or release water" (Saxton and Shiau, 1990). Hence they control the rate of recharge to and discharge from aquifers. Howe (1968) introduced a soil index, *I*, to represent the average permeability rate for each soil type in a soil association area. Surficial soils of Iowa were scored on a six-point scale, based on a scale of one for very slow to six for very rapid permeability rate.

Basin area is the simplest available parameter that is logically related to low flow. Many investigators have correlated flow indices with this parameter (Ginsti, 1962; Howe, 1968; Lara, 1979; Bingham, 1982; Riggs, 1985). As common sense suggests, a stream with larger basin area has higher low flow. There are some exceptions, however. Glymph and Holton (1969) found three different relationships between the mean annual runoff and basin area, as shown in Figure 2.10. According to these authors, the inverse response of the Tombstone basin in Arizona is due to the fact that the streams in this region are influent. The same reason can be valid for streams in Texas, where channel gains and losses are nearly balanced. In a study of low flow of two adjacent streams in northern Vermont, Comer and Zimmerman (1969) found that the stream with a smaller basin area had higher low flow per unit area. Since the climate, geology, and land use were virtually identical, they also concluded that the difference in low flow was due to topography and soil.

Main channel length has been used as a basin characteristic in low flow modeling, although it is correlated with drainage area (Orsborn, 1974).

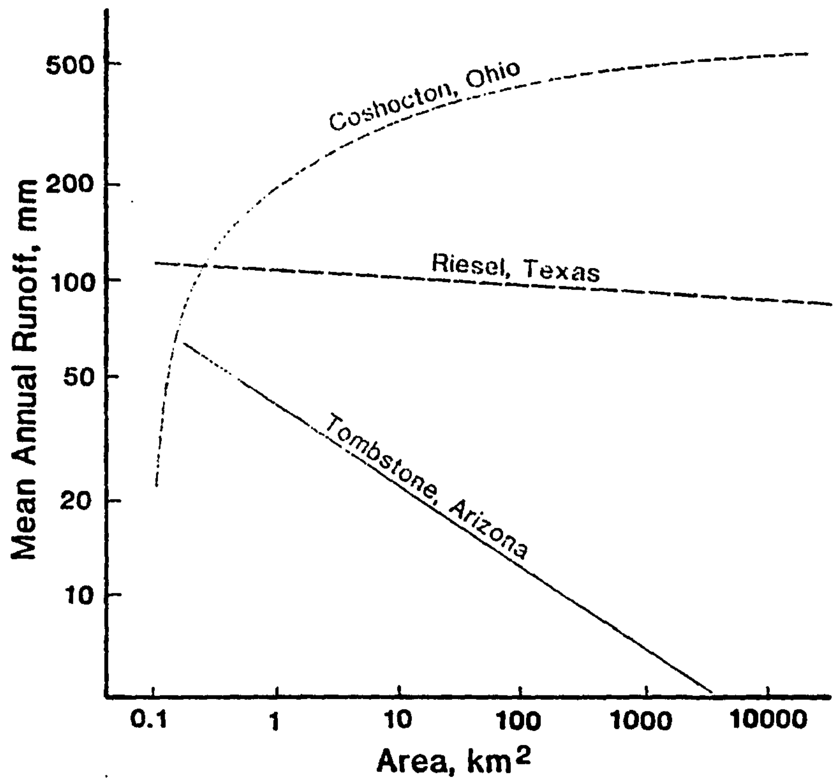

Figure 2.10 Relationship between mean annual runoff and basin area (Glymph and Holton, 1969).

Higher altitude is usually associated with more precipitation, which is in favor of more aquifer recharge and hence more low flow. The role of altitude is especially crucial in mountainous basins, where orographic precipitation and snow storage is prevalent. Figure 2.11 illustrates the relationship between mean elevation and minimum runoff for three basins in Middle Asia.

The effects of other basin characteristics such as mean slope and drainage density have been investigated (Trainer, 1969) and used in correlation (Carlston, 1963; Thomas and Benson, 1970). The influence of basin shape and drainage network cannot be quantified, since they are qualitative features.

Climate

Two major climatic factors affecting low flow are precipitation and temperature (Riggs and Harvey, 1990). While the former serves as an input to the flow-generating process, the latter regulates the type of input as rain or snow and converts part of the input to evaporation. The amount of precipitation and its temporal distribution, especially during the season when the low flow prevails, can increase low streamflow. In effect, streamflow follows a roughly similar pattern as the rainfall. Heavy rainfall or gradual melting of snowpack result in principal recharge of the aquifer and assure a reliable low flow.

The rate of evapotranspiration and evaporation from the stream channel and shallow groundwater is controlled by temperature. If the channel is wide and shallow and the rate of overall evaporation exceeds the base flow rate, the stream may go dry for some time (intermittent stream). Low temperature, on the other hand, reduces the rate of groundwater movement toward the stream

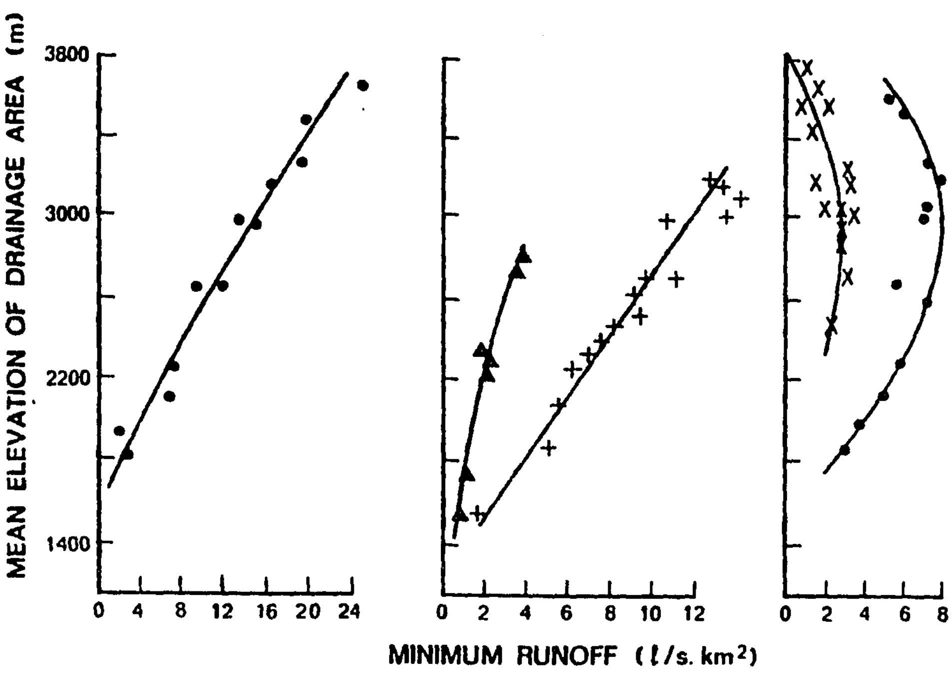

Figure 2.11 Relationship between mean basin elevation and minimum runoff of five mountainous regions of Middle Asia (McMahon and Diaz Arenas, 1982).

due to increased viscosity or freezing (Rogers and Armbruster, 1990). In areas where subzero temperatures dominate, base flow may completely cease under extreme freezing conditions, and low flow becomes zero. In such areas low flow periods during the winter may be longer than summer (Gottschalk and Perzyna, 1989).

Topography

In addition to the interactive influence of topography on climate, basins with high topographic relief and steep slopes tend to have fast hydrologic response to precipitation. In flat basins with minor relief, streamflow rate is relatively slow, allowing for more infiltration and evaporation loss to occur. A visible characteristic of such basins is the presence of lakes, ponds, wetlands, peatlands, and swamps. Streams often terminate in lakes or recharge the aquifers. In special cases, no surface runoff even leaves the basin (Riggs and Harvey, 1990).

Like other surface storages, the presence of large surface water bodies gives the impression that the existence of wetlands in a basin is effective in supporting low flows and recharging aquifers. This is true only if there is reason to believe that it is connected to regional groundwater (e.g. wetlands in areas of high precipitation). Otherwise it may be the result of a local perched water table. Brooks et al. (1991) stated, "Wetlands actually can be isolated from the regional groundwater system and can prevent or impede groundwater recharge."

Not all lakes should be viewed as recharge sites for the groundwater. Siegel and Winter (1980) indicated that in Williams Lake, Minnesota, the 15 percent recharge contribution of groundwater to the lake is balanced by an equal percentage of seepage to the groundwater. There are lakes that act even as discharge zones, gaining a considerable amount of water from groundwater (Winter and Woo, 1990). Since without detailed knowledge of basin geology it was not possible to determine the nature of each individual body of water, the area covered by lakes or wetlands within each drainage area was not considered as an effective factor on low flow in the present research.

Vegetation and land use

The influence of vegetal cover on low flow is attributed to its extensive evapotranspiration. In arid and semiarid regions, 85 to 90% of received annual precipitation is evaporated or transpired (Brooks et al., 1991). Riparian vegetation which often has its root system in the proximity of shallow water table can transpire at almost potential evapotranspiration rate throughout the growing season, using a large amount of groundwater. Phreatophytes are another group of deep rooted plants which are found in flood plains and along the banks of ephemeral stream channels. They have the ability to extract water from the capillary fringe of shallow groundwater. Individuals of this group, such as cottonwood, willow, alder, and saltcedar can consume large quantities of groundwater. Table 2.3 shows the annual estimates of consumptive use of phreatophytes in the southwestern United States.

Significant land use changes that alter the extent and type of natural vegetation on a drainage basin can influence low flow. Examples include conversion of forests and prairies to farmlands, change of cultivated crops, and deforestation. According to Brooks et al. (1991) experiments in controlled basins show increases in base flow after logging and forest harvesting.

Table 2.3. Estimates of annual evapotranspiration of some phreatophytes in the Southwestern United States (Brooks et al., 1991).

Species	Depth of water table (ft)	Annual evapo-transpiration (ft)	Reference
Saltcedar	5 7 9	2.2 1.5 1.0	van Hylckama (1970)
Cottonwood	-	1.1	Horton and Campbell (1974)

Clear cutting of riparian vegetation, though not justified by ecologists, seems to be most effective in low flow augmentation (Dunford and Fletcher, 1947). This is due to reduction of interception and evapotranspiration. In an analysis of discharge of nine small streams in Virginia, Riggs (1965) concluded that discharge per square mile was directly related to the percentage of drainage basin cleared of trees and bushes. In particular, clearing of land adjacent to stream channel (riparian tract) was more effective in increasing summer and fall base flow. Pereira (1973) discussed a case of clear-felling some 30 million acres of evergreen woodland in Western Australia dominated by deep-rooted species (Eucalyptus) and converting it to cropland. The outcome was a raised water level as expected, but this was accompanied by the unwelcome existence of salt springs.

Human activities

Man-induced changes in the basin can significantly disturb streamflow in general and low flows in particular. One purpose of any impounding structure is redistribution of streamflow in time and space by storing the floodwater to augment low streamflow during the dry periods. Impoundment per se also tends to recharge groundwater by induced infiltration, and therefore increases low flow.

Continuous heavy pumpage adjacent to effluent streams may develop a cone of depression which lowers the water table and reduces the base flow accordingly.

Urbanization is a major human modification in the hydrologic cycle. Altered steep slopes, increased impervious surface areas (such as streets, roofs, parking lots, and pavements) and improved surface drainage networks by installation of storm sewerage all inhibit infiltration and thus reduce base flow. By analysis of six streams in Long Island, Simmons and Reynolds (1982) concluded that urbanization reduced base flow from 95% of total annual flow to 20% . They further noticed that base flow in an adjacent urbanized but unsewered area had decreased to 84% of total annual flow. This indicates the major influence of storm and sanitary sewerage on base flow fluctuation.

Some investigators were not certain about the effect of urbanization on low flow. Hirsch et al. (1990) stated that:

> In general, it is not intuitively apparent whether urbanization can be expected to increase or decrease low flows. Decreased infiltration caused by increased imperviousness should decrease base flow. However, the existence of septic tanks, the possibility of [leakage from sewer system] and increased infiltration and dry-weather runoff from lawn watering all have the potential to increase streamflow during dry periods.

Furthermore, low flow is increased in areas where drinking water is imported from adjacent basins and treated waste water is released in the urbanized basin.

Other activities, such as irrigation, drainage works, and mining activities have different effects on low flow magnitude, depending upon the local situation, and should be studied as special cases.

Low flow augmentation

Low flow augmentation refers to any management strategy that can be implemented to increase the magnitude of low flow. Since low flow in streams is sustained by groundwater, all management practices must be somehow effective in recharging aquifers during the wet season. One major practice is the use of instream structures, either temporary or permanent, to retain water, thus encouraging infiltration to the floodplain and recharging the local aquifer(s). Moreover, they are potentially beneficial in terms of regulation of storage and release. Other practices include management of rangeland and upland vegetation, as well as detention of upland runoff.

Low flow augmentation is one way of controlling instream water quality (Dougal, 1969), since stream water quality is directly related to discharge magnitude. Ponce and Lindquist (1990) prepared an excellent review of the subject.

Low flow modeling

One major application of hydrologic techniques in engineering hydrology is the prediction of streamflow regimes, especially the extreme events, for design and operation purposes through mathematical modeling. In brief, mathematical models can be either *theoretical* or *empirical*. They may be further classified as *deterministic* or *stochastic*. While theoretical models are built based upon theories and physical laws, the empirical models rely on the relationships between input and output. Deterministic models always generate the same response for the same input. If a random element is included in a model, it is called stochastic, which simulates processes with a stochastic nature. This means a different outcome is generated for each execution of the model. In practice, a hydrologic model can be a combination of different types. Several investigators have tried to characterize low flows through modeling efforts.

Freeze (1972) examined the mechanism of base-flow generation with a deterministic mathematical model that couples three-dimensional, transient, saturated-unsaturated subsurface flow and one-dimensional gradually varied unsteady channel flow.

Prakash (1979) developed a deterministic model to estimate low streamflow in an effluent stream. His approach is analytical with too many simplifying assumptions, which limit the applicability of the model.

Verma (1979) used the base flow recessions coupled with nonlinear storage routing equation to determine low flows for effluent streams.

Regionalization

Regionalization refers to the possible grouping of streams and their basins based on their homogeneity in climate, topography, and similarity in response. According to U.S. Army Corps of Engineers (1975), a regional analysis is a statistical approach in which generalized equations, graphical relationships, or maps are developed. Such generalization can be used to estimate hydrologic information at sites where no observations have been taken (Singh and Stall, 1971). Regional analysis has been used in the United States to estimate both flood and low flow at ungaged sites. In an attempt to generalize over 70 parameters of streamflow, including low flow indices, Thomas and Benson (1970) used data from four widely separated regions of western, central, eastern, and southern United States. Each streamflow characteristic was then regressed against up to 31 basin characteristics. The study showed that the most important parameters were basin size and mean annual precipitation. Also, the equations defining midrange of flows were more accurate than those of low flows. Riggs (1972) stated "the principal roadblock to regionalization of low-flow characteristics is our inability to describe quantitatively the effects of various geological formations on low flows—even where detailed geologic maps are available."

Leith (1978) developed a regionalized relationship which relates annual 7-day low flows for 85 gaging stations in British Columbia to basin-averaged physiographic parameters. His equation has 10 independent variables.

Regression analysis

Regression analysis is a widely-used statistical procedure for modeling in hydrology. It is usually employed as a functional relationship to relate a desired characteristic (a dependent or response variable denoted by y) to one or a number of easily determined independent or explanatory variables. If more than one independent variable is involved, it is called multiple regression. A multiplr regression equation can also be univariate, consisting of different exponential powers of a single independent variable. Multivariate multiple regression is utilized whenever the use of more than one independent variable statistically improves the estimation of a hydrologic response. Such a relation has a general type of $y = f(x_1, x_2, \cdots\cdots x_n)$. A classic form of equation is

$$y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \cdots\cdots + \beta_n x_{ni} + \varepsilon_i \qquad (2.19)$$

where $x_1, x_2, \cdots\cdots x_n$ are explanatory variables, $\beta_0, \beta_1, \beta_2, \cdots\cdots \beta_n$ are constants estimated by multiple regression analysis, and ε_i is a random error component.

In hydrology a nonlinear form of multiple regression that seems more appropriate and is frequently used has an exponential structure, such as

$$y_i = \beta_0 \cdot x_1^{\beta_1} \cdot x_2^{\beta_2} \cdots\cdots x_n^{\beta_n} \cdot \varepsilon_i \qquad (2.20)$$

It can be transformed into a linear form by logarithmic transformation to simplify the analysis.

$$\log y_i = \log \beta_0 + \beta_1 \log x_{1i} + \beta_2 \log x_{2i} + \cdots\cdots + \beta_n \log x_{ni} + \log \varepsilon_i \qquad (2.21)$$

As Haan (1977) suggested, multiple regression analysis must be preceded by a great deal of study and thought regarding the form of the predictive model and the variables that should be used in the analysis. Otherwise, failure may frequently occur due to improper choices. Another point worth noting is that regression does not imply a cause-and-effect relationship between dependent and independent variables (Riggs, 1985).

Independent variables should be selected such that there is no reasonable evidence that they are strongly related. The number of selected explanatory variables is an important factor. While inclusion of more variables may improve the derived regression equation in terms of reliability and reduction of standard error of estimate, it also increases the variance of the estimated dependent variable and reduces the practicability of the equation.

Multiple regression equations are empirical and deterministic models used in regionalization of hydrologic processes. Calculation of relevant parameters in multiple regression models is tedious and time consuming.

Packages of various computer programs are available for this analysis, using forward selection, backward elimination, and stepwise procedures (Kite, 1977).

Many investigators have used equation 2.20 to characterize low-flow indices at ungaged sites (Schwob, 1958; Carlston, 1963 and 1966; Howe, 1968; Bingham, 1982; Wandle, 1987). Carlston (1963 and 1966) attempted to correlate minimum flows with drainage density. Bingham (1982) used multiple regression methods to estimate the 7-day, 2-year and the 7-day, 10-year low flow of ungaged sites in Alabama using data from 109 gaging stations. He included in his equation three independent variables: basin area, mean annual precipitation, and a recession index. Wandle (1987) developed a multiple regression model based on data from 48 basins for the period of 1942-1971 in New England to estimate $Q_{7,2}$ and $Q_{7,10}$ for ungaged streams. His model included, as independent variables, mean basin elevation; areas underlain by till and bedrock, coarse materials, and fine deposits; and the area of lakes, swamps, and alluvium.

Application of regression model

According to Riggs (1968) a regression analysis usually involves (1) selection of factors which are expected to be used as independent variables, (2) describing these factors quantitatively, (3) choosing the type of regression model, (4) computing the regression coefficients, coefficient of determination, and standard error of estimate, (5) testing significance of the regression coefficients, and (6) assessment of the results.

In multiple regression analysis two parameters are important in terms of reliability of estimated values of dependent variables, and usefulness of the selected model: (1) standard error of estimate and (2) multiple coefficient of determination.

Standard error of estimate

Standard error of estimate of y in a multiple regression analysis is defined as standard deviation of the residuals about the regression plane. The sample standard error of estimate of a multiple regression model is given by

$$s_e = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n-k-1}} \qquad (2.22)$$

where y_i = observed dependent variable

$\hat{y}_i$ = estimated dependent variable

n = number of data points

k = number of independent variables

s_e designates the range of errors which are expected about 68% of the time.

Multiple coefficient of determination

The sample multiple coefficient of determination is a statistic explaining how well a linear model fits a set of data. It represents the percentage of the sample variation of the dependent variable (y values) that is attributable to the regression model. Thus

$$R^2 = \frac{\text{explained variation}}{\text{total variation}} = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}$$

or $$R^2 = 1 - \frac{s_e^2}{s_y^2} \qquad (2.23)$$

where s_y = sample standard deviation of y_i's

Equation 2.23 reveals that if standard error of estimate is close to the standard deviation of y_i's, R^2 will be nearly zero, and the regression equation does not explain any variation in y_i's (Haan, 1977). In other words, the smaller the standard error of estimate, the closer R^2 is to one, and the better the regression equation fits the data. One should notice that even though $R^2 = 0$ indicates no linear relationship between the variables, a curvilinear relationship may exist (Spiegel, 1961).

Transformation

Transformation refers to changes which are made to a set of data according to a certain formula to remove the skewness, reduce the kurtosis, or to make the data follow a given distribution. It is also used to linearize a non-linear regression equation. Furthermore, in a regression analysis, transformation aims to achieve equal variance about the regression line throughout the range of data (Riggs, 1968).

Transformation may be as simple as adding a constant term to each data point or taking the reciprocal, square root, or logarithm of the data.

Equations of the form $y = ax^b$ can be linearized by logarithmic transformation. Likewise, equations such as $y = ab^x$ are linearized on semi-logarithmic paper. Log-transformation is by far the most common form used to achieve linearity in hydrology, but it is not the only one. Prakash (1981) used a special transformation (SMEMAX) to normalize annual low flows of 66 streams in the United States. Other commonly used types of transformations were discussed by Yevjevich (1972) and Bowerman & O'Connell (1990).

CHAPTER 3. METHODS OF ANALYSIS

This chapter is divided into two sections. In the first section, the methodology for quantification of the recession characteristics of stream hydrographs is discussed, and two master recession curves (MRC's) for each individual stream are developed. One MRC is obtained by analyzing observed recession periods of at least 10 days in the months of October through March, which span the winter season. The second MRC results from analysis of the remaining six months (April through September), which include the summer season. Likewise, two storage delay factors, one for summer and the other for winter, are calculated for each stream. In the second section, the procedure for modeling two low flow indices ($Q_{84\%}$ and $Q_{7,10}$) using multiple regression techniques is discussed.

Recession characteristics

Introduction

In dealing with a large amount of daily streamflow record, the application of computers is inevitable. Although overreliance on computer models is not justified and failure to simulate the actual processes by inadequate models has created a skeptical attitude toward their usage, an appropriate computer program can nevertheless be of great help in scanning and analyzing the recession periods within the entire recorded data.

A suitable computer program should have the ability to perform a comprehensive analysis of recession segments. It is also expected to offer a model with a sound mathematical basis to simulate the recession characteristics of streams in the real world.

Source of data

The data used in this study were obtained from two different sources. Mean daily streamflow for 143 gaging stations was taken from an optical hydrodata compact disk (CD-ROM) prepared by Earthinfo Inc. from the USGS daily value data files. Information on basin characteristics and low flow indices was obtained from the most recent publication of USGS, Open-File Report 90-170, containing data through 1988 and authored by Fischer et al. (1990).

Since any kind of regulating structure, such as a dam or reservoir, has the potential to change the streamflow regime, wherever such a structure had been built, that part of the data belonging to the post-regulation period was excluded from the analysis to maintain homogeneity. Also, the probable uptake of water for water treatment plants or input from wastewater treatment facilities has not been taken into consideration.

From the 143 stations initially listed in USGS publications (see Table 1 in Appendix A), nine stations were excluded because their data were not either available or suitable to help calculate a storage delay factor. Three stations with no available data are S75, S121, and S125 (the last two are located in Nebraska). For the remaining six stations, the linear portion of each recession segment was either parallel to the time axis or was too short to define a slope. These stations are: S14, S51, S68, S102, S122, and S127. Figure 4.29 shows the location of these points.

Computer program

Various computer programs have been developed to simulate hydrologic processes. Since most of them are primarily concerned with peak flow, they usually do not go further than base flow separation as far as low flow analysis is concerned. The lack of other comparable programs led the author to use a recently-developed computer program called RECESS, which deals specifically with the recession portion of hydrographs in detail. The USGS has developed this program and its associated model as part of a large regional aquifer system analysis. It was used for the first time for about 200 gaging sites in the Appalachian Valley and Ridge Piedmont Provinces in Virginia (Rutledge, 1991). The unique feature of this program is that it operates in an interactive mode, demanding a considerable amount of user input while being run. It is written in Fortran 77, based upon the mathematical logic described in the preceding chapter under the subheading of the USGS method. The program is capable of analyzing up to 50 selected recession segments for each gaging station from up to 90 years of daily streamflow data. This program was used in the first part of this investigation for two reasons:

1. No alternative program capable of analyzing recessions in detail existed.
2. Application of the program would serve to evaluate the model efficiency and reliability of its results. It would also help explore merits and possible weaknesses of the program.

While it was a suitable program, some modifications were necessary to improve its applicability. Furthermore, it was only able to use input data with a special format, namely z files. Therefore, the daily streamflow data were transformed to z files with the aid of another program, named FORMAT, written in Pascal. Both programs are included in Appendix C.

Model assumptions

The following assumptions are basic to the model:

1. Each individual base flow recession on a logarithmic scale is a linear function of time.
2. For each selected recession segment, the storage delay factor varies linearly with the mean logarithms of daily streamflows (equation 2.17).
3. The master recession equation resulted from integration of equation 2.17. Therefore, it is a half parabola relating time to the second order polynomial expression of logarithm of streamflow (equation 2.18).

Input files

Before the program RECESS could be executed, two input files were provided in its directory as follows:

1. A file called "gaging" was prepared, containing station properties. For each station to be analyzed, one line existed with the following information: (1) latitude and longitude, (2) station number, (3) drainage area in square miles, (4) station file name, and (5) the station name. This file was read automatically by RECESS every time it was run.
2. Since the program RECESS was only able to read mean daily streamflow data with a continuous format, the data files for each station were rearranged prior to its execution to remove headings and spacings, and to fill the blanks. The auxiliary Pascal program FORMAT was utilized to transform the mean daily streamflow data into a readable format for RECESS. Data files in the new format were specified by adding a lowercase z in front of the original file name (e.g., zS10). These were the names which appeared in column 4 of the file "gaging."

Output files

Four output files were established for the program RECESS to record the results.

1. **outrec:** For each time the program was run, a line was added to this file, giving a summary of the session, including input file name, time period, coefficients of the MRC equation, and calculated minimum, median, and maximum storage delay factors (in days per log cycle).
2. **outrecl:** This file contained detailed output of the session, including best-fit regression lines of log Q vs. K and master recession curves. The file was overwritten for each subsequent execution of the program.
3. **outrec2:** The time and log Q were recorded in this file for each analyzed recession segment. These data could be used to generate a master recession curve by matching strip method. This output file is also overwritten whenever the program is run again.
4. **outrec3:** This file records the starting date and the number of selected days in each recession period used during the session. It was not overwritten and provided a sequential, permanent record of analyzed recession periods.

Program initiation

Once the above necessary input and output files are placed in the directory, the program is compiled, loaded, and executed. It initially asks for the name of the file to be read. The user enters the name of the gaging station of interest (without the z). The program reads the file and stores the data in four parallel one-dimensional arrays: (1) streamflow, (2) years, (3) months, and (4) days of the month. The program then asks for the time period of interest. The beginning and ending year is entered by a four-digit number for each. RECESS will also ask for the months of interest. The user specifies the number of months by entering a number from 1 to 12 and then designates each month by its corresponding number (e.g., 1 for January, 2 for February, and so on). Finally, the user is asked for the minimum length of recession periods required for detection.

Obviously, recessions lasting only a few days do not represent the depletion of base flow. On the other hand, the longer the selected period, the smaller the number of detected recession segments. Therefore, a reasonable length of recession should be selected in order to have enough segments for analysis. In this research, recessions lasting at least 10 days since the last peak were chosen. In general, this selection depends on the characteristics of the flow system. In some aquifers the hydraulic conductivity is so low that it may take a considerable amount of time for the recession to become linear or near-linear—and hence to represent the base flow recession. For these cases the user may choose a larger number for the days required to define a period that includes base flow recession. If the required length of recession period never occurs in a particular streamflow record, then that data cannot be used to generate a master recession curve. This was the case for some of the nine previously mentioned stations that were not analyzed.

Zero streamflows

When the user enters the name of the input file, if there is any zero daily streamflow included in this file, the program notifies the user demanding a value to be substituted for zero to make the log-transformation possible. A value of 0.0001 cfs (about 3 ml/sec) was used for this substitution. While 0.0001 cfs is not significantly different from zero, it would solve the problem of logarithm of zero values.

Repetitive process

Once the program receives all the above input from the user, it begins to search through the record to detect recession periods. The repeated steps are described below.

Detection of periods A continuous period is located if (1) its length is greater than or equal to the number specified by the user (10 days in this research) and (2) within this period each pair of consecutive days fits the criterion that the streamflow on the second day is less than or equal to that of the first day. The detected period is then displayed with tabular and graphical options. The graphical option displays the points with the natural logarithm of streamflow on the horizontal axis and time (dates) on the vertical axis. The user views the graph and the tabular display to decide which part exhibits linearity. At this point, if the graph is not good enough to be used, the user can bypass the recession period entirely and advance to the next period.

Selection of segments If the user decides to select part of the graphical display that is linear or near-linear, the segment must be specified by entering its first and last days. The selected segment should be long enough to define a reliable slope; a minimum of five days was chosen for this research. The first three days after a peak were considered as the time for cessation of overland flow and interflow. The segment ended with the last point of the detected recession period that was consistent with the other points in terms of linearity. For consistency, it has been recommended that an identical time interval be selected for all segments. Since this suggestion would eliminate the possibility for many long linear recession segments to be fully included in the analysis, it was not followed.

Calculation of slope After the segment to be analyzed is selected, the program performs a least square linear regression. The program assembles a set of paired data for time and log Q and calculates a best-fit regression equation using time as the dependent variable. The resulting equation, together with the coefficient of determination (R^2) are displayed on the screen. R^2 is used to evaluate the goodness of fit for the straight line that represents the points. A perfect fit is characterized by $R^2 = 1$. The absolute value of the slope of this equation (increment of time per increment of log Q), which is one of its coefficients, is equal to the storage delay factor (K) for the selected segments.

For each selected recession period, the program retains K along with the mean of log Q as paired data for further analysis. After the repetitive steps described above are carried out for all detected recession periods in a data input file, the program yields a set of paired data with K in one column and the corresponding mean log Q in another. This set can have up to 50 rows, corresponding to 50 recession segments. If this limit is reached or if the user chooses the "quit" option, the program stops searching.

Derivation of the MRC's

After the repeated steps are completed for all selected recession segments, the program sorts the resulting data pairs in descending order for log Q and displays a scatter plot of log Q versus K. The user can then eliminate any existing outlier point which is inconsistent with the rest. The user can also evaluate the validity of the basic assumptions of a linear relation between K and log Q upon which the entire method is based. If this assumption does not hold, it may be decided to stop and not use the data set for further analysis. Otherwise, the program proceeds to determine the best-fit regression equation for K as a linear function of log Q using least squares method (equation 2.17). Again the R^2 is calculated by the program to evaluate the goodness of fit.

As was mentioned earlier by integration of equation (2.17), the program derives a second-order polynomial equation for time versus log Q (equation 2.18). This equation is then transformed to a definite integral which represents a master recession curve, by assuming for time = zero, log Q = the maximum observed value in all selected segments. Finally, the program writes the results to the four output files and stops.

Multiple regression

Multiple regression is a powerful method in applied statistics and is broadly used in hydrology to build predictive models. It has already been used in low flow studies, watershed modeling, and flood investigations. While it is potentially very useful, care must be taken to avoid its misuse in terms of underlying assumptions and limitations.

This procedure was used for Iowa streams to develop models for estimation of (1) the discharge which is expected to be equalled or exceeded 84% of the time ($Q_{84\%}$) and (2) seven-day, ten-year low flow ($Q_{7,10}$), as two different response variables. The former is known as *regulated protected low flow,* and the latter has been adopted by the state of Iowa as a basis for stream water quality calculations.

Model building

In statistical modeling the aim is to investigate a functional relationship among pertinent variables to explain the variability in observed data.

Selection of variables

The following four variables were selected as potential explanatory variables for the model:

x_1 = DA = drainage area (in square miles)

x_2 = EL = gaging elevation (in feet above National Geodetic Vertical Datum)

x_3 = Q_m = mean annual streamflow (cfs)

x_4 = SDF = average median storage delay factor $\left(\text{SDF} = \frac{(K_w)_{med} + (K_s)_{med}}{2}\right)$

$(K_w)_{med}$ and $(K_s)_{med}$ are median storage delay factors for winter and summer.

Since annual precipitation was not recorded at all sites, mean annual streamflow, Q_m, which is highly correlated with this parameter, was substituted in Table 3.1. Average median storage delay factor resulted from analysis of recessions in the first phase of this investigation. It serves as an indicator of the overall effect of basin geology. The dependent variables are $y_1 = Q_{84\%}$ and $y_2 = Q_{7,10}$.

Of course many other variables—some even quantifiable—potentially influence low flow in a particular area. However, the intent is to adhere to the *principle of parsimony,* which suggests describing the process with the least possible number of variables while maintaining reasonable accuracy. Table 3.1 gives the variables used in the analysis for all stations.

Table 3.1. Variables used in multiregression models

Name	Independent variables DA	EL	Qm	SDF	Dependent variables Q84%	Q7,10
S1	511.00	850.00	327.00	25.5	73.00	34.00
S2	560.00	829.80	335.00	27.5	74.00	29.00
S3	770.00	660.00	577.00	33.9	173.00	90.00
S4	42.80	850.00	15.90	21.8	2.90	1.50
S5	224.00	664.65	140.00	32.6	33.00	19.00
S6	67500.00	604.84	35470.00	38.9	14660.00	9020.00
S7	177.00	1034.92	125.00	25.5	24.00	9.00
S8	892.00	701.61	487.00	18.4	83.00	27.00
S9	1545.00	634.46	953.00	25.3	207.00	84.00
S10	130.00	612.03	84.90	23.6	17.00	7.40
S11	305.00	895.06	208.00	20.6	46.00	21.00
S12	61.30	728.80	44.90	33.8	7.00	2.80
S13	516.00	666.19	367.00	40.1	162.00	83.00
S15	85600.00	562.68	47420.00	36.8	21100.00	10100.00
S16	95.20	1130.05	66.90	19.3	8.40	4.00
S17	1048.00	882.85	619.00	18.6	69.00	18.00
S18	2330.00	598.81	1547.00	26.3	297.00	103.00
S19	17.80	576.23	15.30	20.4	2.60	0.40
S20	122.00	1180.83	38.20	21.4	1.95	0.30
S21	133.00	1179.33	66.00	18.1	5.20	0.80
S22	429.00	1143.35	215.00	20.3	23.00	6.10
S23	1564.00	853.10	819.00	19.8	99.00	22.00
S24	118.00	849.44	74.30	16.9	4.60	0.39
S25	56.10	788.69	36.30	18.3	2.20	0.21
S26	201.00	781.58	133.00	22.1	13.80	2.90
S27	70.90	786.59	45.00	13.8	2.20	0.00
S28	2455.00	749.82	1156.00	19.7	129.00	45.00
S29	189.00	744.94	124.00	26.3	8.00	0.56
S30	2794.00	720.52	1825.00	23.9	285.00	78.00
S31	25.30	673.72	16.20	13.5	0.30	0.00
S32	98.10	647.48	66.80	16.6	4.20	0.47
S33	3271.00	617.27	1472.00	23.8	218.00	60.00
S34	3.01	663.27	1.77	12.8	0.03	0.00
S35	2.94	678.03	2.44	13.0	0.12	0.00
S36	201.00	637.49	107.00	15.7	1.88	0.20
S37	573.00	633.45	372.00	17.0	18.60	2.50
S38	4293.00	588.16	2993.00	24.2	504.00	138.00
S39	1054.00	973.02	713.00	26.9	186.00	96.00
S40	306.00	973.35	176.00	20.1	25.00	6.50
S41	1661.00	868.26	864.00	20.3	191.00	73.00
S42	846.00	867.54	509.00	17.8	63.00	16.00
S43	300.00	1176.48	162.00	17.4	23.00	3.50
S44	526.00	1069.59	262.00	18.4	27.00	7.30
S45	1330.00	961.17	612.00	18.5	83.00	30.00
S46	1746.00	885.34	980.00	24.4	188.00	69.00

Table 3.1. continued

	Independent variables				Dependent variables	
Name	DA	EL	Qm	SDF	Q84%	Q7,10
S47	347.00	882.44	199.00	33.3	23.00	5.00
S48	303.00	865.03	172.00	16.5	21.00	3.30
S49	5146.00	824.14	3032.00	23.7	676.00	295.00
S50	13.78	931.26	8.98	20.4	0.65	0.07
S52	19.51	905.87	11.90	19.5	1.01	0.00
S53	6510.00	700.47	3476.00	26.6	821.00	353.00
S54	178.00	737.00	134.00	20.5	17.00	0.44
S55	7785.00	581.95	4749.00	33.5	1164.00	501.00
S56	12499.00	538.17	5947.00	30.7	1310.00	555.00
S57	315.00	893.61	163.00	13.8	4.52	0.01
S58	204.00	881.00	130.00	17.7	4.10	0.00
S59	556.00	857.10	301.00	17.3	2.88	0.00
S60	276.00	810.47	190.00	20.9	8.00	0.79
S61	1635.00	685.50	966.00	28.9	76.00	11.00
S62	730.00	651.53	448.00	21.1	28.20	2.60
S63	2890.00	583.00	1350.00	23.1	153.00	23.00
S64	530.00	565.07	376.00	17.2	21.00	2.40
S65	106.00	630.53	66.20	14.4	0.60	0.00
S66	4303.00	521.24	2455.00	19.3	230.00	33.00
S67	119000.00	477.41	62640.00	43.8	26160.00	12000.00
S69	2256.00	1053.54	951.00	33.9	93.00	26.00
S70	1308.00	1038.71	551.00	18.7	31.00	9.50
S71	257.00	1079.30	96.30	15.0	3.06	0.11
S72	4190.00	969.38	1595.00	24.3	131.00	38.00
S73	844.00	989.57	415.00	13.9	22.40	2.30
S74	5452.00	894.00	1986.00	31.7	174.00	41.00
S76	358.00	806.98	212.00	18.1	4.56	0.00
S77	6245.00	773.68	1984.00	22.2	183.00	45.00
S78	80.00	1225.12	42.70	19.5	0.95	0.00
S79	700.00	1132.33	364.00	18.2	21.00	1.80
S80	1619.00	967.09	745.00	19.9	55.00	9.10
S81	24.00	1050.90	10.60	16.6	0.02	0.00
S82	440.00	991.20	193.00	28.7	31.00	13.00
S83	994.00	876.43	468.00	22.9	67.00	26.00
S84	3441.00	841.16	1423.00	21.6	147.00	35.00
S85	78.40	801.04	62.10	15.6	4.20	0.00
S86	9879.00	762.52	4126.00	33.9	391.00	99.00
S87	92.70	795.87	75.20	16.1	3.38	0.00
S88	349.00	788.45	185.00	12.1	4.26	0.04
S89	503.00	776.15	263.00	20.1	12.00	1.50
S90	460.00	769.97	249.00	10.4	4.60	0.82
S91	342.00	759.21	205.00	12.9	4.20	0.36
S92	380.00	734.73	198.00	14.0	2.20	0.56
S93	12479.00	670.91	4229.00	24.7	500.00	122.00
S94	374.00	682.15	218.00	13.1	4.10	0.29

Table 3.1. continued

Name	DA	EL	Qm	SDF	Q84%	Q7,10
	Independent variables				Dependent variables	
S95	13374.00	622.00	4766.00	25.0	564.00	124.00
S96	14038.00	547.36	5159.00	23.3	621.00	143.00
S97	105.00	510.20	70.60	11.7	0.68	0.00
S98	87.70	755.57	49.40	10.2	0.65	0.04
S99	161.00	657.98	97.60	10.2	2.40	0.00
S100	788.00	1331.55	158.00	23.0	10.80	1.60
S101	1592.00	1222.54	419.00	14.9	23.40	1.70
S103	8424.00	1118.90	1039.00	22.7	88.00	19.00
S104	314600.00	1056.98	29580.00	39.9	10540.00	3870.00
S105	65.10	1112.04	17.30	11.7	1.06	0.04
S106	268.00	1269.55	72.40	13.7	1.94	0.00
S107	180.00	1239.40	46.70	11.1	0.90	0.00
S108	886.00	1092.59	224.00	24.1	15.80	2.80
S109	403.00	1045.82	141.00	23.5	21.00	4.00
S110	900.00	1015.00	515.00	22.7	48.00	14.00
S111	426.00	1311.66	251.00	18.3	29.60	0.00
S112	1334.00	1266.84	380.00	25.9	29.00	7.10
S113	1548.00	1223.60	731.00	31.5	69.00	6.40
S114	2500.00	1096.49	831.00	26.7	76.00	15.00
S115	2738.00	1027.02	780.00	26.5	84.00	24.00
S116	39.30	1258.57	15.70	21.9	1.98	0.39
S117	669.00	1085.86	269.00	14.7	37.00	6.90
S118	3526.00	1019.85	1427.00	15.9	183.00	47.00
S119	407.00	1036.53	135.00	24.8	20.00	4.30
S120	871.00	1009.38	333.00	23.0	43.00	6.90
S123	32.00	1222.56	16.60	17.6	0.97	0.01
S124	30.40	936.96	11.20	12.2	1.66	0.00
S126	609.00	1085.83	299.00	21.0	41.00	8.30
S128	1326.00	932.99	595.00	25.9	104.00	29.00
S129	26.00	1261.54	11.10	13.8	0.56	0.00
S130	436.00	1105.83	226.00	19.2	27.00	8.60
S131	894.00	1005.45	400.00	28.0	51.00	15.00
S132	2806.00	894.17	1122.00	19.5	156.00	30.00
S133	49.30	1104.67	29.30	18.4	1.34	0.00
S134	762.00	955.36	355.00	21.2	25.00	6.10
S135	217.00	1095.27	135.00	14.4	5.00	0.57
S136	92.10	1057.51	54.50	14.6	0.54	0.00
S137	52.50	924.70	31.30	9.7	0.13	0.00
S138	701.00	874.04	380.00	13.3	14.80	1.70
S139	104.00	906.26	70.10	9.9	0.96	0.00
S140	182.00	917.90	118.00	8.7	1.48	0.00
S141	168.00	913.70	116.00	8.3	1.86	0.09
S142	549.00	847.92	308.00	9.2	4.50	0.22
S143	708.00	825.68	336.00	11.2	2.90	0.29

Preliminary measures

The data were initially inspected for inaccuracy (gross error and possible transcription error), consistency, and outlying data points. Four data points with unusually high numerical values for dependent variables ($Q_{84\%}$ and $Q_{7,10}$), and for explanatory variables (DA and Q_m) belonging to the stations S6 (Mississippi River at McGreger), S15 (Mississippi River at Clinton), S67 (Mississippi River at Keokuk), and S104 (Missouri River at Sioux City) were initially flagged as outlying, influential, or leverage points. However, careful examinations in further steps proved that they are fairly consistent with the rest of the data and do not influence the fit.

Type of the postulated models

Scatter plots of $y_1 = Q_{84\%}$ and $y_2 = Q_{7,10}$ versus each of four selected regressors were examined (not shown). It was determined that both $Q_{84\%}$ and $Q_{7,10}$ tend to change in a curved fashion with each individual variable. Therefore, usual linear models were not appropriate to establish a functional relationship among variables. Furthermore, attempts to investigate possible linear relationships between $Q_{84\%}$ (and also $Q_{7,10}$) and the reciprocal, square root, and natural logarithm of the explaining variables failed. Even the ln of response variables did not yield a possible linear relationship with any of the four regressors, suggesting that models such as $y = e^{\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \varepsilon}$ are not applicable. However, scatter diagrams of ln $Q_{84\%}$ (and ln $Q_{7,10}$) against the ln of all four explanatory variables, except EL, showed a trend of linearity. Figures 3.1 to 3.8 illustrate the tendency of data points to be linear in logarithmic plots. These plots suggest that the exponential models would be the best choice to define the variabilities.

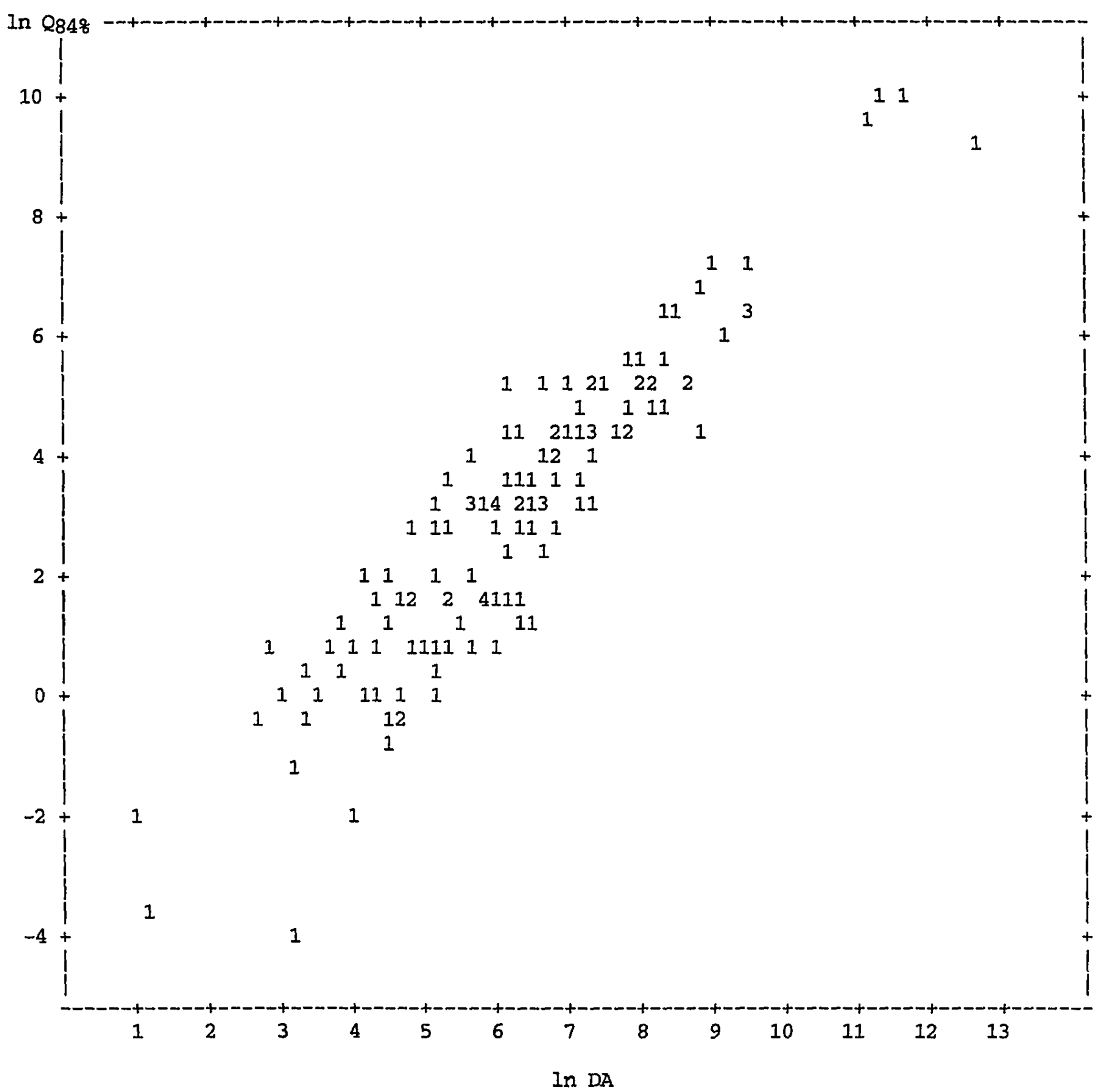

Figure 3.1. Scatter plot of ln $Q_{84\%}$ versus ln DA.

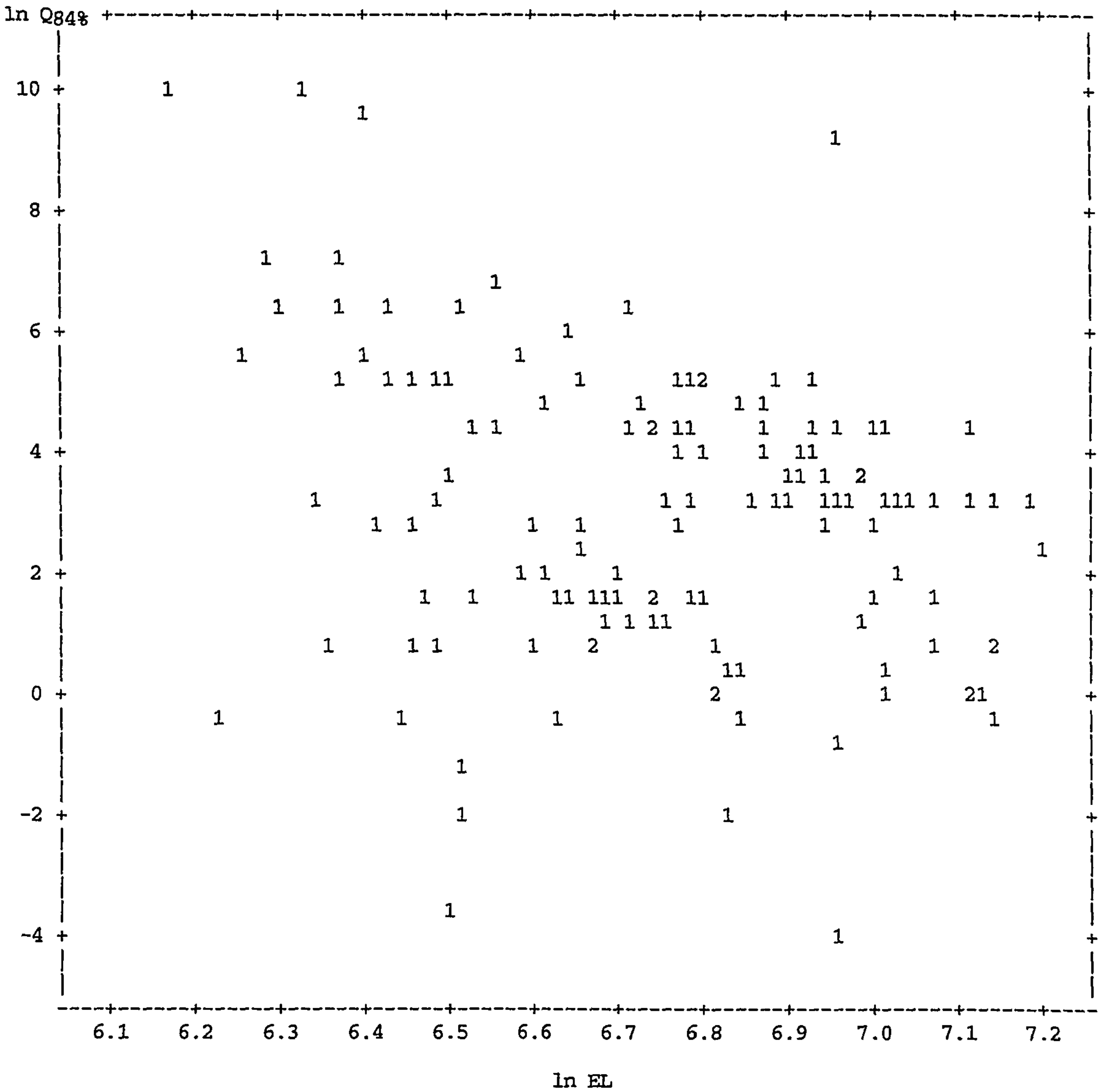

Figure 3.2. Scatter plot of ln $Q_{84\%}$ versus ln EL.

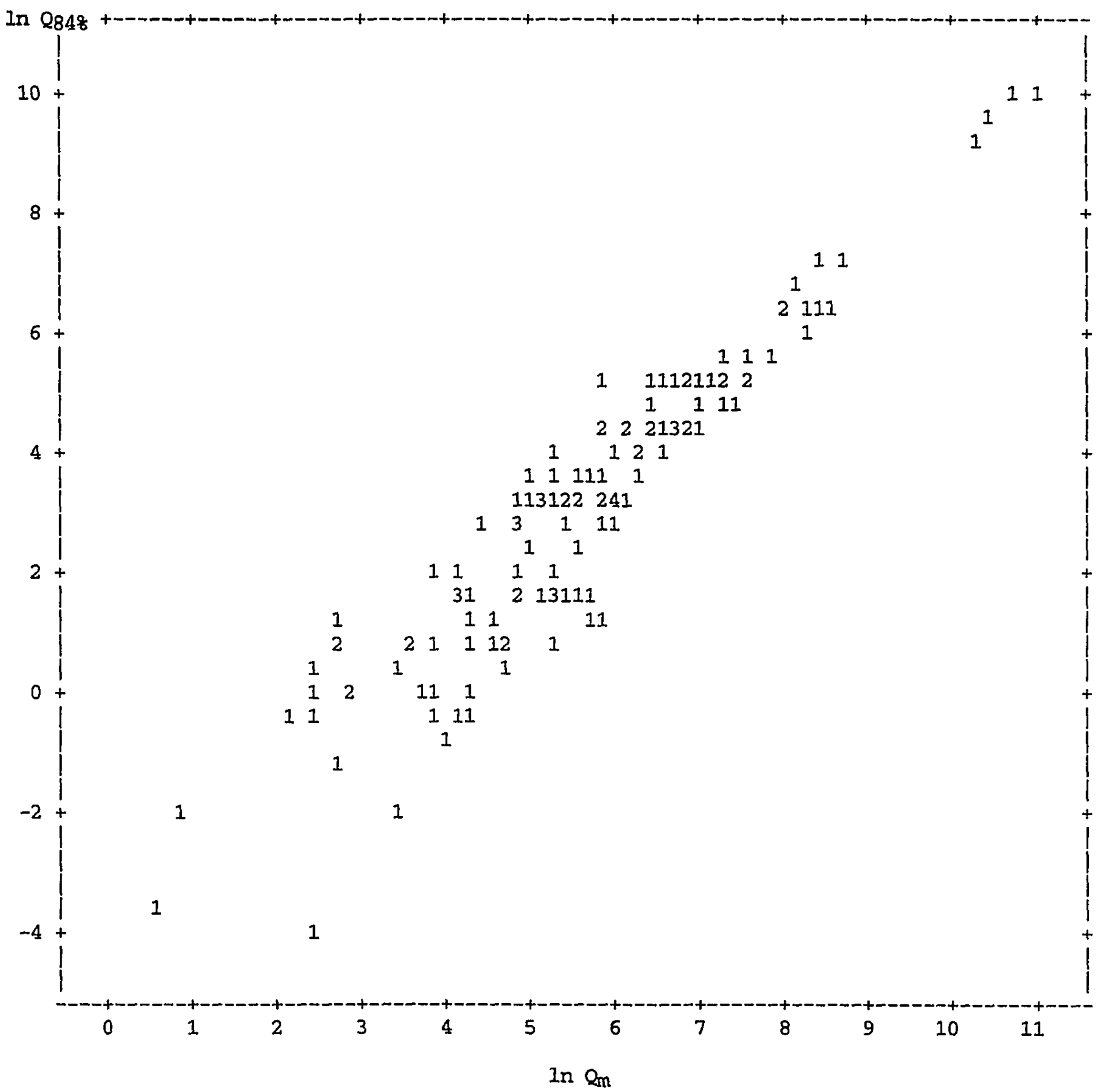

Figure 3.3. Scatter plot of $Q_{84\%}$ versus ln Q_{m}.

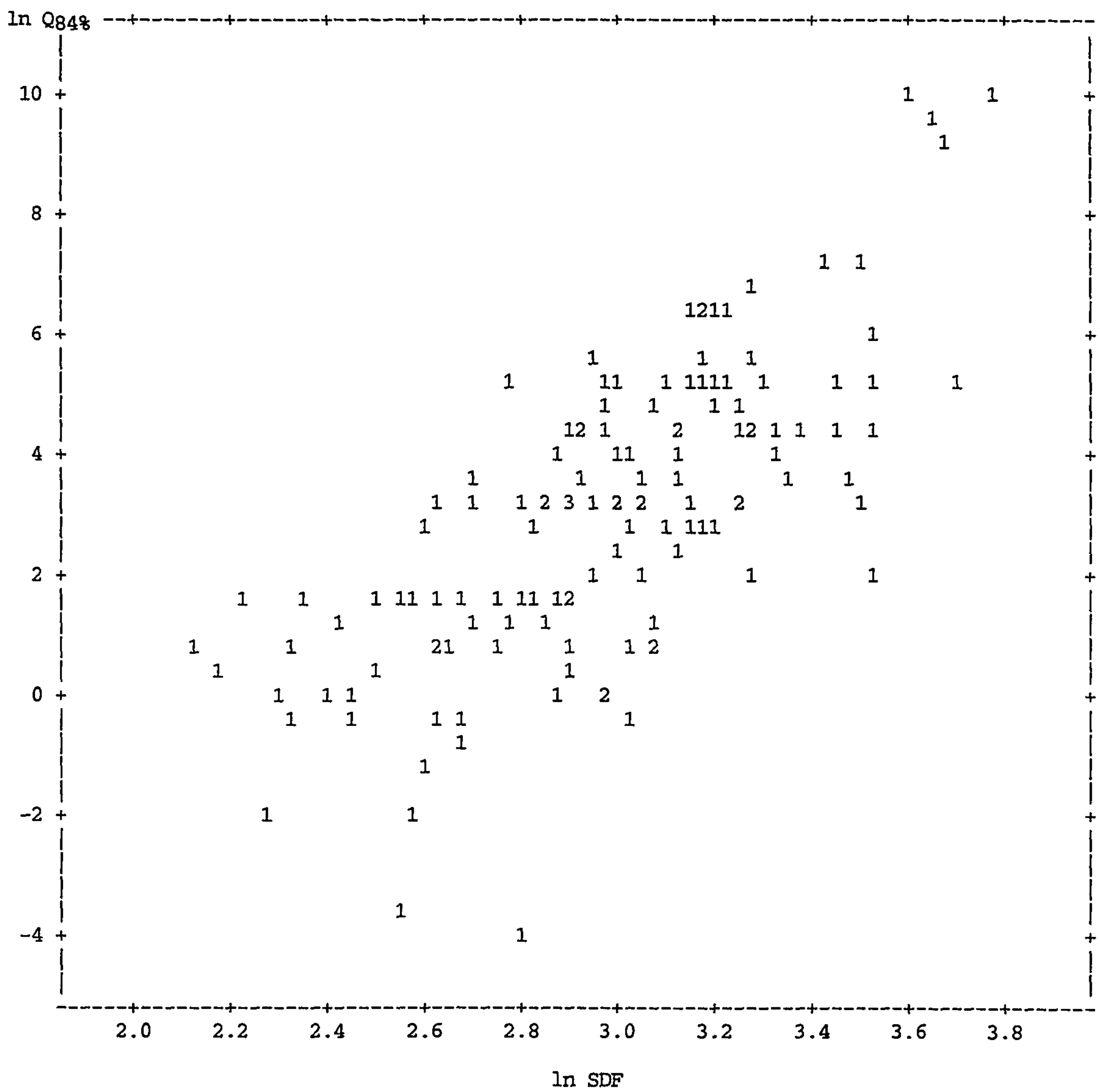

Figure 3.4. Scatter plot of ln $Q_{84\%}$ versus ln SDF.

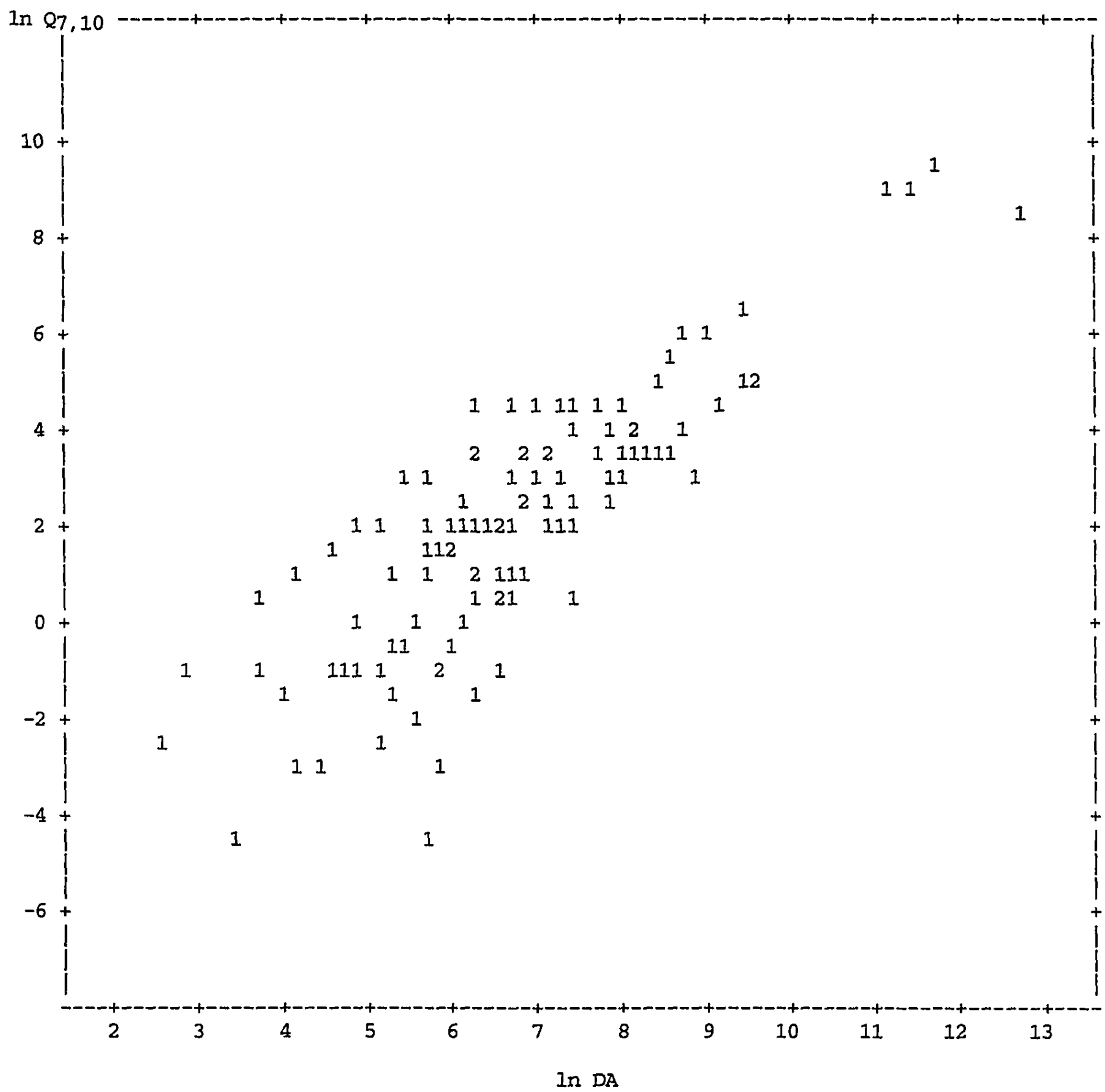

Figure 3.5. Scatter plot of ln $Q_{7,10}$ versus ln DA.

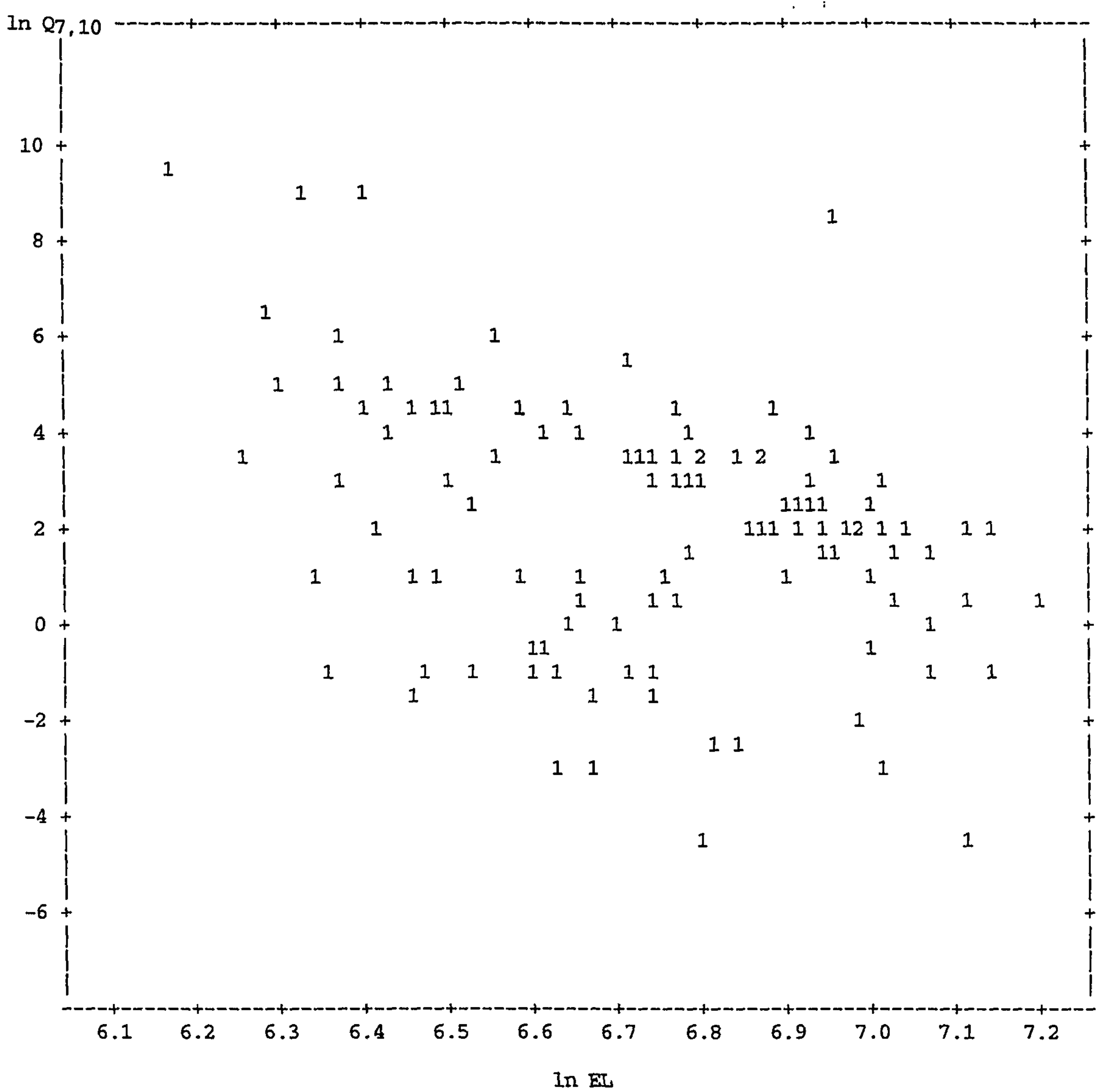

Figure 3.6. Scatter plot of ln $Q_{7,10}$ versus ln EL.

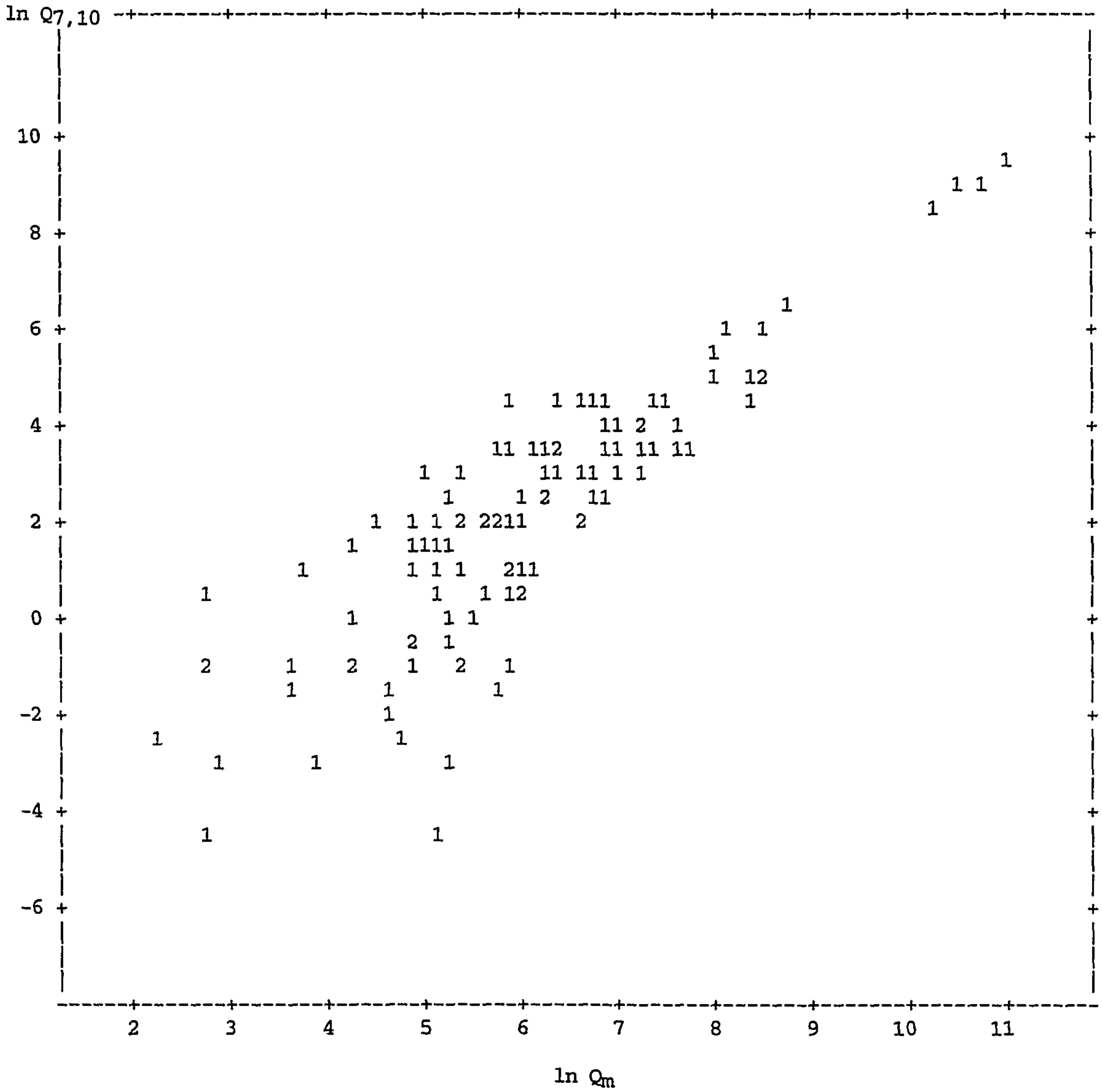

Figure 3.7. Scatter plot of ln $Q_{7,10}$ versus ln Q_m.

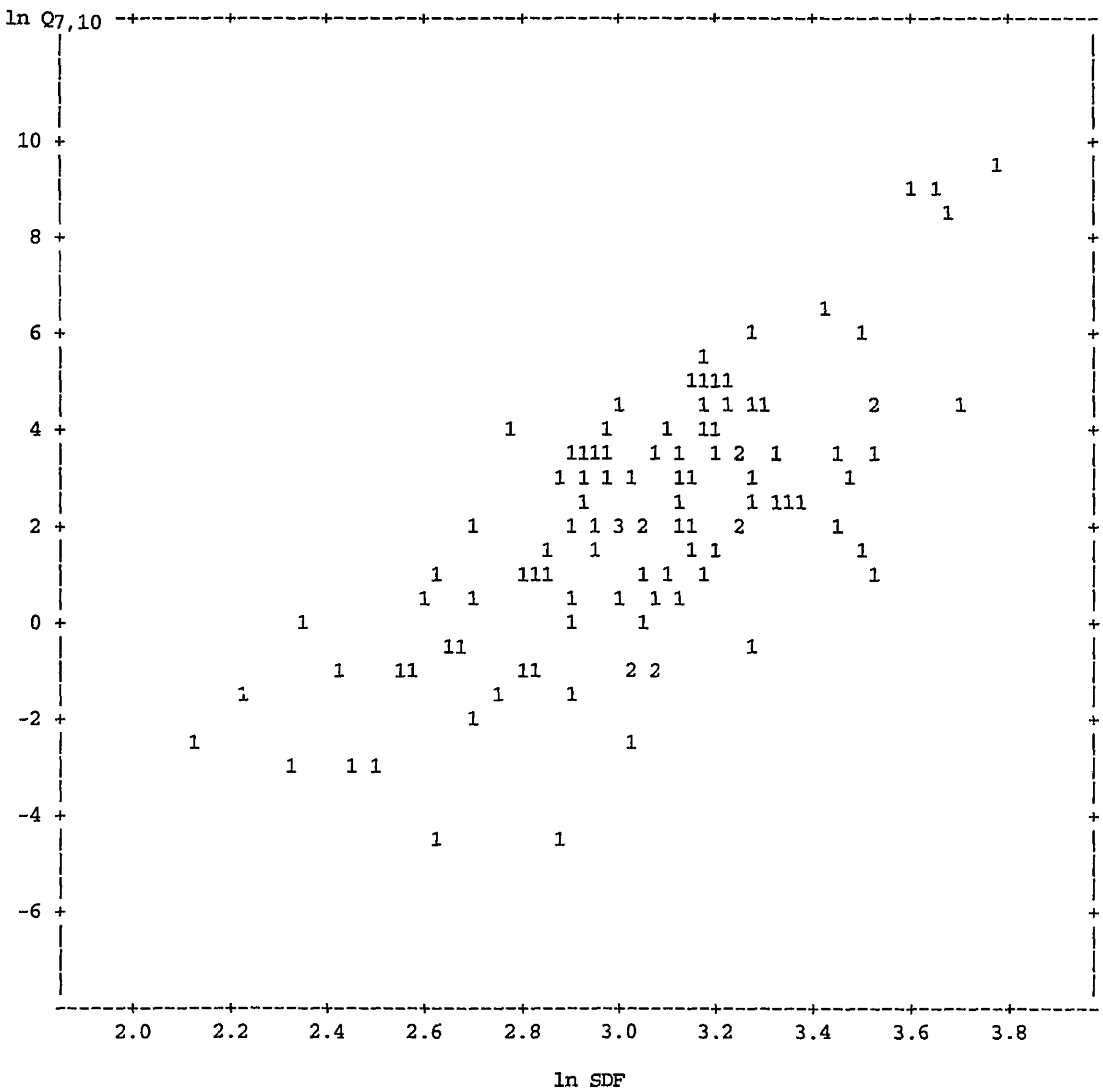

Figure 3.8. Scatter plot of ln $Q_{7,10}$ versus ln SDF.

General models Based upon the appearance of scatter plots shown in Figure 3.1 to 3.8, an exponential model was hypothesized with all four explanatory variables for both response variables $Q_{84\%}$ and $Q_{7,10}$ as follows:

$$(Q_{84\%})_i = \beta_0 \cdot (DA)_i^{\beta_1} \cdot (EL)_i^{\beta_2} \cdot (Q_m)_i^{\beta_3} \cdot (SDF)_i^{\beta_4} \cdot \varepsilon_i \tag{3.1}$$

$$(Q_{7,10})_i = \beta_0' \cdot (DA)_i^{\beta_1'} \cdot (EL)_i^{\beta_2'} \cdot (Q_m)_i^{\beta_3'} \cdot (SDF)_i^{\beta_4'} \cdot \varepsilon_i' \tag{3.2}$$

where ε_i's (and ε_i''s) are random error terms. In these models, terms are multiplied instead of added together, and even the error terms ε_i and ε_i' are multiplicative. The models can be converted into an additive linear form by log-transformation to represent linear regression planes.

In order for the least square method to be applicable, the ln of random error terms should be independent and normally distributed with constant variance and zero expectation. This implies that random error terms should have Log-normal distribution.

To examine whether other types of nonlinear models would fit the data, two more nonlinear additive models were fitted to the data for both $Q_{84\%}$ and $Q_{7,10}$: (1) a second order polynomial model with four second order terms and (2) the same model with all possible interaction terms (cross products). However, the plot of residuals of both models and their unrealistic prediction of negative streamflow suggested their inadequacy. Therefore, they were discarded.

Restricted models Given the fact that the primary objective for low flow modeling is to develop a methodology for estimation of low flow indices at ungaged sites, the constraint is to select those explanatory variables which are known without any previous records. Two variables that have this qualification are drainage area (DA) and datum elevation (EL). The next step, therefore, is to develop models to estimate $Q_{84\%}$ and $Q_{7,10}$ based only upon DA and EL for quick reference, although they may be less accurate. For each response variable, two exponential models were again developed; one includes only DA as the independent variable and the other uses both DA and EL.

For $Q_{84\%}$: $$(Q_{84\%})_i = \beta_0 \cdot (DA)_i^{\beta_1} \cdot \varepsilon_i \qquad (3.3)$$

$$(Q_{84\%})_i = \beta_0 \cdot (DA)_i^{\beta_1} \cdot (EL)_i^{\beta_2} \cdot \varepsilon_i \qquad (3.4)$$

For $Q_{7,10}$: $$(Q_{7,10})_i = \beta_0 \cdot (DA)_i^{\beta_1} \cdot \varepsilon_i \qquad (3.5)$$

$$(Q_{7,10})_i = \beta_0 \cdot (DA)_i^{\beta_1} \cdot (EL)_i^{\beta_2} \cdot \varepsilon_i \qquad (3.6)$$

Subset selection procedures

With four potential explanatory variables, 2^4 different combinations are possible, and 16 possible regression models should therefore be checked to choose the most statistically reliable one. There are a set of procedures that help screen the variables, select the most important ones to be included in the final regression models, and determine the ranking order of their significance. These procedures are classified into two categories, namely forward selection and backward elimination. Another method for selecting the most relevant variables—called stepwise procedure—combines properties from both of the above procedures.

Forward selection (FS) procedure begins with an equation with no variable (only an intercept). Then the variable with the highest R is included in the model, and its regression coefficient is tested to see if it is different from zero with a specified significance level for entry (slentry = 0.05 was assumed). The variable is retained in the equation if it is significantly non-zero, and a search for the second candidate is conducted in the same manner. Once a variable is included, it will not be removed. When the regression coefficient for the variable entering the model is not significant or when all variables have been included in the model, the procedure is terminated.

In backward elimination (BE), a significant level for stay is specified (slstay = 0.10 was assumed). The procedure begins as a first step to compute a model with all variables included and then drops one variable at a time. The first candidate is the one with the lowest F-value—that is, the one whose F is smaller than slstay. The process stops when no more variables can be removed according to the above criterion. Since BE starts with calculation of the full model, it is sometimes preferable to the FS algorithm.

Stepwise procedure, a combination of both FS and BE, is a more commonly used method for screening the variables. Its starting point is similar to the FS, but every time a new variable enters the model, a stepdown iteration is performed to examine the possibility of removing the variables already included. This is the main difference between the two algorithms. For the stepwise method, a value must initially be specified for both slentry and slstay. Selection of different values for these two parameters can change the final structure of the model. For this study, slentry = 0.05 and slstay = 0.10 were specified, but equal values can also be chosen for both.

Residual plots

Residuals, the differences between observed and predicted values, represent the point estimates for random error terms resulting from random fluctuation of actual points about the multiregression surface. They are assumed to be mutually independent and normally distributed with constant variance and zero mean. The assumption of normality can be verified by providing a normal probability plot. The residuals are usually plotted as the ordinate versus values of explanatory variables (x_i's) and/or the predicted values ($\hat{y}_i$'s). Both types of plots were employed in this research. They are expected to display no systematic pattern and to be uniformly distributed on both sides of the zero line. If the form of the postulated model is not correctly selected, the residuals would exhibit a special pattern. The pattern can further be used to determine a more satisfactory model.

It is common to transform the ordinary residuals to a scale-free standardized set, called Student residuals, by dividing each one by its estimated standard error according to the relationship

$$(\varepsilon_i)_s = \frac{\varepsilon_i}{s\sqrt{1-h_{ii}}} \qquad (3.7)$$

where h_{ii} = hat matrix (or leverage value). The standardized residuals have a constant standard deviation of one and zero mean. This standardization makes it more convenient to determine the deviation of the residuals from their mean of zero, since the ordinate is simply scaled by the number of standard deviations from the mean. Also, the residual plots are more visually informative.

Useful information can be extracted from residual plots regarding (1) residual assumptions (Independence, constant variance, and normal distribution), (2) detection of outliers and unusual points, (3) detection of heteroscedasticity, and (4) inadequacy of the model.

Diagnostic measures

Diagnostic measures are the result of considerable advances in the area of regression theory during the past two decades. In fitting a model, these measures help investigators to make necessary corrections and modifications before or even after arriving at the actual form of the final model. Some diagnostic measures utilized in this investigation are briefly mentioned below.

Checking for unusual data points In the early phase of the analysis, diagnostic plots were provided to detect the presence of possible *outlier, influential,* and *leverage* data points. These types of points can potentially distort the results of analysis.

A point was regarded as an outlier if it was inconsistent with the rest of the points and/or its residual was relatively large. An influential point is one whose inclusion in the analysis causes a substantial change in the fitted model in terms of regression coefficients. Among the many quantitative measures of influence that have been proposed, the following three were used to detect influential points in this research: (1) Cook's Distance, (2) DFFIT, and (3) *R* student.

In particular, Cook's *D,* which combines hat matrix and Student residuals, is a widely used measure of influential points given by

$$D = (\frac{h_{ii}}{1-h_{ii}})\frac{(\varepsilon_i)_s^2}{p} \tag{3.8}$$

High leverage points are isolated points which singly dictate the model equation. If a high leverage point is removed, an entirely different regression line would result. A measure of leverage available in SAS is hat matrix, with a suggested cutoff point of 0.60. In this investigation no cutoff point was considered for any of the diagnostic measures. Instead, the relative high-value points were considered within the context of the entire data.

In addition to the above diagnostic tools, the residual plots of a model are also very useful in detecting unusual points and were consulted frequently.

Checking for multicollinearity Multicollinearity refers to the existence of strong linear relationships among the explanatory variables. The absolute lack of multicollinearity—called orthogonality—is desirable, but in practice it is impossible to select several orthogonal explanatory variables. In fact, slight correlation among explanatory variables is not serious enough to affect the model. However, if the variables are strongly interrelated, the problem of multicollinearity would arise. Multicollinearity causes instability in the estimated regression coefficients (β's) and increases standard error of estimate. It also affects the interpretation of the multiregression equation.

A measure of multicollinearity for each explanatory variable called *variance inflation factor* is available in SAS and can be calculated by the following equation

$$VIF(x_i) = \frac{1}{1-R_i^2} \tag{3.9}$$

where R_i^2 is the multiple coefficient of determination that results when x_i is regressed against all the other explanatory variables. When x_i is collinear, R_i^2 is high; therefore, *VIF* would be large. If the variables are orthogonal, $R_i^2 = 0$ and *VIF* would have its minimum value of one. The deviation of *VIF* from one indicates a tendency toward collinearity. The problem of multicollinearity becomes serious when *VIF* approaches two-digit numbers. Multicollinearity is usually checked after the model has been specified.

Evaluating alternate models

The end product of a comprehensive regression analysis is a set of fitted models. Each model has a different number and combination of explanatory variables and needs to be checked in terms of merits and weaknesses. In the past, there were two measures available for comparison and judgement of the models, namely R^2 and standard error of estimate s. However, using a single statistic does not ensure the goodness of fit and several other criteria must be consulted as well. The following are criteria that have concurrently been used in this investigation.

Adjusted R^2

This value refers to a multiple coefficient of determination that has been corrected according to the following equation for the effect of adding more regressors.

$$ADJRSQ = \overline{R}^2 = 1 - \frac{(n-1)(1-R^2)}{n-k} \tag{3.10}$$

The higher $\overline{R}^2$ is desirable.

ANOVA F value

This statistic is a measure of global usefulness of the model. It is used to reject the null hypothesis (H_0: all β's = 0). The higher the F, the more useful the model.

Standard error of estimate

This is a criterion directly related to the confidence interval for prediction. Since a shorter prediction interval is more desirable, a smaller standard error is always preferred.

Mallows C_p

C_p is a measure of total squared error defined as

$$C_p = \frac{SSE_p}{(MSE)^2} + (2p - n) \tag{3.11}$$

where SSE_p = the error sum of squares for a model with p parameters, including the intercept

MSE = mean square errors for the full model

n = number of observations

p = number of parameters

In order for a model to be unbiased, C_p must not only be small but also as close to the p as possible.

The PRESS statistic

PRESS denotes the predicted residual sum of squares of the model, which results from dropping the ith observation (one per time) and estimating the parameters of the model without this point. If the residual for the ith point from this model and from the full model are d_i and e_i respectively,

then $d_i = y_i - \hat{y}_{(i)}$

$e_i = y_i - \hat{y}_i$

It can be proven that d_i is related to e_i according to

$$d_i = \frac{e_i}{1 - h_{ii}}$$

where h_{ii} = the leverage value, which is between zero and one.

The *PRESS* is then defined as

$$\sum_{i-1}^{n} d_i^2 = \sum_{i=1}^{n} \left(\frac{e_i}{1-h_{ii}}\right)^2 \qquad (3.12)$$

PRESS is larger than the usual residual sum of squares, and the model with the smallest difference is always selected.

Model validation

After analysis of residuals and plotting of observed versus predicted values for the response variable prove the adequacy of the model, it must be validated. Validation of a selected model is the final step in the model building process. It involves checking the predictive ability and stability of the model using possibly a different data set; a new data set may be collected for this purpose. A reasonable alternative is to split the existing data into two subsets, excluding one subset from the analysis. The hold-out subset is then regarded as an independent new set and used for model validation. This procedure is more practical and often called *cross validation.* In the present research, data from 13 streams (10% of the total) were initially removed at random from the regression analysis and later used to check the predictive ability of the models. These data belonged to stations S2, S12, S24, S28, S35, S47, S52, S58, S78, S97, S106, S129, and S133.

Program REGRESS

Several small programs in the Statistical Analysis System (SAS) language were written to handle different parts of the multiregression analysis. A comprehensive program called REGRESS, which is a combination of these subprograms, is listed in Appendix C.

This chapter ends with two general remarks regarding regression models. Even if all statistical assumptions hold true, there are certain restrictions still remaining to be considered.

1. The developed models are more appropriate to be used within the range of explanatory variables upon which they are based. Extrapolation of the models would lead to erroneous results and is not recommended.
2. It is assumed that the combined causal factors responsible for an existing situation will continue to operate with the same pattern in the future as they did in the past—an assumption that can neither be justified nor rejected.

CHAPTER 4. RESULTS AND DISCUSSION

In this chapter, the results of the research are presented first, followed by a general discussion.

Results

The application of the methods described in the preceding chapter has yielded the following results which are discussed in the same order as in Chapter 3.

Master Recession Curves (MRC's)

Using the program RECESS for each gaging station, two master recession curves have been developed, each based on half of the records. One MRC, denoted "for winter," evolved from the records of October through March. The other covers the April-to-September data and is designated "for summer." For each gaging station, both MRC's appear on one page for the sake of comparison. Altogether, 134 pairs of MRC's have been developed. Both MRC's and their equations are presented in Appendix B.

Comparison of winter and summer MRC's

By common sense, it is expected that winter MRC's recede over a longer period of time with a gentler slope compared to the summer MRC's on account of relatively negligible evaporation and transpiration from shallow aquifers during the winter. This is a reasonable expectation, and it of course holds true for some of the stations. Considering S33, Iowa River at Iowa City, as an example, it takes about 15 days for streamflow to recede from 3000 to 1000 cfs during winter time (Figure 32.1 in Appendix B); whereas in the summer period, recession of the same range takes place within 12 days (Figure 32.2 in Appendix B). However, there are stations, such as S66, Skunk River at Augusta (Figures 64.1 and 64.2 in Appendix B), in which no significant difference between the slopes of winter and summer MRC's can be seen. This may be attributed to the tendency for lower hydraulic conductivity in winter time, which would compensate for the summer evapotranspiration. If the base flow emanates from a confined aquifer, this inference is not valid because deeper aquifers are not affected by surface evaporation or low temperatures. In Table 4.1, there are 71 stations where $K_w > K_s$ and 63 stations with $K_w < K_s$.

Application of the MRC's

The curves can be used to predict the general behavior of streams during a dry period. For the purpose of clarification, an example is given below:

Suppose that in station S66 (Skunk River at Augusta) during the winter period, and a few days after the peak, the flow rate is 4000 cfs; and the streamflow 10 days later needs to be estimated. Using the equation of the MRC in this station $T = 8.727 (\log Q)^2 - 80.20 (\log Q) + 180.2$

Step 1. Find the corresponding time value for the initial streamflow.

$$T_{initial} = 8.727 (\log 4000)^2 - 80.20 (\log 4000) + 180.2 = 4.546 \text{ days}$$

Step 2. Add ten days to the initial time value.

$$T_{final} = T_{initial} + 10 = 4.546 + 10 = 14.55 \text{ days}$$

Step 3. Plug the value of T_{final} into the MRC equation and solve for Q.

$$14.55 = 8.727 (\log Q_{final})^2 - 80.20 (\log Q_{final}) + 180.2$$

$\log Q_{final} = 3.135$ and 6.055 $\qquad Q_{final} = 1365$ and 1135011 cfs

Mathematically, the MRC equation represents a parabola; thus, it always yields two values for Q. The smaller one, corresponding to the lower limb of the hydrograph, should be selected. Therefore, Q_{final} = 1365 cfs is the answer.

The same procedure can be used graphically to estimate the streamflow using the MRC of S66, illustrated in (Figure 64.1 in Appendix B).

Reliability of the MRC's

To examine the reliability and applicability of the MRC's in real situations, the master recession curves for five stations have been randomly selected and some actual recession segments from these stations plotted on their MRC's in Figures 4.1 to 4.5. These recession segments are represented by squares, together with full lines depicting the master recession curves which have been developed for each station. The initial time for each segment has been adjusted as was shown in the previous example.

Storage delay factors

As a second output of the program RECESS, numerical values were obtained for minimum, median, and maximum storage delay factors, which are defined as the time required for the hydrograph to recede by one log cycle. Only the median storage delay factors were listed. The selection of the median (instead of the mean) stems from the fact that the median is less sensitive to the elimination or inclusion of extreme values. Table 4.1, columns 2 to 4, shows the median storage delay factors for the months of October through March $(K_w)_{\text{med}}$, April through September $(K_s)_{\text{med}}$, and the average values of the two quantities for each stream (SDF). As the Table shows, the calculated SDF's range from 8.3 (for S141) to 43.8 (for S67) days/log cycle .

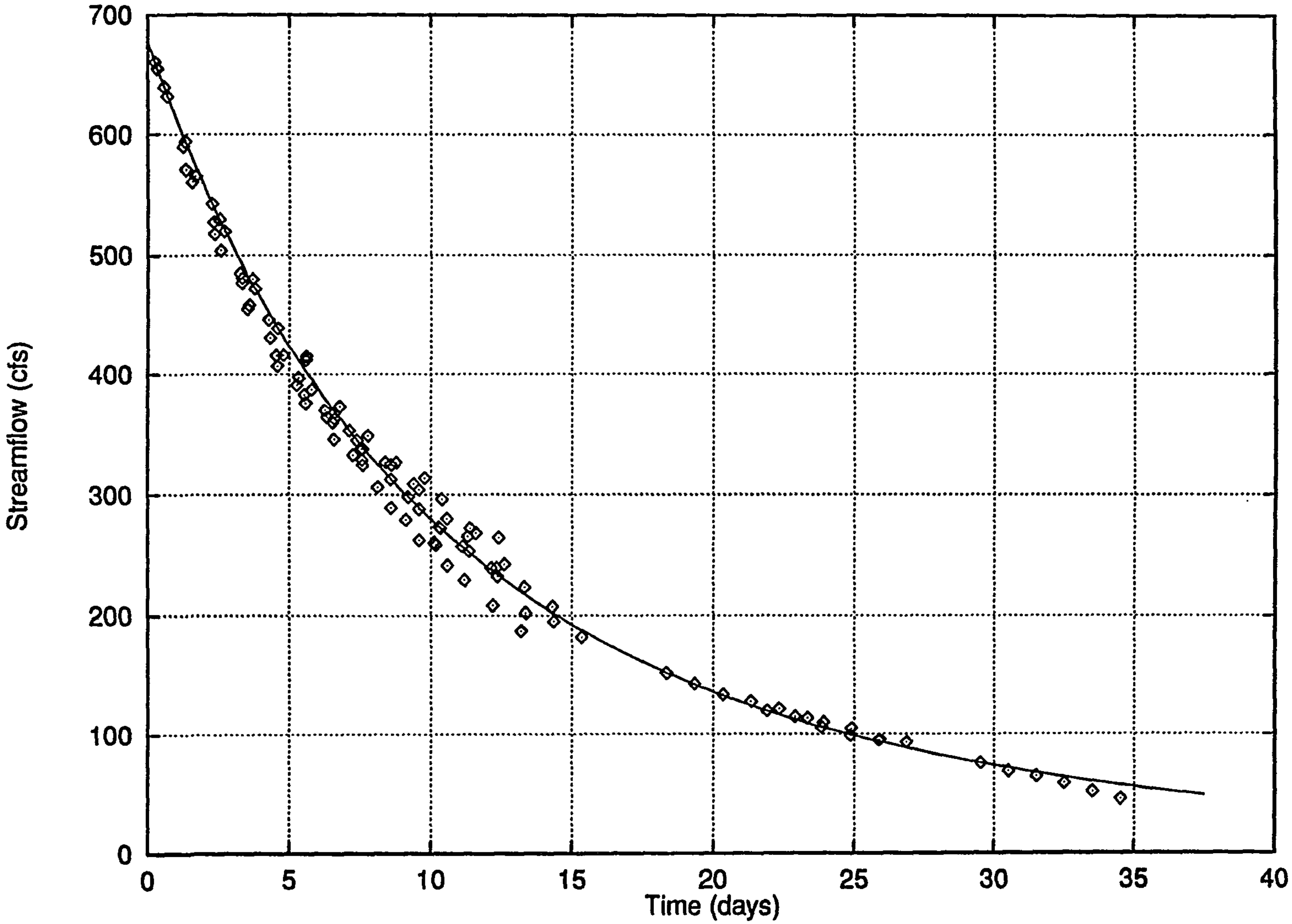

Figure 4.1. Some actual recession segments in station S2 plotted with squares on its MRC

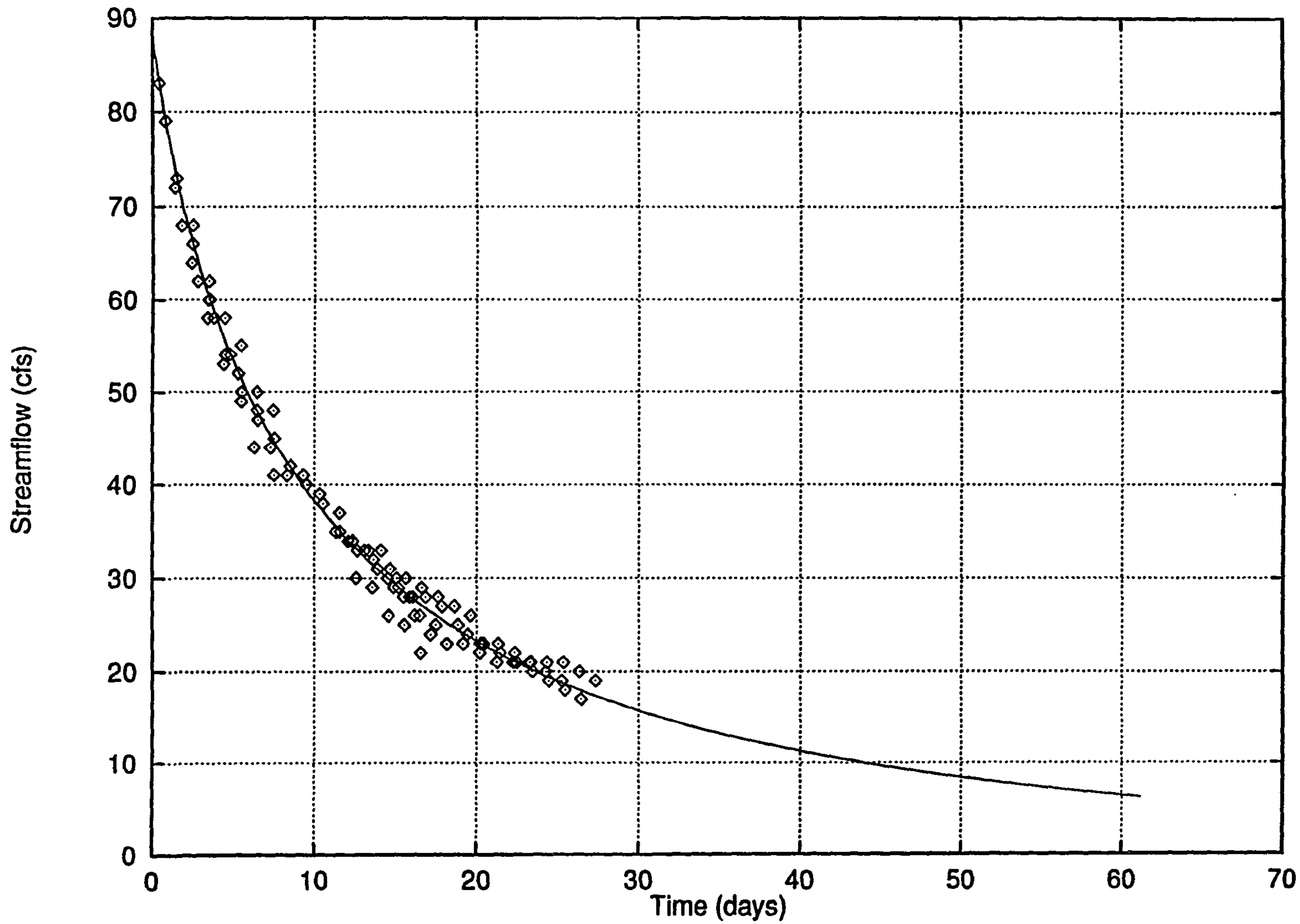

Figure 4.2. Some actual recession segments in station S12 plotted with squares on its MRC

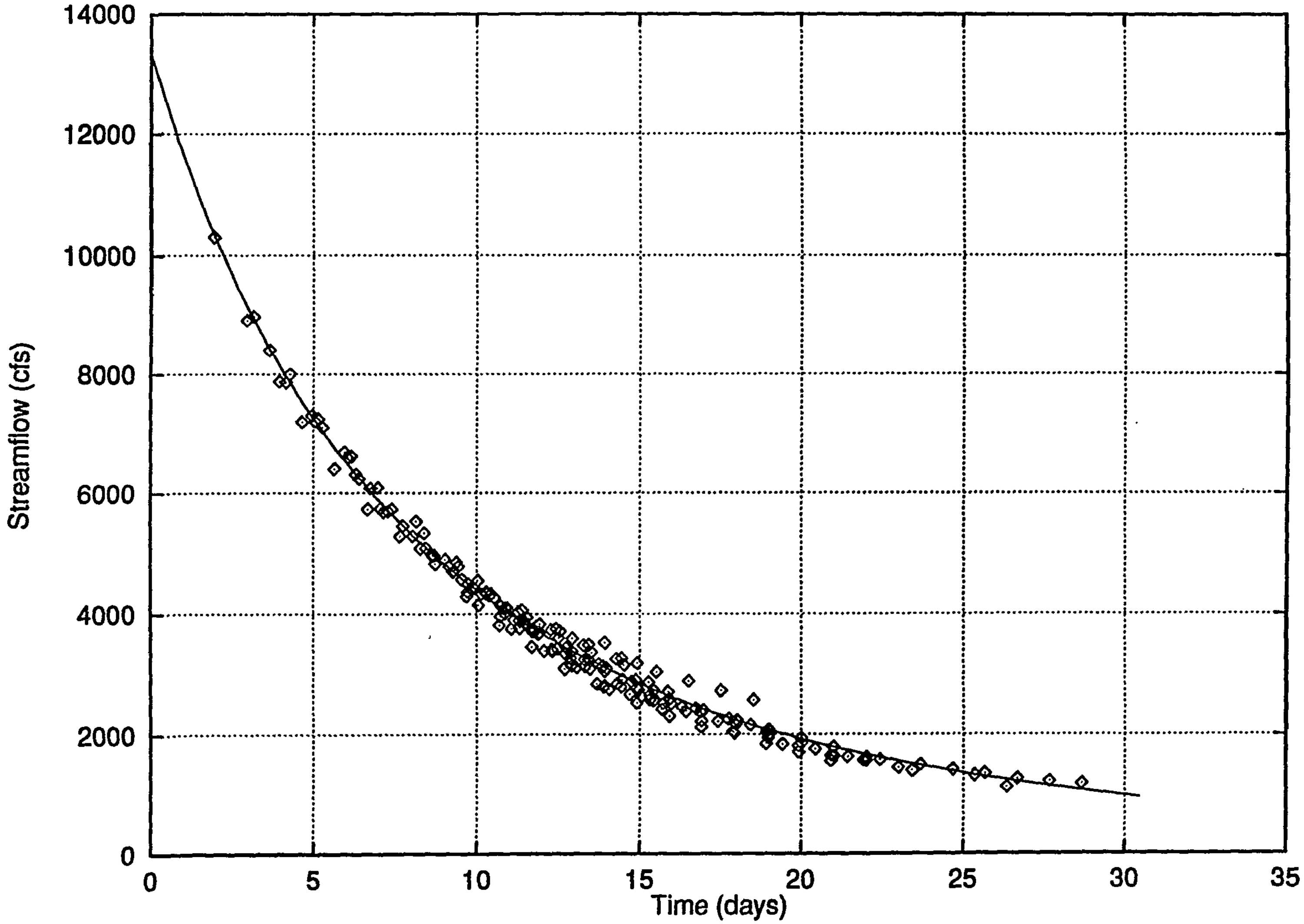

Figure 4.3. Some actual recession segments in station S49 plotted with squares on its MRC

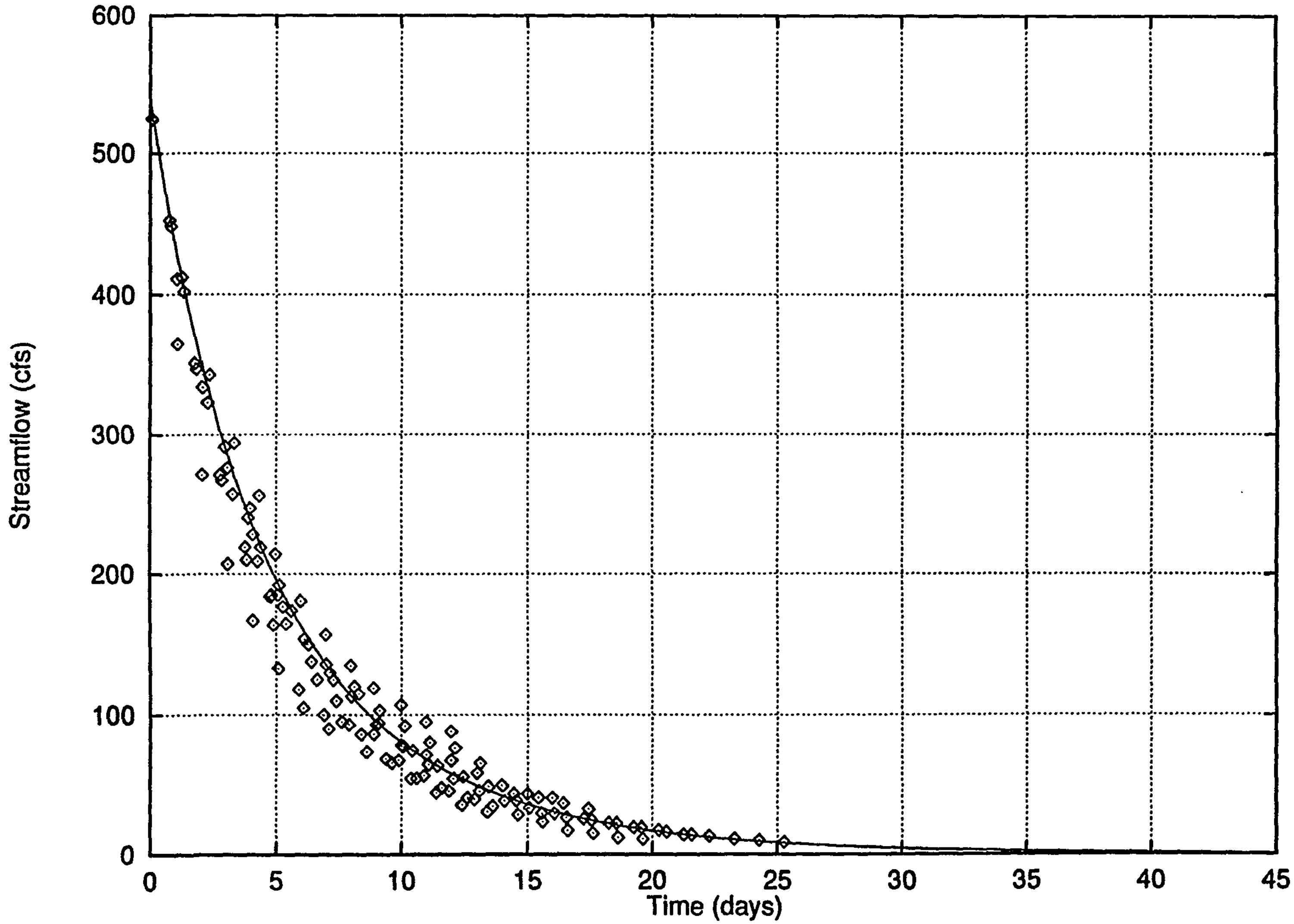

Figure 4.4. Some actual recession segments in station S57 plotted with squares on its MRC

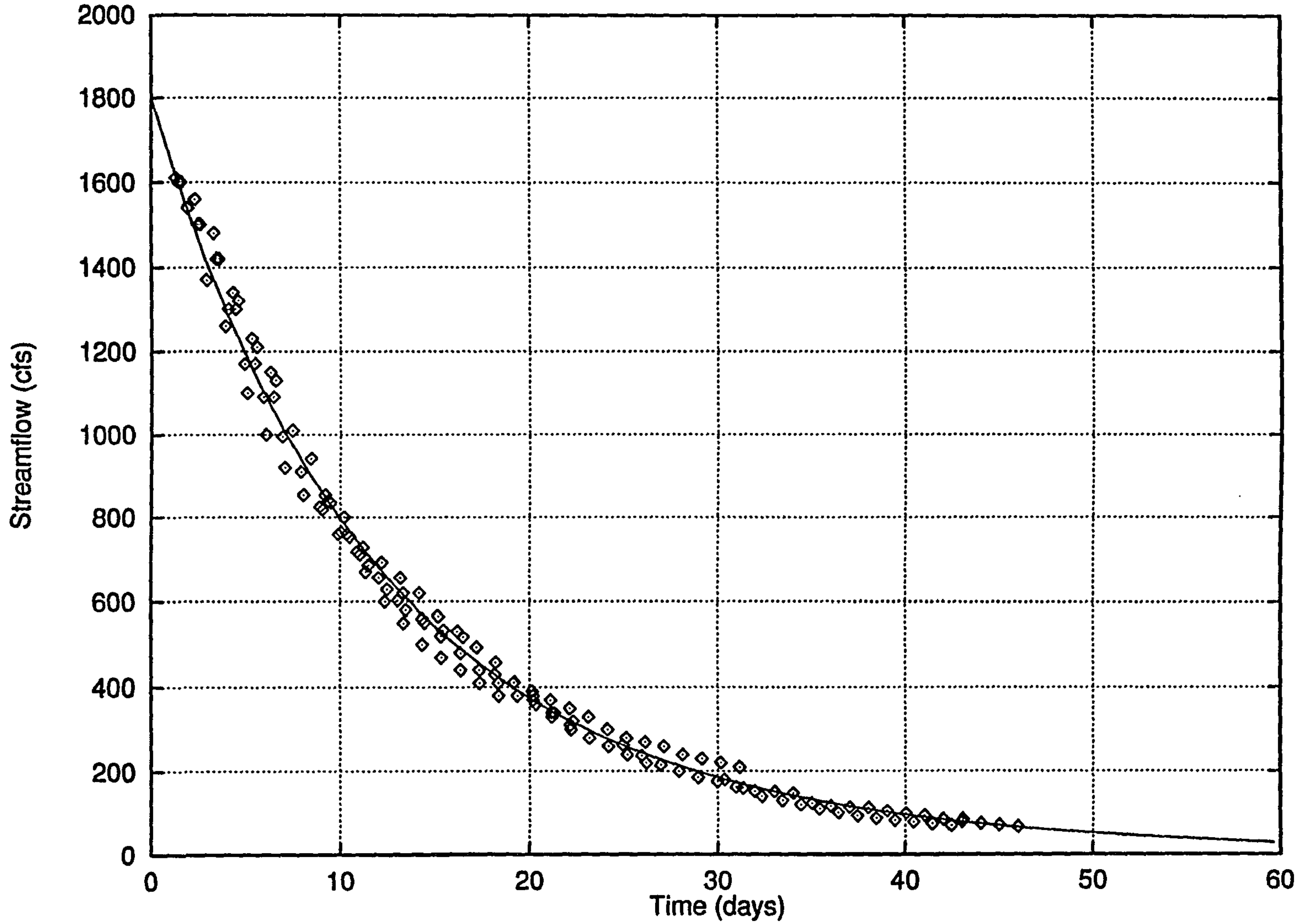

Figure 4.5. Some actual recession segments in station S61 plotted with squares on its MRC

Table 4.1. Calculated parameters relevant to low flow of stream gaging stations in Iowa

ID	Median storage delay factor for winter, summer & mean (days)			$T/(a^2 \cdot S)$[a] (day^{-1})	Low flow indices (csm)							
	Kw	Ks	SDF	0.933/SDF	Qm/A	Q99%/A	Q90%/A	Q84%/A	Q7,2/A	Q7,5/A	Q7,10/A	Q7,20/A
S1	26.5	24.5	25.5	0.037	0.640	0.067	0.119	0.143	0.119	0.082	0.067	0.057
S2	28.1	26.9	27.5	0.034	0.598	0.055	0.113	0.132	0.109	0.070	0.052	0.041
S3	33.0	34.8	33.9	0.028	0.749	0.126	0.190	0.225	0.188	0.136	0.117	0.104
S4	24.1	19.5	21.8	0.043	0.372	0.035	0.056	0.068	0.068	0.044	0.035	0.030
S5	38.0	27.2	32.6	0.029	0.625	0.089	0.125	0.147	0.125	0.098	0.085	0.076
S6	38.1	39.6	38.9	0.024	0.525	0.135	0.193	0.217	0.191	0.151	0.134	0.121
S7	25.6	25.4	25.5	0.037	0.706	0.047	0.107	0.136	0.119	0.068	0.051	0.038
S8	18.6	18.1	18.4	0.051	0.546	0.038	0.076	0.093	0.053	0.036	0.030	0.027
S9	26.2	24.4	25.3	0.037	0.617	0.055	0.106	0.134	0.113	0.070	0.054	0.043
S10	24.0	23.2	23.6	0.040	0.653	0.062	0.108	0.131	0.108	0.070	0.057	0.048
S11	19.8	21.3	20.6	0.046	0.682	0.075	0.128	0.151	0.134	0.089	0.069	0.056
S12	38.2	29.3	33.8	0.028	0.732	0.039	0.088	0.114	0.098	0.059	0.046	0.036
S13	41.2	39.0	40.1	0.023	0.711	0.174	0.281	0.314	0.260	0.192	0.161	0.136
S15	36.5	37.1	36.8	0.025	0.554	0.145	0.220	0.246	0.181	0.137	0.118	0.104
S16	19.6	18.9	19.3	0.049	0.703	0.034	0.075	0.088	0.075	0.051	0.042	0.035
S17	18.5	18.6	18.6	0.050	0.591	0.009	0.047	0.066	0.052	0.025	0.017	0.011
S18	28.3	24.3	26.3	0.035	0.664	0.045	0.097	0.127	0.103	0.060	0.044	0.034
S19	21.9	18.9	20.4	0.046	0.860	0.019	0.101	0.146	0.073	0.036	0.022	0.015
S20	22.5	20.3	21.4	0.044	0.313	0.003	0.011	0.016	0.010	0.004	0.002	0.002
S21	21.1	15.1	18.1	0.052	0.496	0.007	0.029	0.039	0.027	0.011	0.006	0.004
S22	20.0	20.5	20.3	0.046	0.501	0.014	0.042	0.054	0.040	0.021	0.014	0.011
S23	18.3	21.2	19.8	0.047	0.524	0.017	0.047	0.063	0.047	0.022	0.014	0.010
S24	11.1	22.7	16.9	0.055	0.630	0.003	0.024	0.039	0.036	0.008	0.003	0.000
S25	18.4	18.1	18.3	0.051	0.647	0.004	0.020	0.039	0.032	0.009	0.004	0.002
S26	20.6	23.5	22.1	0.042	0.662	0.016	0.044	0.069	0.050	0.022	0.014	0.009
S27	10.1	17.4	13.8	0.068	0.635	0.000	0.014	0.031	0.024	0.003	0.000	0.000
S28	19.8	19.6	19.7	0.047	0.471	0.016	0.037	0.053	0.044	0.025	0.018	0.015

Table 4.1 continued

ID	Median storage delay factor for winter, summer & mean (days)			$T/(a^2 \cdot S)$ (day^{-1})	Low flow indices (csm)							
	Kw	Ks	SDF	0.933/SDF	Qm/A	Q99%/A	Q90%/A	Q84%/A	Q7,2/A	Q7,5/A	Q7,10/A	Q7,20/A
S29	25.7	26.8	26.3	0.036	0.656	0.002	0.025	0.042	0.033	0.008	0.003	0.000
S30	23.4	24.3	23.9	0.039	0.653	0.026	0.075	0.102	0.085	0.042	0.028	0.019
S31	11.7	15.2	13.5	0.070	0.640	0.000	0.004	0.012	0.005	0.000	0.000	0.000
S32	19.4	13.7	16.6	0.057	0.681	0.004	0.025	0.043	0.035	0.010	0.005	0.002
S33	23.8	23.8	23.8	0.039	0.450	0.019	0.048	0.067	0.047	0.025	0.018	0.014
S34	12.4	13.2	12.8	0.073	0.588	0.000	0.003	0.010	0.000	0.000	0.000	0.000
S35	13.0	12.9	13.0	0.072	0.830	0.000	0.010	0.041	0.000	0.000	0.000	0.000
S36	12.7	18.6	15.7	0.060	0.532	0.001	0.005	0.009	0.009	0.002	0.001	0.001
S37	18.6	15.3	17.0	0.055	0.649	0.004	0.019	0.032	0.019	0.007	0.004	0.003
S38	24.8	23.6	24.2	0.039	0.697	0.037	0.082	0.117	0.079	0.044	0.032	0.025
S39	24.8	29.0	26.9	0.035	0.676	0.093	0.152	0.176	0.155	0.111	0.091	0.077
S40	21.4	18.7	20.1	0.047	0.575	0.019	0.062	0.082	0.065	0.032	0.021	0.015
S41	20.1	20.5	20.3	0.046	0.520	0.047	0.095	0.115	0.092	0.057	0.044	0.036
S42	17.4	18.2	17.8	0.052	0.602	0.015	0.053	0.074	0.061	0.028	0.019	0.013
S43	15.9	18.8	17.4	0.054	0.540	0.011	0.060	0.077	0.067	0.027	0.012	0.004
S44	19.2	17.5	18.4	0.051	0.498	0.013	0.038	0.051	0.040	0.021	0.014	0.010
S45	17.5	19.4	18.5	0.051	0.460	0.019	0.050	0.062	0.047	0.029	0.023	0.018
S46	24.3	24.4	24.4	0.038	0.561	0.039	0.087	0.108	0.096	0.054	0.040	0.030
S47	37.0	29.5	33.3	0.028	0.573	0.014	0.049	0.066	0.052	0.022	0.014	0.010
S48	12.4	20.6	16.5	0.057	0.568	0.013	0.053	0.069	0.059	0.022	0.011	0.006
S49	21.9	25.5	23.7	0.039	0.589	0.055	0.107	0.131	0.113	0.073	0.057	0.047
S50	19.8	21.0	20.4	0.046	0.652	0.001	0.031	0.047	0.031	0.012	0.005	0.000
S52	13.2	25.8	19.5	0.048	0.610	0.001	0.034	0.052	0.033	0.011	0.000	0.000
S53	24.7	28.5	26.6	0.035	0.534	0.053	0.102	0.126	0.102	0.067	0.054	0.046
S54	20.0	20.9	20.5	0.046	0.753	0.003	0.056	0.096	0.073	0.011	0.002	0.001
S55	30.7	36.3	33.5	0.028	0.610	0.057	0.117	0.150	0.130	0.083	0.064	0.052
S56	26.5	34.8	30.7	0.030	0.476	0.046	0.085	0.105	0.079	0.054	0.044	0.038

Table 4.1 continued

ID	Median storage delay factor for winter, summer & mean (days)			$T/(a^2 \cdot S)$ (day^{-1})	Low flow indices (csm)							
	Kw	Ks	SDF	0.933/SDF	Qm/A	Q99%/A	Q90%/A	Q84%/A	Q7,2/A	Q7,5/A	Q7,10/A	Q7,20/A
S57	13.9	13.7	13.8	0.068	0.517	0.000	0.007	0.014	0.008	0.001	0.000	0.000
S58	21.2	14.1	17.7	0.053	0.637	0.000	0.007	0.020	0.010	0.001	0.000	0.000
S59	18.7	15.9	17.3	0.054	0.541	0.000	0.001	0.005	0.003	0.000	0.000	0.000
S60	21.5	20.3	20.9	0.045	0.688	0.003	0.018	0.029	0.022	0.006	0.003	0.001
S61	30.1	27.7	28.9	0.032	0.591	0.005	0.032	0.046	0.041	0.013	0.007	0.004
S62	21.2	20.9	21.1	0.044	0.614	0.003	0.023	0.039	0.033	0.009	0.004	0.002
S63	21.2	25.0	23.1	0.040	0.467	0.008	0.036	0.053	0.032	0.013	0.008	0.005
S64	17.0	17.4	17.2	0.054	0.709	0.004	0.023	0.040	0.012	0.006	0.005	0.004
S65	15.4	13.3	14.4	0.065	0.625	0.000	0.001	0.006	0.000	0.000	0.000	0.000
S66	19.0	19.6	19.3	0.048	0.571	0.007	0.033	0.053	0.035	0.013	0.008	0.005
S67	39.4	48.2	43.8	0.021	0.526	0.122	0.193	0.220	0.164	0.119	0.101	0.087
S69	38.5	29.2	33.9	0.028	0.422	0.009	0.030	0.041	0.035	0.017	0.012	0.008
S70	18.3	19.1	18.7	0.050	0.421	0.007	0.018	0.024	0.020	0.011	0.007	0.005
S71	13.6	16.3	15.0	0.063	0.375	0.000	0.006	0.012	0.005	0.001	0.000	0.000
S72	28.7	19.8	24.3	0.039	0.381	0.008	0.023	0.031	0.025	0.013	0.009	0.007
S73	15.0	12.7	13.9	0.068	0.492	0.005	0.018	0.027	0.026	0.008	0.003	0.001
S74	34.4	29.0	31.7	0.029	0.364	0.008	0.023	0.032	0.022	0.011	0.008	0.006
S76	22.2	14.0	18.1	0.052	0.592	0.000	0.005	0.013	0.006	0.001	0.000	0.000
S77	23.7	20.6	22.2	0.042	0.318	0.008	0.021	0.029	0.018	0.010	0.007	0.006
S78	23.0	16.0	19.5	0.048	0.534	0.000	0.006	0.012	0.009	0.000	0.000	0.000
S79	21.2	15.2	18.2	0.051	0.520	0.004	0.020	0.030	0.043	0.010	0.003	0.001
S80	15.8	23.9	19.9	0.047	0.460	0.007	0.024	0.034	0.030	0.011	0.006	0.003
S81	19.9	13.2	16.6	0.057	0.442	0.000	0.000	0.001	0.000	0.000	0.000	0.000
S82	36.7	20.7	28.7	0.033	0.439	0.039	0.059	0.070	0.048	0.034	0.030	0.027
S83	24.0	21.7	22.9	0.041	0.471	0.030	0.055	0.067	0.051	0.032	0.026	0.023
S84	22.3	20.9	21.6	0.043	0.414	0.011	0.031	0.043	0.030	0.015	0.010	0.008
S85	14.0	17.2	15.6	0.060	0.792	0.000	0.026	0.054	0.031	0.006	0.000	0.000

Table 4.1 continued

ID	Median storage delay factor for winter, summer & mean (days)			$T/(a^2 \cdot S)$ (day^{-1})	Low flow indices (csm)							
	Kw	Ks	SDF	0.933/SDF	Qm/A	Q99%/A	Q90%/A	Q84%/A	Q7,2/A	Q7,5/A	Q7,10/A	Q7,20/A
S86	35.8	31.9	33.9	0.028	0.418	0.010	0.029	0.040	0.028	0.014	0.010	0.008
S87	17.6	14.5	16.1	0.058	0.811	0.000	0.023	0.036	0.025	0.008	0.000	0.000
S88	12.7	11.4	12.1	0.078	0.530	0.000	0.005	0.012	0.006	0.001	0.000	0.000
S89	21.6	18.5	20.1	0.047	0.523	0.003	0.015	0.024	0.017	0.006	0.003	0.002
S90	9.8	11.0	10.4	0.090	0.541	0.002	0.007	0.010	0.007	0.003	0.002	0.001
S91	13.0	12.7	12.9	0.073	0.599	0.002	0.007	0.012	0.006	0.002	0.001	0.001
S92	13.4	14.6	14.0	0.067	0.521	0.001	0.004	0.006	0.004	0.002	0.001	0.001
S93	26.9	22.4	24.7	0.038	0.339	0.011	0.029	0.040	0.027	0.014	0.010	0.007
S94	13.9	12.2	13.1	0.072	0.583	0.000	0.006	0.011	0.006	0.002	0.001	0.000
S95	24.7	25.2	25.0	0.037	0.356	0.008	0.030	0.042	0.028	0.014	0.009	0.007
S96	21.0	25.6	23.3	0.040	0.368	0.010	0.032	0.044	0.029	0.015	0.010	0.007
S97	11.6	11.8	11.7	0.080	0.672	0.000	0.000	0.006	0.000	0.000	0.000	0.000
S98	10.8	9.6	10.2	0.091	0.563	0.001	0.005	0.007	0.003	0.001	0.000	0.000
S99	11.3	9.1	10.2	0.091	0.606	0.003	0.009	0.015	0.004	0.002	0.000	0.000
S100	24.6	21.4	23.0	0.041	0.201	0.003	0.009	0.014	0.007	0.003	0.002	0.001
S101	11.0	18.8	14.9	0.063	0.263	0.001	0.009	0.015	0.009	0.003	0.001	0.000
S103	17.1	28.2	22.7	0.041	0.150	0.004	0.010	0.013	0.009	0.004	0.003	0.002
S104	38.5	41.2	39.9	0.023	0.094	0.016	0.028	0.034	0.020	0.014	0.012	0.011
S105	12.9	10.4	11.7	0.080	0.266	0.002	0.011	0.016	0.011	0.002	0.001	0.000
S106	15.7	11.6	13.7	0.069	0.270	0.000	0.004	0.007	0.004	0.000	0.000	0.000
S107	10.9	11.3	11.1	0.084	0.259	0.000	0.002	0.005	0.003	0.000	0.000	0.000
S108	23.6	24.6	24.1	0.039	0.253	0.004	0.012	0.018	0.014	0.005	0.003	0.002
S109	21.2	25.7	23.5	0.040	0.350	0.012	0.042	0.052	0.050	0.018	0.010	0.006
S110	21.3	24.0	22.7	0.041	0.572	0.016	0.042	0.053	0.046	0.022	0.016	0.012
S111	18.8	17.8	18.3	0.051	0.589	0.000	0.047	0.069	0.061	0.019	0.000	0.000
S112	26.0	25.7	25.9	0.036	0.285	0.002	0.016	0.022	0.015	0.007	0.005	0.004
S113	36.6	26.3	31.5	0.030	0.472	0.005	0.026	0.045	0.044	0.010	0.004	0.002

Table 4.1 continued

ID	Median storage delay factor for winter, summer & mean (days)			$T/(a^2 \cdot S)$ (day^{-1})	Low flow indices (csm)							
Kw	Ks	SDF		0.933/SDF	Qm/A	Q99%/A	Q90%/A	Q84%/A	Q7,2/A	Q7,5/A	Q7,10/A	Q7,20/A
S114	24.8	28.6	26.7	0.035	0.332	0.005	0.020	0.030	0.024	0.010	0.006	0.004
S115	21.4	31.6	26.5	0.035	0.285	0.008	0.022	0.031	0.023	0.012	0.009	0.007
S116	19.8	24.0	21.9	0.043	0.399	0.007	0.036	0.050	0.033	0.015	0.010	0.007
S117	12.7	16.7	14.7	0.063	0.402	0.008	0.039	0.055	0.042	0.016	0.010	0.007
S118	15.6	16.2	15.9	0.059	0.405	0.008	0.040	0.052	0.048	0.021	0.013	0.009
S119	21.7	27.9	24.8	0.038	0.332	0.014	0.037	0.049	0.042	0.017	0.011	0.007
S120	19.8	26.1	23.0	0.041	0.382	0.008	0.036	0.049	0.040	0.014	0.008	0.005
S123	16.9	18.2	17.6	0.053	0.519	0.001	0.018	0.030	0.011	0.002	0.000	0.000
S124	12.5	11.9	12.2	0.076	0.368	0.002	0.036	0.055	0.032	0.003	0.000	0.000
S126	18.0	23.9	21.0	0.045	0.491	0.020	0.049	0.067	0.059	0.023	0.014	0.009
S128	22.2	29.5	25.9	0.036	0.449	0.017	0.060	0.078	0.075	0.034	0.022	0.015
S129	11.6	16.0	13.8	0.068	0.427	0.000	0.010	0.022	0.016	0.000	0.000	0.000
S130	18.7	19.7	19.2	0.049	0.518	0.020	0.048	0.062	0.062	0.030	0.020	0.014
S131	31.0	25.0	28.0	0.033	0.447	0.018	0.041	0.057	0.047	0.023	0.017	0.012
S132	20.4	18.6	19.5	0.048	0.400	0.011	0.038	0.056	0.050	0.019	0.011	0.007
S133	19.6	17.2	18.4	0.051	0.594	0.000	0.013	0.027	0.006	0.000	0.000	0.000
S134	23.1	19.3	21.2	0.044	0.466	0.009	0.024	0.033	0.026	0.012	0.008	0.006
S135	14.6	14.1	14.4	0.065	0.622	0.004	0.016	0.023	0.012	0.005	0.003	0.002
S136	15.9	13.3	14.6	0.064	0.592	0.000	0.003	0.006	0.002	0.000	0.000	0.000
S137	10.0	9.3	9.7	0.097	0.596	0.000	0.000	0.002	0.000	0.000	0.000	0.000
S138	12.5	14.1	13.3	0.070	0.542	0.002	0.013	0.021	0.014	0.005	0.002	0.001
S139	11.3	8.5	9.9	0.094	0.674	0.000	0.005	0.009	0.003	0.000	0.000	0.000
S140	9.0	8.3	8.7	0.108	0.648	0.000	0.005	0.008	0.003	0.001	0.000	0.000
S141	8.4	8.2	8.3	0.112	0.690	0.001	0.007	0.011	0.004	0.001	0.001	0.000
S142	10.0	8.3	9.2	0.103	0.561	0.001	0.004	0.008	0.003	0.001	0.000	0.000
S143	11.6	10.7	11.2	0.084	0.475	0.001	0.003	0.004	0.002	0.001	0.000	0.000

[a] T=transmissivity, a=half width of the aquifer, and S=storage coefficient.

In addition to SDF's, Table 4.1 includes several other calculated indices relevant to low flow.

Classification of stations

Based on the calculated SDF's, the gaging stations are classified below:

Class 1	SDF < 10 days/log cycle	5 stations
Class 2	$10 \leq SDF < 20$	62 stations
Class 3	$20 \leq SDF < 30$	52 stations
Class 4	$30 \leq SDF < 40$	13 stations
Class 5	$40 \leq SDF$	2 stations

Low storage delay factors characterize the streams that receive little input from groundwater. Therefore, they recede faster and have smaller low flow indices. There are five stations in the above list which have the lowest SDF's (SDF < 10 days/log cycle). These stations are: S137, S139, S140, S141, and S142. They are all located close to each other in the Missouri River basin in the south central part of the state, southwest of the natural divide between the Missouri and Mississippi River basins, where the streams are generally low-yielding. All five stations are near the divide with very little alluvium present. The underlying bed rock is Pennsylvanian, which is not a good water bearing formation. Other low flow indices for these stations are also small as expected (e.g., $Q_{7,10}$/A is zero csm for all five, and $Q_{84\%}$/A is between 0.002 to 0.011 csm).

On the other extreme, high storage delay factors are theoretically characteristic of streams with good groundwater/surface water connections. They are well-sustained streams with high low flow indices. The two stations with the highest SDF's (SDF > 40 days/log cycle) are S13 (North Fork

Maquoketa River at Fulton) and S67 (Mississippi River at Keokuk). Both stations have the highest low flow indices. In fact, S13 is the station at which both $Q_{84\%}$/A and $Q_{7,10}$/A are maximum (see Table 4.1, columns 9 and 12). It is situated in Jackson County in the eastern part of Iowa, where groundwater is well connected to the streams through solution channels and caves developed in the silurian karst formation. The gaging station S67 at Keokuk is located further downstream on the Mississippi than any other station in Iowa, and the streamflow at this location is greater than anywhere else in the entire state.

The stations in Class 4, (with SDF values between 30 and 40 days/log cycle), exhibit also high low flow indices as compared with Class 1 and 2. Table 4.2 lists the SDF's along with other indices for stations in this Class.

Table 4.2. SDF's and low flow indices for stations in Class 4

No.	Assigned name	SDF day/log cycle	Q84%/A csm	Q7,10/A csm
1	S3	33.9	0.225	0.104
2	S5	32.6	0.147	0.076
3	S6	38.9	0.217	0.121
4	S12	33.8	0.114	0.036
5	S15	36.8	0.246	0.104
6	S47	33.3	0.066	0.010
7	S55	33.5	0.150	0.052
8	S56	30.7	0.105	0.038
9	S69	33.9	0.041	0.008
10	S74	31.7	0.032	0.006
11	S86	33.9	0.040	0.008
12	S104	39.9	0.034	0.011
13	S113	31.5	0.045	0.002

Spatial variability of SDF's

The variability of SDF values follow a general trend with respect to location. Stations on the tributaries are usually in Class 2, and as one moves in the downstream direction the storage delay factors increase. In some occasions, however, the trend is not perfect due to locally influential factors which vary from one station to another. Extent and type of feeding aquifer(s), geology of the drainage basin, and existence of incised channel banks are some examples of such factors. There are regions where a trend is more regular due to a prevalent cause and effect relationship. For instance, the SDF value for S67 is high because this stream drains thick alluvial deposits, and stations in Class 1 are low-yielding points since they are all located within loess hills near the natural divide, with limited alluvial deposits to provide base flow.

In those streams where the basin geology remains relatively uniform, a trend of increasing SDF's from upstream to downstream is observed. Considering several stations along the Des Moines River, for example, this trend is evident, as demonstrated below:

Lizard Creek near Clare (S71), a tributary	SDF = 15.0
Des Moines River at Fort Dodge (S72)	SDF = 24.3
Des Moines River near Stratford (S74)	SDF = 31.7
Des Moines River at Des Moines (S86)	SDF = 33.9

All these stations are located within the Des Moines lobe.

As another example, one can refer to stations along the Raccoon River.

North Raccoon River near Sac City (S79)	SDF = 18.2
North Raccoon River near Jefferson (S80)	SDF = 19.9
Middle Raccoon River at Panora (S82)	SDF = 28.7
South Raccoon River at Redfield (S83)	SDF = 22.9
Raccoon River at van Meter (S84)	SDF = 21.6

The first three stations in this series are situated within the Des Moines lobe and therefore have similar geology, while the last two are not. In short, only if the basin geology remains unchanged do the SDF values increase in the downstream direction.

Comparison of SDF's and the work of Howe

Howe (1968) calculated recession constants (k) for 76 gaging stations in Iowa. The k values obtained by Howe were assumed to be constant for each station, whereas in this investigation a *range* for recession constants was instead calculated. Two stations used by Howe (Spring Valley Creek at Tabor with DA = 7.6 sq miles, and Honey Creek at Russell with DA = 13.2 sq miles) are no longer active. The average k values calculated by Howe for the remaining 74 stations have been converted to storage delay factors (K) according to equation (2.2C) and tabulated in Table 4.3 together with the SDF's obtained in this research, for comparison.

It is important to notice unreasonably high values for SDF's as recession constant values approach unity (k = 0.99 corresponds to SDF = 229 days/log cycle), a matter which was referred to as "bunching" by Martin (1973).

As is evident from Table 4.3, although the k values calculated by Howe vary within a narrow range (0.858 to 0.990), the range of the corresponding storage delay factors (SDF) are unrealistically wide (15 to 229). The reason is that as k takes on values close to one, log k approaches zero; thus SDF values increase drastically according to equation (2.2C).

Columns 4 and 5 in Table 4.3 show large differences between storage delay factors calculated by two different methods. While the range of the SDF's in the present research is between 9.2 and 33.9 days per log cycle, the storage delay factors calculated by Howe range between 13.2 and 229 days per log cycle. The two SDF values are only comparable in a few stations, such as S12, S29,

Table 4.3. Storage delay factors for 74 gaging stations in Iowa as calculated by Howe and in this research

No.	Assigned name	*k*	Calculated SDF (days/log cycle) By Howe	In this research
1	S1	0.980	114	25.5
2	S4	0.940	37.2	21.8
3	S7	0.970	75.6	25.5
4	S9	0.980	114	25.3
5	S12	0.935	34.3	33.8
6	S14	0.980	114	-
7	S16	0.910	24.4	19.3
8	S17	0.980	114	18.6
9	S18	0.980	114	26.3
10	S20	0.943	39.2	21.4
11	S21	0.980	114	18.1
12	S23	0.967	68.6	19.8
13	S24	0.960	56.4	16.9
14	S26	0.955	50.0	22.1
15	S27	0.883	18.5	13.8
16	S28	0.973	84.1	19.7
17	S29	0.920	27.6	26.3
18	S30	0.980	114	23.9
19	S31	0.887	19.2	13.5
20	S32	0.930	31.7	16.6
21	S33	0.970	75.6	23.8
22	S37	0.928	30.8	17.0
23	S41	0.980	114	20.3
24	S42	0.972	81.1	17.8
25	S43	0.910	24.4	17.4
26	S44	0.960	56.4	18.4
27	S47	0.965	64.6	33.3
28	S48	0.973	84.1	16.5
29	S56	0.960	56.4	30.7
30	S57	0.910	24.4	13.8
31	S60	0.960	56.4	20.9
32	S61	0.950	44.6	28.9
33	S62	0.940	37.2	21.1
34	S65	0.860	15.3	14.4
35	S66	0.957	52.4	19.3
36	S73	0.940	37.2	13.9
37	S77	0.957	52.4	22.2
38	S78	0.930	31.7	19.5
39	S80	0.965	64.6	19.9
40	S81	0.898	21.4	16.6
41	S82	0.970	75.6	28.7
42	S83	0.970	75.6	22.9
43	S84	0.970	75.6	21.6
44	S86	0.950	44.9	33.9

Table 4.3 continued

No.	Assigned name	*k*	Calculated SDF (days/log cycle) By Howe	In this research
45	S88	0.930	31.7	12.1
46	S89	0.960	56.4	20.1
47	S90	0.967	68.6	10.4
48	S92	0.970	75.6	14.0
49	S93	0.967	68.6	24.7
50	S96	0.970	75.6	23.3
51	S101	0.960	56.4	14.9
52	S102	0.907	23.6	-
53	S105	0.860	15.3	11.7
54	S108	0.963	61.1	24.1
55	S112	0.940	37.2	25.9
56	S114	0.950	44.9	26.7
57	S115	0.973	84.1	26.5
58	S116	0.960	56.4	21.9
59	S117	0.980	114	14.7
60	S120	0.960	56.4	23.0
61	S124	0.900	21.9	12.2
62	S126	0.980	114	21.0
63	S128	0.955	50.0	25.9
64	S129	0.950	44.9	13.8
65	S130	0.970	75.6	19.2
66	S131	0.962	59.4	28.0
67	S132	0.965	64.6	19.5
68	S133	0.910	24.4	18.4
69	S134	0.940	37.2	21.1
70	S136	0.840	13.2	14.6
71	S138	0.947	42.3	13.3
72	S139	0.990	229	9.9
73	S142	0.880	18.0	9.2
74	S143	0.858	15.0	11.2

and S65. However, Howe's data in column 4 are much higher for almost all the other stations (with the exception of S136).

The contrast is more noticeable by looking at the station S139 where the SDF calculated by Howe is 229 days (about 7.5 months), whereas the value calculated in this research is 9.9 days.

In general, no sign of a regular trend is evident in the data. In order to visualize the comparison and contrast of the two groups of the data, 11 stations in column 4 which have storage delay factors of more than 100 are eliminated and for the rest of the stations a plot of storage delay factors calculated by Howe versus those calculated in this research is given in Figure 4.6.

Diffusivity of the aquifer(s)

A lumped parameter T/a^2S, which includes the diffusivity of aquifer(s) providing base flow to the streams, has been calculated by equation (2.15) according to the method used by Bevans (1986) and reported in column 5 of Table 4.1. Equation (2.15) relates the characteristics of the contributing aquifer(s) to the slope of the base flow recession curve (or to the storage delay factor) of each stream.

T = transmissivity of the aquifer(s) in ft^2/day (or m^2/day)

S = storage coefficient of the aquifer(s)

T/S = hydraulic diffusivity in day^{-1}

a = distance between the station and groundwater divide in ft (or m)

In fact, a is a function of the width of the aquifer, and it is difficult to determine its value for each station. However, according to Bevans (1986), a corresponds to the drainage basin divide for a stream-aquifer system.

The lumped parameter ranges between 0.021 and 0.112 day^{-1}. Although this parameter consists of three variables and is difficult to interpret, it was calculated solely for the sake of comparison with similar parameters which were calculated for 18 selected streams in Eastern Kansas by Bevans (1986). His data range between 0.012 to 0.049 day^{-1}.

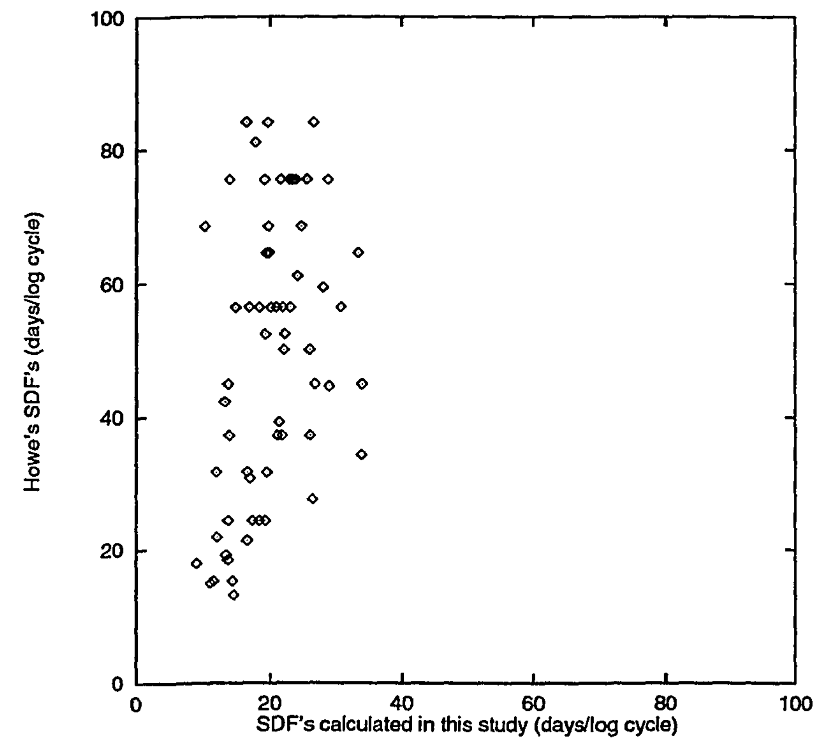

Figure4.6. Scatter plot of storage delay factors calculated by Howe versus those calculated in this research

The application of multiple regression principles to the data yielded several predictive models for $y_1 = Q_{84\%}$ and $y_2 = Q_{7,10}$, each one taking a different number of explanatory variables into consideration.

Useful Statistics

As a first step in analysis, it would be helpful to obtain a general idea about the data by looking at the range, variability, and extreme values of the variables. This would later aid in the selection of an appropriate type for the model. Table 4.4 shows these statistics for all variables. Table 4.5 contains the same information for the natural logarithm of variables.

Table 4.4. Informative statistics about variables

Variable	N	Mean	Std Dev.	Sum	Minimum	Maximum
Q84%	134	632.19836	3254.11702	84715	0.02	26160
Q7,10	134	290.79754	1579.83379	38967	0.00	12000
DA	134	5831.13612	30248	781372	2.94	314600
EL	134	878.57903	206.26410	117730	477.41	1331.55
Qm	134	1958.41560	7761.62128	262428	1.77	62640
SDF	134	20.77015	7.12834	2783.2	8.30	43.80

Table 4.5. Statistics about natural logarithms of variables

Variable	N	Mean	Std Dev.	Sum	Minimum	Maximum
ln Q84%	134	2.97568	2.49777	398.74088	-3.91202	10.17199
ln Q7,10	109[a]	1.99254	2.72928	217.18647	-4.60517	9.39266
ln DA	134	6.27077	1.93500	840.28261	1.07841	12.65906
ln EL	134	6.75005	0.24130	904.50706	6.16838	7.19410
ln Qm	134	5.58349	1.82785	748.18699	0.57098	11.04516
ln SDF	134	2.97537	0.34613	398.69899	2.11626	3.77963

[a] SAS treats the zero points as missing data

Correlation matrices

In order to show how the explanatory variables individually and jointly affect the response variable, the correlation structure among variables was studied. The correlation matrices are shown in Tables 4.6 and 4.7 below.

Table 4.6. Correlation matrix for $Q_{84\%}$ with Prob > |R| under Ho: Rho=0

	ln $Q_{84\%}$	ln DA	ln EL	ln Q_m	ln SDF
ln $Q_{84\%}$	1.00000 0.0				
ln DA	0.92065 0.0001	1.00000 0.0			
ln EL	-0.27370 0.0014	-0.21631 0.0121	1.00000 0.0		
ln Q_m	0.93667 0.0001	0.98609 0.0001	-0.31084 0.0003	1.00000 0.0	
ln SDF	0.72505 0.0001	0.56287 0.0001	-0.14799 0.0879	0.56758 0.0001	1.00000 0.0

Table 4.7. Correlation matrix for $Q_{7,10}$ with Prob > |R| under Ho: Rho=0

	ln $Q_{7,10}$	ln DA	ln EL	ln Q_m	ln SDF
ln $Q_{7,10}$	1.00000 0.0 109				
ln DA	0.83514 0.0001 109	1.00000 0.0 134			
ln EL	-0.34285 0.0003 109	-0.21631 0.0121 134	1.00000 0.0 134		
ln Q_m	0.86052 0.0001 109	0.98609 0.0001 134	-0.31084 0.0003 134	1.00000 0.0 134	
ln SDF	0.72284 0.0001 109	0.56287 0.0001 134	-0.14799 0.0879 134	0.56758 0.0001 134	1.00000 0.0 134

Although correlation matrices of other algebraic functions of the explanatory variables, such as $1/x_i$'s, x_i^2's, and their cross products, were studied while searching for the best type of model, they are not mentioned here. This is because the possible second order and interactive models obtained from these data proved faulty due to poor predictive ability. They predicted unrealistic negative values for response variables and therefore, were discarded from further analysis.

Tables 4.6 and 4.7 show the correlation existed not only between response and explanatory variables, but among explanatory variables as well. The four explanatory variables in descending order of their correlation coefficients with ln $Q_{84\%}$ can be listed as ln Q_{m} (R = 0.937), ln DA (R = 0.921), ln SDF (R = 0.725), and ln EL (R = -0.274). Likewise, the same variables in decreasing order of their correlation coefficients with the other response variable, ln $Q_{7,10}$, would be ranked as ln Q_{m}(R = 0.861), ln DA (R = 0.835), ln SDF (R = 0.723), and ln EL (R = -0.343). Therefore, it is reasonable to expect these variables to be included in the models in the same order of preference. One additional important point that should be noticed is the presence of high dependency between two of the explanatory variables, ln DA and ln Q_{m} (R = 0.986), suggesting possible collinearity problem if they were both picked after the screening process.

Models for $Q_{84\%}$

For $y_1 = Q_{84\%}$ as a response variable, different exponential models have been proposed. These models can be divided into two categories: (1) general models and (2) restricted models. The word *general* is used within the context of nonrestriction in terms of the selection among four available explanatory variables, whereas restricted models contain only those explanatory variables that are readily available for all ungaged sites. The independent variables which satisfy this condition are drainage area (DA) and datum elevation (EL).

General models To explain the model building process, the approach that has been taken to obtain the final results is discussed in more detail for the first model. The remaining models are mentioned briefly.

After it was realized that the exponential model was the best choice, the next step was to use all 134 stations' data points to estimate the multiregression coefficients (β's) with this model. It must then be decided how many and which variables should be included in the model. While the stepwise procedure will later answer this question through its screening ability, a good insight can be gained by looking at Table 4.8.

Table 4.8. R-square and *Cp* for possible regression models for ln $Q_{84\%}$ (N = 134)

Number of variables in the Model	R-square	Cp	Variables in Model
1	0.87735290	109.32426	ln Qm
1	0.84759992	167.38198	ln DA
1	0.52569515	795.52257	ln SDF
1	0.07491404	1675	ln EL
2	0.93253957	3.63717	ln Qm ln SDF
2	0.91022405	47.18199	ln DA ln SDF
2	0.87768983	110.66681	ln EL ln Qm
2	0.87767730	110.69125	ln DA ln Qm
2	0.85343139	158.00289	ln DA ln EL
2	0.55400613	742.27866	ln EL ln SDF
3	0.93309096	4.56123	ln DA ln Qm ln SDF
3	0.93263611	5.44880	ln EL ln Qm ln SDF
3	0.91488421	40.08850	ln DA ln EL ln SDF
3	0.87889446	110.31618	ln DA ln EL ln Qm
4	0.93389105	5.00000	ln DA ln EL ln Qm ln SDF

This table gives the R^2 and Cp for all possible combinations of explanatory variables which have the potential to be included in the model. It is notable that the best one-variable model should include ln Q_m with $R^2 = 0.877$ and $Cp = 109.32$, and the best two-variable model must include ln Q_m and ln SDF with $R^2 = 0.933$ and $Cp = 3.64$. Also, the inclusion of the other two variables does not improve the models significantly.

Part of the output resulting from application of the exponential model fitted by stepwise procedure to the complete data set is given in Table 4.9.

Table 4.9. Analysis of variance and parameter estimates for ln $Q_{84\%}$ (N=134)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	773.79176	386.89588	905.440	0.0001
Error	131	55.97652	0.42730		
C Total	133	829.76829			

Root MSE	0.65368	R-square	0.9325
Dep Mean	2.97568	Adj R-sq	0.9315
C.V.	21.96754		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|	Variance Inflation
INTERCEP	1	-9.061799	0.50633126	-17.897	0.0001	0.00000000
ln Q_m	1	1.058665	0.03766460	28.108	0.0001	1.47524596
ln SDF	1	2.059053	0.19890208	10.352	0.0001	1.47524596

The fitted model for $y_1 = Q_{84\%}$ is:

$$\ln Q_{84\%} = -9.062 + 1.059 \ln Q_m + 2.059 \ln \text{SDF} \quad (4.1)$$

The R^2 is 0.933, the mean square error (MSE) is 0.427, with standard error of estimate $s_e = 0.65$ and a high F value of 905.44 in the analysis of variance (ANOVA) table. The variance inflation factor is small (1.475) for both ln Q_m

and ln SDF indicating no collinearity between the two explanantory variables. The regression results are given in Table 4.10.

The table shows the actual and predicted values for ln $Q_{84\%}$, together with standard error of estimates, and 95% confidence intervals for both mean and predicted values. Residuals, the difference between actual and predicted values, are also included in the last column. A quick examination of this table gives a preliminary indication of goodness of fit. There are many points with the same integer for actual and predicted values; some even have the same value to one decimal place. Figures 4.7 to 4.9 give a graphical view of the residuals. A possible outlier point is shown with a zero character (0). For an unbiased model the residuals are expected to be evenly distributed within the three standard deviations on both sides of the zero line.

Table 4.10. Results of regression analysis for response variable ln $Q_{84\%}$ (N=134)

Assigned name	Dep Var ln Q84%	Predict Value	Std Err Predict	Lower95% Mean	Upper95% Mean	Lower95% Predict	Upper95% Predict	Residual
S1	4.2905	3.7364	0.074	3.5893	3.8836	2.4349	5.0379	0.5540
S2	4.3041	3.9175	0.085	3.7503	4.0847	2.6136	5.2214	0.3866
S3	5.1533	4.9239	0.111	4.7044	5.1434	3.6123	6.2356	0.2294
S4	1.0647	0.2126	0.132	-0.0487	0.4739	-1.1067	1.5319	0.8521
S5	3.4965	3.3441	0.130	3.0877	3.6005	2.0258	4.6625	0.1524
S6	9.5929	9.5674	0.165	9.2410	9.8938	8.2337	10.9011	0.0254
S7	3.1781	2.7184	0.092	2.5367	2.9000	1.4125	4.0242	0.4597
S8	4.4188	3.4862	0.065	3.3581	3.6142	2.1867	4.7857	0.9327
S9	5.3327	4.8526	0.073	4.7085	4.9968	3.5515	6.1538	0.4801
S10	2.8332	2.1494	0.091	1.9701	2.3287	0.8439	3.4549	0.6838
S11	3.8286	2.8181	0.059	2.7014	2.9348	1.5197	4.1165	1.0105
S12	1.9459	2.2146	0.166	1.8855	2.5438	0.8803	3.5490	-0.2687
S13	5.0876	4.7907	0.147	4.4996	5.0819	3.4652	6.1163	0.2969
S15	9.9570	9.7605	0.171	9.4223	10.0988	8.4239	11.0972	0.1965
S16	2.1282	1.4830	0.076	1.3334	1.6326	0.1812	2.7848	0.6452
S17	4.2341	3.7624	0.068	3.6270	3.8977	2.4621	5.0626	0.4717
S18	5.6937	5.4453	0.081	5.2846	5.6061	4.1422	6.7484	0.2484
S19	0.9555	0.0352	0.126	-0.2134	0.2839	-1.2816	1.3521	0.9203
S20	0.6678	1.1024	0.101	0.9017	1.3031	-0.2062	2.4111	-0.4346
S21	1.6487	1.3365	0.072	1.1931	1.4799	0.0354	2.6376	0.3122
S22	3.1355	2.8229	0.058	2.7082	2.9377	1.5247	4.1212	0.3126
S23	4.5951	4.1875	0.070	4.0492	4.3258	2.8870	5.4880	0.4076
S24	1.5261	1.3206	0.069	1.1842	1.4571	0.0203	2.6210	0.2054
S25	0.7885	0.7262	0.089	0.5510	0.9014	-0.5788	2.0312	0.0623
S26	2.6247	2.4894	0.072	2.3474	2.6314	1.1885	3.7903	0.1353

Table 4.10 continued

Assigned name	Dep Var ln $Q_{84\%}$	Predict Value	Std Err Predict	Lower95% Mean	Upper95% Mean	Lower95% Predict	Upper95% Predict	Residual
S27	0.7885	0.3725	0.085	0.2043	0.5408	-0.9315	1.6766	0.4159
S28	4.8598	4.5419	0.079	4.3863	4.6975	3.2394	5.8444	0.3179
S29	2.0794	2.7735	0.097	2.5822	2.9648	1.4663	4.0807	-0.6940
S30	5.6525	5.4233	0.082	5.2606	5.5859	4.1199	6.7266	0.2292
S31	-1.2040	-0.7543	0.105	-0.9611	-0.5476	-2.0639	0.5552	-0.4496
S32	1.4351	1.1711	0.071	1.0307	1.3115	-0.1296	2.4719	0.2640
S33	5.3845	5.1871	0.078	5.0337	5.3404	3.8848	6.4893	0.1974
S34	-3.5066	-3.2079	0.167	-3.5380	-2.8777	-4.5425	-1.8732	-0.2987
S35	-2.1203	-2.8361	0.157	-3.1470	-2.5252	-4.1661	-1.5061	0.7158
S36	0.6313	1.5551	0.068	1.4210	1.6892	0.2550	2.8552	-0.9238
S37	2.9232	3.0381	0.067	2.9046	3.1716	1.7380	4.3381	-0.1149
S38	6.2226	5.9727	0.094	5.7858	6.1595	4.6661	7.2792	0.2499
S39	5.2257	4.6717	0.077	4.5200	4.8235	3.3697	5.9738	0.5540
S40	3.2189	2.5907	0.060	2.4729	2.7084	1.2921	3.8892	0.6282
S41	5.2523	4.2955	0.070	4.1576	4.4333	2.9950	5.5959	0.9568
S42	4.1431	3.4647	0.068	3.3293	3.6001	2.1645	4.7649	0.6784
S43	3.1355	2.2059	0.060	2.0873	2.3245	0.9073	3.5045	0.9296
S44	3.2958	2.8299	0.058	2.7156	2.9442	1.5317	4.1281	0.4659
S45	4.4188	3.7392	0.069	3.6034	3.8750	2.4390	5.0395	0.6796
S46	5.2364	4.8076	0.071	4.6668	4.9485	3.5068	6.1084	0.4288
S47	3.1355	3.7602	0.125	3.5120	4.0083	2.4434	5.0769	-0.6247
S48	3.0445	2.1599	0.063	2.0350	2.2849	0.8608	3.4591	0.8846
S49	6.5162	5.9434	0.095	5.7548	6.1319	4.6366	7.2502	0.5728
S50	-0.4308	-0.5289	0.144	-0.8135	-0.2443	-1.8530	0.7952	0.0981
S52	0.0100	-0.3237	0.129	-0.5798	-0.0677	-1.6420	0.9945	0.3337
S53	6.7105	6.3257	0.098	6.1322	6.5193	5.0182	7.6333	0.3848
S54	2.8332	2.3426	0.065	2.2144	2.4708	1.0431	3.6421	0.4906
S55	7.0596	7.1310	0.115	6.9037	7.3583	5.8180	8.4440	-0.0714
S56	7.1778	7.1894	0.114	6.9639	7.4149	5.8768	8.5021	-0.0116
S57	1.5085	1.7351	0.083	1.5704	1.8998	0.4315	3.0387	-0.2266
S58	1.4110	2.0081	0.061	1.8877	2.1285	0.7094	3.3069	-0.5971
S59	1.0578	2.8499	0.063	2.7254	2.9743	1.5508	4.1490	-1.7921
S60	2.0794	2.7520	0.061	2.6318	2.8723	1.4533	4.0508	-0.6726
S61	4.3307	5.1409	0.085	4.9724	5.3094	3.8368	6.4450	-0.8102
S62	3.3322	3.6797	0.059	3.5633	3.7962	2.3814	4.9781	-0.3475
S63	5.0304	5.0340	0.076	4.8842	5.1837	3.7322	6.3358	-0.0036
S64	3.0445	3.0735	0.066	2.9420	3.2049	1.7737	4.3733	-0.0289
S65	-0.5108	0.8688	0.078	0.7150	1.0226	-0.4335	2.1711	-1.3796
S66	5.4381	5.2970	0.102	5.0944	5.4997	3.9881	6.6060	0.1410
S67	10.1720	10.4138	0.184	10.0504	10.7772	9.0706	11.7570	-0.2418
S69	4.5326	5.4529	0.107	5.2414	5.6645	4.1426	6.7633	-0.9203
S70	3.4340	3.6502	0.066	3.5202	3.7802	2.3505	4.9499	-0.2162
S71	1.1184	1.3496	0.072	1.2074	1.4919	0.0487	2.6506	-0.2312
S72	4.8752	5.3148	0.079	5.1579	5.4718	4.0122	6.6175	-0.4396
S73	3.1091	2.7393	0.097	2.5472	2.9315	1.4320	4.0467	0.3697
S74	5.1591	6.0943	0.099	5.8980	6.2907	4.7863	7.4023	-0.9353
S76	1.5173	2.5719	0.058	2.4572	2.6865	1.2736	3.8701	-1.0545
S77	5.2095	5.3598	0.086	5.1896	5.5299	4.0555	6.6641	-0.1503
S78	-0.0513	1.0289	0.089	0.8535	1.2043	-0.2761	2.3339	-1.0802
S79	3.0445	3.1555	0.061	3.0345	3.2765	1.8567	4.4543	-0.1110
S80	4.0073	4.0976	0.068	3.9639	4.2313	2.7976	5.3977	-0.0903
S81	-3.9120	-0.7777	0.120	-1.0156	-0.5398	-2.0926	0.5371	-3.1343
S82	3.4340	3.4217	0.101	3.2225	3.6208	2.1133	4.7301	0.0123
S83	4.2047	3.8945	0.062	3.7717	4.0173	2.5956	5.1935	0.3101
S84	4.9904	4.9515	0.079	4.7962	5.1068	3.6491	6.2540	0.0389

Table 4.10 continued

Assigned name	Dep Var ln $Q_{84\%}$	Predict Value	Std Err Predict	Lower95% Mean	Upper95% Mean	Lower95% Predict	Upper95% Predict	Residual
S85	1.4351	0.9659	0.074	0.8202	1.1117	-0.3354	2.2673	0.4691
S86	5.9687	7.0066	0.114	6.7814	7.2317	5.6939	8.3192	-1.0378
S87	1.2179	1.2335	0.070	1.0955	1.3716	-0.0670	2.5340	-0.0157
S88	1.4493	1.5985	0.105	1.3902	1.8067	0.2886	2.9083	-0.1492
S89	2.4849	3.0159	0.057	2.9037	3.1281	1.7179	4.3139	-0.5310
S90	1.5261	1.6012	0.137	1.3306	1.8719	0.2801	2.9224	-0.0752
S91	1.4351	1.8390	0.096	1.6484	2.0295	0.5318	3.1461	-0.4039
S92	0.7885	1.9707	0.083	1.8058	2.1355	0.6670	3.2743	-1.1822
S93	6.2146	6.3807	0.104	6.1759	6.5856	5.0715	7.6900	-0.1661
S94	1.4110	1.9357	0.095	1.7483	2.1232	0.6291	3.2424	-0.5247
S95	6.3351	6.5322	0.107	6.3212	6.7431	5.2219	7.8424	-0.1971
S96	6.4313	6.4710	0.112	6.2500	6.6920	5.1591	7.7829	-0.0397
S97	-0.3857	0.5094	0.102	0.3077	0.7111	-0.7994	1.8182	-0.8951
S98	-0.4308	-0.1511	0.121	-0.3912	0.0890	-1.4664	1.1641	-0.2796
S99	0.8755	0.5697	0.126	0.3202	0.8193	-0.7473	1.8868	0.3057
S100	2.3795	2.7539	0.073	2.6100	2.8979	1.4528	4.0551	-0.3744
S101	3.1527	2.8925	0.087	2.7211	3.0640	1.5881	4.1970	0.2602
S103	4.4773	4.7208	0.071	4.5813	4.8603	3.4202	6.0215	-0.2435
S104	9.2629	9.4274	0.162	9.1073	9.7476	8.0953	10.7596	-0.1645
S105	0.0583	-0.9794	0.111	-1.1990	-0.7598	-2.2911	0.3322	1.0377
S106	0.6627	0.8610	0.082	0.6991	1.0229	-0.4423	2.1642	-0.1983
S107	-0.1054	-0.0365	0.109	-0.2519	0.1789	-1.3475	1.2744	-0.0688
S108	2.7600	3.2197	0.072	3.0767	3.3627	1.9186	4.5207	-0.4597
S109	3.0445	2.6777	0.078	2.5239	2.8315	1.3754	3.9800	0.3668
S110	3.8712	3.9778	0.062	3.8553	4.1003	2.6789	5.2767	-0.1066
S111	3.3878	2.7733	0.058	2.6589	2.8877	1.4751	4.0715	0.6145
S112	3.3673	3.9275	0.075	3.7795	4.0756	2.6259	5.2291	-0.5602
S113	4.2341	5.0232	0.097	4.8307	5.2157	3.7158	6.3306	-0.7891
S114	4.3307	4.8185	0.076	4.6676	4.9694	3.5166	6.1204	-0.4878
S115	4.4308	4.7360	0.075	4.5870	4.8850	3.4343	6.0377	-0.3052
S116	0.6831	0.2086	0.133	-0.0546	0.4719	-1.1110	1.5283	0.4745
S117	3.6109	2.3955	0.081	2.2362	2.5549	1.0926	3.6985	1.2154
S118	5.2095	4.3236	0.109	4.1078	4.5395	3.0126	5.6347	0.8859
S119	2.9957	2.7425	0.086	2.5724	2.9126	1.4383	4.0468	0.2532
S120	3.7612	3.5432	0.063	3.4186	3.6679	2.2441	4.8424	0.2180
S123	-0.0305	-0.1824	0.110	-0.3994	0.0345	-1.4937	1.1288	0.1520
S124	0.5068	-1.3536	0.116	-1.5838	-1.1234	-2.6670	-0.0401	1.8604
S126	3.7136	3.2419	0.058	3.1278	3.3560	1.9437	4.5401	0.4717
S128	4.6444	4.4022	0.073	4.2585	4.5459	3.1011	5.7033	0.2422
S129	-0.5798	-1.1093	0.114	-1.3340	-0.8847	-2.4218	0.2032	0.5295
S130	3.2958	2.7611	0.057	2.6489	2.8732	1.4630	4.0591	0.5348
S131	3.9318	4.1423	0.085	3.9742	4.3105	2.8383	5.4464	-0.2105
S132	5.0499	4.4893	0.079	4.3337	4.6449	3.1868	5.7918	0.5605
S133	0.2927	0.5106	0.095	0.3223	0.6990	-0.7962	1.8174	-0.2180
S134	3.2189	3.4432	0.058	3.3285	3.5578	2.1449	4.7414	-0.2243
S135	1.6094	1.6232	0.076	1.4723	1.7741	0.3213	2.9251	-0.0138
S136	-0.6162	0.6913	0.079	0.5354	0.8473	-0.6112	1.9938	-1.3075
S137	-2.0402	-0.7377	0.128	-0.9915	-0.4840	-2.0555	0.5801	-1.3025
S138	2.6946	2.5552	0.102	2.3526	2.7578	1.2463	3.8641	0.1394
S139	-0.0408	0.1579	0.128	-0.0956	0.4113	-1.1599	1.4757	-0.1987
S140	0.3920	0.4432	0.157	0.1329	0.7534	-0.8867	1.7730	-0.0511
S141	0.6206	0.3281	0.165	0.0013	0.6550	-1.0057	1.6620	0.2924
S142	1.5041	1.5739	0.164	1.2502	1.8977	0.2409	2.9070	-0.0698
S143	1.0647	2.0711	0.129	1.8150	2.3272	0.7528	3.3893	-1.0064

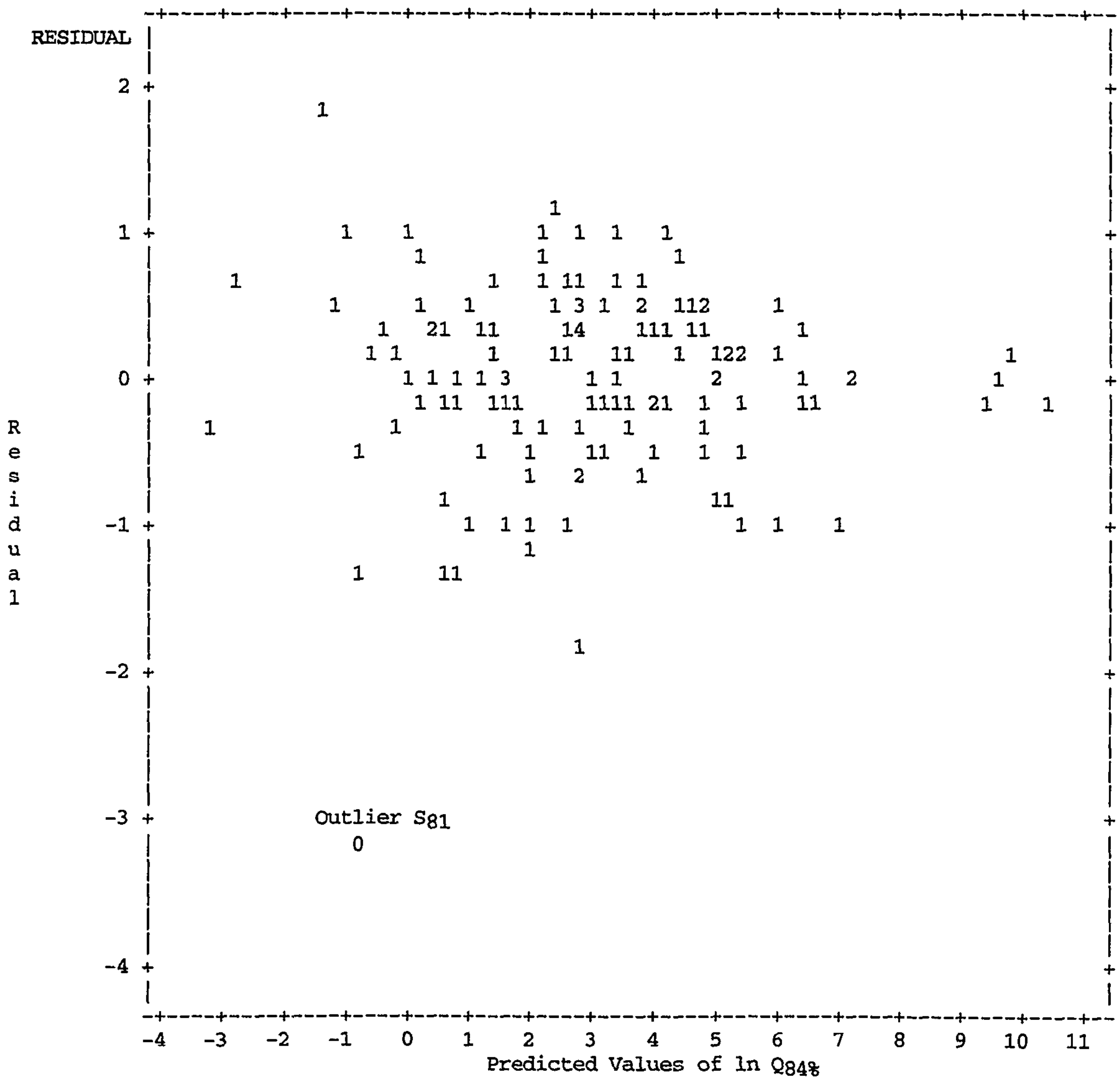

Figure 4.7. Scatter plot of residuals versus predicted values of ln $Q_{84\%}$.

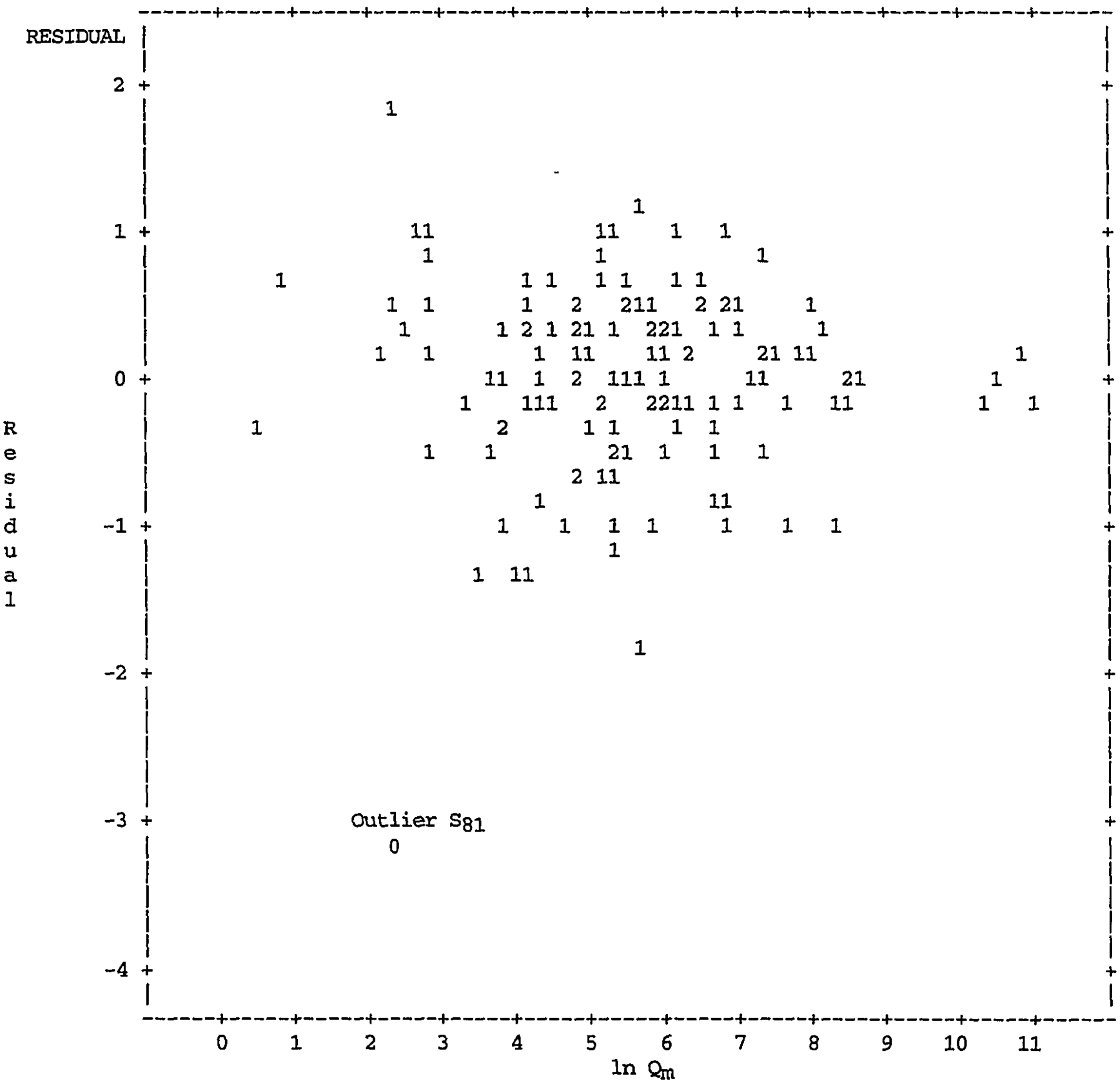

Figure 4.8. Scatter plot of residuals versus ln Q_m

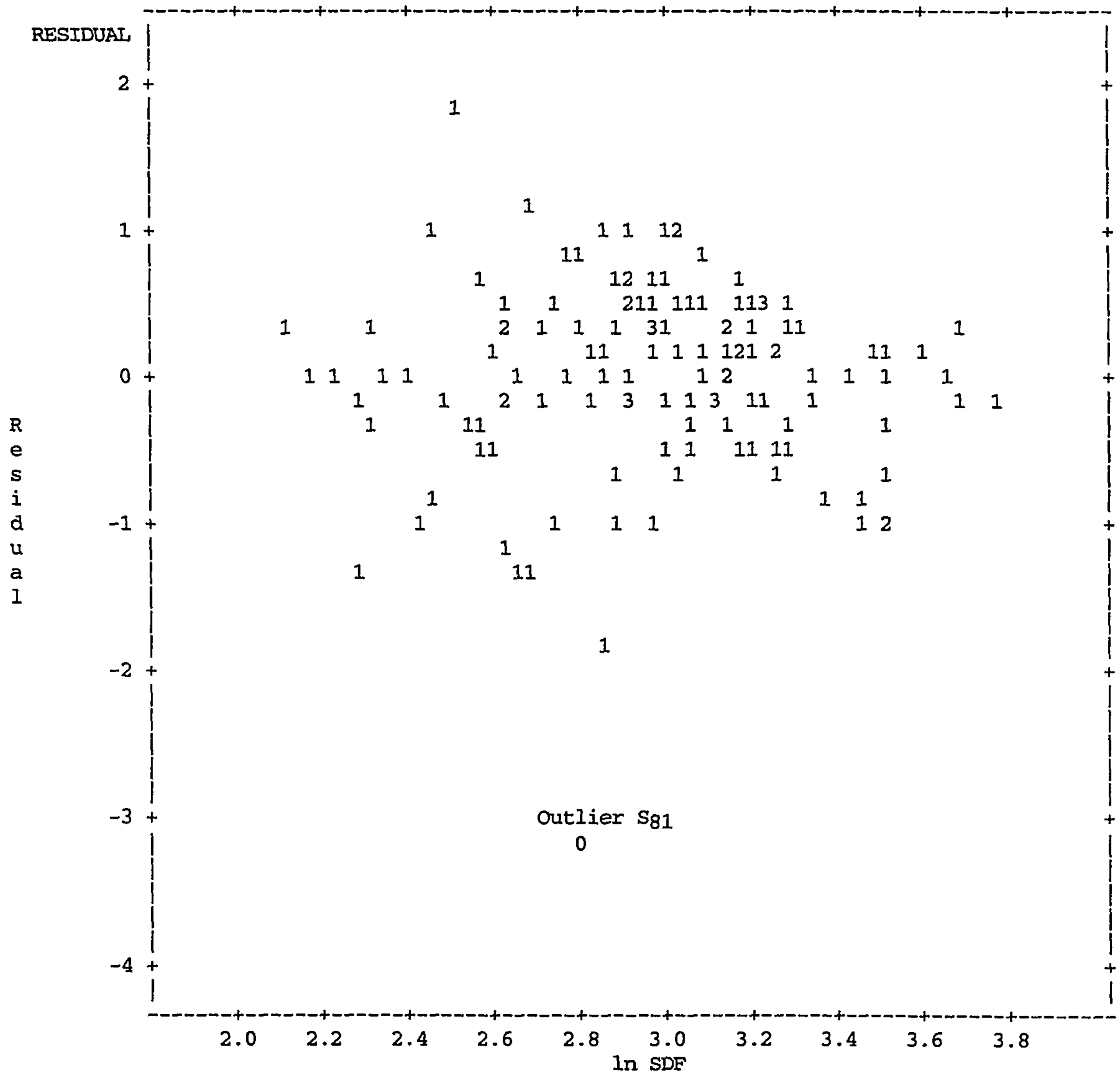

Figure 4.9. Scatter plot of residuals versus ln SDF.

Table 4.11 shows several diagnostic measures used to detect any sign of inconsistency among the results. It shows station S81 as a potential outlier (Residuals = -3.134, Student residual = -4.878, Cook's D = 0.278, and Rstudent = -5.3717). This conclusion is further confirmed by examining the residual plots in Figures 4.7 to 4.9, which show this point with a zero (0).

Table 4.11. Diagnostic measures for regression analysis of ln $Q_{84\%}$ (N =134)

Assigned name	Std Err Residual	Student Residual	-2-1-0 1 2	Cook's D	Rstudent	Hat Diag H	Cov Ratio
S1	0.649	0.853	|*	0.003	0.8522	0.0129	1.0195
S2	0.648	0.596	|*	0.002	0.5949	0.0167	1.0322
S3	0.644	0.356	|	0.001	0.3549	0.0288	1.0506
S4	0.640	1.331	|**	0.025	1.3349	0.0408	1.0241
S5	0.641	0.238	|	0.001	0.2370	0.0393	1.0638
S6	0.633	0.040	|	0.000	0.0401	0.0637	1.0928
S7	0.647	0.710	|*	0.003	0.7089	0.0197	1.0318
S8	0.650	1.434	|**	0.007	1.4397	0.0098	0.9855
S9	0.650	0.739	|*	0.002	0.7377	0.0124	1.0232
S10	0.647	1.056	|**	0.007	1.0567	0.0192	1.0169
S11	0.651	1.552	|***	0.007	1.5607	0.0081	0.9758
S12	0.632	-0.425	|	0.004	-0.4238	0.0648	1.0896
S13	0.637	0.466	|	0.004	0.4647	0.0507	1.0725
S15	0.631	0.311	|	0.002	0.3103	0.0684	1.0960
S16	0.649	0.994	|*	0.004	0.9937	0.0134	1.0139
S17	0.650	0.726	|*	0.002	0.7243	0.0110	1.0222
S18	0.649	0.383	|	0.001	0.3817	0.0155	1.0358
S19	0.641	1.435	|**	0.026	1.4405	0.0370	1.0132
S20	0.646	-0.673	*|	0.004	-0.6716	0.0241	1.0377
S21	0.650	0.481	|	0.001	0.4791	0.0123	1.0305
S22	0.651	0.480	|	0.001	0.4786	0.0079	1.0259
S23	0.650	0.627	|*	0.002	0.6257	0.0114	1.0258
S24	0.650	0.316	|	0.000	0.3149	0.0111	1.0324
S25	0.648	0.096	|	0.000	0.0958	0.0184	1.0422
S26	0.650	0.208	|	0.000	0.2074	0.0121	1.0347
S27	0.648	0.642	|*	0.002	0.6403	0.0169	1.0311
S28	0.649	0.490	|	0.001	0.4884	0.0145	1.0326
S29	0.646	-1.074	**|	0.009	-1.0742	0.0219	1.0188
S30	0.648	0.353	|	0.001	0.3523	0.0158	1.0367
S31	0.645	-0.697	*|	0.004	-0.6955	0.0256	1.0385
S32	0.650	0.406	|	0.001	0.4049	0.0118	1.0316
S33	0.649	0.304	|	0.000	0.3031	0.0141	1.0356
S34	0.632	-0.473	|	0.005	-0.4712	0.0652	1.0890
S35	0.635	1.128	|**	0.026	1.1294	0.0578	1.0547
S36	0.650	-1.421	**|	0.007	-1.4265	0.0107	0.9873
S37	0.650	-0.177	|	0.000	-0.1761	0.0107	1.0335
S38	0.647	0.386	|	0.001	0.3851	0.0209	1.0415
S39	0.649	0.853	|*	0.003	0.8525	0.0138	1.0203
S40	0.651	0.965	|*	0.003	0.9648	0.0083	1.0100
S41	0.650	1.472	|**	0.008	1.4787	0.0114	0.9845
S42	0.650	1.044	|**	0.004	1.0440	0.0110	1.0090
S43	0.651	1.428	|**	0.006	1.4339	0.0084	0.9845

Table 4.11 continued

Assigned name	Std Err Residual	Student Residual	-2-1-0 1 2	Cook's D	Rstudent	Hat Diag H	Cov Ratio
S44	0.651	0.716	*	0.001	0.7143	0.0078	1.0193
S45	0.650	1.045	**	0.004	1.0458	0.0110	1.0090
S46	0.650	0.660	*	0.002	0.6585	0.0119	1.0253
S47	0.642	-0.974	*	0.012	-0.9735	0.0368	1.0395
S48	0.651	1.360	**	0.006	1.3640	0.0093	0.9898
S49	0.647	0.886	*	0.006	0.8850	0.0213	1.0268
S50	0.638	0.154		0.000	0.1533	0.0484	1.0748
S52	0.641	0.521	*	0.004	0.5193	0.0392	1.0584
S53	0.646	0.595	*	0.003	0.5939	0.0224	1.0382
S54	0.650	0.754	*	0.002	0.7530	0.0098	1.0200
S55	0.644	-0.111		0.000	-0.1105	0.0309	1.0556
S56	0.644	-0.018		0.000	-0.0180	0.0304	1.0553
S57	0.648	-0.349		0.001	-0.3483	0.0162	1.0372
S58	0.651	-0.917	*	0.002	-0.9169	0.0087	1.0124
S59	0.651	-2.754	*****	0.024	-2.8268	0.0093	0.8636
S60	0.651	-1.033	**	0.003	-1.0337	0.0087	1.0071
S61	0.648	-1.250	**	0.009	-1.2528	0.0170	1.0041
S62	0.651	-0.534	*	0.001	-0.5324	0.0081	1.0249
S63	0.649	-0.005		0.000	-0.0055	0.0134	1.0372
S64	0.650	-0.045		0.000	-0.0443	0.0103	1.0339
S65	0.649	-2.126	****	0.022	-2.1550	0.0141	0.9342
S66	0.646	0.218		0.000	0.2177	0.0246	1.0479
S67	0.627	-0.385		0.004	-0.3842	0.0790	1.1072
S69	0.645	-1.427	**	0.019	-1.4328	0.0268	1.0031
S70	0.650	-0.332		0.000	-0.3313	0.0101	1.0311
S71	0.650	-0.356		0.001	-0.3547	0.0121	1.0328
S72	0.649	-0.678	*	0.002	-0.6761	0.0147	1.0277
S73	0.646	0.572	*	0.002	0.5705	0.0221	1.0385
S74	0.646	-1.448	**	0.016	-1.4537	0.0231	0.9979
S76	0.651	-1.620	***	0.007	-1.6298	0.0079	0.9706
S77	0.648	-0.232		0.000	-0.2311	0.0173	1.0400
S78	0.648	-1.668	***	0.017	-1.6794	0.0184	0.9774
S79	0.651	-0.171		0.000	-0.1699	0.0088	1.0316
S80	0.650	-0.139		0.000	-0.1383	0.0107	1.0339
S81	0.643	-4.878	******	0.278	-5.3717	0.0338	0.5804
S82	0.646	0.019		0.000	0.0190	0.0237	1.0481
S83	0.651	0.477		0.001	0.4752	0.0090	1.0272
S84	0.649	0.060		0.000	0.0598	0.0144	1.0381
S85	0.650	0.722	*	0.002	0.7210	0.0127	1.0241
S86	0.644	-1.612	***	0.027	-1.6223	0.0303	0.9937
S87	0.650	-0.024		0.000	-0.0240	0.0114	1.0350
S88	0.645	-0.231		0.000	-0.2304	0.0259	1.0492
S89	0.651	-0.815	*	0.002	-0.8143	0.0075	1.0154
S90	0.639	-0.118		0.000	-0.1172	0.0438	1.0698
S91	0.647	-0.625	*	0.003	-0.6232	0.0217	1.0366
S92	0.648	-1.823	***	0.018	-1.8399	0.0162	0.9630
S93	0.645	-0.257		0.001	-0.2565	0.0251	1.0480
S94	0.647	-0.811	*	0.005	-0.8102	0.0210	1.0295
S95	0.645	-0.306		0.001	-0.3046	0.0266	1.0490
S96	0.644	-0.062		0.000	-0.0614	0.0292	1.0540
S97	0.646	-1.386	**	0.016	-1.3912	0.0243	1.0033
S98	0.642	-0.435		0.002	-0.4340	0.0345	1.0552
S99	0.641	0.477		0.003	0.4753	0.0372	1.0573
S100	0.650	-0.576	*	0.001	-0.5749	0.0124	1.0282
S101	0.648	0.402		0.001	0.4003	0.0176	1.0377

Table 4.11 continued

Assigned name	Std Err Residual	Student Residual	-2-1-0	1 2	Cook's D	Rstudent	Hat Diag H	Cov Ratio
S103	0.650	-0.375			0.001	-0.3734	0.0116	1.0320
S104	0.633	-0.260			0.001	-0.2588	0.0613	1.0884
S105	0.644	1.611		***	0.026	1.6208	0.0288	0.9923
S106	0.649	-0.306			0.000	-0.3047	0.0157	1.0373
S107	0.645	-0.107			0.000	-0.1064	0.0277	1.0522
S108	0.650	-0.708	*		0.002	-0.7062	0.0122	1.0241
S109	0.649	0.565		*	0.002	0.5637	0.0141	1.0304
S110	0.651	-0.164			0.000	-0.1632	0.0090	1.0319
S111	0.651	0.944		*	0.002	0.9434	0.0078	1.0104
S112	0.649	-0.863	*		0.003	-0.8618	0.0131	1.0193
S113	0.646	-1.221	**		0.011	-1.2230	0.0222	1.0111
S114	0.649	-0.751	*		0.003	-0.7501	0.0136	1.0240
S115	0.649	-0.470			0.001	-0.4686	0.0133	1.0318
S116	0.640	0.741		*	0.008	0.7401	0.0415	1.0541
S117	0.649	1.874		***	0.018	1.8919	0.0152	0.9577
S118	0.645	1.374		**	0.018	1.3792	0.0279	1.0077
S119	0.648	0.391			0.001	0.3895	0.0173	1.0376
S120	0.651	0.335			0.000	0.3339	0.0093	1.0302
S123	0.644	0.236			0.001	0.2350	0.0281	1.0516
S124	0.643	2.892		*****	0.091	2.9778	0.0317	0.8670
S126	0.651	0.724		*	0.001	0.7231	0.0078	1.0189
S128	0.650	0.373			0.001	0.3716	0.0123	1.0328
S129	0.644	0.823		*	0.007	0.8215	0.0302	1.0388
S130	0.651	0.821		*	0.002	0.8202	0.0075	1.0152
S131	0.648	-0.325			0.001	-0.3237	0.0169	1.0383
S132	0.649	0.864		*	0.004	0.8630	0.0145	1.0207
S133	0.647	-0.337			0.001	-0.3359	0.0212	1.0427
S134	0.651	-0.344			0.000	-0.3433	0.0079	1.0286
S135	0.649	-0.021			0.000	-0.0211	0.0136	1.0374
S136	0.649	-2.015	****		0.020	-2.0391	0.0145	0.9448
S137	0.641	-2.032	****		0.055	-2.0569	0.0385	0.9667
S138	0.646	0.216			0.000	0.2152	0.0245	1.0479
S139	0.641	-0.310			0.001	-0.3089	0.0384	1.0618
S140	0.635	-0.081			0.000	-0.0802	0.0576	1.0856
S141	0.632	0.462			0.005	0.4610	0.0639	1.0878
S142	0.633	-0.110			0.000	-0.1099	0.0627	1.0914
S143	0.641	-1.571	***		0.034	-1.5796	0.0392	1.0060

Sum of Residuals = 0
Sum of Squared Residuals (SSR) = 55.9765
Predicted Residual Sum of Squared (PRESS) = 58.6176

Figure 4.10 depicts the actual recorded values of $\ln Q_{84\%}$ versus what was predicted by the model. It gives an immediate visual impression of the model's performance. Ideally, it should be a 45-degree straight line passing through the origin. This graphic is also useful in detecting outliers and gross errors in the model. The corresponding point for the outlier S81 can be seen on this plot.

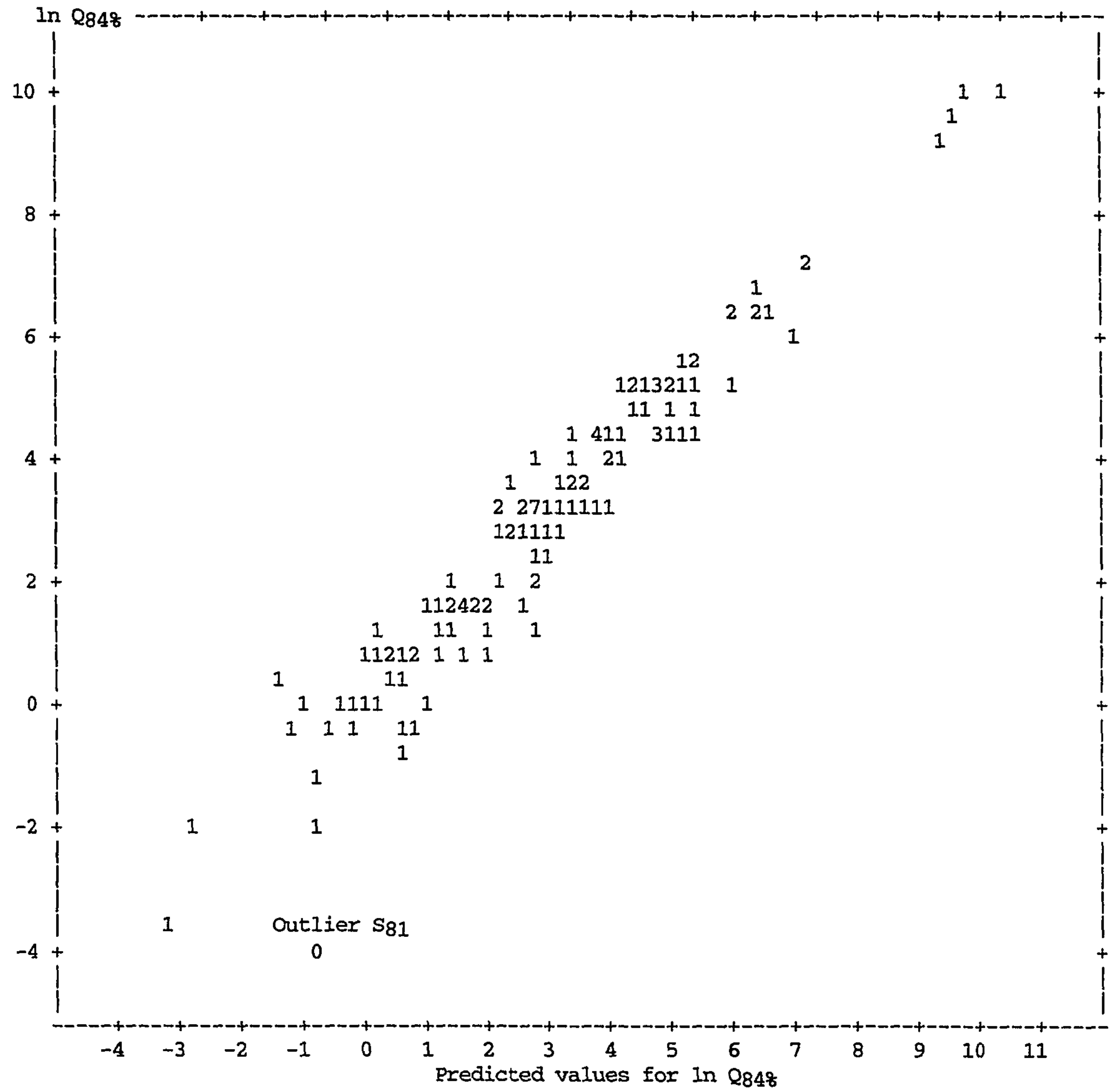

Figure 4.10. The actual versus predicted values of ln $Q_{84\%}$ (N = 134 obs.)

Figure 4.11 is a normal plot of residuals. The closer this plot is to a straight line, the more likely the residual assumption will hold. Again the effect of the outlier point S81, shown by a zero character, in distorting the straight line can be visualized.

For the time being there is no way to explain why the point belonging to station S81 (East Fork Hardin Creek near Churdan) is significantly different from the others, except that its location within the Des Moines lobe might be responsible for this abnormality. Nevertheless, it was removed and regression analysis was performed again with 133 observations to see how the absence of this point would affect the results.

The new results after deletion of station S81 from the regression analysis are given in Table 4.12.

Table 4.12. Analysis of variance and parameter estimates for ln $Q_{84\%}$ (N = 133)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	736.16256	368.08128	1044.576	0.0001
Error	130	45.80861	0.35237		
C Total	132	781.97116			

Root MSE	0.59361	R-square	0.9414
Dep Mean	3.02747	Adj R-sq	0.9405
C.V.	19.60752		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|	Variance Inflation
INTERCEP	1	-9.034927	0.45982756	-19.649	0.0001	0.00000000
ln Q_m	1	1.029314	0.03463698	29.717	0.0001	1.47726946
ln SDF	1	2.113237	0.18090478	11.681	0.0001	1.47726946

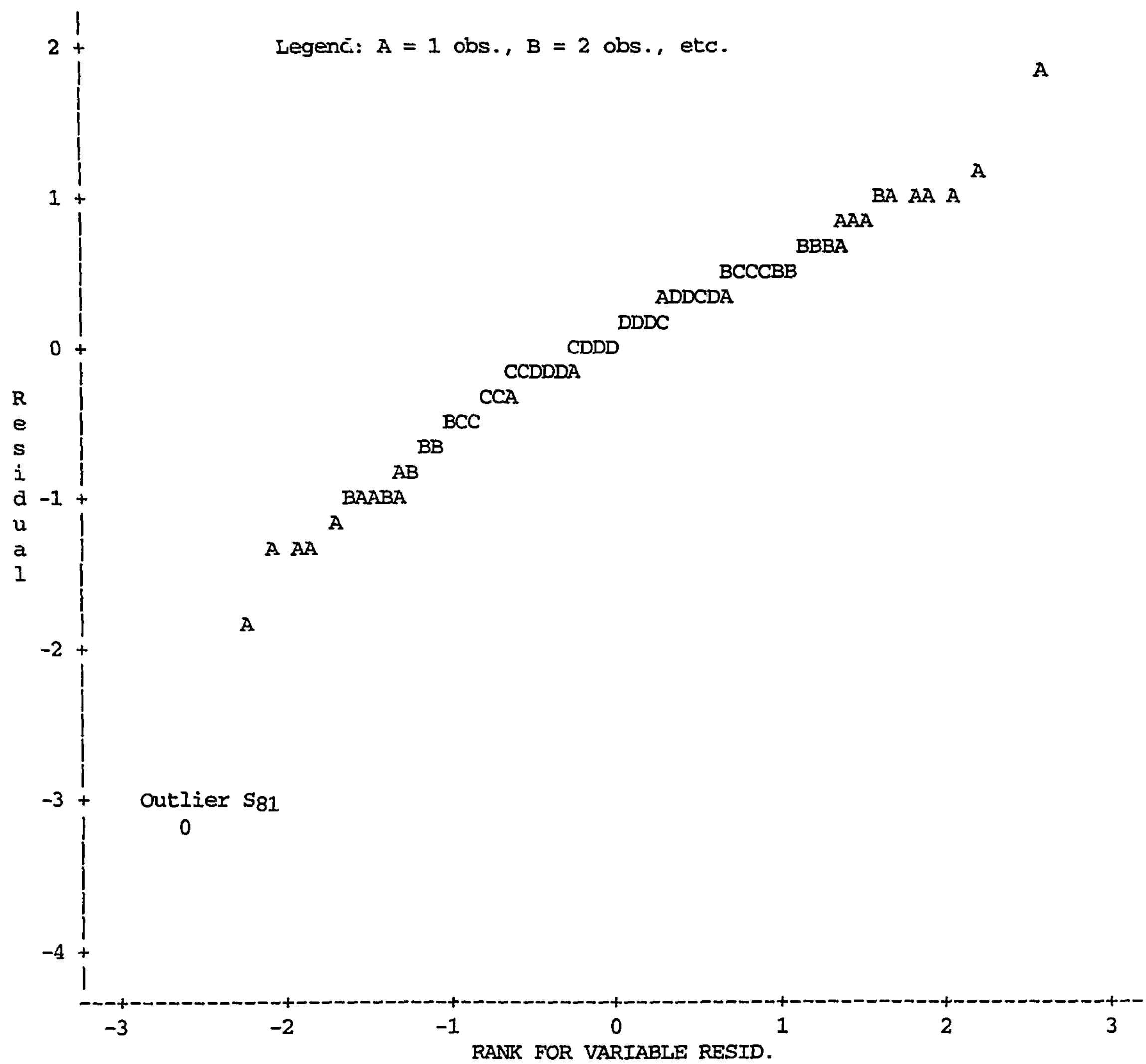

Figure 4.11. Normal plot of residuals for regression model (4.1) (N=134 obs.)

$$\ln Q_{84\%} = -9.062 + 1.059 \ln Q_m + 2.059 \ln SDF$$

Comparison of Tables 4.8 and 4.11 shows that the removal of S81 as an outlier reduced the MSE to 0.352 and s_e to 0.59, and increased R^2 to 0.941. Furthermore, the new residual plots were improved (Figures 4.12 to 4.14). They appear to be more symmetrically distributed about the zero line. The PRESS is smaller (47.7 as compared to 58.6). The plot of actual versus predicted values for ln $Q_{84\%}$ appears to be more satisfactory (Figure 4.15), and the normal plot of residuals is more linear (Figure 4.16).

The new model after deletion of S81 is:

$$\ln Q_{84\%} = -9.035 + 1.029 \ln Q_m + 2.113 \ln \text{SDF} \qquad (4.2)$$

Comparison between models (4.1) and (4.2) indicates the superiority of the latter. The new predicted values are given in Table 2 (in Appendix A).

In order to check the validity of the model, 10% of the stations (S2, S12, S24, S28, S35, S47, S52, S58, S78, S97, S106, S129, and S133) were deleted at random to be used subsequently as a new set of data, and regression analysis was repeated without them. The results of this stage appear in Table 4.13.

Table 4.13. Analysis of variance and parameter estimates for ln $Q_{84\%}$ (N=120)

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	641.63583	320.81792	903.530	0.0001
Error	117	41.54340	0.35507		
C Total	119	683.17923			

Root MSE	0.59588	R-square	0.9392
Dep Mean	3.23035	Adj R-sq	0.9382
C.V.	18.44625		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|	Variance Inflation
INTERCEP	1	-9.085690	0.48565692	-18.708	0.0001	0.00000000
ln Q_m	1	1.019664	0.03864303	26.387	0.0001	1.54958683
ln SDF	1	2.155299	0.19488291	11.059	0.0001	1.54958683

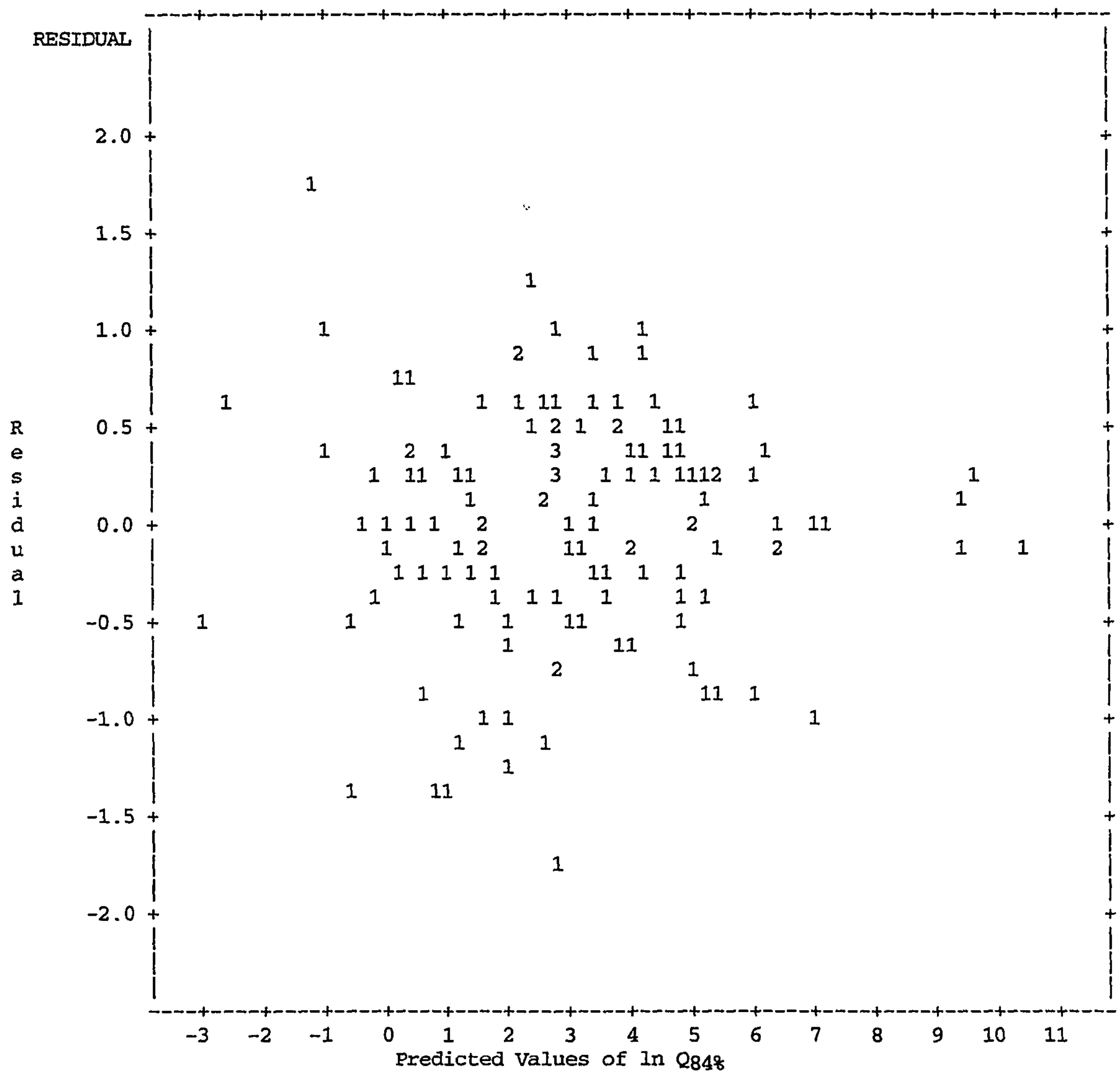

Figure 4.12. Scatter plot of residuals versus predicted values of ln $Q_{84\%}$ by model (4.2), $\ln Q_{84\%} = -9.035 + 1.029 \ln Q_m + 2.113 \ln SDF$

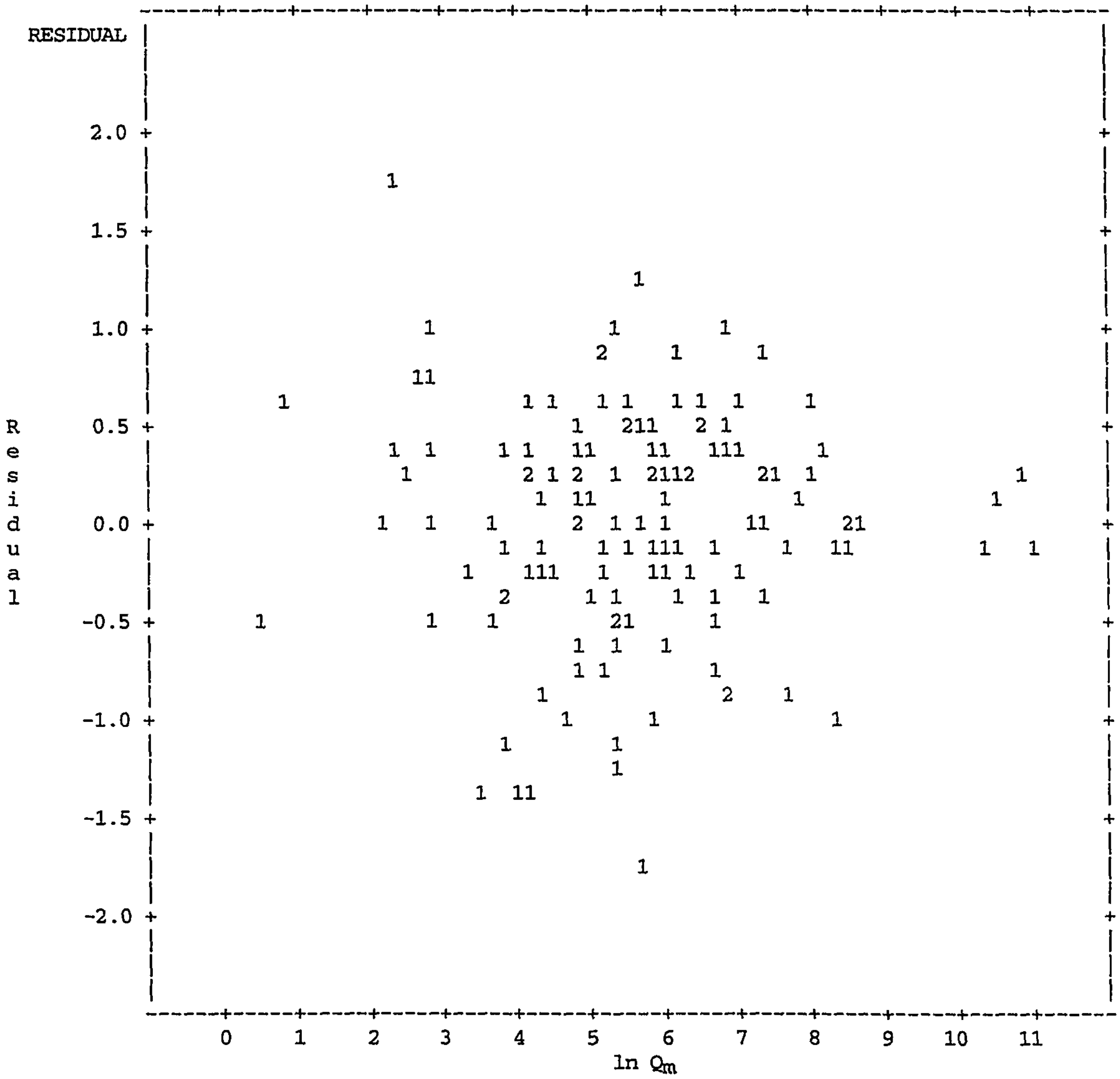

Figure 4.13. Scatter plot of residuals versus ln Q_m for model (4.2)

$$\ln Q_{84\%} = -9.035 + 1.029 \ln Q_m + 2.113 \ln \text{SDF}$$

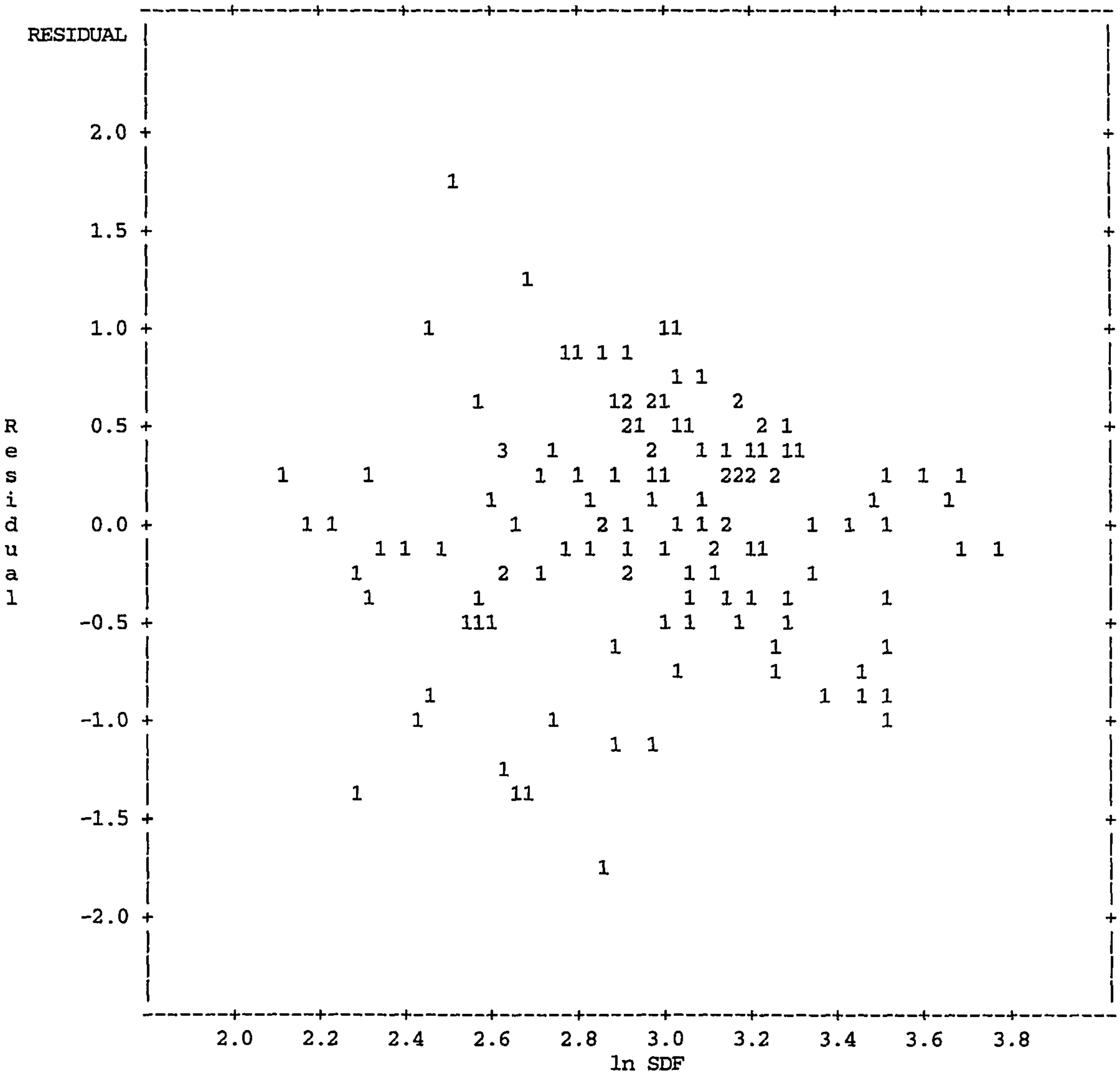

Figure 4.14. Scatter plot of residuals versus ln SDF for model (4.2)

$$\ln Q_{84\%} = -9.035 + 1.029 \ln Q_m + 2.113 \ln \text{SDF}$$

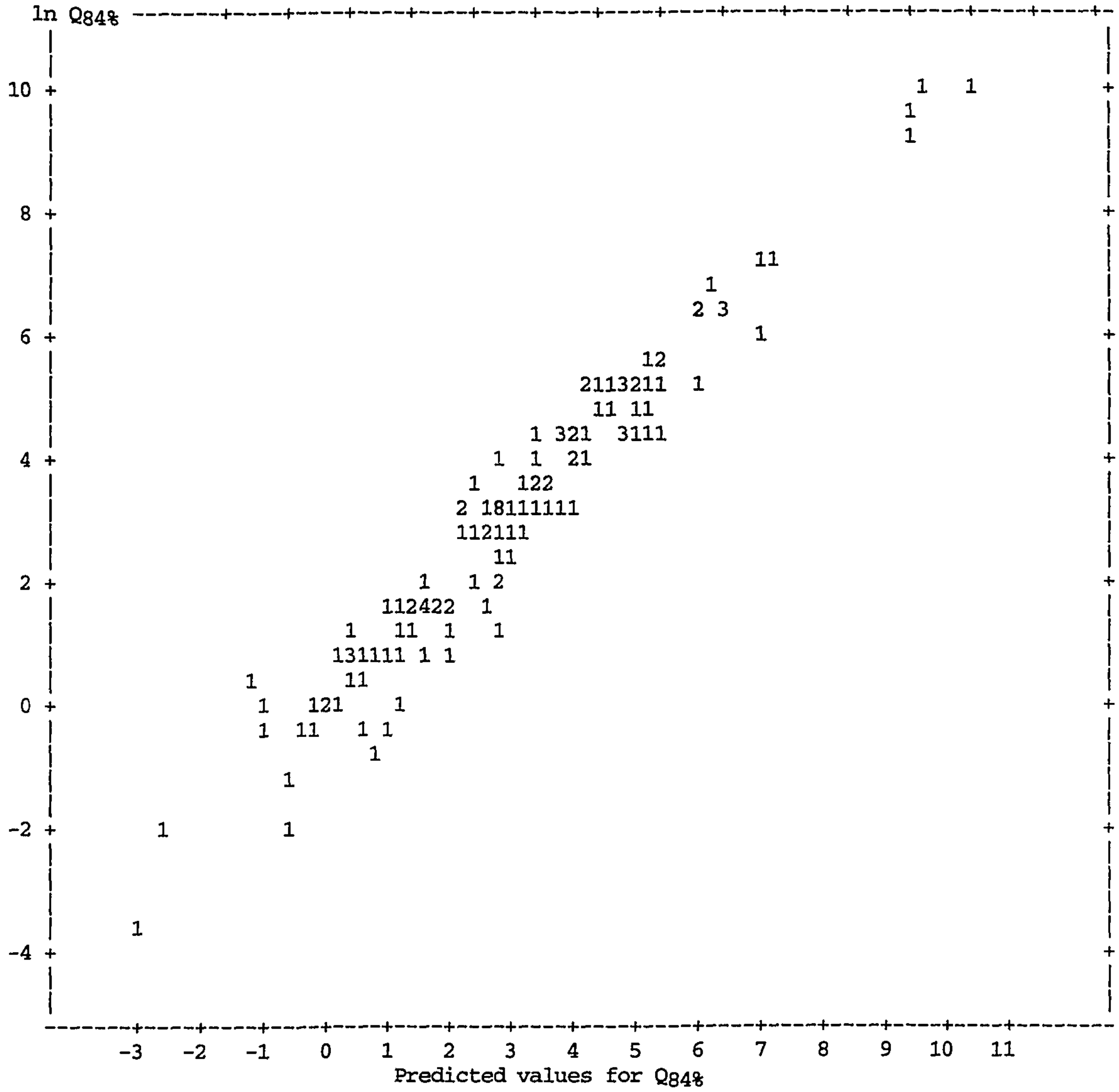

Figure 4.15. The actual versus predicted values of ln $Q_{84\%}$ by model (4.2)

$$\ln Q_{84\%} = -9.035 + 1.029 \ln Q_m + 2.113 \ln SDF$$ after deletion of S81

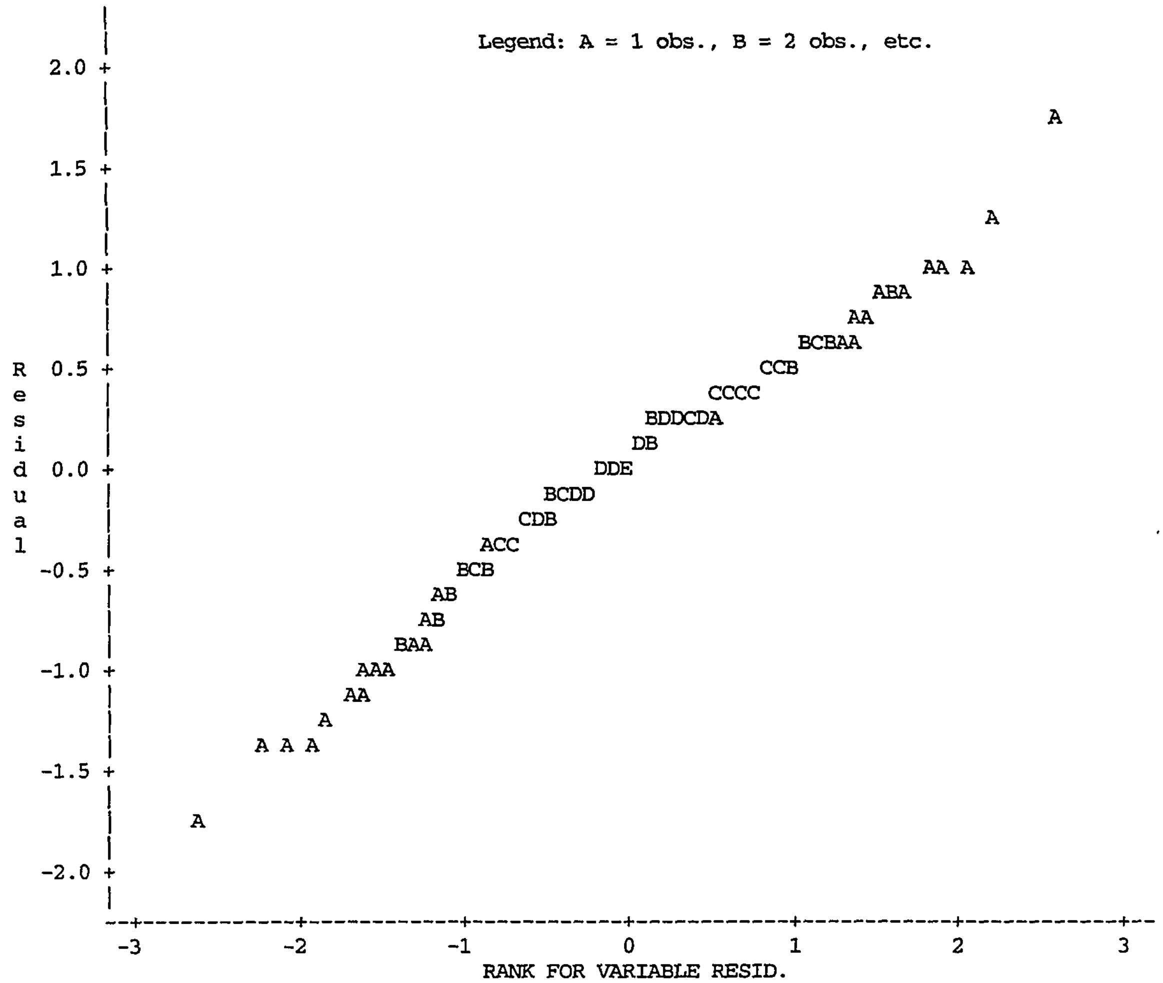

Figure 4.16. Normal plot of residuals for regression model (4.2)

$\ln Q_{84\%} = -9.035 + 1.029 \ln Q_m + 2.113 \ln \text{SDF}$ (N = 133 obs,) Comparison of Table 4.13 with Table 4.12 indicates that the regression coefficients remain fairly stable subsequent to the removal of the 13 points. Small changes are in the direction of improvement. For example, the PRESS statistic is 43.49 (as compared to 47.73 for model 4.2). However, R^2 is slightly reduced to 0.939, and s_e increased by 0.002. The model for this step is:

$$\ln Q_{84\%} = -9.086 + 1.020 \ln Q_m + 2.155 \ln \text{SDF} \qquad (4.3)$$

The results of this analysis are given in Table 3 (Appendix A) The dots in the second column of this table represent the deleted points.

Figure 4.17 depicts the actual versus predicted values for regression model (4.3), which was built upon 120 observations. The residual plots of this model look satisfactory (not shown). The normal plot of these residuals in Figure 4.18 is a fairly straight line, confirming that the basic residual assumption holds. Table 4.14 shows the actual and predicted values for 13 deleted stations which were left off deliberately.

Restricted models With the two possible choices for restricted models of $Q_{84\%}$, two exponential models were tried consisting of either DA or DA and EL as independent variables. However, as was expected from Table 4.6, addition of EL as a second independent variable to the univariate model did not improve it significantly. ANOVA tables for both models (for N = 120) are given in Tables 4.15 and 4.16 for comparison. As is evident from these tables, inclusion of EL increased R^2 by only 0.005 and reduced MSE by 0.023. Additionally, the T statistic for ln EL and especially for the intercept became lower. Therefore, it was decided to stay with the model which contains only DA as the independent variable. The equation of this model is:

$$\ln Q_{84\%} = -4.428 + 1.183 \ln \text{DA} \qquad (4.4)$$

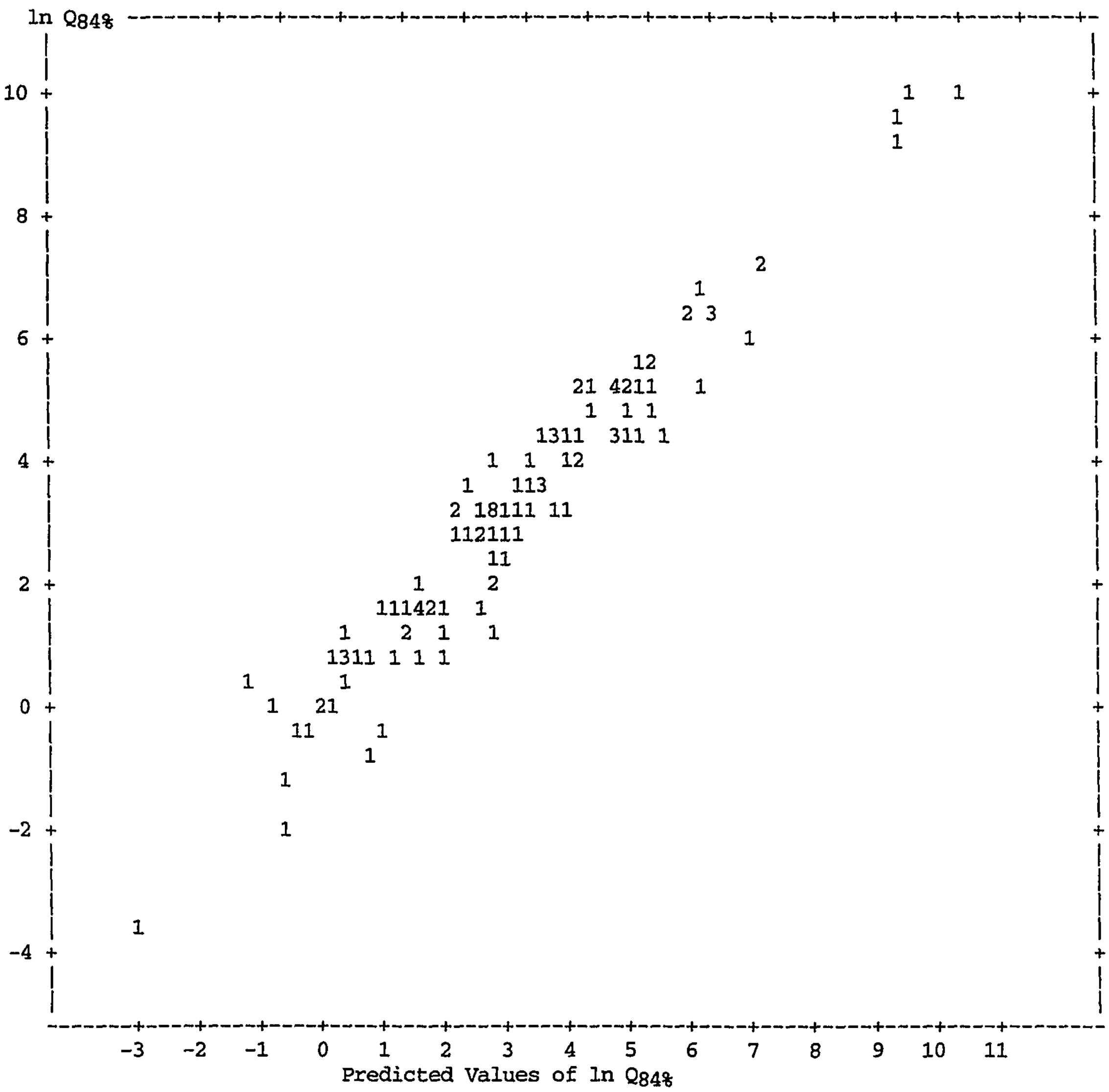

Figure 4.17. Actual versus predicted values of $\ln Q_{84\%}$ by model (4.3),

$$\ln Q_{84\%} = -9.086 + 1.020 \ln Q_m + 2.155 \ln \mathrm{SDF}$$

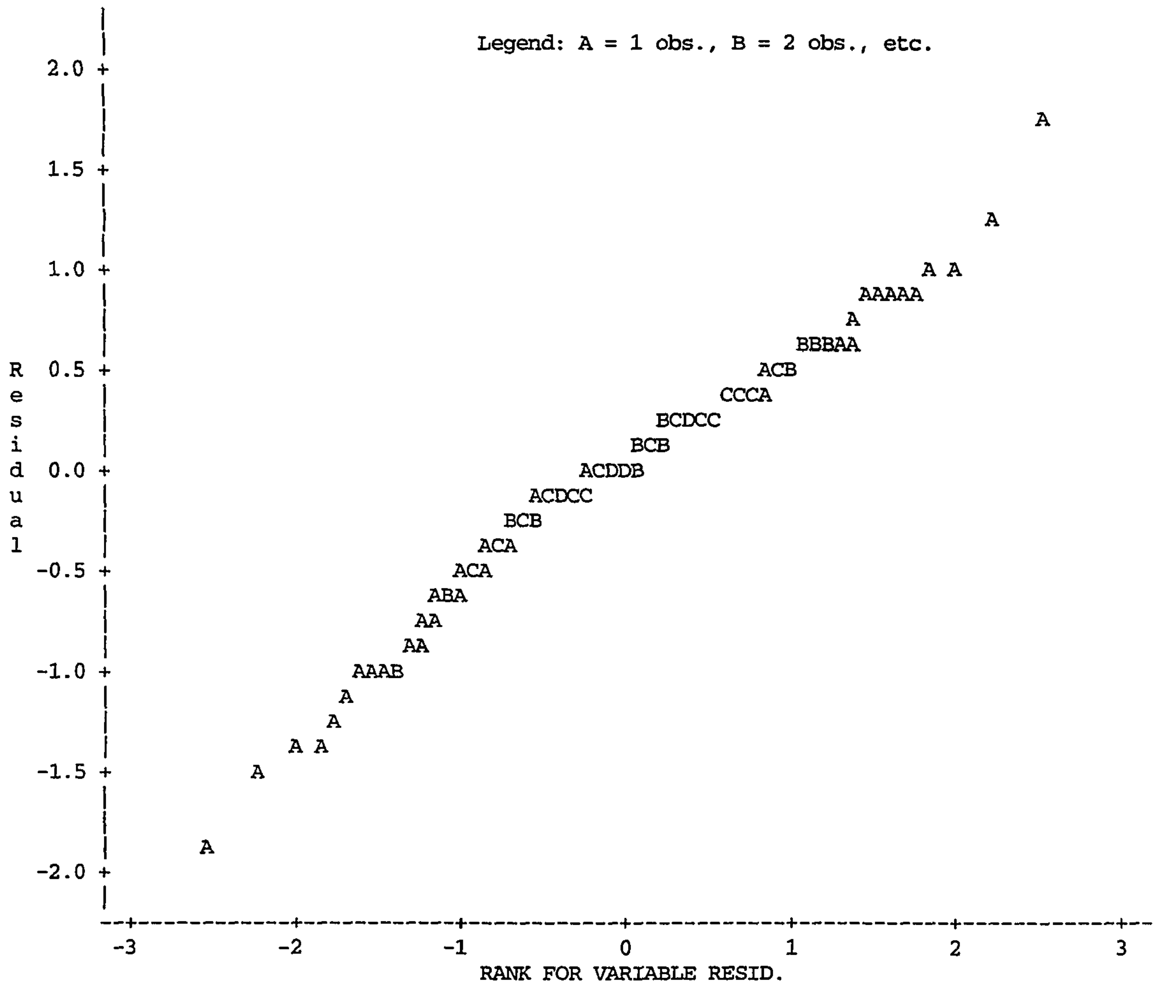

Figure 4.18. Normal plot of residuals for regression model (4.3),

$\ln Q_{84\%} = -9.086 + 1.020 \ln Q_m + 2.155 \ln SDF$ (N = 120)

Table 4.14. Actual and predicted values by model (4.3) for 13 deleted observations

Assigned name	ln Q84%		Q84%	
	Actual	Predicted	Actual	Predicted
S2	4.3041	3.9858	74.00	53.83
S12	1.9459	2.3812	7.00	10.82
S24	1.5261	1.4008	4.60	4.06
S28	4.8598	4.5298	129.00	92.84
S35	-2.1203	-2.6479	0.12	0.07
S47	3.1355	3.8672	23.00	47.81
S52	0.0100	-0.1583	1.01	0.85
S58	1.4110	2.0709	4.10	7.93
S78	-0.0513	1.1445	0.95	3.14
S97	-0.3857	0.5562	0.68	1.74
S106	0.6627	0.9220	1.94	2.51
S129	-0.5798	-0.9745	0.56	0.38
S133	0.2927	0.6353	1.34	1.89

The results of this model may not be as precise as those of model (4.3), but it can be used as a quick reference to estimate $Q_{84\%}$ at any site for which no records other than drainage area are available.

Table 4 (Appendix A) presents the results of model (4.4) using the data set of N = 120 observations. PRESS for this model is 108.10, and s_e = 0.94 as opposed to 43.49 and 0.60 for model (4.3) respectively. The residual plots shown in Figures 4.19 and 4.19 are satisfactory. Figure 4.21 shows the actual versus predicted values by model (4.4), and Figure 4.22 depicts the normal plot of residuals. Finally, the actual versus predicted values for 13 deleted points are listed in Table 4.17.

Table 4 (Appendix A), together with Figures 4.19 to 4.22, shows that model (4.4), despite its simple structure, has a fairly good predictive ability and reasonable residual performance.

Table 4.15. Analysis of variance and parameter estimates for univariate model, $\ln Q_{84\%} = -4.428 + 1.183 \ln DA$ (N=120)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	578.78042	578.78042	654.185	0.0001
Error	118	104.39881	0.88474		
C Total	119	683.17923			

Root MSE	0.94060	R-square	0.8472
Dep Mean	3.23035	Adj R-sq	0.8459
C.V.	29.11769		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	-4.427900	0.31148774	-14.215	0.0001
ln DA	1	1.182613	0.04623731	25.577	0.0001

Table 4.15. Analysis of variance and parameter estimates for univariate model, $\ln Q_{84\%} = 0.710 + 1.161 \ln DA - 0{,}741 \ln EL$ (N=120)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	582.34412	291.17206	337.850	0.0001
Error	117	100.83511	0.86184		
C Total	119	683.17923			

Root MSE	0.92835	R-square	0.8524
Dep Mean	3.23035	Adj R-sq	0.8499
C.V.	28.73843		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|	Variance Inflation
INTERCEP	1	0.709596	2.54510490	0.279	0.7809	0.00000000
ln DA	1	1.161364	0.04681619	24.807	0.0001	1.05243338
ln EL	1	-0.741328	0.36456307	-2.033	0.0443	1.05243338

Table 4.17. Actual and predicted values by model (4.4) for 13 randomly deleted observations

Assigned name	ln Q84%		Q84%	
	Actual	Predicted	Actual	predicted
S2	4.3041	3.0556	74.00	21.23
S12	1.9459	0.4395	7.00	1.55
S24	1.5261	1.2140	4.60	3.37
S28	4.8598	4.8034	129.00	121.92
S35	-2.1203	-3.1526	0.12	0.04
S47	3.1355	2.4896	23.00	12.06
S52	0.0100	-0.9144	1.01	0.40
S58	1.4110	1.8614	4.10	6.43
S78	-0.0513	0.7543	0.95	2.13
S97	-0.3857	1.0759	0.68	2.93
S106	0.6627	2.1841	1.94	8.88
S129	-0.5798	-0.5748	0.56	0.56
S133	0.2927	0.1818	1.34	1.20

Models for $Q_{7,10}$

General models The approach that has been discussed in detail for regressing $y_1 = Q_{84\%}$ against different explanatory variables was repeated to reach the final decision regarding the most appropriate models for defining the $Q_{7,10}$ magnitudes in terms of four possible explanatory variables.

Table 4.18 gives the order of preference for explanatory variables to be included in the model. The most preferred variable is ln Q_m. Although the correlation matrix for $y_2 = Q_{7,10}$ in Table 4.7 shows a lower correlation coefficient between ln Q_m and ln $Q_{7,10}$ than in the case of ln $Q_{84\%}$ (0.86 as opposed to 0.94). Therefore, the models for ln $Q_{7,10}$ are anticipated to be less adequate. Table 4.7 also reveals that there are 25 observations with $Q_{7,10} = 0$ which are automatically excluded from analysis. A small value of 0.0001 cfs was added to each points, but this addition made the model biased. Therefore, only 109 observations were included in the analysis.

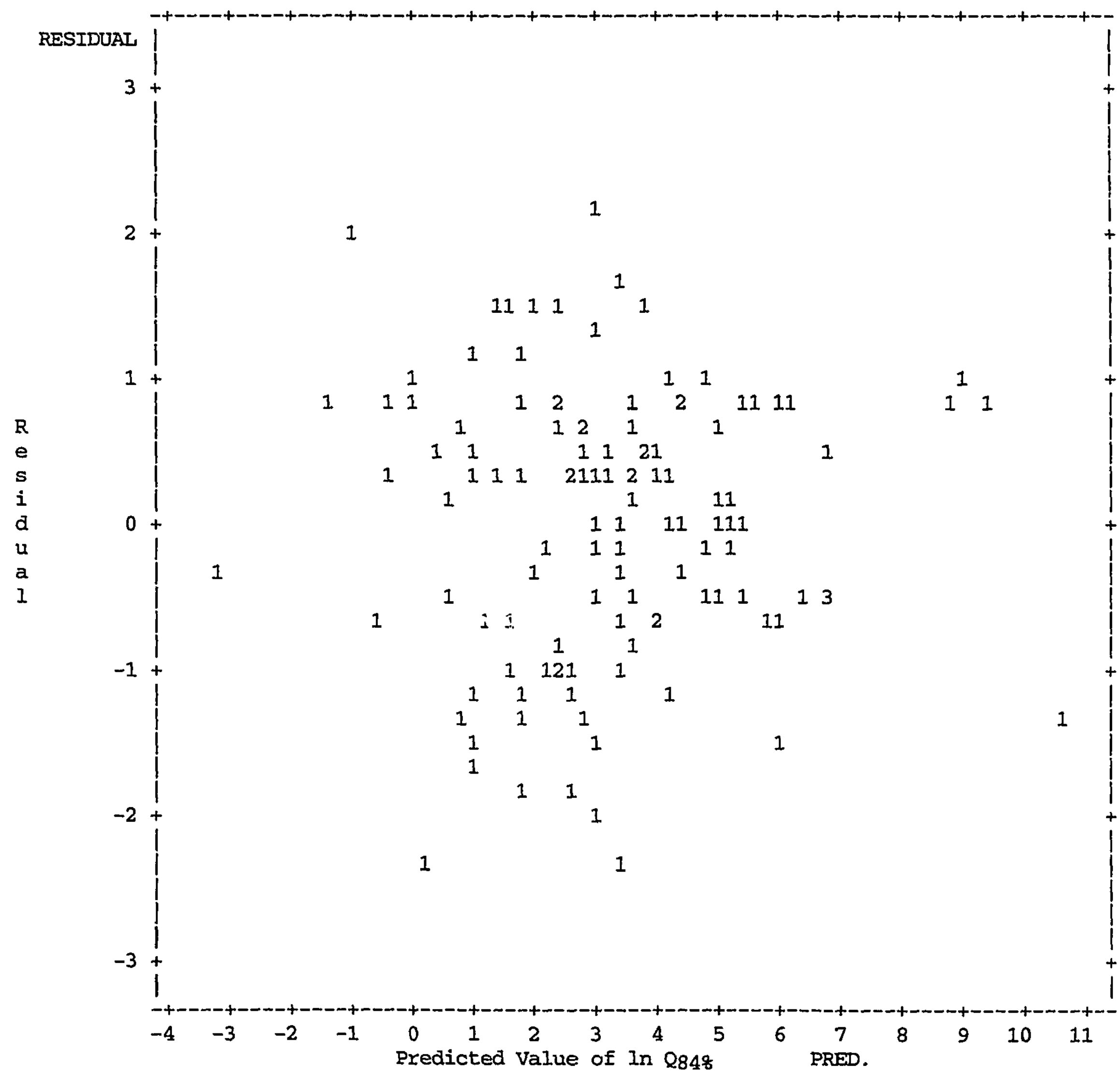

Figure 4.19. Scatter plot of residuals versus predicted values for model (4.4), $\ln Q_{84\%} = -4.428 + 1.183 \ln \mathrm{DA}$

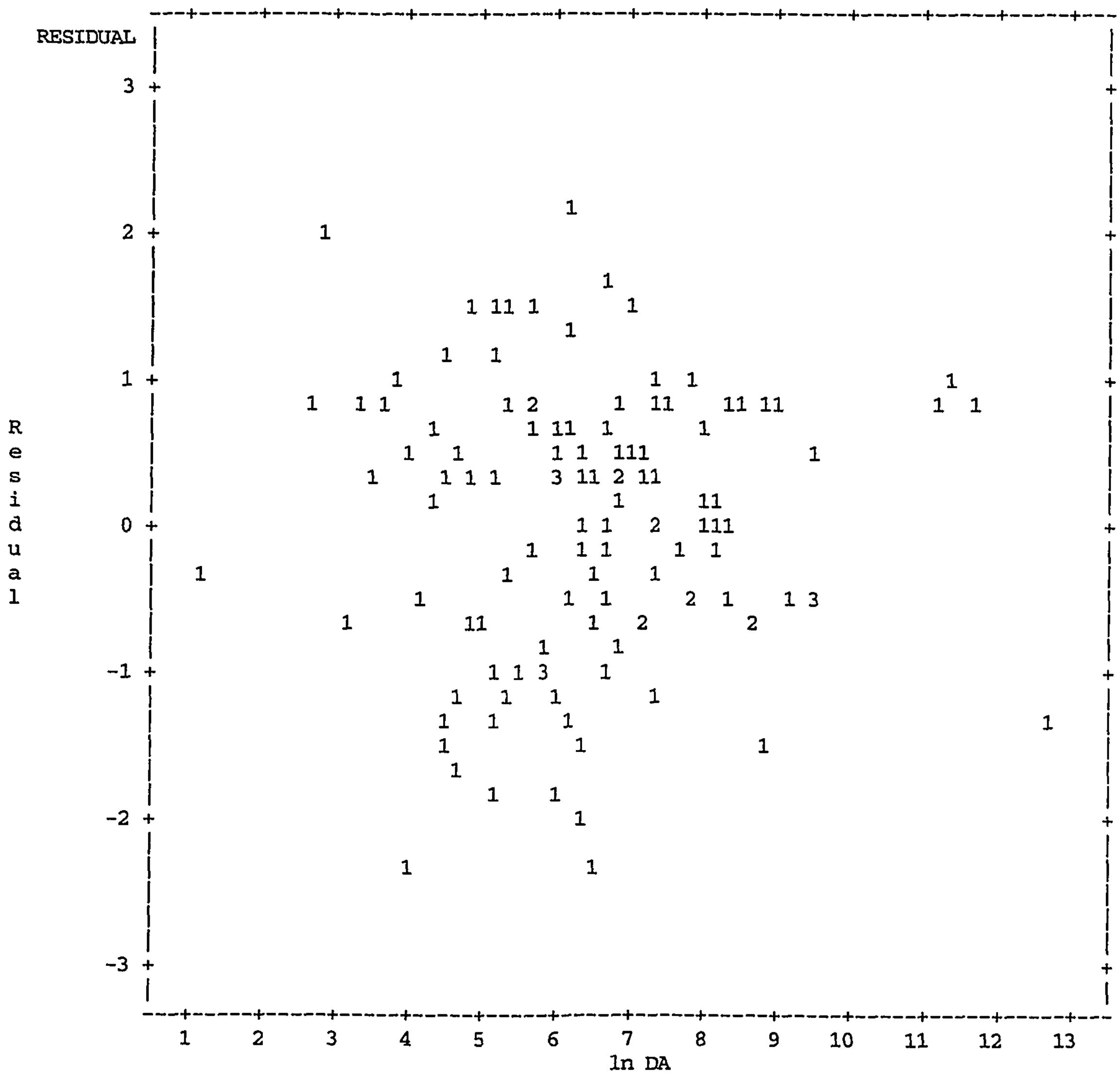

Figure 4.20. Scatter plot of residuals versus ln DA for model (4.4),
$\ln Q_{84\%} = -4.428 + 1.183 \ln DA$

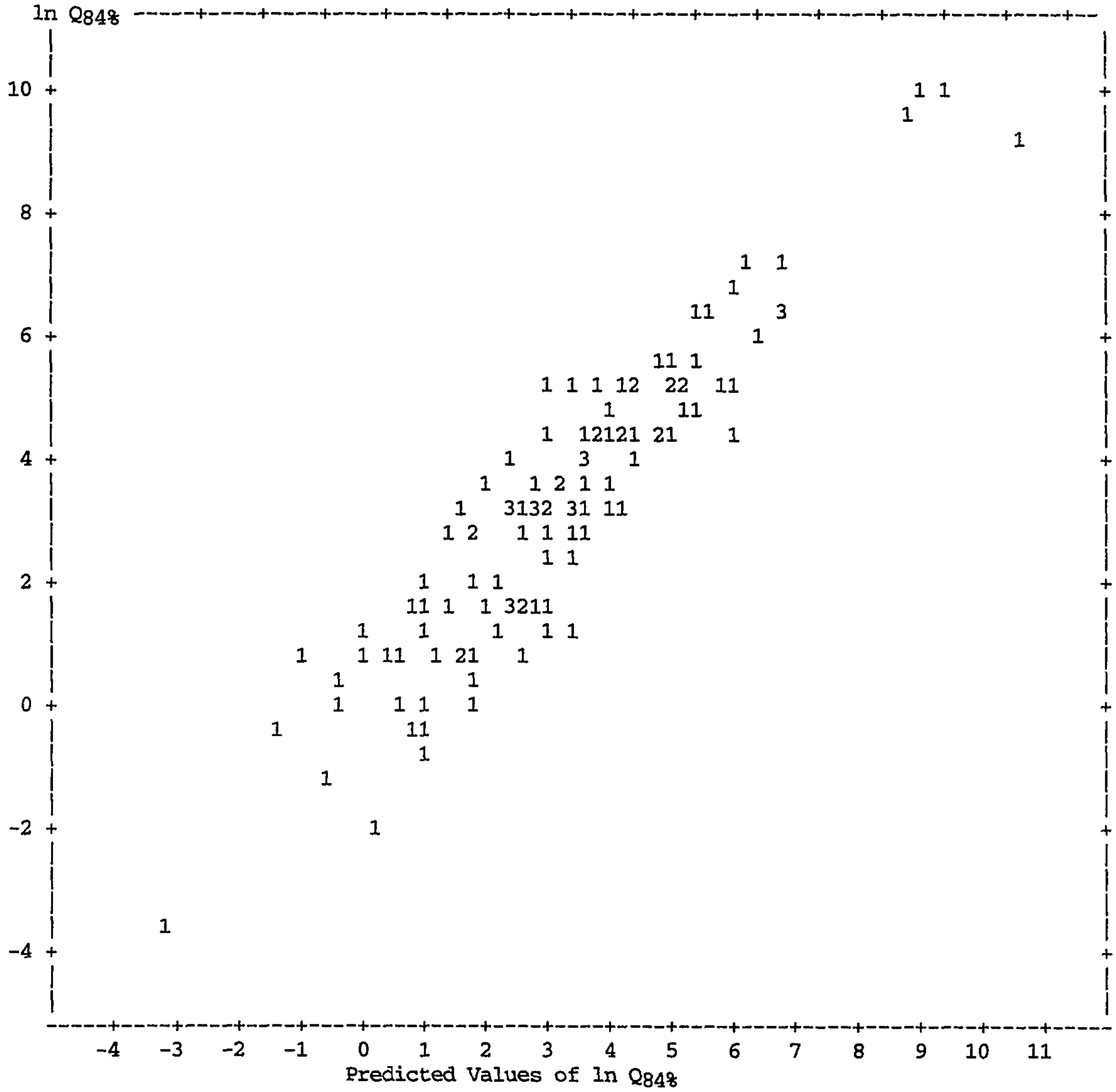

Figure 4.21 Scatter plot of the actual versus predicted values for model (4.4)

$\ln Q_{84\%} = -4.428 + 1.183 \ln \mathrm{DA}$

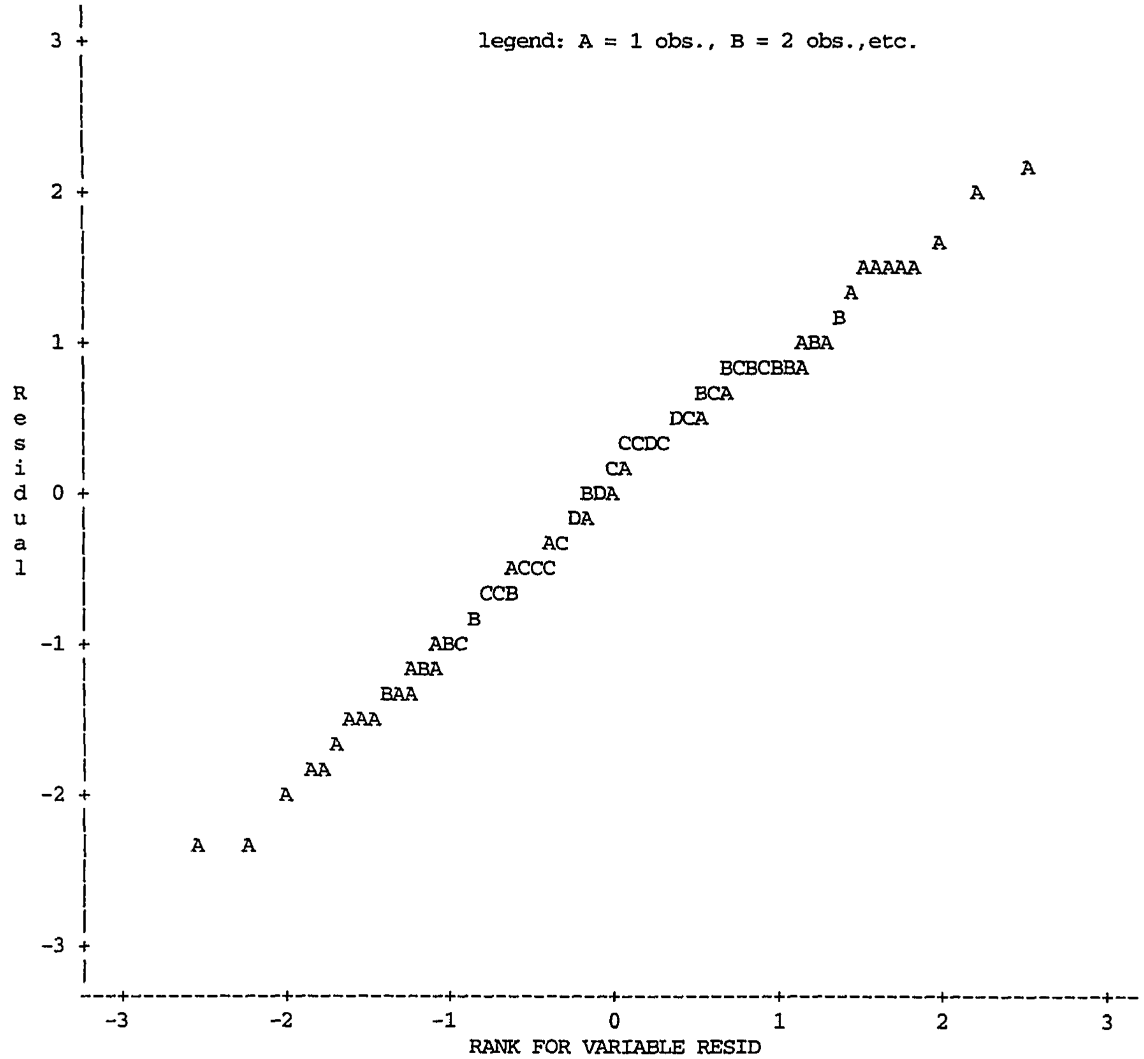

Figure 4.22. Normal plot of residuals for model (4.4),

$\ln Q_{84\%} = -4.428 + 1.183 \ln DA$

Table 4.18. R-square and *Cp* for possible models for ln $Q_{7,10}$ (N = 109)

Number of variables in the Model	R-square	Cp	Variables in Model
1	0.74048938	102.68978	ln Qm
1	0.69746387	137.12367	ln DA
1	0.52250327	277.14694	ln SDF
1	0.11754458	601.24074	ln EL
2	0.86428635	5.61343	ln Qm ln SDF
2	0.83476428	29.24033	ln DA ln SDF
2	0.74351245	102.27038	ln DA ln Qm
2	0.74049442	104.68575	ln EL ln Qm
2	0.70832718	130.42961	ln DA ln EL
2	0.56513726	245.02640	ln EL ln SDF
3	0.86777447	4.82184	ln DA ln Qm ln SDF
3	0.86429359	7.60763	ln EL ln Qm ln SDF
3	0.84114147	26.13658	ln DA ln EL ln SDF
3	0.74545599	102.71494	ln DA ln EL ln Qm
4	0.87005088	5.00000	ln DA ln EL ln Qm ln SDF

Using subset selection procedures to screen variables, the first model for $Q_{7,10}$ obtained by stepwise algorithm is

$$\ln Q_{7,10} = -15.013 + 1.103 \ln Q_{\mathrm{m}} + 3.397 \ln \mathrm{SDF} \qquad (4.5)$$

The backward elimination algorithm offers a model for this case which includes ln DA as well. While comparison of R^2, mean square error, and PRESS for this model and model (4.5) shows a slight improvement for the latter, the high variance inflation factors (VIF = 28.72 for ln DA and 28.96 for ln Q_{m}) indicate the presence of multicollinearity. Therefore, it was not selected.

Table 4.19 gives the ANOVA for model (4.5). R^2 for this model is 0.86, MSE = 1.03, F values are significant at the 0.0001 level, and VIF's are low (1.30), showing no signs of multicollinearity. However, examination of diagnostic measures indicates the presence of one significant outlier, S57 (South Skunk River near Ames) with a high Cook's D = 0.148, Residual = -4.129

Table 4.19. Analysis of variance and parameter estimates for model (4.5) (N=109)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	695.31083	347.65542	337.528	0.0001
Error	106	109.18045	1.03000		
C Total	108	804.49128			

Root MSE	1.01489	R-square	0.8643
Dep Mean	1.99254	Adj R-sq	0.8617
C.V.	50.93464		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|	Variance Inflation
INTERCEP	1	-15.013222	0.93463217	-16.063	0.0001	0.00000000
ln Qm	1	1.103243	0.06752344	16.339	0.0001	1.30213219
ln SDF	1	3.397451	0.34550717	9.833	0.0001	1.30213219

and Rstudent = -4.4757. Other diagnostic measures also have high values corresponding to S57. Residual plots of this model also point to S57 as an outlier. It is important to notice that S57 is also located within Des Moines lobe as is the case for the first outlier, S81—a fact that confirms the impact of geology on low flow. A second point, belonging to station S123 (Mosquito Creek near Earling), has a relatively high Cook's D value = 0.096 and Student residual = -2.456; but since this point is within three standard deviations from the zero line, it is not as far off as the first one.

Only station S57 was therefore removed, and regression analysis was rerun without it. The resulting model that evolved from the rest of the data is

$$\ln Q_{7,10} = -14.479 + 1.106 \ln Q_m + 3.230 \ln \mathrm{SDF} \qquad (4.6)$$

The ANOVA for this model is given in Table 4.20.

As is evident from this table, deletion of S57 reduced the MSE (from 1.03 to 0.87) and slightly increased R^2 (from 0.86 to 0.88). Furthermore, s_e was

Table 4.20. Analysis of variance and parameter estimates for model (4.6) (N=108)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	668.87049	334.43524	382.991	0.0001
Error	105	91.68800	0.87322		
C Total	107	760.55849			

Root MSE	0.93446	R-square	0.8794
Dep Mean	2.05363	Adj R-sq	0.8772
C.V.	45.50302		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|	Variance Inflation
INTERCEP	1	-14.479308	0.86879204	-16.666	0.0001	0.00000000
ln Qm	1	1.105672	0.06217463	17.783	0.0001	1.29842588
ln SDF	1	3.230440	0.32030698	10.085	0.0001	1.29842588

reduced from 1.01 to 0.93, the PRESS was reduced from 115.10 to 96.79, and the appearance of the residual plots was improved. As a word of caution, regression models are not expected to be good predictors outside the region in which the data fall. Thus, model (4.6) should not be used to predict a value for any of the 25 deleted points since they fall outside the range of the data. The results of the model after removal of the outlier are listed in Table 5 (Appendix A).

Figures 4.23 and 4.24 are residual plots for models (4.5) and (4.6). Considerable improvement can be seen in Figure 4.24 in terms of residuals distribution. Also, the actual versus predicted values of ln $Q_{7,10}$ both before and after deletion of the outlier are given in Figures 4.25 and 4.26 for comparison. The outlier point has been plotted with a zero character (0). Figure 4.27 gives the normal plot of residuals for model (4.6).

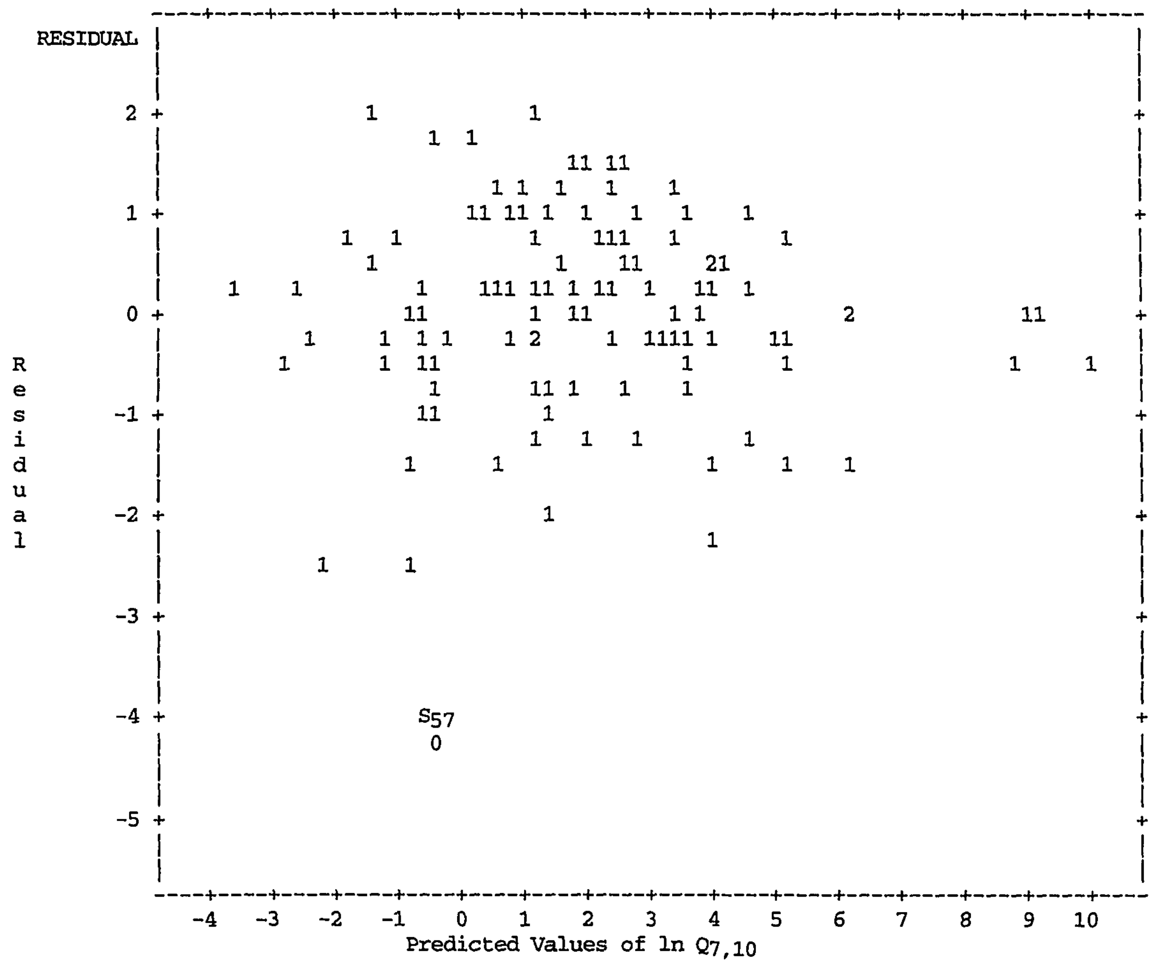

Figure 4.23. Scatter plot of residuals versus predicted values for model (4.5)

$$\ln Q_{7,10} = -15.013 + 1.103 \ln Q_m + 3.397 \ln \text{SDF} \qquad (N = 109)$$

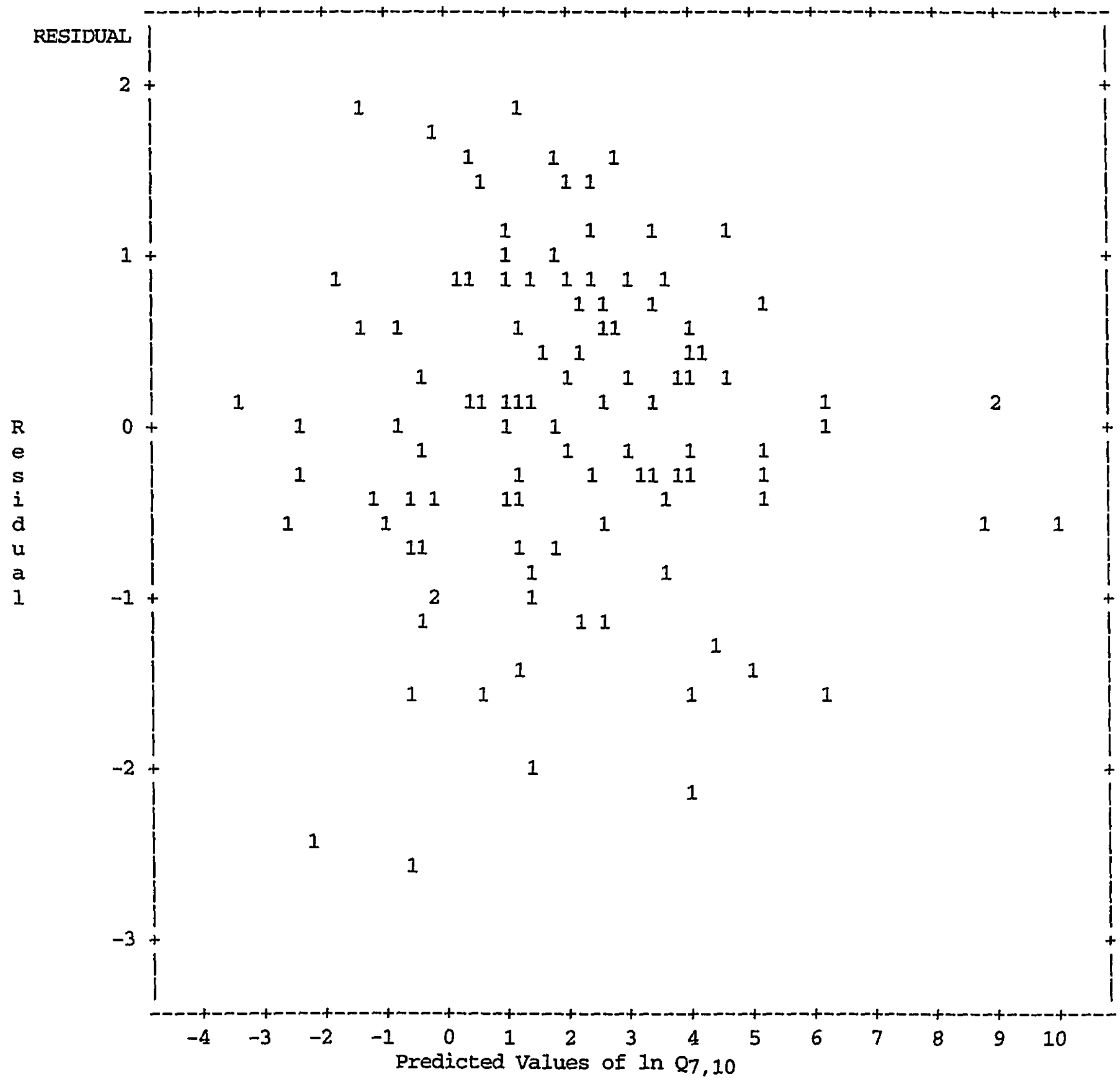

Figure 4.24. Scatter plot of residuals versus predicted values for model (4.6)

$$\ln Q_{7,10} = -14.479 + 1.106 \ln Q_m + 3.230 \ln \mathrm{SDF} \qquad (N = 108)$$

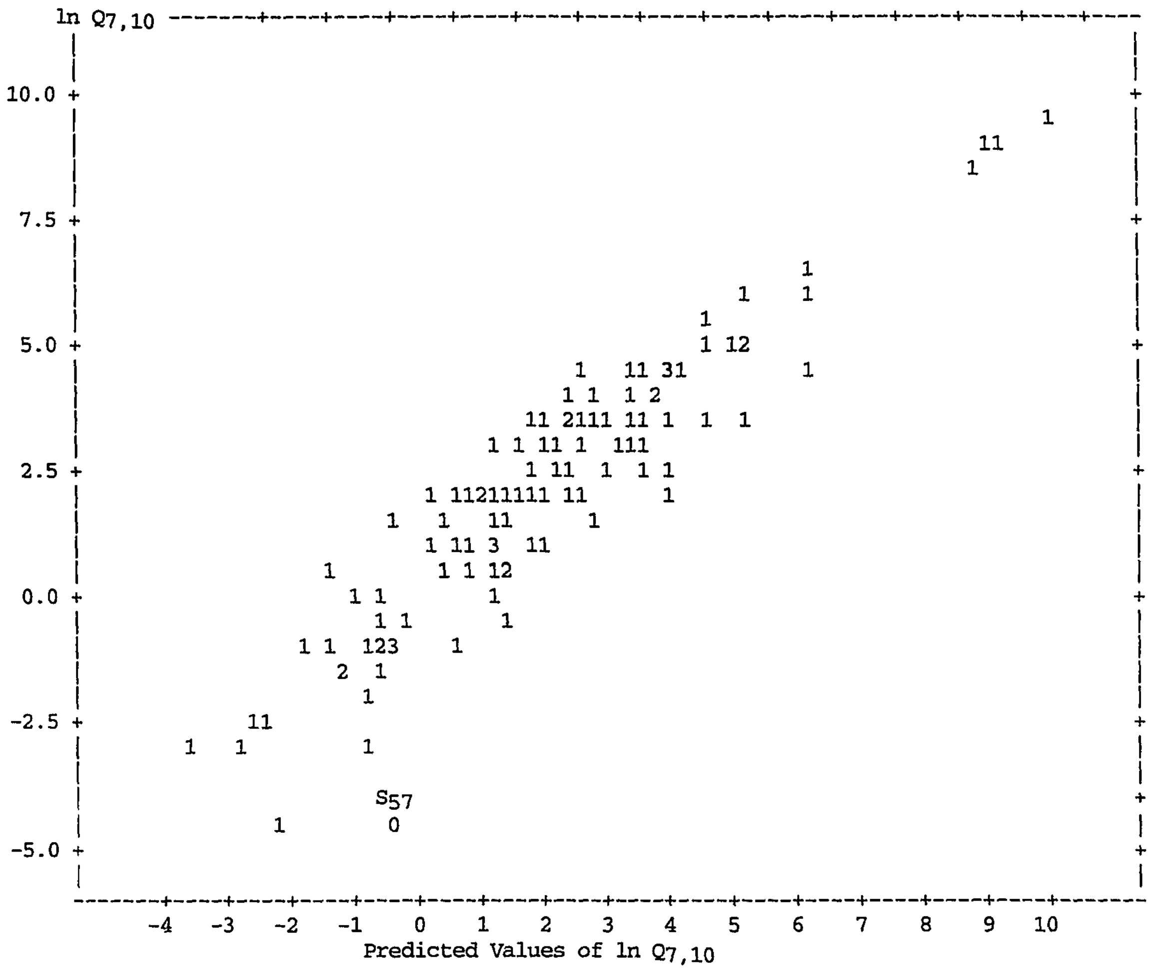

Figure 4.25. Actual versus predicted values for model (4.5),

$\ln Q_{7,10} = -15.013 + 1.103 \ln Q_m + 3.397 \ln \mathrm{SDF}$ (N = 109)

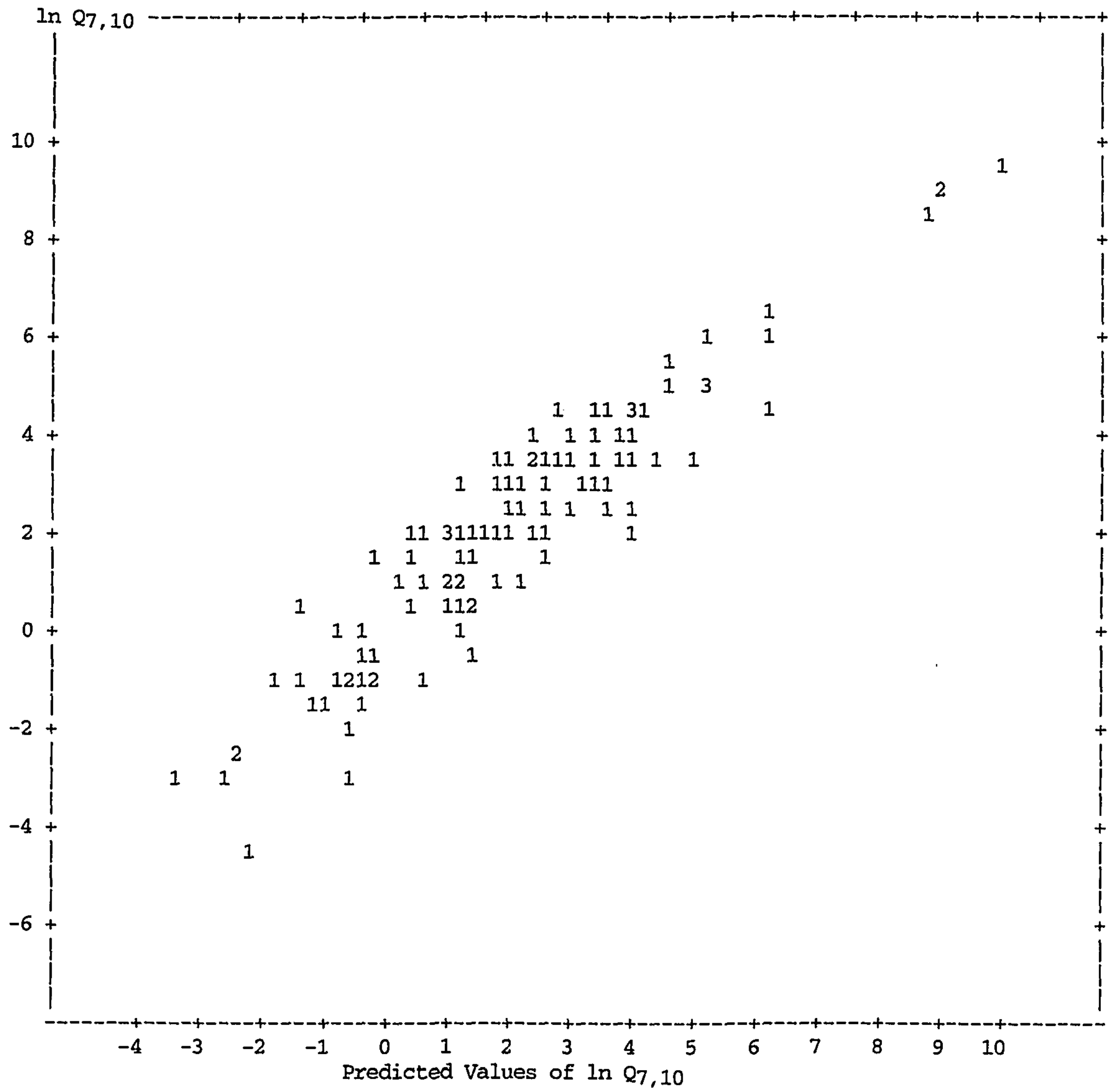

Figure 4.26. Actual versus predicted values for model (4.6),

$$\ln Q_{7,10} = -14.479 + 1.106 \ln Q_m + 3.230 \ln \text{SDF} \qquad (N = 108)$$

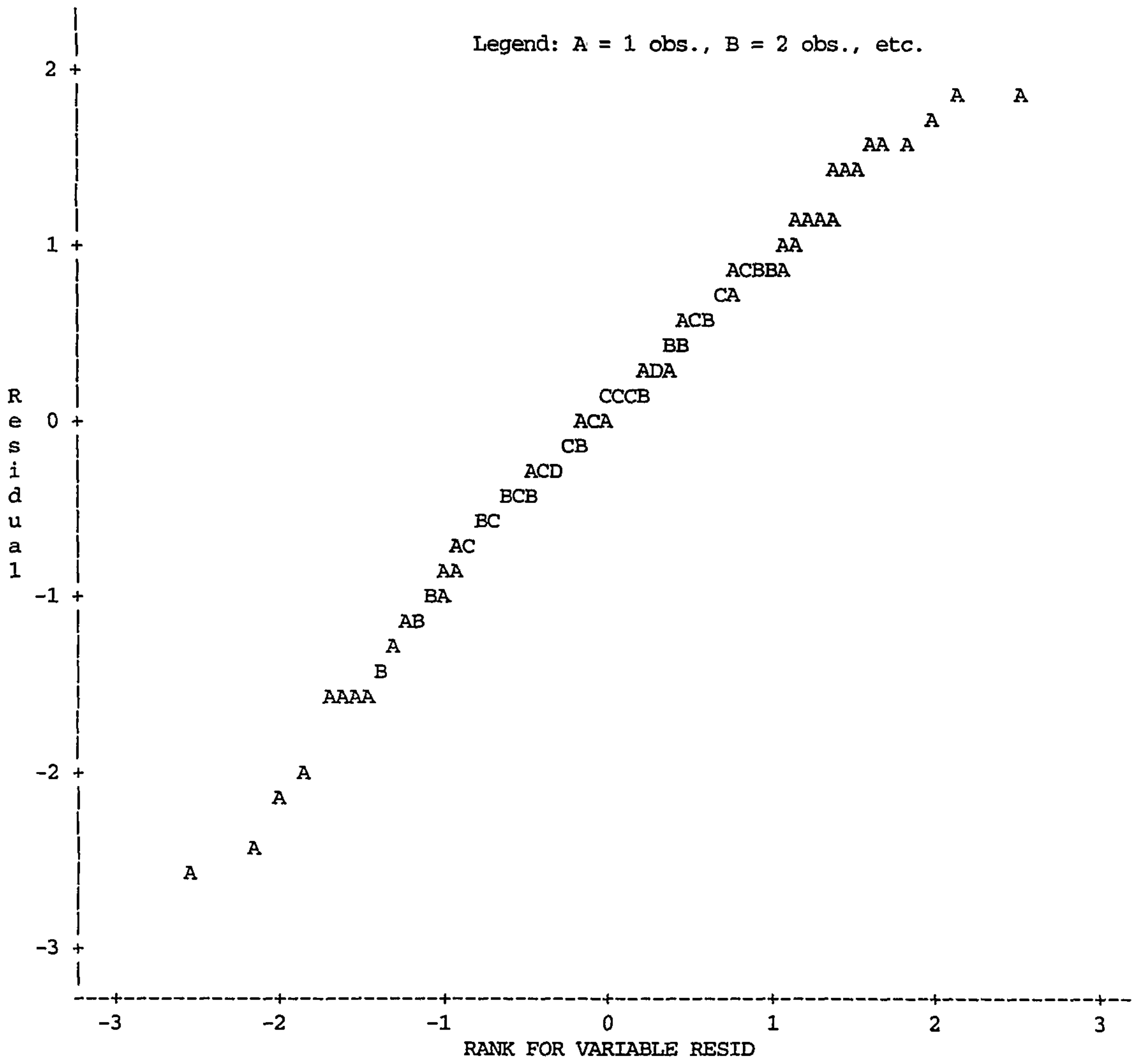

Figure 4.27. Normal plot of residuals for model (4.6),

$$\ln Q_{7,10} = -14.479 + 1.106 \ln Q_m + 3.230 \ln SDF \qquad (N = 108)$$

Again, similar to the case of the general model for $Q_{84\%,}$ 13 observations (S2, S12, S24, S28, S36, S47, S54, S61, S79, S98, S108, S130, and S135) were deleted from the regression analysis to be used later for cross validation of the model for $Q_{7,10}$. This set is not quite the same as the previous 13 points, since 8 points which had $Q_{7,10} = 0$ were replaced. The model for this case is given below.

$$\ln Q_{7,10} = -14.483 + 1.076 \ln Q_m + 3.310 \ln \text{SDF} \quad (4.7)$$

The R^2 for this model is 0.88, MSE = 0.87, s_e = 0.93, and PRESS = 84.99. The ANOVA is shown in Table 4.21.

Table 4.21. Analysis of variance and parameter estimates for model (4.7)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	602.90250	301.45125	348.279	0.0001
Error	92	79.63010	0.86554		
C Total	94	682.53259			

Root MSE	0.93035	R-square	0.8833
Dep Mean	2.24173	Adj R-sq	0.8808
C.V.	41.50123		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|	Variance Inflation
INTERCEP	1	-14.483112	0.93437823	-15.500	0.0001	0.00000000
ln Qm	1	1.075897	0.06518298	16.506	0.0001	1.33701093
ln SDF	1	3.309947	0.34755217	9.524	0.0001	1.33701093

Table 6 (Appendix A) presents the results generated by model (4.7).

Comparison of the residual plots with and without the 13 points shows no considerable change on their pattern; they are satisfactory in both cases.

Table 4.22 lists the actual values and those predicted by model (4.7) for the 13 deleted points.

Table 4.22. Actual and predicted values by model (4.7) for 13 deleted points

Assigned name	ln Q7,10		Q7,10	
	Actual	Predicted	Actual	predicted
S2	3.3673	2.7421	29.00	14.56
S12	1.0296	1.2626	2.80	3.22
S24	-0.9416	-0.4898	0.39	0.56
S28	3.8067	2.9706	45.00	18.67
S36	-1.6094	-0.3412	0.20	0.71
S47	1.6094	2.8151	5.00	16.69
S54	-0.8210	0.7839	0.44	2.19
S61	2.3979	4.0458	11.00	57.15
S79	0.5878	1.4652	1.80	4.33
S98	-3.2189	-2.6002	0.04	0.07
S108	1.0296	1.8722	2.80	6.50
S130	2.1518	1.1294	8.60	3.09
S135	-o.5621	-0.3772	0.57	0.68

Restricted models Two models with the restriction of employing either DA or DA and EL as explanatory variables were calculated and tested for accuracy and predictive ability. It was found that the univariate model which includes only DA explains 71.8% of variability among $Q_{7,10}$ data, with MSE = 2.02, high F = 269.60, significant at the 0.0001 level, and PRESS = 222.94. This model developed after deletion of station S57 as an outlier. It has the following mathematical equation:

$$\ln Q_{7,10} = -6.587 + 1.282 \ln DA \qquad (4.8)$$

The model, as its R^2 = 0.72 implies, is not as accurate as model (4.6). However, it can be used for sites without any hydrologic data to obtain first estimations for $Q_{7,10}$.

The ANOVA for this model is given in Table 4.23 The results of this model are listed in Table 7 (Appendix A). Figure 4.28 shows the predictive ability, and Figure 4.29 gives the normal plot of residuals of the model.

Table 4.23. Analysis of variance and parameter estimates for model (4.8) (N=108)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	545.91956	545.91956	269.604	0.0001
Error	106	214.63893	2.02490		
C Total	107	760.55849			

Root MSE	1.42299	R-square	0.7178
Dep Mean	2.05363	Adj R-sq	0.7151
C.V.	69.29149		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	-6.587120	0.54376755	-12.114	0.0001
ln DA	1	1.282263	0.07809336	16.420	0.0001

The second model, which includes both DA and EL, has a slightly larger R^2 of 0.729 and a smaller MSE of 1.96, but at the expense of instability in estimated parameters in terms of their significance levels. Therefore, it was not considered as an alternative.

Comparison of the results from the two restricted models (univariate and bivariate), for $Q_{84\%}$, with the two corresponding models for $Q_{7,10}$ reveals that elevation (EL) is not a sensitive explanatory variable to define the variations among the data for $Q_{84\%}$ and $Q_{7,10}$. This conclusion is also confirmed from the calculated correlation matrix Tables. The correlation coefficients between both low flow indices and elevation, in logarithmic scale, are fairly low (-0.27 and -0.34 respectively, in Table 4.6 and Table 4.7).

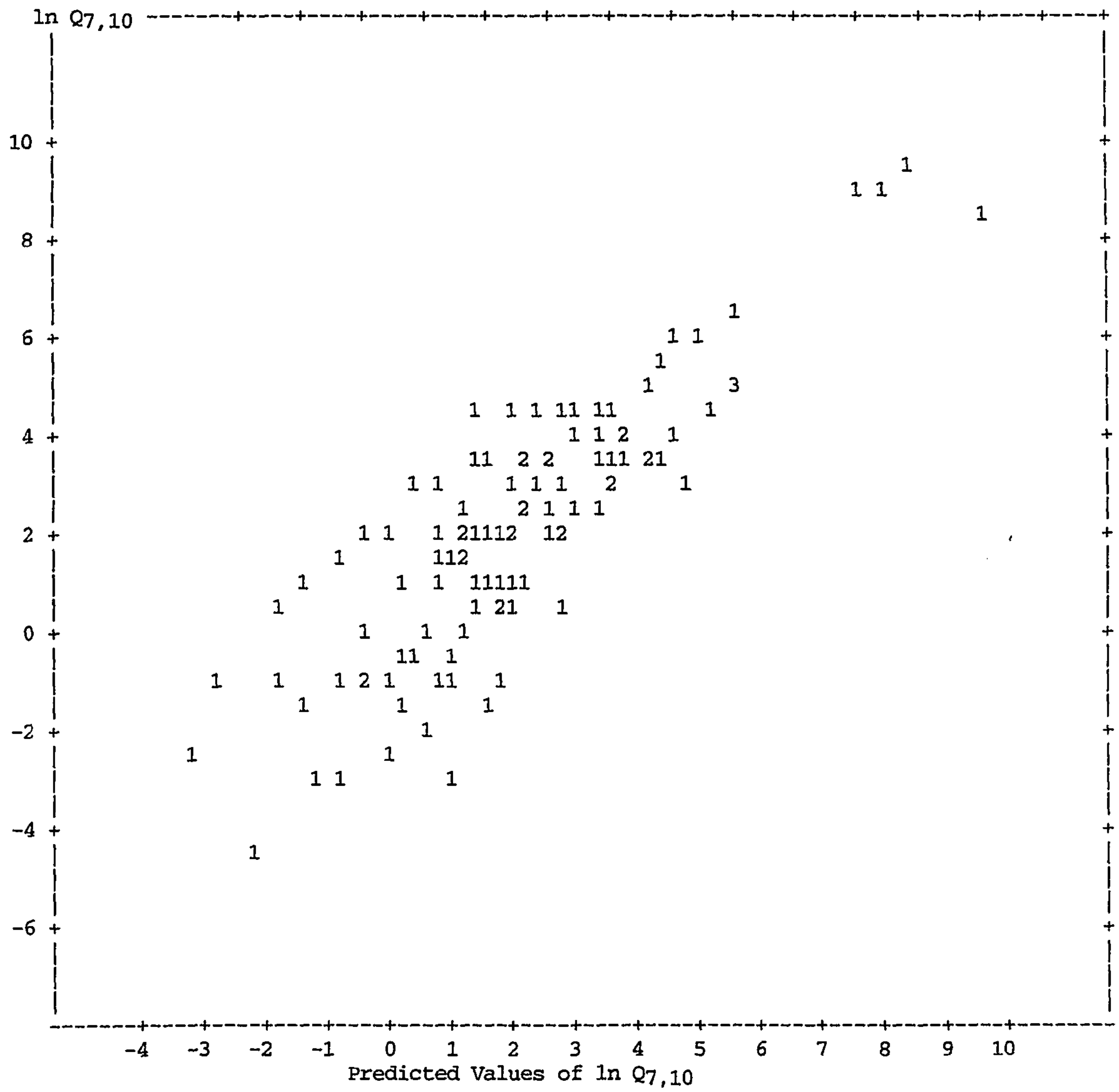

Figure 4.28. Actual versus predicted values of $\ln Q_{7,10}$ by model (4.8),

$\ln Q_{7,10} = -6.587 + 1.282 \ln DA$

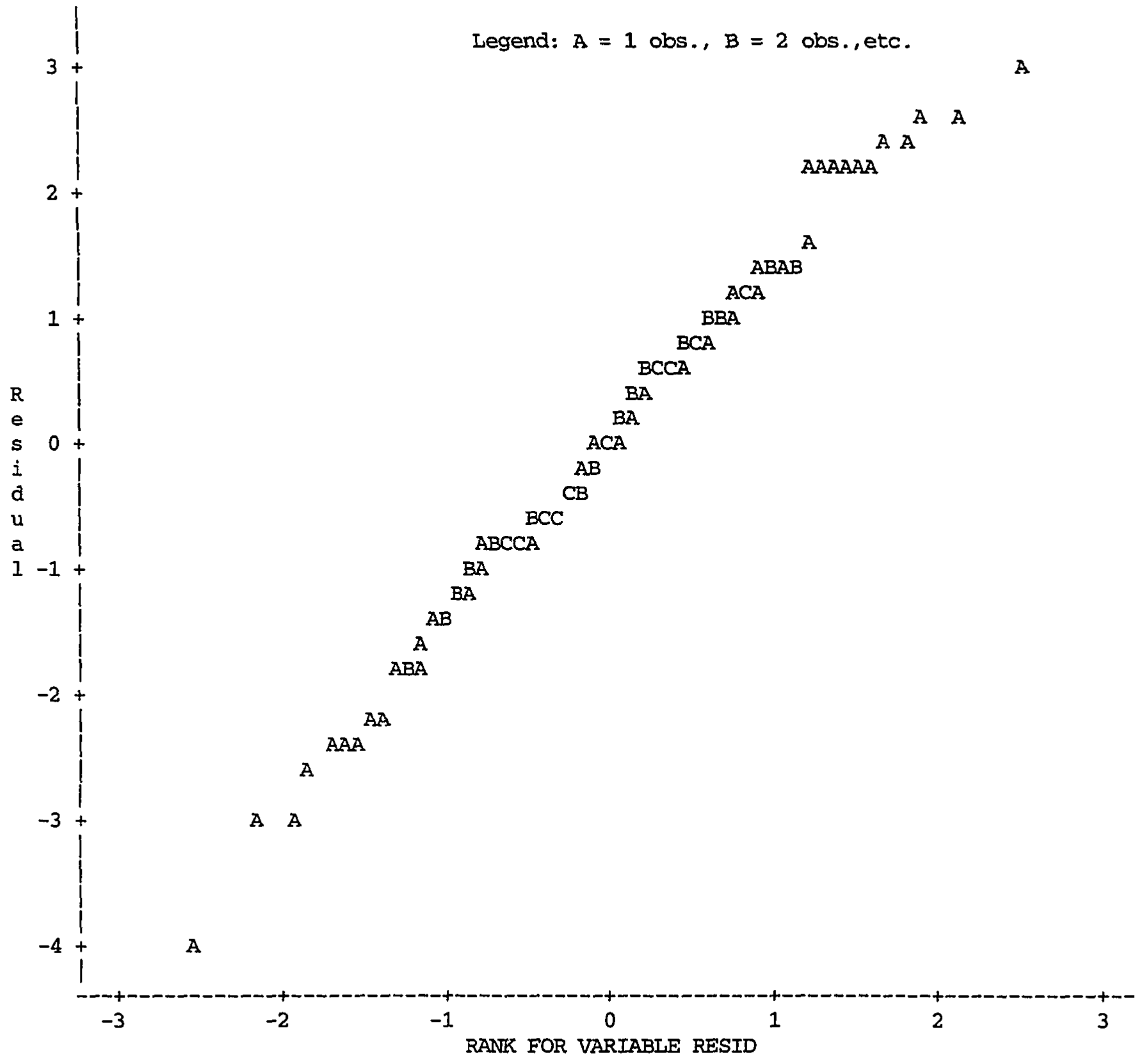

Figure 4.29. The normal plot of residuals for model (4.8)

Discussion

Excluded stations

As mentioned earlier nine stations were excluded from further analysis after being initially tested, either because the data were not available (for S57, S121, and S125) or the number of available linear segments was not sufficient to define a reliable master recession curve.

The hydrologic data for these stations are listed in Table 4.24, and their geographic distribution is shown in Figure 4.30.

Table 4.24 Hydrologic data for the nine excluded stations

ID number	Descriptive name	Assigned name	Drainage area (sq miles)	elevation (ft above NGVD)	Period of record
05418500	Maquoketa R. near Maquoketa	S14	1553	625.96	75
05464133	Half Mile Cr. near Gladbrook	S51	1.33	948.16	10
05476500	Des Moines R. at Estherville	S68	1372	1247.55	37
05481650	Des Moines R. near Saylorville	S75	5841	787.42	-
06484000	Dry Creek at Hawardin	S102	48.4	1170.42	25
06610000	Missouri River at Omaha	S121	322800	948.24	-
06610500	Indian Creek at Council Bluffs	S122	7.99	1038.86	22
06807000	Missouri R. at Nebraska City	S125	410000	905.36	-
06808000	Mule Creek near Malvern	S127	10.6	874.20	15

The following information is obtained from Table 4.24 and Figure 4.30:

1. The first four stations are located in the Mississippi basin, and the last five are situated along the western border of the state in the Missouri River basin, where the geology and soils are significantly different from the Mississippi River basin.
2. Four stations, S51, S102, S122, and S127 have small drainage areas (less than 50 sq miles). This can be the cause of instability in recession periods.

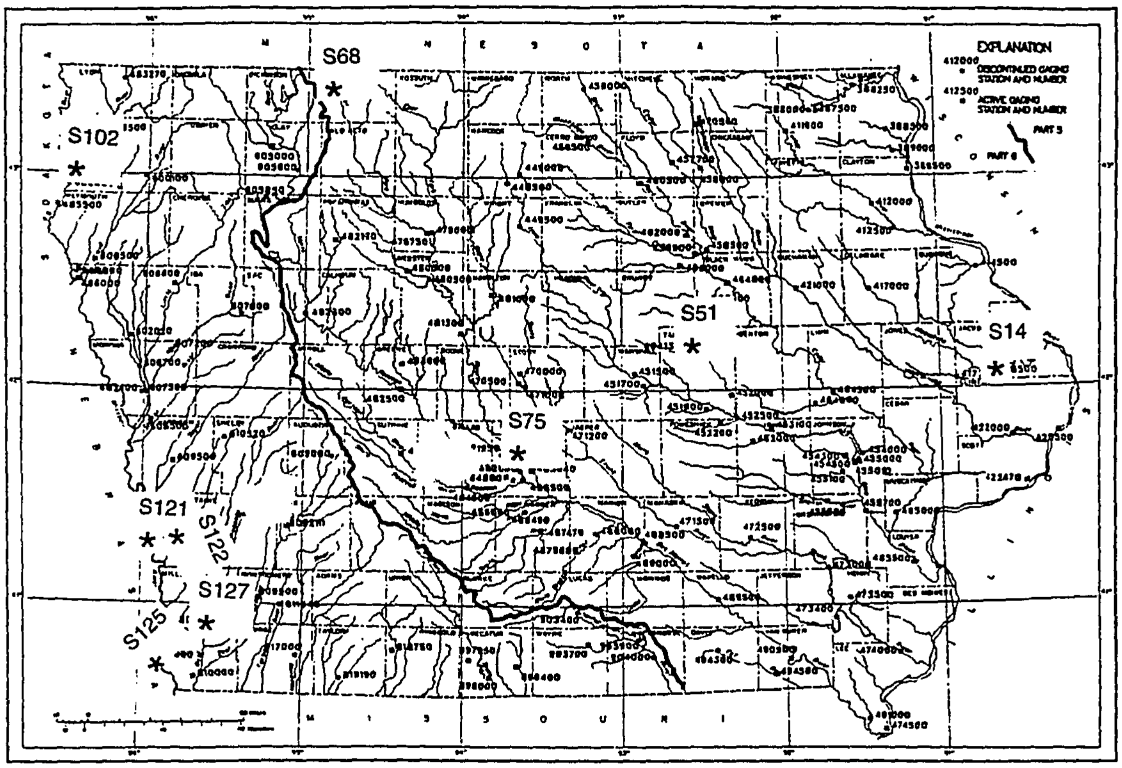

Figure 4.30. Location of the nine stations excluded from the analysis

3. Even if data had been available for stations S121 and S125, these two would have been excluded because they are located at downstream points on the Missouri River in the southwest corner of the state; therefore, the effects of all regulations due to the construction of different main-stem reservoirs have eventually been transferred to these points.
4. The abnormality observed in station S14 is due to bedrock aquifer discharge, as is evident by the presence of springs.
5. Station S68 is situated in the Des Moines lobe, which is known as poor natural drainage region.
6. Station S75 is affected by Saylorville Dam. Also, the data from pre-regulation period were not available.

Study of outliers

In modeling $Q_{84\%}$, station S81 (East Fork Hardin Creek near Churdan) was detected by the regression model to be a definite outlier. The actual value for $Q_{84\%}$ at this station is 0.02 cfs, whereas the model prediction is 0.46 cfs. Also, the regression model for $Q_{7,10}$ regarded station S57 (South Skunk River near Ames) as an outlier. The actual value for $Q_{7,10}$ at this site is 0.01 cfs, but the model predicts a value of 0.62 for it. Both values are overestimated by the models. Obviously, one or more factors must be responsible for keeping the low flow indices at these two stations lower than expected.

In an attempt to find possible reason(s) for this abnormality, some similarities were found between S81 and S57 as follows:

1. Both are the first stations on their respective streams (no previous upstream stations exist), where there is usually more variability than

the downstream stations. At these upland locations, the alluvial aquifers do not contribute significantly to the base flow.

2. Both have the same soil permeability index of I = 3.4 according to Howe (1968).

3. Both are located within the Des Moines lobe (Region II in Figure 1.3), with depressional watersheds. Significant artificial drainage, which is in operation especially within the Hardin Creek watershed, reduces base flow contribution.

Based on these remarks, it seems plausible to conclude that the geology of their drainage areas can account for these low values of $Q_{84\%}$ and $Q_{7,10}$. The locations of these two stations are indicated in Figure 1.3 by stars.

Variability of low flow indices

The data of Fischer *et al.* (1990) show that in all stations the mean annual streamflow is exceeded between 20 to 30% of the time. It means the discharge is below average 70 to 80% of the time, which indicates high variability.

The variation in low flow indices of Iowa streams is also substantial. The Iowa regulated protected low flow ($Q_{84\%}$) per unit area ranges from 0.00 for S81 to 0.31 for S13 csm (cubic feet per second per square mile), and the 7-day 10-year low flow ($Q_{7,10}$) varies between 0.00 (for 25 stations) and 0.16 for S13 csm in magnitude (one csm = 11 l/sec per square kilometer). Although the low flow indices ($Q_{84\%}$ and $Q_{7,10}$) in Table 4.25 have been standardized by dividing by the drainage area (DA) of each stream, those streams with larger drainage areas still exhibit higher values for $Q_{84\%}$/ (DA) and $Q_{7,10}$/ (DA). As the drainage area increases the extent and storage volume of alluvial aquifer usually increases.

Table 4.25. Low flow indices at some stations with different drainage areas

Assigned name[a]	Drainage area(A) sq mile	Q84%/A csm	Q7,10/A csm
S4	42	0.068	0.035
S36	201	0.009	0.001
S50	13.78	0.047	0.005
S60	276	0.029	0.003
S6	67500	0.217	0.134
S15	85600	0.246	0.118
S67	119000	0.220	0.101

[a] For ID numbers and site description, refer to Table 1 in Appendix A

Inspection of the data presented in Table 4.1 also reveals that there are 24 stations with small drainage areas (DA < 100 square miles). All these stations exhibit lower low flow magnitudes compared to the others regardless of location, indicating that the drainage area has a profound influence on low flow indices. This fact can be attributed to the increase in seepage area of the stream channel as the drainage area increases.

There are two stations which are exceptions to this rule. Station S19 (Crow Creek at Bettendorf with DA = 17.8 square miles has $Q_{7,10}$ = 0.40 cfs), located near the Mississippi River in a glacial drift-free zone and bedrock-controlled terrain. This zone is characterized by a sharply dissected landscape and steep valleys receiving the maximum precipitation in the state. The second station is S116 (Odebolt Creek near Arthur with DA = 39.9 square miles has $Q_{7,10}$ = 0.39 cfs), situated in the Missouri basin.

The inference regarding the effect of drainage area on the improvement of low flow characteristics is further confirmed by moving along an individual stream channel and comparing the downstream stations having larger drainage areas with upstream stations in terms of discharge per unit drainage area (cfs per square mile, csm). Table 4.26 illustrates such a comparison for stations in the Skunk River basin in central Iowa. The Table shows that as one moves in the downstream direction along the Skunk River channel, both low flow indices tend to increase. This fact is due to the presence of more alluvial deposits and, therefore, more base flow contribution in lowland areas. As streams slow down in the lowlands, their suspended solids are gradually deposited, providing more potential for groundwater storage. Furthermore, the water table in lowlands is usually closer to the surface.

Table 4.26. Comparison of low flow indices in the Skunk River basin

Assigned name[a]	Drainage area(A) sq mile	Q84%/A csm	Q7,10/A csm
S57	315	0.014	0.000
S62	730	0.039	0.004
S61	1635	0.046	0.007
S63	2890	0.0528	0.0077
S66	4303	0.0534	0.0080

[a] For ID numbers refer to Table 1 in Appendix A

There are stations, however, whose low flow indices are not consistent with the size of drainage area (see Table 4.27). In other words, with almost the same size of drainage area, their low flow indices vary by a factor of 4. One station, S39, has a smaller drainage area than the others in Table 4.27 while it has higher low flow indices. This discrepancy may be attributed to the differences between surficial soil types and the characteristics of aquifers contributing base flow to these streams in terms of transmissivity and storage coefficient. A more detailed geological study of these sites is probably justifiable. These gage locations are indicated by asterisks (*) on the map of Iowa (see Figure 1.1).

Table 4.27. Examples of stations with similar drainage areas but inconsistent low flow indices.

Assigned name[a]	Drainage area sq mile	Q84% cfs	Q7,10 cfs
S23	1564	99.2	22
S39	1054	185.6	96
S41	1661	191.4	73
S61	1635	76.0	11
S80	1619	54.6	6.40
S113	1548	68.8	9.10

[a] For ID numbers refer to Table 1 in Appendix A

Topography is another major factor affecting low flow features. There are many stations in Table 4.1 which, in spite of their medium-sized drainage area (usually three-digit size; in one case—S101—more than 1500 square miles), yield lower than expected low flow characteristics ($Q_{84\%}$/A = 0.015 csm; $Q_{7,10}$/A = 0.001 csm). These stations are: S24, S29, S36, S54, S58, S60, S65, S71, S76, S88, S94, S97, S99, S101, S106, S107, S111, S139, S140, S141, S142, and S143.

Tracing these stations on a hydrologic map of Iowa, such as Figure 1.1, makes it clear that they are located on tributaries. Tributaries usually start from higher elevations in upland areas of the basin, where the slopes are steeper and the water table is relatively deeper. Therefore, they have poor low flow characteristics, compared with the downstream reaches.

Regional trend in low flow

Apart from the observed local variabilities that have already been discussed, a general trend of decreasing low flow indices can be observed as one moves from the northeast and east to the southwest and west, in the same direction as annual precipitation decreases across the state.

Streams located in the northeast and east have larger low flow indices compared to the rest and can be viewed as well-sustained streams. More aquifer recharge due to higher precipitation, existence of deeply incised, narrow valleys which can possibly augment the seepage area, lack of glacial material, presence of surficial alluvium, and karst formations are known factors responsible for high low flow indices. Moving to the southwest and west, the dry-weather streamflow gradually lessens. Significant drops in low flow indices are observed for gaging stations located within the Des Moines lobe (S20, S21, S57, S58, S59, S71, S78, and S81, to give some examples). The streams with the lowest low flow indices generally lie in the southwestern corner of the state, draining loess hills to the Missouri River.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The results of this investigation provide a new foundation to enhance our understanding about low flow characteristics of Iowa streams.

Development of 134 pairs of master recession curves for 134 hydrologic gaging stations based on their available streamflow records would make it possible to characterize the recession behavior of each stream at different sites. They also help determine the general pattern of recession in the future days of a dry period given the present magnitude of streamflow.

The master curves are supplemented by calculated values of median storage delay factors (SDF's) for each station. These values are believed to represent the collective influence of basin geology, extent and type of aquifer(s), and surficial soils on low flow characteristics. The calculated SDF's are between 8.3 days per log cycle for S141 (South Fork Chariton River near Promise City) and 43.8 days per log cycle for S67 (Mississippi River at Keokuk). Higher values for SDF imply gentle recession and therefore, more sustained low flow.

Both master recession curves and storage delay factors are useful in setting stream management strategies in terms of water allocation for different uses and permit issuance during the low flow periods.

The output of the second part of this research offers predictive models for low flow indices. Specifically, based on multiple regression analysis, three regression models have been proposed for estimation of $Q_{84\%}$ (regulated protected flow). The mathematical expressions for these models are:

$$\ln Q_{84\%} = -9.035 + 1.029 \ln Q_m + 2.113 \ln SDF \quad (5.1)$$

with n = 133, adjusted R-squared = 0.941, and $s_e = 0.594$

$$\ln Q_{84\%} = -9.086 + 1.020 \ln Q_m + 2.155 \ln SDF \quad (5.2)$$

with n = 120, adjusted R-squared = 0.938, and $s_e = 0.596$ and

$$\ln Q_{84\%} = -4.428 + 1.183 \ln DA \quad (5.3)$$

with n = 120, adjusted R-squared = 0.846, and $s_e = 0.941$

Models (5.1) and (5.2) include Q_m (mean annual streamflow) and SDF (median storage delay factor) as explanatory variables; the former is an indirect measure of input to the shallow aquifers, and the latter, which represents the overall effect of geology and surficial soils of the drainage area, is an inverse measure for the rate of recession of base flow (output from the groundwater).

Model (5.3) is a univariate model consisting of only DA (drainage area), proposed as a quick reference to estimate $Q_{84\%}$ for those sites with no previous hydrologic data. The drainage area can be determined by topographic maps and aerial photographs.

Likewise, three regression models have been developed for estimation of $Q_{7,10}$ (7-day, 10-year low flow). Equations for these models are:

$$\ln Q_{7,10} = -14.479 + 1.106 \ln Q_m + 3.230 \ln SDF \quad (5.4)$$

with n = 108, adjusted R-squared = 0.877 and $s_e = 0.934$

$$\ln Q_{7,10} = -14.483 + 1.076 \ln Q_m + 3.310 \ln SDF \quad (5.5)$$

with n = 95, adjusted R-squared = 0.881, and $s_e = 0.930$ and

$$\ln Q_{7,10} = -6.587 + 1.282 \ln DA \quad (5.6)$$

with n = 108, adjusted R-squared = 0.715 and $s_e = 1.42$

Again, model (5.6) is to be used for preliminary estimation of $Q_{7,10}$ at sites where no hydrologic records are available.

In summary, based on the results of this investigation, the following conclusions can be drawn:

1. The state-of-the-art mathematical modeling used in this study to develop master recession curves appears to be useful in extracting meaningful information from many individual recession segments which are otherwise difficult to use in practice.
2. The developed master recession curves together with calculated storage delay factors can be used to predict the daily low flows during a dry period.
3. Among the four explanatory variables initially used to develop regression models for $Q_{84\%}$ and $Q_{7,10}$, the two most effective variables turned out to be mean annual precipitation (Q_m), and storage delay factor (SDF).
4. Attempts for modeling low flow characteristics using multiple regression techniques appear to be successful. The models for $Q_{84\%}$ have a higher predictive ability than those for $Q_{7,10}$. Although the same explanatory variables have been employed in both cases, the number of observations (n), for $Q_{7,10}$ models were smaller since 25 observations had a value of $Q_{7,10} = 0$ and were excluded from analysis.
5. Not only do regression methods provide reliable predictive models, but they can also be used as detectors for further investigation. Flagging a

certain point as an outlier justifies additional efforts focusing on that point, which can lead to valuable information.

6. Exponential models are the best choices among other alternatives, for modeling low flow indices, although they cannot handle zero values.

Recommendations

In order to maintain a reasonable scope for the present investigation, the effects of some factors on low flow characteristics have not been studied. However, in similar studies performed on a smaller scale, where only several streams are encountered, the following areas are suggested to be emphasized:

Basin geology

A general knowledge of geology of the drainage areas is required to discover the nature, type, and extent of aquifer(s) contributing base flow to the streams, and to assist interpretation of some unusual observations on low flow characteristics in multiaquifer basins.

Land use

The impact of land use changes on low flow yields needs to be investigated. Controversy regarding the nature of hydrologic influence of forests and urbanization is evident in the current literature. This is partly because the yearly weather variability complicates the study of the effects of a specific change in land use on low flow characteristics and overshadows the comparison of low flow records before and after change. For this reason, it has even been recommended that experiments on land use changes be carried out in tropical areas, where the pattern of weather is more consistent and the growth of vegetation is fast.

The portions devoted to different modes of land use, such as forest, rangeland, cropland, urban, and industrial areas, need to be identified in each individual drainage basin from aerial photographs or appropriate maps. Also, the extent of lakes, swamps, and wetlands should be measured to identify any possible influence on low flow magnitudes and frequencies.

Air temperature

In cold regions, a knowledge of air temperature at sites is desirable to determine the magnitude and duration of subzero periods, during which the rate of base flow to the streams would be significantly decreased. Groundwater contribution can even cease under extremely cold conditions (Rogers and Armbruster, 1990) due to freezing of surface soil layers, even though the hydraulic gradient still exists. Conversely, an unusual warming period in the winter can cause unpredictable increases in baseflow input due to aquifer recharge. Access to the temperature records can be accomplished by installation of a thermograph at each site to depict temperature fluctuations.

Precipitation

Daily precipitation during the recession period is required to interpret any unusual situation that is encountered. Frequently, a recession segment is found that has a constant baseflow for several days. This may occur due to runoff-producing precipitation (or snowmelt runoff) that is just enough to maintain a constant streamflow for some time, masking the regular decline in base flow.

In terms of low flow modeling, considerable research remains to be conducted to improve the efficiency of the existing model and to develop a more vigorous conceptual basis for new models.

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APPENDIX A

Table 1. List of Iowa gaging stations initially used in analysis

ID number	Stream gaging station	Assigned name
05387500	Upper Iowa River at Decorah	S1
05388000	Upper Iowa River near Decorah	S2
05388250	Upper Iowa River near Dorchester	S3
05388500	Paint Creek at Waterville	S4
05389000	Yellow River at Ion	S5
05389500	Mississippi River at McGregor	S6
05411600	Turkey River at Spillville	S7
05412000	Turkey River at Elkader	S8
05412500	Turkey River at Garber	S9
05414500	Little Maquoketa River near Durango	S10
05417000	Maquoketa River near Manchester	S11
05417700	Bear Creek near Monmouth	S12
05418450	North Fork Maquoketa River at Fulton	S13
05418500	Maquoketa River near Maquoketa	S14
05420500	Mississippi River at Clinton	S15
05420560	Wapsipinicon River near Elma	S16
05421000	Wapsipinicon River at Independence	S17
05422000	Wapsipinicon River near DeWitt	S18
05422470	Crow Creek at Bettendorf	S19
05448500	West Branch Iowa River near Klemme	S20
05449000	East Branch Iowa River near Klemme	S21
05449500	Iowa River near Rowan	S22
05451500	Iowa River at Marshalltown	S23
05451700	Timber Creek near Marshalltown	S24
05451900	Richland Creek near Haven	S25
05452000	Salt Creek near Elberon	S26
05452200	Walnut Creek near Hartwick	S27
05452500	Iowa River near Belle Plaine	S28
05453000	Big Bear Creek at Ladora	S29
05453100	Iowa River at Marengo	S30
05454000	Rapid Creek near Iowa City	S31
05454300	Clear Creek near Coralville	S32
05454500	Iowa River at Iowa City	S33
05455000	Ralston Creek at Iowa City	S34
05455010	South Branch Ralston Creek at Iowa City	S35
05455100	Old Mans Creek near Iowa City	S36
05455500	English River at Kalona	S37
05455700	Iowa River near Lone Tree	S38
05457700	Cedar River at Charles City	S39
05458000	Little Cedar River near Ionia	S40
05458500	Cedar River at Janesville	S41
05458900	West Fork Cedar River at Finchford	S42
05459000	Shell Rock River near Northwood	S43
05459500	Winnebago River at Mason City	S44
05460500	Shell Rock River at Marble Rock	S45

Table 1 continued

ID number	Stream gaging station	Assigned name
05462000	Shell Rock River at Shell Rock	S46
05463000	Beaver Creek at New Hartford	S47
05463500	Black Hawk Creek at Hudson	S48
05464000	Cedar River at Waterloo	S49
05464130	Fourmile Creek near Lincoln	S50
05464133	Half Mile Creek near Gladbrook	S51
05464137	Four Mile Creek near Traer	S52
05464500	Cedar River at Cedar Rapids	S53
05464640	Prairie Creek at Fairfax	S54
05465000	Cedar River near Conesville	S55
05465500	Iowa River at Wapello	S56
05470000	South Skunk River near Ames	S57
05470500	Squaw Creek at Ames	S58
05471000	South Skunk R. below Squaw Creek near Ames	S59
05471200	Indian Creek near Mingo	S60
05471500	South Skunk River near Oskaloosa	S61
05472500	North Skunk River near Sigourney	S62
05473000	Skunk River at Coppock	S63
05473400	Cedar Creek near Oakland Mills	S64
05473500	Big Creek near Mount Pleasant	S65
05474000	Skunk River at Augusta	S66
05474500	Mississippi River at Keokuk	S67
05476500	Des Moines River at Estherville	S68
05476750	Des Moines River at Humboldt	S69
05479000	East Fork Des Moines River at Dakota City	S70
05480000	Lizard Creek near Clare	S71
05480500	Des Moines River at Fort Dodge	S72
05481000	Boone River near Webster City	S73
05481300	Des Moines River near Stratford	S74
05481650	Des Moines River near Saylorville	S75
05481950	Beaver Creek near Grimes	S76
05482000	Des Moines River at Des Moines	S77
05482170	Big Cedar Creek near Varina	S78
05482300	North Raccoon River near Sac City	S79
05482500	North Raccoon River near Jefferson	S80
05483000	East Fork Hardin Creek near Churdan	S81
05483600	Middle Raccoon River at Panora	S82
05484000	South Raccoon River at Redfield	S83
05484500	Raccoon River at van Meter	S84
05484800	Walnut Creek at Des Moines	S85
05485500	Des Moines R. below Racc. R. at Des Moines	S86
05485640	Fourmile Creek at Des Moines	S87
05486000	North River near Norwalk	S88
05486490	Middle River near Indianola	S89
05487470	South River near Ackworth	S90

Table 1 continued

ID number	Stream gaging station	Assigned name
05487980	White Breast Creek near Dallas	S91
05488000	white Breast Creek near Knoxville	S92
05488500	Des Moines River near Tracy	S93
05489000	Cedar Creek near Bussey	S94
05489500	Des Moines River at Ottumwa	S95
05490500	Des Moines River at Keosauqua	S96
05491000	Sugar Creek near Keokuk	S97
05494300	Fox River at Bloomfield	S98
05494500	Fox River at Cantril	S99
06483270	Rock River at Rock Rapids	S100
06483500	Rock River near Rock valley	S101
06484000	Dry Creek at Hawarden	S102
06485500	Big Sioux River at Akron	S103
06486000	Missouri River at Sioux City	S104
06600000	Perry Creek at 38th Street, Sioux City	S105
06600100	Floyd River at Alton	S106
06600300	West Branch Floyd River near Struble	S107
06600500	Floyd River at James	S108
06602020	West Fork Ditch at Hornick	S109
06602400	Monona-Harrison Ditch near Turin	S110
06605000	Ocheyedan River near Spencer	S111
06605600	Little Sioux River at Gillett Grove	S112
06605850	Little Sioux River at Linn Grove	S113
06606600	LIttle Sioux River at Correctionville	S114
06606700	Little Sioux River near Kennebec	S115
06607000	Odebolt Creek near Arthur	S116
06607200	Maple River at Mapleton	S117
06607500	Little Sioux River near Turin	S118
06608500	Soldier River at Pisgah	S119
06609500	Boyer River at Logan	S120
06610000	Missouri River at Omaha, Nebraska	S121
06610500	Indian Creek at Council Bluffs	S122
06610520	Mosquito Creek near Earling	S123
06806000	Waubonsie Creek near Bartlett	S124
06807000	Missouri River at Nebraska City, Nebraska	S125
06807410	West Nishnabotna River at Hancock	S126
06808000	Mule Creek near Malvern	S127
06808500	West Nishnabotna River at Randolph	S128
06809000	Davids Creek near Hamlin	S129
06809210	East Nishnabotna River near Atlantic	S130
06809500	East Nishnabotna River at Red Oak	S131
06810000	Nishnabotna River above Hamburg	S132
06811840	Tarkio River at Stanton	S133
06817000	Nodaway River at Clarinda	S134
06818750	Platte River near Diagonal	S135

Table 1 continued

ID number	Stream gaging station	Assigned name
06819190	East Fork 102 River at Bedford	S136
06897950	Elk Creek near Decatur City	S137
06898000	Thompson River at Davis City	S138
06898400	Weldon River near Leon	S139
06903400	Chariton River Near Chariton	S140
06903700	South Fork Chariton R. near Promise City	S141
06903900	Chariton River near Rathbun	S142
06904000	Chariton River near Centerville	S143

Table 2. Actual versus predicted values for response variable ln $Q_{84\%}$ (N = 133)

Assigned name	Dep Var ln $Q_{84\%}$	Predict Value	Std Err Predict	Lower95% Mean	Upper95% Mean	Lower95% Predict	Upper95% Predict	Residual
S1	4.2905	3.7689	0.068	3.6347	3.9030	2.5868	4.9509	0.5216
S2	4.3041	3.9533	0.077	3.8009	4.1057	2.7691	5.1375	0.3508
S3	5.1533	4.9551	0.101	4.7554	5.1548	3.7638	6.1464	0.1982
S4	1.0647	0.3253	0.122	0.0844	0.5662	-0.8736	1.5241	0.7394
S5	3.4965	3.4148	0.118	3.1805	3.6491	2.2172	4.6123	0.0818
S6	9.5929	9.4852	0.151	9.1872	9.7831	8.2736	10.6968	0.1077
S7	3.1781	2.7790	0.084	2.6125	2.9455	1.5929	3.9652	0.3990
S8	4.4188	3.4892	0.059	3.3729	3.6055	2.3091	4.6694	0.9296
S9	5.3327	4.8532	0.066	4.7223	4.9841	3.6716	6.0349	0.4795
S10	2.8332	2.2172	0.083	2.0525	2.3819	1.0313	3.4031	0.6160
S11	3.8286	2.8522	0.054	2.7455	2.9589	1.6730	4.0315	0.9764
S12	1.9459	2.3206	0.152	2.0192	2.6220	1.1081	3.5331	-0.3747
S13	5.0876	4.8443	0.134	4.5792	5.1094	3.6403	6.0483	0.2433
S15	9.9570	9.6668	0.156	9.3576	9.9759	8.4524	10.8812	0.2903
S16	2.1282	1.5469	0.070	1.4090	1.6848	0.3644	2.7294	0.5813
S17	4.2341	3.7589	0.062	3.6360	3.8819	2.5781	4.9398	0.4752
S18	5.6937	5.4338	0.074	5.2877	5.5799	4.2504	6.6173	0.2599
S19	0.9555	0.1454	0.116	-0.0840	0.3749	-1.0512	1.3420	0.8101
S20	0.6678	1.1884	0.093	1.0034	1.3733	-0.0005	2.3772	-0.5205
S21	1.6487	1.3973	0.067	1.2652	1.5294	0.2155	2.5791	0.2514
S22	3.1355	2.8553	0.053	2.7504	2.9602	1.6762	4.0344	0.2802
S23	4.5951	4.1793	0.064	4.0536	4.3049	2.9982	5.3604	0.4159
S24	1.5261	1.3743	0.063	1.2488	1.4997	0.1932	2.5553	0.1518
S25	0.7885	0.8052	0.082	0.6434	0.9669	-0.3803	1.9906	-0.0167
S26	2.6247	2.5405	0.066	2.4102	2.6708	1.3589	3.7221	0.0842
S27	0.7885	0.4299	0.078	0.2756	0.5841	-0.7546	1.6144	0.3586
S28	4.8598	4.5233	0.072	4.3818	4.6648	3.3404	5.7062	0.3365
S29	2.0794	2.8360	0.089	2.6608	3.0113	1.6486	4.0234	-0.7566
S30	5.6525	5.4017	0.075	5.2538	5.5496	4.2180	6.5854	0.2508
S31	-1.2040	-0.6682	0.096	-0.8586	-0.4777	-1.8579	0.5216	-0.5358
S32	1.4351	1.2269	0.065	1.0977	1.3560	0.0454	2.4084	0.2082
S33	5.3845	5.1716	0.070	5.0322	5.3109	3.9889	6.3542	0.2129
S34	-3.5066	-3.0596	0.154	-3.3644	-2.7549	-4.2729	-1.8463	-0.4469
S35	-2.1203	-2.6964	0.145	-2.9834	-2.4094	-3.9054	-1.4875	0.5762
S36	0.6313	1.5940	0.062	1.4714	1.7166	0.4132	2.7748	-0.9627
S37	2.9232	3.0447	0.061	2.9235	3.1660	1.8641	4.2254	-0.1216
S38	6.2226	5.9373	0.086	5.7671	6.1074	4.7506	7.1239	0.2853
S39	5.2257	4.6842	0.070	4.5463	4.8220	3.5017	5.8666	0.5416
S40	3.2189	2.6284	0.055	2.5205	2.7362	1.4490	3.8077	0.5905
S41	5.2523	4.2870	0.063	4.1618	4.4122	3.1060	5.4681	0.9653
S42	4.1431	3.4647	0.062	3.3417	3.5876	2.2838	4.6455	0.6785
S43	3.1355	2.2382	0.055	2.1298	2.3466	1.0588	3.4176	0.8973
S44	3.2958	2.8511	0.053	2.7470	2.9552	1.6721	4.0301	0.4447
S45	4.4188	3.7358	0.062	3.6125	3.8592	2.5550	4.9167	0.6830
S46	5.2364	4.8054	0.065	4.6775	4.9334	3.6241	5.9868	0.4310
S47	3.1355	3.8216	0.114	3.5951	4.0481	2.6256	5.0177	-0.6861
S48	3.0445	2.1876	0.058	2.0737	2.3016	1.0077	3.3675	0.8569
S49	6.5162	5.9065	0.087	5.7347	6.0782	4.7196	7.0934	0.6097
S50	-0.4308	-0.4030	0.133	-0.6656	-0.1404	-1.6064	0.8004	-0.0277
S52	0.0100	-0.2086	0.119	-0.4450	0.0278	-1.4065	0.9893	0.2186
S53	6.7105	6.2911	0.089	6.1148	6.4673	5.1035	7.4786	0.4195
S54	2.8332	2.3894	0.059	2.2717	2.5070	1.2091	3.5696	0.4438
S55	7.0596	7.0997	0.105	6.8929	7.3064	5.9072	8.2921	-0.0400
S56	7.1778	7.1468	0.104	6.9413	7.3522	5.9545	8.3390	0.0310
S57	1.5085	1.7547	0.076	1.6049	1.9045	0.5708	2.9386	-0.2462

Table 2 continued

Assigned name	Dep Var ln $Q_{84\%}$	Predict Value	Std Err Predict	Lower95% Mean	Upper95% Mean	Lower95% Predict	Upper95% Predict	Residual
S58	1.4110	2.0478	0.056	1.9375	2.1582	0.8682	3.2274	-0.6368
S59	1.0578	2.8637	0.057	2.7506	2.9768	1.6839	4.0435	-1.8059
S60	2.0794	2.7896	0.056	2.6795	2.8997	1.6101	3.9692	-0.7102
S61	4.3307	5.1483	0.077	4.9952	5.3014	3.9640	6.3326	-0.8176
S62	3.3322	3.6927	0.053	3.5868	3.7985	2.5135	4.8718	-0.3605
S63	5.0304	5.0194	0.069	4.8833	5.1555	3.8372	6.2017	0.0110
S64	3.0445	3.0805	0.060	2.9610	3.1999	1.9000	4.2609	-0.0359
S65	-0.5108	0.9171	0.071	0.7763	1.0580	-0.2657	2.1000	-1.4280
S66	5.4381	5.2552	0.093	5.0705	5.4399	4.0664	6.4440	0.1829
S67	10.1720	10.3213	0.168	9.9895	10.6530	9.1009	11.5416	-0.1493
S69	4.5326	5.4694	0.097	5.2772	5.6616	4.2794	6.6594	-0.9368
S70	3.4340	3.6505	0.060	3.5324	3.7686	2.4702	4.8308	-0.2165
S71	1.1184	1.3892	0.066	1.2592	1.5192	0.2076	2.5708	-0.2708
S72	4.8752	5.2981	0.072	5.1555	5.4408	4.1151	6.4811	-0.4229
S73	3.1091	2.7319	0.088	2.5573	2.9064	1.5446	3.9192	0.3772
S74	5.1591	6.0856	0.090	5.9072	6.2639	4.8977	7.2734	-0.9265
S76	1.5173	2.5984	0.053	2.4939	2.7030	1.4194	3.7775	-1.0811
S77	5.2095	5.3318	0.078	5.1769	5.4867	4.1472	6.5163	-0.1223
S78	-0.0513	1.1065	0.082	0.9447	1.2683	-0.0790	2.2920	-1.1578
S79	3.0445	3.1665	0.056	3.0565	3.2765	1.9870	4.3460	-0.1220
S80	4.0073	4.0924	0.061	3.9710	4.2139	2.9118	5.2731	-0.0851
S81	-	-	-	-	-	-	-	-
S82	3.4340	3.4760	0.092	3.2940	3.6579	2.2875	4.6644	-0.0420
S83	4.2047	3.9106	0.056	3.7989	4.0223	2.7309	5.0903	0.2941
S84	4.9904	4.9318	0.071	4.7905	5.0730	3.7489	6.1146	0.0587
S85	1.4351	1.0205	0.068	0.8866	1.1544	-0.1615	2.2025	0.4146
S86	5.9687	6.9800	0.103	6.7753	7.1847	5.7879	8.1721	-1.0113
S87	1.2179	1.2842	0.064	1.1574	1.4109	0.1030	2.4654	-0.0663
S88	1.4493	1.6072	0.096	1.4180	1.7964	0.4177	2.7967	-0.1579
S89	2.4849	3.0418	0.052	2.9395	3.1441	1.8630	4.2207	-0.5569
S90	1.5261	1.5931	0.124	1.3472	1.8389	0.3932	2.7929	-0.0670
S91	1.4351	1.8482	0.087	1.6751	2.0212	0.6611	3.0352	-0.4131
S92	0.7885	1.9853	0.076	1.8355	2.1351	0.8014	3.1692	-1.1969
S93	6.2146	6.3363	0.094	6.1496	6.5230	5.1471	7.5254	-0.1217
S94	1.4110	1.9440	0.086	1.7737	2.1142	0.7573	3.1306	-0.5330
S95	6.3351	6.4849	0.097	6.2925	6.6772	5.2948	7.6749	-0.1498
S96	6.4313	6.4176	0.102	6.2159	6.6193	5.2260	7.6092	0.0137
S97	-0.3857	0.5446	0.093	0.3610	0.7282	-0.6441	1.7333	-0.9303
S98	-0.4308	-0.1129	0.110	-0.3314	0.1056	-1.3074	1.0817	-0.3179
S99	0.8755	0.5880	0.115	0.3612	0.8147	-0.6081	1.7841	0.2875
S100	2.3795	2.8021	0.067	2.6702	2.9341	1.6203	3.9839	-0.4226
S101	3.1527	2.8886	0.079	2.7329	3.0443	1.7039	4.0732	0.2642
S103	4.4773	4.7130	0.064	4.5863	4.8397	3.5318	5.8942	-0.2357
S104	9.2629	9.3519	0.148	9.0598	9.6440	8.1417	10.5621	-0.0890
S105	0.0583	-0.9030	0.102	-1.1044	-0.7016	-2.0945	0.2886	0.9612
S106	0.6627	0.9040	0.075	0.7561	1.0519	-0.2797	2.0877	-0.2413
S107	-0.1054	0.0079	0.099	-0.1884	0.2042	-1.1828	1.1986	-0.1133
S108	2.7600	3.2601	0.066	3.1294	3.3909	2.0785	4.4418	-0.5001
S109	3.0445	2.7304	0.071	2.5894	2.8714	1.5476	3.9132	0.3141
S110	3.8712	3.9906	0.056	3.8792	4.1020	2.8109	5.1703	-0.1194
S111	3.3878	2.7955	0.053	2.6912	2.8997	1.6165	3.9745	0.5923
S112	3.3673	3.9564	0.068	3.8215	4.0912	2.7742	5.1385	-0.5891
S113	4.2341	5.0434	0.088	4.8684	5.2184	3.8561	6.2308	-0.8093
S114	4.3307	4.8260	0.069	4.6890	4.9631	3.6437	6.0084	-0.4953
S115	4.4308	4.7450	0.068	4.6096	4.8803	3.5628	5.9271	-0.3141

Table 2 continued

Assigned name	Dep Var ln $Q_{84\%}$	Predict Value	Std Err Predict	Lower95% Mean	Upper95% Mean	Lower95% Predict	Upper95% Predict	Residual
S116	0.6831	0.3219	0.123	0.0792	0.5646	-0.8773	1.5212	0.3612
S117	3.6109	2.4038	0.073	2.2591	2.5486	1.2206	3.5871	1.2071
S118	5.2095	4.2872	0.099	4.0907	4.4837	3.0965	5.4779	0.9223
S119	2.9957	2.7994	0.079	2.6435	2.9553	1.6147	3.9841	0.1963
S120	3.7612	3.5695	0.057	3.4559	3.6831	2.3896	4.7494	0.1917
S123	-0.0305	-0.0826	0.101	-0.2830	0.1178	-1.2740	1.1088	0.0522
S124	0.5068	-1.2621	0.107	-1.4738	-1.0503	-2.4554	-0.0687	1.7689
S126	3.7136	3.2664	0.053	3.1624	3.3705	2.0874	4.4454	0.4472
S128	4.6444	4.4179	0.066	4.2873	4.5485	3.2363	5.5995	0.2265
S129	-0.5798	-1.0109	0.105	-1.2181	-0.8037	-2.2034	0.1817	0.4311
S130	3.2958	2.7889	0.052	2.6866	2.8913	1.6101	3.9678	0.5069
S131	3.9318	4.1739	0.077	4.0208	4.3271	2.9896	5.3583	-0.2421
S132	5.0499	4.4710	0.072	4.3295	4.6125	3.2881	5.6539	0.5789
S133	0.2927	0.5962	0.088	0.4222	0.7701	-0.5911	1.7834	-0.3035
S134	3.2189	3.4632	0.053	3.3588	3.5675	2.2841	4.6422	-0.2443
S135	1.6094	1.6506	0.069	1.5132	1.7881	0.4682	2.8330	-0.0412
S136	-0.6162	0.7461	0.072	0.6031	0.8892	-0.4370	1.9292	-1.3623
S137	-2.0402	-0.6888	0.117	-0.9200	-0.4577	-1.8857	0.5081	-1.3514
S138	2.6946	2.5479	0.093	2.3639	2.7320	1.3592	3.7367	0.1467
S139	-0.0408	0.1842	0.116	-0.0461	0.4146	-1.0125	1.3810	-0.2251
S140	0.3920	0.4472	0.142	0.1654	0.7290	-0.7605	1.6550	-0.0552
S141	0.6206	0.3302	0.150	0.0333	0.6270	-0.8812	1.5415	0.2904
S142	1.5041	1.5529	0.149	1.2587	1.8470	0.3422	2.7635	-0.0488
S143	1.0647	2.0581	0.118	1.8255	2.2907	0.8609	3.2553	-0.9934

Table 3. Results of the regression analysis for model (4.3) (N=120)

Assigned name	Dep Var ln $Q_{84\%}$	Predict Value	Std Err Predict	Lower95% Mean	Upper95% Mean	Lower95% Predict	Upper95% Predict	Residual
S1	4.2905	3.7984	0.074	3.6523	3.9446	2.6093	4.9876	0.4920
S2	.a	3.9858	0.084	3.8194	4.1522	2.7940	5.1776	.
S3	5.1533	4.9912	0.109	4.7760	5.2063	3.7916	6.1908	0.1621
S4	1.0647	0.3775	0.140	0.1002	0.6547	-0.8348	1.5897	0.6872
S5	3.4965	3.4629	0.132	3.2017	3.7240	2.2542	4.6715	0.0336
S6	9.5929	9.4873	0.158	9.1752	9.7994	8.2666	10.7080	0.1056
S7	3.1781	2.8179	0.095	2.6299	3.0059	1.6229	4.0129	0.3602
S8	4.4188	3.5012	0.060	3.3817	3.6208	2.3151	4.6874	0.9176
S9	5.3327	4.8722	0.068	4.7371	5.0072	3.6843	6.0600	0.4606
S10	2.8332	2.2566	0.095	2.0686	2.4445	1.0616	3.4515	0.5767
S11	3.8286	2.8772	0.059	2.7601	2.9943	1.6913	4.0631	0.9514
S12	.	2.3812	0.171	2.0419	2.7205	1.1533	3.6091	.
S13	5.0876	4.8918	0.146	4.6026	5.1810	3.6768	6.1068	0.1958
S15	9.9570	9.6637	0.164	9.3383	9.9892	8.4396	10.8879	0.2933
S16	2.1282	1.5801	0.080	1.4219	1.7382	0.3894	2.7707	0.5482
S17	4.2341	3.7691	0.064	3.6429	3.8953	2.5823	4.9559	0.4650
S18	5.6937	5.4497	0.076	5.2998	5.5996	4.2601	6.6393	0.2440
S19	0.9555	0.1952	0.134	-0.0692	0.4596	-1.0142	1.4046	0.7603
S20	0.6678	1.2313	0.108	1.0181	1.4445	0.0321	2.4305	-0.5635
S21	1.6487	1.4279	0.076	1.2773	1.5785	0.2382	2.6176	0.2208
S22	3.1355	2.8793	0.058	2.7648	2.9939	1.6937	4.0650	0.2562
S23	4.5951	4.1893	0.065	4.0607	4.3179	3.0022	5.3764	0.4058
S24	.	1.4008	0.071	1.2601	1.5416	0.2124	2.5893	.
S25	0.7885	0.8420	0.094	0.6558	1.0282	-0.3527	2.0367	-0.0535
S26	2.6247	2.5727	0.074	2.4253	2.7201	1.3834	3.7620	0.0520
S27	0.7885	0.4528	0.085	0.2838	0.6218	-0.7394	1.6449	0.3357
S28	.	4.5298	0.073	4.3844	4.6753	3.3408	5.7189	.
S29	2.0794	2.8763	0.100	2.6786	3.0739	1.6797	4.0728	-0.7968
S30	5.6525	5.4120	0.077	5.2604	5.5635	4.2222	6.6018	0.2405
S31	-1.2040	-0.6363	0.108	-0.8497	-0.4229	-1.8356	0.5629	-0.5676
S32	1.4351	1.2537	0.073	1.1088	1.3987	0.0648	2.4427	0.1813
S33	5.3845	5.1837	0.072	5.0412	5.3263	3.9950	6.3724	0.2008
S34	-3.5066	-3.0087	0.174	-3.3537	-2.6637	-4.2382	-1.7792	-0.4979
S35	.	-2.6479	0.164	-2.9729	-2.3229	-3.8720	-1.4239	.
S36	0.6313	1.6140	0.067	1.4812	1.7467	0.4264	2.8015	-0.9827
S37	2.9232	3.0560	0.063	2.9306	3.1814	1.8693	4.2428	-0.1329
S38	6.2226	5.9433	0.089	5.7676	6.1189	4.7502	7.1364	0.2793
S39	5.2257	4.7085	0.073	4.5635	4.8534	3.5195	5.8975	0.5173
S40	3.2189	2.6539	0.060	2.5346	2.7732	1.4678	3.8400	0.5650
S41	5.2523	4.2976	0.065	4.1696	4.4257	3.1106	5.4847	0.9546
S42	4.1431	3.4748	0.064	3.3483	3.6014	2.2880	4.6617	0.6683
S43	3.1355	2.2585	0.059	2.1415	2.3755	1.0726	3.4444	0.8770
S44	3.2958	2.8691	0.055	2.7593	2.9790	1.6839	4.0544	0.4267
S45	4.4188	3.7459	0.064	3.6193	3.8725	2.5590	4.9328	0.6730
S46	5.2364	4.8226	0.066	4.6911	4.9540	3.6352	6.0100	0.4139
S47	.	3.8672	0.127	3.6165	4.1179	2.6608	5.0737	.
S48	3.0445	2.2051	0.061	2.0839	2.3263	1.0188	3.3914	0.8394
S49	6.5162	5.9115	0.090	5.7339	6.0890	4.7181	7.1049	0.6047
S50	-0.4308	-0.3481	0.153	-0.6502	-0.0461	-1.5663	0.8700	-0.0826
S52	.	-0.1583	0.138	-0.4307	0.1140	-1.3695	1.0528	.
S53	6.7105	6.2996	0.092	6.1179	6.4813	5.1056	7.4936	0.4109
S54	2.8332	2.4184	0.067	2.2858	2.5509	1.2308	3.6059	0.4148
S55	7.0596	7.1149	0.108	6.9012	7.3286	5.9156	8.3142	-0.0553
S56	7.1778	7.1562	0.107	6.9437	7.3686	5.9571	8.3552	0.0216
S57	1.5085	1.7652	0.079	1.6080	1.9224	0.5746	2.9557	-0.2567

Table 3 continued

Assigned name	Dep Var ln $Q_{84\%}$	Predict Value	Std Err Predict	Lower95% Mean	Upper95% Mean	Lower95% Predict	Upper95% Predict	Residual
S58	.	2.0709	0.061	1.9496	2.1923	0.8846	3.2573	.
S59	1.0578	2.8778	0.059	2.7601	2.9955	1.6918	4.0637	-1.8200
S60	2.0794	2.8161	0.062	2.6942	2.9379	1.6297	4.0025	-0.7366
S61	4.3307	5.1727	0.081	5.0124	5.3330	3.9818	6.3637	-0.8420
S62	3.3322	3.7112	0.056	3.6011	3.8214	2.5260	4.8965	-0.3790
S63	5.0304	5.0312	0.070	4.8920	5.1703	3.8429	6.2195	-0.0008
S64	3.0445	3.0921	0.062	2.9687	3.2156	1.9056	4.2787	-0.0476
S65	-0.5108	0.9381	0.077	0.7848	1.0914	-0.2519	2.1281	-1.4489
S66	5.4381	5.2536	0.098	5.0605	5.4467	4.0578	6.4494	0.1845
S67	10.1720	10.3229	0.176	9.9749	10.6709	9.0925	11.5533	-0.1509
S69	4.5326	5.5007	0.103	5.2967	5.7047	4.3031	6.6983	-0.9681
S70	3.4340	3.6620	0.061	3.5408	3.7832	2.4757	4.8483	-0.2280
S71	1.1184	1.4082	0.071	1.2680	1.5485	0.2198	2.5967	-0.2898
S72	4.8752	5.3104	0.074	5.1644	5.4564	4.1213	6.4995	-0.4352
S73	3.1091	2.7336	0.092	2.5513	2.9160	1.5395	3.9278	0.3754
S74	5.1591	6.1069	0.093	5.9220	6.2918	4.9124	7.3014	-0.9479
S76	1.5173	2.6178	0.056	2.5061	2.7294	1.4324	3.8032	-1.1005
S77	5.2095	5.3381	0.081	5.1786	5.4976	4.1473	6.5290	-0.1286
S78	.	1.1445	0.094	0.9579	1.3311	-0.0503	2.3392	.
S79	3.0445	3.1809	0.058	3.0669	3.2948	1.9953	4.3665	-0.1363
S80	4.0073	4.1036	0.063	3.9794	4.2279	2.9170	5.2903	-0.0963
S81	-	-	-	-	-	-	-	-
S82	3.4340	3.5156	0.102	3.3132	3.7180	2.3183	4.7130	-0.0816
S83	4.2047	3.9322	0.059	3.8147	4.0497	2.7463	5.1182	0.2725
S84	4.9904	4.9402	0.073	4.7954	5.0850	3.7512	6.1291	0.0503
S85	1.4351	1.0454	0.075	0.8968	1.1941	-0.1440	2.2349	0.3897
S86	5.9687	6.9971	0.107	6.7854	7.2088	5.7981	8.1960	-1.0284
S87	1.2179	1.3086	0.071	1.1680	1.4492	0.1201	2.4971	-0.0907
S88	1.4493	1.6109	0.100	1.4126	1.8093	0.4143	2.8076	-0.1617
S89	2.4849	3.0635	0.055	2.9537	3.1732	1.8783	4.2487	-0.5786
S90	1.5261	1.5875	0.131	1.3286	1.8465	0.3793	2.7957	-0.0615
S91	1.4351	1.8536	0.091	1.6724	2.0347	0.6596	3.0475	-0.4185
S92	0.7885	1.9945	0.079	1.8378	2.1512	0.8040	3.1850	-1.2061
S93	6.2146	6.3398	0.098	6.1461	6.5336	5.1439	7.5357	-0.1252
S94	1.4110	1.9494	0.090	1.7713	2.1276	0.7559	3.1429	-0.5384
S95	6.3351	6.4877	0.101	6.2878	6.6877	5.2908	7.6847	-0.1527
S96	6.4313	6.4168	0.106	6.2059	6.6276	5.2180	7.6156	0.0146
S97	.	0.5562	0.098	0.3618	0.7506	-0.6398	1.7522	.
S98	-0.4308	-0.1036	0.117	-0.3347	0.1275	-1.3061	1.0989	-0.3272
S99	0.8755	0.5907	0.120	0.3521	0.8293	-0.6133	1.7947	0.2848
S100	2.3795	2.8344	0.075	2.6860	2.9828	1.6450	4.0238	-0.4548
S101	3.1527	2.8931	0.082	2.7312	3.0551	1.7020	4.0843	0.2596
S103	4.4773	4.7265	0.065	4.5970	4.8560	3.5393	5.9137	-0.2492
S104	9.2629	9.3568	0.154	9.0516	9.6620	8.1379	10.5758	-0.0939
S105	0.0583	-0.8778	0.111	-1.0982	-0.6573	-2.0783	0.3227	0.9360
S106	.	0.9220	0.080	0.7630	1.0810	-0.2688	2.1128	.
S107	-0.1054	0.0213	0.105	-0.1874	0.2300	-1.1771	1.2198	-0.1267
S108	2.7600	3.2910	0.073	3.1461	3.4359	2.1020	4.4800	-0.5310
S109	3.0445	2.7647	0.080	2.6055	2.9239	1.5739	3.9555	0.2799
S110	3.8712	4.0109	0.059	3.8946	4.1272	2.8251	5.1967	-0.1397
S111	3.3878	2.8137	0.056	2.7035	2.9238	1.6284	3.9989	0.5741
S112	3.3673	3.9852	0.074	3.8392	4.1311	2.7960	5.1743	-0.6179
S113	4.2341	5.0741	0.094	4.8877	5.2606	3.8794	6.2689	-0.8400
S114	4.3307	4.8486	0.072	4.7055	4.9916	3.6598	6.0373	-0.5178
S115	4.4308	4.7678	0.071	4.6263	4.9093	3.5792	5.9563	-0.3370

Table 3 continued

Assigned name	Dep Var $\ln Q_{84\%}$	Predict Value	Std Err Predict	Lower95% Mean	Upper95% Mean	Lower95% Predict	Upper95% Predict	Residual
S116	0.6831	0.3744	0.141	0.0952	0.6537	-0.8383	1.5871	0.3087
S117	3.6109	2.4121	0.076	2.2613	2.5629	1.2224	3.6019	1.1988
S118	5.2095	4.2827	0.104	4.0762	4.4893	3.0847	5.4808	0.9268
S119	2.9957	2.8364	0.089	2.6604	3.0123	1.6432	4.0295	0.1594
S120	3.7612	3.5946	0.062	3.4722	3.7170	2.4081	4.7810	0.1666
S123	-0.0305	-0.0399	0.117	-0.2707	0.1909	-1.2423	1.1626	0.0094
S124	0.5068	-1.2309	0.119	-1.4661	-0.9957	-2.4343	-0.0276	1.7377
S126	3.7136	3.2887	0.056	3.1773	3.4001	2.1033	4.4741	0.4249
S128	4.6444	4.4424	0.070	4.3044	4.5803	3.2542	5.6305	0.2020
S129	.	-0.9745	0.118	-1.2085	-0.7404	-2.1776	0.2286	.
S130	3.2958	2.8101	0.056	2.7000	2.9203	1.6249	3.9954	0.4857
S131	3.9318	4.2055	0.084	4.0394	4.3715	3.0137	5.3972	-0.2737
S132	5.0499	4.4774	0.073	4.3318	4.6230	3.2883	5.6665	0.5725
S133	.	0.6353	0.101	0.4348	0.8358	-0.5617	1.8323	.
S134	3.2189	3.4842	0.056	3.3737	3.5947	2.2989	4.6695	-0.2653
S135	1.6094	1.6647	0.073	1.5194	1.8100	0.4757	2.8537	-0.0553
S136	-0.6162	0.7695	0.079	0.6121	0.9269	-0.4210	1.9601	-1.3857
S137	-2.0402	-0.6772	0.124	-0.9226	-0.4319	-1.8826	0.5281	-1.3630
S138	2.6946	2.5487	0.097	2.3561	2.7413	1.3530	3.7444	0.1459
S139	-0.0408	0.1889	0.123	-0.0538	0.4316	-1.0159	1.3937	-0.2297
S140	0.3920	0.4414	0.150	0.1444	0.7385	-0.7755	1.6583	-0.0494
S141	0.6206	0.3225	0.158	0.0094	0.6357	-0.8984	1.5435	0.2980
S142	1.5041	1.5401	0.157	1.2289	1.8514	0.3197	2.7606	-0.0361
S143	1.0647	2.0528	0.124	1.8078	2.2978	0.8475	3.2581	-0.9881

[a] Dots refer to deleted points

Table 4. Results of the regression analysis for model (4.4) (N=120 obs.)

Assigned name	Dep Var $\ln Q_{84\%}$	Predict Value	Std Err Predict	Lower95% Mean	Upper95% Mean	Lower95% Predict	Upper95% Predict	Residual
S1	4.2905	2.9473	0.087	2.7759	3.1188	1.0768	4.8179	1.3431
S2	.[a]	3.0556	0.086	2.8850	3.2262	1.1851	4.9261	.
S3	5.1533	3.4322	0.086	3.2615	3.6030	1.5617	5.3027	1.7211
S4	1.0647	0.0146	0.152	-0.2869	0.3161	-1.8723	1.9015	1.0501
S5	3.4965	1.9720	0.099	1.7760	2.1680	0.0990	3.8449	1.5245
S6	9.5929	8.7226	0.231	8.2646	9.1806	6.8045	10.6408	0.8703
S7	3.1781	1.6935	0.105	1.4859	1.9010	-0.1807	3.5677	1.4846
S8	4.4188	3.6061	0.087	3.4336	3.7787	1.7355	5.4768	0.8127
S9	5.3327	4.2558	0.095	4.0681	4.4434	2.3837	6.1279	1.0770
S10	2.8332	1.3285	0.114	1.1036	1.5534	-0.5477	3.2047	1.5047
S11	3.8286	2.3370	0.093	2.1534	2.5206	0.4653	4.2087	1.4916
S12	.	0.4395	0.139	0.1645	0.7144	-1.4434	2.3223	.
S13	5.0876	2.9588	0.087	2.7875	3.1302	1.0883	4.8294	2.1288
S15	9.9570	9.0036	0.241	8.5253	9.4818	7.0805	10.9266	0.9535
S16	2.1282	0.9601	0.123	0.7155	1.2046	-0.9186	2.8387	1.1682
S17	4.2341	3.7967	0.089	3.6211	3.9723	1.9258	5.6677	0.4374
S18	5.6937	4.7416	0.104	4.5352	4.9480	2.8676	6.6157	0.9521
S19	0.9555	-1.0229	0.187	-1.3935	-0.6523	-2.9221	0.8763	1.9784
S20	0.6678	1.2534	0.116	1.0246	1.4822	-0.6233	3.1301	-0.5856
S21	1.6487	1.3555	0.113	1.1319	1.5791	-0.5205	3.2315	0.2932
S22	3.1355	2.7405	0.088	2.5662	2.9147	0.8697	4.6113	0.3950
S23	4.5951	4.2702	0.095	4.0821	4.4584	2.3981	6.1424	0.3249
S24	.	1.2140	0.117	0.9831	1.4448	-0.6629	3.0909	.
S25	0.7885	0.3346	0.142	0.0533	0.6160	-1.5492	2.2184	0.4538
S26	2.6247	1.8439	0.102	1.6428	2.0449	-0.0296	3.7173	0.7808
S27	0.7885	0.6115	0.134	0.3469	0.8762	-1.2698	2.4929	0.1769
S28	.	4.8034	0.106	4.5943	5.0126	2.9291	6.6778	.
S29	2.0794	1.7711	0.103	1.5669	1.9752	-0.1028	3.6449	0.3084
S30	5.6525	4.9564	0.109	4.7401	5.1727	3.0812	6.8316	0.6961
S31	-1.2040	-0.6071	0.173	-0.9494	-0.2648	-2.5010	1.2868	-0.5969
S32	1.4351	0.9955	0.123	0.7530	1.2381	-0.8828	2.8739	0.4395
S33	5.3845	5.1428	0.114	4.9173	5.3683	3.2665	7.0191	0.2417
S34	-3.5066	-3.1247	0.263	-3.6453	-2.6041	-5.0588	-1.1907	-0.3818
S35	.	-3.1526	0.264	-3.6752	-2.6299	-5.0872	-1.2180	.
S36	0.6313	1.8439	0.102	1.6428	2.0449	-0.0296	3.7173	-1.2126
S37	2.9232	3.0827	0.086	2.9123	3.2532	1.2123	4.9532	-0.1596
S38	6.2226	5.4644	0.122	5.2218	5.7069	3.5860	7.3427	0.7582
S39	5.2257	3.8035	0.089	3.6278	3.9792	1.9326	5.6744	1.4222
S40	3.2189	2.3409	0.093	2.1574	2.5243	0.4692	4.2126	0.8780
S41	5.2523	4.3414	0.096	4.1508	4.5319	2.4690	6.2138	0.9109
S42	4.1431	3.5435	0.087	3.3718	3.7153	1.6730	5.4141	0.5996
S43	3.1355	2.3175	0.093	2.1333	2.5016	0.4457	4.1892	0.8180
S44	3.2958	2.9815	0.086	2.8104	3.1527	1.1110	4.8520	0.3143
S45	4.4188	4.0786	0.092	3.8963	4.2608	2.2070	5.9501	0.3403
S46	5.2364	4.4004	0.097	4.2077	4.5931	2.5278	6.2730	0.8360
S47	.	2.4896	0.091	2.3101	2.6690	0.6183	4.3609	.
S48	3.0445	2.3292	0.093	2.1454	2.5130	0.4575	4.2009	0.7153
S49	6.5162	5.6787	0.129	5.4240	5.9333	3.7987	7.5587	0.8375
S50	-0.4308	-1.3256	0.198	-1.7172	-0.9341	-3.2290	0.5777	0.8949
S52	.	-0.9144	0.183	-1.2776	-0.5513	-2.8122	0.9833	.
S53	6.7105	5.9567	0.137	5.6857	6.2278	4.0745	7.8390	0.7538
S54	2.8332	1.7001	0.105	1.4929	1.9074	-0.1740	3.5743	1.1331
S55	7.0596	6.1683	0.143	5.8843	6.4523	4.2841	8.0525	0.8914
S56	7.1778	6.7282	0.161	6.4084	7.0479	4.8383	8.6181	0.4496
S57	1.5085	2.3752	0.092	2.1927	2.5576	0.5036	4.2468	-0.8667

Table 4 continued

Assigned name	Dep Var ln $Q_{84\%}$	Predict Value	Std Err Predict	Lower95% Mean	Upper95% Mean	Lower95% Predict	Upper95% Predict	Residual
S58	.	1.8614	0.101	1.6610	2.0617	-0.0120	3.7348	.
S59	1.0578	3.0471	0.086	2.8765	3.2178	1.1767	4.9176	-1.9893
S60	2.0794	2.2189	0.095	2.0317	2.4061	0.3468	4.0909	-0.1394
S61	4.3307	4.3227	0.096	4.1328	4.5126	2.4504	6.1950	0.0080
S62	3.3322	3.3691	0.086	3.1987	3.5395	1.4987	5.2396	-0.0369
S63	5.0304	4.9964	0.110	4.7782	5.2146	3.1210	6.8718	0.0341
S64	3.0445	2.9905	0.086	2.8194	3.1615	1.1200	4.8610	0.0540
S65	-0.5108	1.0871	0.120	0.8496	1.3247	-0.7906	2.9649	-1.5980
S66	5.4381	5.4671	0.123	5.2244	5.7098	3.5887	7.3455	-0.0290
S67	10.1720	9.3932	0.256	8.8866	9.8997	7.4628	11.3235	0.7788
S69	4.5326	4.7035	0.103	4.4987	4.9082	2.8296	6.5774	-0.1709
S70	3.4340	4.0588	0.092	3.8771	4.2406	2.1873	5.9303	-0.6248
S71	1.1184	2.1345	0.096	1.9445	2.3245	0.2622	4.0068	-1.0161
S72	4.8752	5.4356	0.122	5.1947	5.6766	3.5574	7.3138	-0.5604
S73	3.1091	3.5407	0.087	3.3690	3.7125	1.6702	5.4113	-0.4317
S74	5.1591	5.7470	0.131	5.4884	6.0056	3.8665	7.6275	-0.5879
S76	1.5173	2.5265	0.090	2.3479	2.7051	0.6553	4.3977	-1.0092
S77	5.2095	5.9076	0.135	5.6395	6.1757	4.0257	7.7895	-0.6981
S78	.	0.7543	0.129	0.4981	1.0106	-1.1259	2.6346	.
S79	3.0445	3.3195	0.086	3.1493	3.4897	1.4491	5.1899	-0.2750
S80	4.0073	4.3111	0.096	4.1216	4.5006	2.4388	6.1834	-0.3038
S81	-	-	-	-	-	-	-	-
S82	3.4340	2.7704	0.088	2.5967	2.9441	0.8996	4.6411	0.6636
S83	4.2047	3.7342	0.088	3.5597	3.9086	1.8634	5.6050	0.4705
S84	4.9904	5.2027	0.115	4.9742	5.4313	3.3261	7.0794	-0.2123
S85	1.4351	0.7305	0.130	0.4728	0.9881	-1.1499	2.6108	0.7046
S86	5.9687	6.4500	0.152	6.1482	6.7517	4.5630	8.3369	-0.4813
S87	1.2179	0.9286	0.124	0.6823	1.1749	-0.9503	2.8075	0.2893
S88	1.4493	2.4964	0.091	2.3171	2.6757	0.6251	4.3677	-1.0471
S89	2.4849	2.9287	0.087	2.7570	3.1003	1.0581	4.7992	-0.4437
S90	1.5261	2.8230	0.087	2.6500	2.9959	0.9523	4.6936	-1.2969
S91	1.4351	2.4724	0.091	2.2925	2.6523	0.6011	4.3438	-1.0373
S92	0.7885	2.5970	0.089	2.4201	2.7740	0.7260	4.4681	-1.8086
S93	6.2146	6.7263	0.161	6.4066	7.0459	4.8364	8.6162	-0.5117
S94	1.4110	2.5782	0.090	2.4008	2.7556	0.7071	4.4493	-1.1672
S95	6.3351	6.8082	0.164	6.4832	7.1332	4.9174	8.6990	-0.4731
S96	6.4313	6.8655	0.166	6.5367	7.1943	4.9740	8.7570	-0.4342
S97	.	1.0759	0.120	0.8377	1.3141	-0.8019	2.9538	.
S98	-0.4308	0.8630	0.126	0.6130	1.1130	-1.0164	2.7424	-1.2938
S99	0.8755	1.5814	0.107	1.3688	1.7941	-0.2933	3.4562	-0.7060
S100	2.3795	3.4595	0.086	3.2886	3.6305	1.5890	5.3300	-1.0800
S101	3.1527	4.2912	0.095	4.1024	4.4800	2.4190	6.1634	-1.1385
S103	4.4773	6.0319	0.139	5.7563	6.3075	4.1489	7.9148	-1.5545
S104	9.2629	10.5429	0.299	9.9517	11.1340	8.5886	12.4971	-1.2799
S105	0.0583	0.5106	0.137	0.2399	0.7813	-1.3716	2.3928	-0.4523
S106	.	2.1841	0.095	1.9957	2.3724	0.3119	4.0562	.
S107	-0.1054	1.7134	0.104	1.5067	1.9200	-0.1607	3.5875	-1.8187
S108	2.7600	3.5982	0.087	3.4258	3.7706	1.7275	5.4688	-0.8382
S109	3.0445	2.6665	0.089	2.4910	2.8421	0.7956	4.5374	0.3780
S110	3.8712	3.6167	0.087	3.4441	3.7893	1.7461	5.4874	0.2545
S111	3.3878	2.7322	0.088	2.5578	2.9065	0.8614	4.6030	0.6556
S112	3.3673	4.0821	0.092	3.8997	4.2645	2.2105	5.9537	-0.7148
S113	4.2341	4.2581	0.095	4.0703	4.4458	2.3860	6.1302	-0.0240
S114	4.3307	4.8249	0.106	4.6148	5.0350	2.9504	6.6994	-0.4942
S115	4.4308	4.9325	0.109	4.7173	5.1476	3.0574	6.8075	-0.5016

Table 4 continued

Assigned name	Dep Var ln $Q_{84\%}$	Predict Value	Std Err Predict	Lower95% Mean	Upper95% Mean	Lower95% Predict	Upper95% Predict	Residual
S116	0.6831	-0.0863	0.156	-0.3942	0.2217	-1.9742	1.8017	0.7694
S117	3.6109	3.2659	0.086	3.0959	3.4360	1.3955	5.1363	0.3450
S118	5.2095	5.2316	0.116	5.0015	5.4616	3.3548	7.1084	-0.0221
S119	2.9957	2.6782	0.089	2.5029	2.8535	0.8073	4.5491	0.3175
S120	3.7612	3.5780	0.087	3.4058	3.7501	1.7074	5.4486	0.1832
S123	-0.0305	-0.3293	0.164	-0.6531	-0.0054	-2.2199	1.5613	0.2988
S124	0.5068	-0.3899	0.166	-0.7178	-0.0621	-2.2812	1.5014	0.8968
S126	3.7136	3.1548	0.086	2.9847	3.3249	1.2844	5.0252	0.5588
S128	4.6444	4.0750	0.092	3.8928	4.2572	2.2034	5.9465	0.5694
S129	.	-0.5748	0.172	-0.9150	-0.2347	-2.4683	1.3186	.
S130	3.2958	2.7596	0.088	2.5857	2.9335	0.8888	4.6304	0.5362
S131	3.9318	3.6088	0.087	3.4362	3.7813	1.7382	5.4794	0.3230
S132	5.0499	4.9615	0.109	4.7450	5.1780	3.0863	6.8367	0.0884
S133	.	0.1818	0.147	-0.1091	0.4727	-1.7034	2.0671	.
S134	3.2189	3.4199	0.086	3.2492	3.5905	1.5494	5.2903	-0.2010
S135	1.6094	1.9344	0.100	1.7370	2.1319	0.0613	3.8075	-0.3250
S136	-0.6162	0.9209	0.125	0.6742	1.1677	-0.9580	2.7998	-1.5371
S137	-2.0402	0.2562	0.145	-0.0300	0.5425	-1.6283	2.1407	-2.2964
S138	2.6946	3.3212	0.086	3.1510	3.4914	1.4508	5.1916	-0.6266
S139	-0.0408	1.0646	0.121	0.8258	1.3034	-0.8133	2.9425	-1.1054
S140	0.3920	1.7264	0.104	1.5203	1.9325	-0.1476	3.6005	-1.3344
S141	0.6206	1.6318	0.106	1.4215	1.8421	-0.2427	3.5063	-1.0112
S142	1.5041	3.0321	0.086	2.8614	3.2029	1.1617	4.9026	-1.5281
S143	1.0647	3.3329	0.086	3.1627	3.5032	1.4625	5.2034	-2.2682

a Dots refer to deleted points

Table 5. Results of the regression model (4.6) (N=108)

Assigned name	Dep Var ln $Q_{7,10}$	Predict Value	Std Err Predict	Lower95% Mean	Upper95% Mean	Lower95% Predict	Upper95% Predict	Residual
S1	3.5264	2.3848	0.112	2.1626	2.6071	0.5187	4.2510	1.1415
S2	3.3673	2.6555	0.127	2.4034	2.9075	0.7856	4.5254	0.7118
S3	4.4998	3.9326	0.167	3.6008	4.2643	2.0502	5.8149	0.5672
S4	0.4055	-1.4647	0.225	-1.9119	-1.0176	-3.3708	0.4413	1.8702
S5	2.9444	2.2404	0.201	1.8421	2.6387	0.3452	4.1356	0.7040
S6	9.1072	8.9308	0.266	8.4031	9.4585	7.0043	10.8574	0.1764
S7	2.1972	1.3216	0.146	1.0326	1.6106	-0.5537	3.1969	0.8756
S8	3.2958	1.7711	0.104	1.5656	1.9766	-0.0932	3.6353	1.5248
S9	4.4308	3.5421	0.106	3.3329	3.7513	1.6774	5.4068	0.8887
S10	2.0015	0.6437	0.149	0.3488	0.9386	-1.2325	2.5199	1.3578
S11	3.0445	1.1953	0.098	1.0009	1.3897	-0.6678	3.0583	1.8492
S12	1.0296	1.0998	0.263	0.5788	1.6207	-0.8249	3.0245	-0.0702
S13	4.4188	3.9749	0.226	3.5268	4.4229	2.0686	5.8811	0.4440
S15	9.2203	9.0726	0.276	8.5251	9.6200	7.1405	11.0047	0.1477
S16	1.3863	-0.2695	0.136	-0.5394	0.0004	-2.1419	1.6029	1.6558
S17	2.8904	2.0712	0.107	1.8582	2.2841	0.2061	3.9362	0.8192
S18	4.6347	4.2030	0.119	3.9674	4.4386	2.3352	6.0708	0.4318
S19	-0.9163	-1.7217	0.219	-2.1550	-1.2884	-3.6246	0.1812	0.8054
S20	-1.2040	-0.5554	0.174	-0.9011	-0.2098	-2.4403	1.3294	-0.6485
S21	-0.2231	-0.4919	0.135	-0.7588	-0.2249	-2.3639	1.3802	0.2687
S22	1.8083	1.1845	0.097	0.9924	1.3766	-0.6783	3.0473	0.6238
S23	3.0910	2.5827	0.106	2.3719	2.7935	0.7179	4.4475	0.5083
S24	-0.9416	-0.5825	0.132	-0.8436	-0.3213	-2.4537	1.2887	-0.3591
S25	-1.5606	-1.1174	0.162	-1.4391	-0.7956	-2.9980	0.7632	-0.4433
S26	1.0647	0.9279	0.119	0.6925	1.1633	-0.9399	2.7957	0.1368
S27	*[a]	-1.7916	0.167	-2.1228	-1.4603	-3.6738	0.0907	*
S28	3.8067	2.9474	0.119	2.7110	3.1838	1.0795	4.8153	0.8593
S29	-0.5798	1.4125	0.153	1.1097	1.7153	-0.4650	3.2899	-1.9923
S30	4.3567	4.0766	0.121	3.8363	4.3169	2.2082	5.9450	0.2801
S31	*	-2.9922	0.204	-3.3970	-2.5873	-4.8888	-1.0956	*
S32	-0.7550	-0.7580	0.136	-1.0283	-0.4877	-2.6305	1.1145	0.00297
S33	4.0943	3.8254	0.114	3.6003	4.0504	1.9589	5.6919	0.2690
S34	*	-5.6122	0.311	-6.2286	-4.9957	-7.5649	-3.6594	*
S35	*	-5.2071	0.294	-5.7905	-4.6238	-7.1497	-3.2646	*
S36	-1.6094	-0.4172	0.129	-0.6735	-0.1608	-2.2877	1.4534	-1.1923
S37	0.9163	1.2176	0.113	0.9937	1.4415	-0.6488	3.0839	-0.3013
S38	4.9273	4.6638	0.142	4.3832	4.9445	2.7898	6.5379	0.2634
S39	4.5643	3.4194	0.112	3.1976	3.6412	1.5533	5.2855	1.1449
S40	1.8718	0.9312	0.102	0.7297	1.1327	-0.9326	2.7950	0.9406
S41	4.2905	2.7224	0.105	2.5142	2.9306	0.8579	4.5869	1.5681
S42	2.7726	1.7128	0.110	1.4943	1.9313	-0.1529	3.5785	1.0598
S43	1.2528	0.3736	0.109	0.1565	0.5907	-1.4920	2.2391	0.8792
S44	1.9879	1.0856	0.099	0.8899	1.2814	-0.7776	2.9488	0.9022
S45	3.4012	2.0412	0.108	1.8271	2.2553	0.1760	3.9064	1.3600
S46	4.2341	3.4560	0.103	3.2513	3.6606	1.5918	5.3201	0.7781
S47	1.6094	2.6978	0.193	2.3153	3.0803	0.8059	4.5898	-1.0884
S48	1.1939	0.2682	0.116	0.0390	0.4974	-1.5988	2.1352	0.9257
S49	5.6870	4.6107	0.143	4.3270	4.8945	2.7362	6.4852	1.0763
S50	-2.6593	-2.3109	0.249	-2.8047	-1.8170	-4.2284	-0.3933	-0.3484
S52	*	-2.1453	0.227	-2.5963	-1.6943	-4.0523	-0.2383	*
S53	5.8665	5.1347	0.147	4.8430	5.4265	3.2590	7.0104	0.7317
S54	-0.8210	0.6934	0.111	0.4729	0.9139	-1.1726	2.5594	-1.5144
S55	6.2166	6.2248	0.177	5.8746	6.5750	4.3391	8.1105	-0.0082
S56	6.3190	6.1916	0.175	5.8440	6.5392	4.3064	8.0768	0.1274
S57	-	-	-	-	-	-	-	-

Table 5 continued

Assigned name	Dep Var ln $Q_{7,10}$	Predict Value	Std Err Predict	Lower95% Mean	Upper95% Mean	Lower95% Predict	Upper95% Predict	Residual
S58	*	0.1855	0.112	-0.0375	0.4084	-1.6808	2.0517	*
S59	*	1.0399	0.107	0.8269	1.2529	-0.8252	2.9050	*
S60	-0.2357	1.1419	0.101	0.9415	1.3423	-0.7218	3.0056	-1.3776
S61	2.3979	3.9868	0.125	3.7390	4.2347	2.1175	5.8562	-1.5890
S62	0.9555	2.1211	0.090	1.9424	2.2998	0.2596	3.9826	-1.1656
S63	3.1355	3.6333	0.111	3.4132	3.8533	1.7674	5.4992	-0.4978
S64	0.8755	1.2672	0.111	1.0474	1.4870	-0.5987	3.1331	-0.3917
S65	*	-1.2273	0.152	-1.5277	-0.9269	-3.1043	0.6498	*
S66	3.4965	3.7139	0.157	3.4033	4.0244	1.8352	5.5926	-0.2174
S67	9.3927	9.9429	0.300	9.3484	10.5374	7.9970	11.8888	-0.5502
S69	3.2581	4.4850	0.161	4.1667	4.8034	2.6050	6.3651	-1.2269
S70	2.2513	1.9598	0.104	1.7542	2.1655	0.0956	3.8241	0.2915
S71	-2.2073	-0.6810	0.138	-0.9544	-0.4075	-2.5539	1.1920	-1.5263
S72	3.6376	3.9813	0.116	3.7507	4.2118	2.1141	5.8484	-0.3437
S73	0.8329	0.6882	0.163	0.3652	1.0111	-1.1927	2.5690	0.1448
S74	3.7136	5.0825	0.149	4.7879	5.3770	3.2063	6.9586	-1.3689
S76	*	0.7984	0.102	0.5963	1.0005	-1.0655	2.6623	*
S77	3.8067	3.9306	0.128	3.6762	4.1850	2.0603	5.8008	-0.1239
S78	*	-0.7326	0.158	-1.0466	-0.4187	-2.6119	1.1466	*
S79	0.5878	1.4139	0.101	1.2135	1.6142	-0.4498	3.2776	-0.8261
S80	2.2083	2.4943	0.103	2.2903	2.6983	0.6302	4.3583	-0.2860
S81	*	-2.7934	0.221	-3.2322	-2.3545	-4.6975	-0.8892	*
S82	2.5649	2.1838	0.155	1.8764	2.4911	0.3056	4.0620	0.3812
S83	3.2581	2.4338	0.092	2.2505	2.6172	0.5719	4.2958	0.8243
S84	3.5553	3.4746	0.117	3.2433	3.7059	1.6073	5.3419	0.0807
S85	*	-1.0394	0.143	-1.3238	-0.7549	-2.9140	0.8352	*
S86	4.5951	6.1077	0.174	5.7617	6.4536	4.2228	7.9926	-1.5125
S87	*	-0.7258	0.135	-0.9931	-0.4585	-2.5979	1.1462	*
S88	-3.2189	-0.6532	0.185	-1.0209	-0.2854	-2.5422	1.2359	-2.5657
S89	0.4055	1.3753	0.093	1.1902	1.5604	-0.4868	3.2374	-0.9698
S90	-0.1985	-0.8137	0.233	-1.2764	-0.3511	-2.7235	1.0960	0.6153
S91	-1.0217	-0.3328	0.170	-0.6693	0.0036	-2.2160	1.5503	-0.6888
S92	-0.5798	-0.1069	0.149	-0.4018	0.1880	-1.9831	1.7693	-0.4729
S93	4.8040	5.1121	0.157	4.8011	5.4232	3.2333	6.9909	-0.3081
S94	-1.2379	-0.2152	0.166	-0.5452	0.1149	-2.0972	1.6669	-1.0227
S95	4.8203	5.2833	0.162	4.9618	5.6048	3.4027	7.1639	-0.4630
S96	4.9628	5.1434	0.171	4.8051	5.4817	3.2599	7.0269	-0.1806
S97	*	-1.8269	0.191	-2.2057	-1.4481	-3.7181	0.0643	*
S98	-3.2189	-2.6649	0.226	-3.1125	-2.2173	-4.5711	-0.7587	-0.5540
S99	*	-1.9120	0.226	-2.3602	-1.4639	-3.8183	-0.0057	*
S100	0.4700	1.2473	0.117	1.0144	1.4801	-0.6202	3.1147	-0.7773
S101	0.5306	0.9232	0.145	0.6355	1.2109	-0.9519	2.7983	-0.3926
S103	2.9444	3.2873	0.103	3.0827	3.4919	1.4232	5.1515	-0.3429
S104	8.2610	8.8120	0.261	8.2952	9.3289	6.8884	10.7357	-0.5510
S105	-3.2189	-3.3818	0.218	-3.8133	-2.9503	-5.2843	-1.4793	0.1629
S106	*	-1.2893	0.158	-1.6024	-0.9761	-3.1684	0.5899	*
S107	*	-2.4539	0.206	-2.8633	-2.0445	-4.3515	-0.5563	*
S108	1.0296	1.7841	0.113	1.5610	2.0073	-0.0821	3.6504	-0.7545
S109	1.3863	1.1909	0.125	0.9424	1.4394	-0.6786	3.0604	0.1954
S110	2.6391	2.5113	0.092	2.3291	2.6936	0.6495	4.3731	0.1277
S111	*	1.0206	0.100	0.8233	1.2179	-0.8428	2.8840	*
S112	1.9601	2.6012	0.112	2.3797	2.8227	0.7351	4.4673	-0.6411
S113	1.8563	3.9569	0.145	3.6695	4.2443	2.0819	5.8320	-2.1006
S114	2.7081	3.5646	0.111	3.3447	3.7845	1.6987	5.4305	-0.8566
S115	3.1781	3.4703	0.110	3.2532	3.6874	1.6048	5.3359	-0.2923

Table 5 continued

Assigned name	Dep Var ln $Q_{7,10}$	Predict Value	Std Err Predict	Lower95% Mean	Upper95% Mean	Lower95% Predict	Upper95% Predict	Residual
S116	-0.9416	-1.4640	0.227	-1.9139	-1.0140	-3.3707	0.4428	0.5223
S117	1.9315	0.3895	0.140	0.1115	0.6675	-1.4841	2.2632	1.5420
S118	3.8501	2.4880	0.172	2.1478	2.8282	0.6041	4.3718	1.3622
S119	1.4586	1.3168	0.137	1.0454	1.5881	-0.5559	3.1894	0.1419
S120	1.9315	2.0716	0.096	1.8809	2.2624	0.2090	3.9343	-0.1401
S123	-4.6052	-2.1085	0.200	-2.5058	-1.7111	-4.0034	-0.2135	-2.4967
S124	*	-3.7274	0.228	-4.1785	-3.2763	-5.6344	-1.8204	*
S126	2.1163	1.6587	0.092	1.4765	1.8408	-0.2031	3.5205	0.4576
S128	3.3673	3.0970	0.106	2.8865	3.3074	1.2322	4.9618	0.2703
S129	*	-3.3392	0.219	-3.7735	-2.9049	-5.2423	-1.4361	*
S130	2.1518	1.0597	0.097	0.8677	1.2517	-0.8031	2.9225	1.0921
S131	2.7081	2.9098	0.127	2.6581	3.1615	1.0399	4.7797	-0.2017
S132	3.4012	2.8814	0.120	2.6443	3.1186	1.0134	4.7494	0.5198
S133	*	-1.3366	0.173	-1.6803	-0.9929	-3.2211	0.5479	*
S134	1.8083	1.8791	0.090	1.6999	2.0583	0.0176	3.7406	-0.0708
S135	-0.5621	-0.4394	0.142	-0.7205	-0.1582	-2.3134	1.4347	-0.1228
S136	*	-1.3977	0.154	-1.7041	-1.0914	-3.2758	0.4803	*
S137	*	-3.3318	0.241	-3.8102	-2.8534	-5.2455	-1.4182	*
S138	0.5306	0.4482	0.173	0.1058	0.7905	-1.4360	2.3324	0.0824
S139	*	-2.3744	0.233	-2.8358	-1.9130	-4.2838	-0.4649	*
S140	*	-2.2160	0.273	-2.7572	-1.6749	-4.1463	-0.2857	*
S141	-2.4079	-2.3870	0.286	-2.9550	-1.8190	-4.3249	-0.4490	-0.0210
S142	-1.5141	-0.9747	0.275	-1.5195	-0.4299	-2.9060	0.9566	-0.5394
S143	-1.2379	-0.2430	0.218	-0.6761	0.1900	-2.1458	1.6598	-0.9949

[a] Asterisks refer to the points with Q7,10 = 0

Table 6. Results generated by regression model (4.7) (N = 95)

Assigned name	Dep Var $\ln Q_{7,10}$	Predict Value	Std Err Predict	Lower95% Mean	Upper95% Mean	Lower95% Predict	Upper95% Predict	Residual
S1	3.5264	2.4661	0.122	2.2241	2.7082	0.6026	4.3297	1.0602
S2	.[a]	2.7421	0.138	2.4670	3.0171	0.8740	4.6102	.
S3	4.4998	4.0196	0.181	3.6594	4.3798	2.1371	5.9021	0.4802
S4	0.4055	-1.3059	0.243	-1.7881	-0.8236	-3.2155	0.6038	1.7113
S5	2.9444	2.3665	0.220	1.9297	2.8032	0.4678	4.2652	0.5780
S6	9.1072	8.9062	0.271	8.3675	9.4448	6.9815	10.8308	0.2010
S7	2.1972	1.4315	0.160	1.1145	1.7485	-0.4432	3.3063	0.7657
S8	3.2958	1.8145	0.109	1.5975	2.0316	-0.0459	3.6750	1.4813
S9	4.4308	3.5909	0.110	3.3728	3.8090	1.7303	5.4515	0.8399
S10	2.0015	0.7590	0.162	0.4365	1.0816	-1.1167	2.6347	1.2425
S11	3.0445	1.2731	0.106	1.0619	1.4843	-0.5867	3.1329	1.7714
S12	.	1.2626	0.287	0.6935	1.8317	-0.6708	3.1960	.
S13	4.4188	4.0887	0.246	3.5992	4.5782	2.1772	6.0002	0.3301
S15	9.2203	9.0349	0.281	8.4772	9.5925	7.1048	10.9649	0.1854
S16	1.3863	-0.1631	0.147	-0.4559	0.1297	-2.0339	1.7077	1.5494
S17	2.8904	2.1084	0.113	1.8848	2.3319	0.2471	3.9696	0.7820
S18	4.6347	4.2405	0.122	3.9981	4.4828	2.3769	6.1040	0.3943
S19	-0.9163	-1.5670	0.235	-2.0333	-1.1006	-3.4727	0.3387	0.6507
S20	-1.2040	-0.4241	0.189	-0.7990	-0.0493	-2.3095	1.4613	-0.7798
S21	-0.2231	-0.3902	0.145	-0.6789	-0.1014	-2.2603	1.4800	0.1670
S22	1.8083	1.2601	0.105	1.0517	1.4685	-0.5993	3.1196	0.5482
S23	3.0910	2.6165	0.110	2.3975	2.8356	0.7558	4.4772	0.4745
S24	.	-0.4898	0.142	-0.7715	-0.2080	-2.3589	1.3793	.
S25	-1.5606	-0.9970	0.175	-1.3439	-0.6501	-2.8770	0.8830	-0.5637
S26	1.0647	1.0246	0.130	0.7671	1.2821	-0.8410	2.8902	0.0401
S27	*[b]	-1.7000	0.179	-2.0550	-1.3451	-3.5816	0.1815	*
S28	.	2.9706	0.123	2.7262	3.2150	1.1067	4.8344	.
S29	-0.5798	1.5251	0.167	1.1929	1.8573	-0.3523	3.4025	-2.1049
S30	4.3567	4.1015	0.123	3.8569	4.3462	2.2376	5.9654	0.2552
S31	*	-2.8720	0.217	-3.3032	-2.4408	-4.7694	-0.9746	*
S32	-0.7550	-0.6635	0.147	-0.9549	-0.3722	-2.5341	1.2070	-0.0915
S33	4.0943	3.8564	0.116	3.6264	4.0864	1.9944	5.7184	0.2380
S34	*	-5.4303	0.328	-6.0811	-4.7794	-7.3893	-3.4712	*
S35	*	-5.0336	0.310	-5.6500	-4.4171	-6.9814	-3.0857	*
S36	.	-0.3412	0.139	-0.6172	-0.0651	-2.2094	1.5271	.
S37	0.9163	1.2628	0.120	1.0243	1.5013	-0.6003	3.1259	-0.3465
S38	4.9273	4.6751	0.143	4.3903	4.9598	2.8055	6.5446	0.2522
S39	4.5643	3.4817	0.119	3.2457	3.7178	1.6190	5.3445	1.0826
S40	1.8718	1.0120	0.110	0.7930	1.2311	-0.8487	2.8727	0.8598
S41	4.2905	2.7566	0.109	2.5409	2.9724	0.8963	4.6169	1.5338
S42	2.7726	1.7524	0.116	1.5215	1.9833	-0.1098	3.6145	1.0202
S43	1.2528	0.4454	0.118	0.2111	0.6796	-1.4172	2.3079	0.8074
S44	1.9879	1.1476	0.106	0.9374	1.3578	-0.7121	3.0073	0.8403
S45	3.4012	2.0783	0.113	1.8534	2.3032	0.2169	3.9397	1.3229
S46	4.2341	3.5011	0.107	3.2889	3.7133	1.6412	5.3610	0.7330
S47	.	2.8151	0.211	2.3958	3.2345	0.9204	4.7099	.
S48	1.1939	0.3340	0.124	0.0873	0.5808	-1.5301	2.1982	0.8599
S49	5.6870	4.6199	0.145	4.3318	4.9080	2.7498	6.4900	1.0671
S50	-2.6593	-2.1403	0.267	-2.6702	-1.6103	-4.0625	-0.2180	-0.5190
S52	*	-1.9867	0.244	-2.4707	-1.5027	-3.8968	-0.0766	*
S53	5.8665	5.1490	0.149	4.8529	5.4451	3.2777	7.0203	0.7175
S54	.	0.7839	0.121	0.5435	1.0243	-1.0794	2.6472	.
S55	6.2166	6.2481	0.181	5.8878	6.6085	4.3656	8.1307	-0.0315
S56	6.3190	6.2013	0.178	5.8473	6.5552	4.3199	8.0826	0.1177
S57	-	-	-	-	-	-	-	-

Table 6 continued

Assigned name	Dep Var $\ln Q_{7,10}$	Predict Value	Std Err Predict	Lower95% Mean	Upper95% Mean	Lower95% Predict	Upper95% Predict	Residual
S58	*	0.2652	0.121	0.0241	0.5063	-1.5982	2.1286	*
S59	*	1.0928	0.115	0.8651	1.3205	-0.7689	2.9546	*
S60	-0.2357	1.2236	0.110	1.0053	1.4418	-0.6370	3.0842	-1.4593
S61	.	4.0458	0.132	3.7833	4.3084	2.1795	5.9122	.
S62	0.9555	2.1779	0.096	1.9883	2.3676	0.3205	4.0354	-1.2224
S63	3.1355	3.6645	0.113	3.4393	3.8896	1.8031	5.5259	-0.5290
S64	0.8755	1.3130	0.118	1.0790	1.5470	-0.5495	3.1755	-0.4375
S65	*	-1.1438	0.162	-1.4665	-0.8212	-3.0195	0.7319	*
S66	3.4965	3.7130	0.161	3.3926	4.0335	1.8377	5.5883	-0.2165
S67	9.3927	9.9107	0.306	9.3024	10.5191	7.9654	11.8561	-0.5181
S69	3.2581	4.5572	0.172	4.2152	4.8991	2.6781	6.4363	-1.2991
S70	2.2513	2.0009	0.109	1.7845	2.2174	0.1405	3.8613	0.2504
S71	-2.2073	-0.6055	0.148	-0.8997	-0.3113	-2.4765	1.2655	-1.6018
S72	3.6376	4.0115	0.119	3.7762	4.2469	2.1488	5.8742	-0.3740
S73	0.8329	0.7141	0.174	0.3685	1.0597	-1.1657	2.5939	0.1188
S74	3.7136	5.1273	0.155	4.8197	5.4350	3.2542	7.0005	-1.4138
S76	*	0.8653	0.110	0.6476	1.0831	-0.9952	2.7259	*
S77	3.8067	3.9472	0.131	3.6879	4.2065	2.0813	5.8130	-0.1405
S78	*	-0.6121	0.171	-0.9517	-0.2724	-2.4908	1.2667	*
S79	.	1.4652	0.107	1.2519	1.6785	-0.3949	3.3252	.
S80	2.2083	2.5313	0.107	2.3189	2.7437	0.6714	4.3913	-0.3231
S81	*	-2.6441	0.236	-3.1124	-2.1758	-4.5503	-0.7379	*
S82	2.5649	2.2902	0.170	1.9529	2.6274	0.4119	4.1684	0.2748
S83	3.2581	2.4959	0.098	2.3003	2.6915	0.6378	4.3540	0.7622
S84	3.5553	3.4989	0.119	3.2621	3.7358	1.6360	5.3618	0.0564
S85	*	-0.9477	0.154	-1.2535	-0.6418	-2.8206	0.9252	*
S86	4.5951	6.1361	0.180	5.7787	6.4935	4.2541	8.0181	-1.5410
S87	*	-0.6373	0.145	-0.9252	-0.3494	-2.5074	1.2327	*
S88	-3.2189	-0.6142	0.199	-1.0098	-0.2185	-2.5038	1.2755	-2.6047
S89	0.4055	1.4442	0.101	1.2445	1.6439	-0.4143	3.3027	-1.0387
S90	-0.1985	-0.7956	0.251	-1.2941	-0.2972	-2.7094	1.1182	0.5972
S91	-1.0217	-0.2918	0.182	-0.6535	0.0699	-2.1746	1.5910	-0.7298
S92	-0.5798	-0.0583	0.160	-0.3752	0.2585	-1.9331	1.8164	-0.5215
S93	4.8040	5.1147	0.159	4.7993	5.4301	3.2402	6.9892	-0.3107
S94	-1.2379	-0.1747	0.179	-0.5294	0.1799	-2.0562	1.7067	-1.0631
S95	4.8203	5.2833	0.164	4.9573	5.6092	3.4070	7.1595	-0.4630
S96	4.9628	5.1354	0.173	4.7913	5.4795	3.2559	7.0149	-0.1726
S97	*	-1.7619	0.205	-2.1688	-1.3550	-3.6539	0.1302	*
S98	.	-2.6002	0.242	-3.0807	-2.1197	-4.5094	-0.6910	.
S99	*	-1.8676	0.243	-2.3501	-1.3851	-3.7773	0.0421	*
S100	0.4700	1.3420	0.128	1.0870	1.5971	-0.5232	3.2073	-0.8720
S101	0.5306	0.9544	0.155	0.6472	1.2615	-0.9187	2.8275	-0.4237
S103	2.9444	3.3249	0.106	3.1143	3.5356	1.4652	5.1847	-0.3805
S104	8.2610	8.7948	0.266	8.2662	9.3234	6.8729	10.7167	-0.5338
S105	-3.2189	-3.2749	0.231	-3.7346	-2.8152	-5.1790	-1.3709	0.0561
S106	*	-1.2125	0.169	-1.5488	-0.8761	-3.0906	0.6657	*
S107	*	-2.3808	0.221	-2.8198	-1.9417	-4.2800	-0.4816	*
S108	.	1.8722	0.123	1.6280	2.1164	0.00839	3.7360	.
S109	1.3863	1.2907	0.137	1.0184	1.5631	-0.5770	3.1585	0.0955
S110	2.6391	2.5698	0.097	2.3765	2.7632	0.7120	4.4277	0.0692
S111	*	1.0834	0.107	0.8714	1.2954	-0.7765	2.9433	*
S112	1.9601	2.6793	0.121	2.4387	2.9198	0.8159	4.5426	-0.7192
S113	1.8563	4.0311	0.156	3.7215	4.3406	2.1576	5.9046	-2.1748
S114	2.7081	3.6218	0.117	3.3896	3.8541	1.7595	5.4841	-0.9138
S115	3.1781	3.5288	0.116	3.2990	3.7586	1.6668	5.3908	-0.3507

Table 6 continued

Assigned name	Dep Var $\ln Q_{7,10}$	Predict Value	Std Err Predict	Lower95% Mean	Upper95% Mean	Lower95% Predict	Upper95% Predict	Residual
S116	-0.9416	-1.3043	0.244	-1.7897	-0.8190	-3.2148	0.6061	0.3627
S117	1.9315	0.4329	0.150	0.1348	0.7309	-1.4388	2.3045	1.4987
S118	3.8501	2.4879	0.180	2.1296	2.8461	0.6057	4.3700	1.3623
S119	1.4586	1.4222	0.150	1.1246	1.7198	-0.4494	3.2938	0.0364
S120	1.9315	2.1442	0.104	1.9378	2.3506	0.2849	4.0034	-0.2126
S123	-4.6052	-1.9679	0.214	-2.3936	-1.5422	-3.8640	-0.0717	-2.6373
S124	*	-3.6042	0.241	-4.0835	-3.1249	-5.5131	-1.6953	*
S126	2.1163	1.7272	0.099	1.5308	1.9236	-0.1310	3.5854	0.3891
S128	3.3673	3.1617	0.113	2.9369	3.3865	1.3003	5.0231	0.2056
S129	*	-3.2060	0.232	-3.6677	-2.7442	-5.1106	-1.3014	*
S130	.	1.1294	0.104	0.9221	1.3367	-0.7299	2.9888	.
S131	2.7081	2.9925	0.138	2.7186	3.2664	1.1246	4.8605	-0.2845
S132	3.4012	2.9047	0.124	2.6592	3.1501	1.0407	4.7687	0.4965
S133	*	-1.2094	0.186	-1.5795	-0.8394	-3.0939	0.6750	*
S134	1.8083	1.9433	0.097	1.7511	2.1355	0.0855	3.8010	-0.1350
S135	.	-0.3772	0.152	-0.6795	-0.0748	-2.2495	1.4952	.
S136	*	-1.3074	0.166	-1.6362	-0.9787	-3.1842	0.5694	*
S137	*	-3.2575	0.258	-3.7701	-2.7449	-5.1751	-1.3400	*
S138	0.5306	0.4733	0.185	0.1063	0.8403	-1.4106	2.3571	0.0574
S139	*	-2.3225	0.250	-2.8188	-1.8262	-4.2357	-0.4092	*
S140	*	-2.1899	0.294	-2.7734	-1.6063	-4.1276	-0.2521	*
S141	-2.4079	-2.3640	0.308	-2.9768	-1.7513	-4.3107	-0.4174	-0.0439
S142	-1.5141	-0.9727	0.296	-1.5602	-0.3852	-2.9116	0.9662	-0.5415
S143	-1.2379	-0.2280	0.235	-0.6939	-0.2379	-2.1335	1.6776	-1.0099

[a] Dots refer to 13 deleted points

[b] Asterisks refer to the points with $Q_{7,10} = 0$

Table 7. Results of the regression model (4.8) (N=108)

Assigned name	Dep Var ln $Q_{7,10}$	Predict Value	Std Err Predict	Lower95% Mean	Upper95% Mean	Lower95% Predict	Upper95% Predict	Residual
S1	3.5264	1.4095	0.142	1.1272	1.6919	-1.4258	4.2449	2.1168
S2	3.3673	1.5270	0.141	1.2481	1.8058	-1.3080	4.3619	1.8403
S3	4.4998	1.9353	0.137	1.6635	2.2071	-0.8990	4.7696	2.5645
S4	0.4055	-1.7702	0.270	-2.3059	-1.2346	-4.6419	1.1014	2.1757
S5	2.9444	0.3520	0.172	0.0116	0.6925	-2.4897	3.1937	2.5924
S6	9.1072	7.6715	0.369	6.9409	8.4021	4.7572	10.5858	1.4357
S7	2.1972	0.0501	0.183	-0.3136	0.4137	-2.7945	2.8946	2.1472
S8	3.2958	2.1239	0.137	1.8523	2.3955	-0.7104	4.9582	1.1719
S9	4.4308	2.8283	0.145	2.5411	3.1154	-0.0076	5.6641	1.6026
S10	2.0015	-0.3457	0.200	-0.7427	0.0514	-3.1947	2.5034	2.3471
S11	3.0445	0.7478	0.158	0.4339	1.0618	-2.0908	3.5865	2.2967
S12	1.0296	-1.3096	0.246	-1.7981	-0.8211	-4.1728	1.5536	2.3392
S13	4.4188	1.4220	0.142	1.1401	1.7040	-1.4133	4.2573	2.9968
S15	9.2203	7.9761	0.386	7.2112	8.7410	5.0530	10.8992	1.2442
S16	1.3863	-0.7452	0.219	-1.1786	-0.3117	-3.5995	2.1092	2.1314
S17	2.8904	2.3306	0.138	2.0570	2.6041	-0.5039	5.1650	0.5598
S18	4.6347	3.3551	0.158	3.0414	3.6687	0.5164	6.1937	1.2797
S19	-0.9163	-2.8952	0.331	-3.5516	-2.2389	-5.7918	0.0013	1.9789
S20	-1.2040	-0.4271	0.204	-0.8314	-0.0228	-3.2771	2.4229	-0.7769
S21	-0.2231	-0.3164	0.199	-0.7109	0.0780	-3.1651	2.5323	0.0933
S22	1.8083	1.1853	0.147	0.8942	1.4763	-1.6509	4.0215	0.6230
S23	3.0910	2.8439	0.145	2.5562	3.1317	0.0081	5.6798	0.2471
S24	-0.9416	-0.4698	0.206	-0.8779	-0.0618	-3.3204	2.3807	-0.4718
S25	-1.5606	-1.4233	0.252	-1.9232	-0.9233	-4.2885	1.4419	-0.1374
S26	1.0647	0.2131	0.177	-0.1377	0.5639	-2.6298	3.0561	0.8516
S27	*[a]	-1.1231	0.237	-1.5930	-0.6531	-3.9832	1.7370	*
S28	3.8067	3.4221	0.160	3.1043	3.7399	0.5830	6.2611	0.3846
S29	-0.5798	0.1342	0.180	-0.2228	0.4911	-2.7095	2.9779	-0.7140
S30	4.3567	3.5879	0.166	3.2593	3.9166	0.7476	6.4282	0.7688
S31	*	-2.4444	0.306	-3.0516	-1.8372	-5.3302	0.4415	*
S32	-0.7550	-0.7067	0.217	-1.1365	-0.2768	-3.5605	2.1471	-0.0483
S33	4.0943	3.7900	0.173	3.4470	4.1331	0.9480	6.6321	0.3043
S34	*	-5.1741	0.461	-6.0881	-4.2602	-8.1397	-2.2086	*
S35	*	-5.2043	0.463	-6.1218	-4.2869	-8.1710	-2.2377	*
S36	-1.6094	0.2131	0.177	-0.1377	0.5639	-2.6298	3.0561	-1.8225
S37	0.9163	1.5564	0.140	1.2784	1.8344	-1.2785	4.3913	-0.6401
S38	4.9273	4.1387	0.187	3.7684	4.5089	1.2933	6.9841	0.7886
S39	4.5643	2.3379	0.138	2.0642	2.6115	-0.4966	5.1723	2.2265
S40	1.8718	0.7520	0.158	0.4383	1.0657	-2.0866	3.5906	1.1198
S41	4.2905	2.9211	0.147	2.6301	3.2121	0.0849	5.7573	1.3694
S42	2.7726	2.0560	0.137	1.7845	2.3275	-0.7783	4.8903	0.7166
S43	1.2528	0.7266	0.159	0.4114	1.0419	-2.1122	3.5654	0.5261
S44	1.9879	1.4466	0.142	1.1655	1.7278	-1.3886	4.2819	0.5412
S45	3.4012	2.6361	0.141	2.3557	2.9165	-0.1990	5.4712	0.7651
S46	4.2341	2.9851	0.148	2.6912	3.2789	0.1486	5.8216	1.2490
S47	1.6094	0.9133	0.154	0.6089	1.2177	-1.9244	3.7509	0.6962
S48	1.1939	0.7394	0.159	0.4249	1.0538	-2.0993	3.5781	0.4545
S49	5.6870	4.3711	0.197	3.9812	4.7609	1.5230	7.2191	1.3159
S50	-2.6593	-3.2235	0.349	-3.9161	-2.5309	-6.1285	-0.3185	0.5642
S52	*	-2.7776	0.325	-3.4210	-2.1342	-5.6713	0.1161	*
S53	5.8665	4.6726	0.210	4.2558	5.0893	1.8207	7.5244	1.1939
S54	-0.8210	0.0573	0.183	-0.3058	0.4203	-2.7872	2.9018	-0.8783
S55	6.2166	4.9019	0.221	4.4637	5.3401	2.0468	7.7570	1.3147
S56	6.3190	5.5090	0.251	5.0112	6.0068	2.6442	8.3738	0.8100
S57	-	-	-	-	-	-	-	-

Table 7 continued

Assigned name	Dep Var $\ln Q_{7,10}$	Predict Value	Std Err Predict	Lower95% Mean	Upper95% Mean	Lower95% Predict	Upper95% Predict	Residual
S58	*	0.2321	0.176	-0.1173	0.5815	-2.6107	3.0749	*
S59	*	1.5178	0.141	1.2387	1.7968	-1.3172	4.3528	*
S60	-0.2357	0.6197	0.162	0.2977	0.9417	-2.2198	3.4593	-0.8554
S61	2.3979	2.9009	0.146	2.6107	3.1910	0.0647	5.7370	-0.5030
S62	0.9555	1.8669	0.137	1.5945	2.1393	-0.9675	4.7012	-0.9114
S63	3.1355	3.6312	0.167	3.2996	3.9629	0.7906	6.4719	-0.4958
S64	0.8755	1.4564	0.142	1.1755	1.7372	-1.3788	4.2915	-0.5809
S65	*	-0.6074	0.212	-1.0280	-0.1867	-3.4598	2.2451	*
S66	3.4965	4.1417	0.187	3.7712	4.5122	1.2962	6.9871	-0.6452
S67	9.3927	8.3985	0.410	7.5857	9.2113	5.4626	11.3345	0.9941
S69	3.2581	3.3137	0.157	3.0025	3.6249	0.4753	6.1520	-0.0556
S70	2.2513	2.6147	0.141	2.3349	2.8945	-0.2203	5.4498	-0.3634
S71	-2.2073	0.5283	0.165	0.2002	0.8563	-2.3120	3.3685	-2.7355
S72	3.6376	4.1075	0.185	3.7398	4.4752	1.2624	6.9526	-0.4700
S73	0.8329	2.0530	0.137	1.7815	2.3244	-0.7813	4.8872	-1.2201
S74	3.7136	4.4451	0.200	4.0488	4.8415	1.5962	7.2941	-0.7316
S76	*	0.9533	0.152	0.6510	1.2555	-1.8841	3.7906	*
S77	3.8067	4.6193	0.208	4.2074	5.0312	1.7681	7.4704	-0.8126
S78	*	-0.9682	0.229	-1.4230	-0.5134	-3.8259	1.8894	*
S79	0.5878	1.8131	0.138	1.5401	2.0861	-1.0213	4.6475	-1.2253
S80	2.2083	2.8882	0.146	2.5987	3.1778	0.0522	5.7243	-0.6800
S81	*	-2.5120	0.310	-3.1265	-1.8975	-5.3994	0.3754	*
S82	2.5649	1.2177	0.146	0.9281	1.5074	-1.6183	4.0538	1.3472
S83	3.2581	2.2627	0.138	1.9901	2.5354	-0.5717	5.0971	0.9954
S84	3.5553	3.8550	0.175	3.5071	4.2029	1.0124	6.6976	-0.2997
S85	*	-0.9941	0.231	-1.4514	-0.5368	-3.8522	1.8639	*
S86	4.5951	5.2073	0.236	4.7397	5.6750	2.3476	8.0671	-0.6122
S87	*	-0.7793	0.220	-1.2160	-0.3426	-3.6341	2.0756	*
S88	-3.2189	0.9206	0.153	0.6166	1.2246	-1.9169	3.7582	-4.1395
S89	0.4055	1.3893	0.143	1.1062	1.6724	-1.4461	4.2247	-0.9838
S90	-0.1985	1.2747	0.145	0.9874	1.5620	-1.5611	4.1105	-1.4732
S91	-1.0217	0.8946	0.154	0.5892	1.2001	-1.9431	3.7324	-1.9163
S92	-0.5798	1.0297	0.150	0.7314	1.3280	-1.8072	3.8667	-1.6096
S93	4.8040	5.5069	0.251	5.0094	6.0045	2.6422	8.3717	-0.7029
S94	-1.2379	1.0093	0.151	0.7100	1.3087	-1.8277	3.8464	-2.2472
S95	4.8203	5.5957	0.256	5.0892	6.1023	2.7294	8.4621	-0.7755
S96	4.9628	5.6579	0.259	5.1450	6.1708	2.7904	8.5254	-0.6950
S97	*	-0.6195	0.213	-1.0413	-0.1978	-3.4721	2.2331	*
S98	-3.2189	-0.8504	0.224	-1.2938	-0.4069	-3.7062	2.0055	-2.3685
S99	*	-0.0714	0.188	-0.4450	0.3021	-2.9173	2.7744	*
S100	0.4700	1.9649	0.137	1.6932	2.2366	-0.8694	4.7992	-1.4949
S101	0.5306	2.8667	0.146	2.5780	3.1554	0.0307	5.7026	-2.3361
S103	2.9444	4.7540	0.214	4.3297	5.1783	1.9011	7.6070	-1.8096
S104	8.2610	9.6451	0.482	8.6891	10.6011	6.6663	12.6239	-1.3841
S105	-3.2189	-1.2325	0.242	-1.7133	-0.7517	-4.0944	1.6294	-1.9864
S106	*	0.5820	0.164	0.2575	0.9065	-2.2578	3.4218	*
S107	*	0.0716	0.183	-0.2903	0.4335	-2.7727	2.9160	*
S108	1.0296	2.1152	0.137	1.8437	2.3868	-0.7190	4.9495	-1.0856
S109	1.3863	1.1051	0.149	0.8105	1.3997	-1.7315	3.9417	0.2812
S110	2.6391	2.1353	0.137	1.8637	2.4070	-0.6989	4.9696	0.5037
S111	*	1.1763	0.147	0.8849	1.4677	-1.6600	4.0125	*
S112	1.9601	2.6400	0.142	2.3594	2.9205	-0.1952	5.4751	-0.6799
S113	1.8563	2.8307	0.145	2.5435	3.1180	-0.00507	5.6666	-0.9744
S114	2.7081	3.4454	0.161	3.1261	3.7646	0.6061	6.2846	-0.7373
S115	3.1781	3.5620	0.165	3.2351	3.8889	0.7219	6.4021	-0.3839

Table 7 continued

Assigned name	Dep Var ln $Q_{7,10}$	Predict Value	Std Err Predict	Lower95% Mean	Upper95% Mean	Lower95% Predict	Upper95% Predict	Residual
S116	-0.9416	-1.8796	0.276	-2.4267	-1.3326	-4.7534	0.9941	0.9380
S117	1.9315	1.7550	0.138	1.4811	2.0289	-1.0795	4.5895	0.1765
S118	3.8501	3.8863	0.177	3.5361	4.2365	1.0434	6.7292	-0.0362
S119	1.4586	1.1178	0.148	0.8237	1.4118	-1.7188	3.9543	0.3409
S120	1.9315	2.0933	0.137	1.8218	2.3649	-0.7409	4.9276	-0.1618
S123	-4.6052	-2.1431	0.290	-2.7180	-1.5683	-5.0223	0.7361	-2.4620
S124	*	-2.2089	0.293	-2.7908	-1.6270	-5.0895	0.6717	*
S126	2.1163	1.6345	0.139	1.3584	1.9107	-1.2002	4.4692	0.4817
S128	3.3673	2.6323	0.141	2.3519	2.9126	-0.2029	5.4674	0.7350
S129	*	-2.4094	0.304	-3.0128	-1.8060	-5.2944	0.4757	*
S130	2.1518	1.2060	0.146	0.9159	1.4961	-1.6301	4.0421	0.9457
S131	2.7081	2.1268	0.137	1.8551	2.3984	-0.7075	4.9610	0.5813
S132	3.4012	3.5934	0.166	3.2644	3.9225	0.7531	6.4338	-0.1922
S133	*	-1.5890	0.261	-2.1058	-1.0721	-4.4571	1.2792	*
S134	1.8083	1.9219	0.137	1.6500	2.1938	-0.9124	4.7562	-0.1136
S135	-0.5621	0.3113	0.173	-0.0321	0.6548	-2.5307	3.1534	-0.8734
S136	*	-0.7876	0.221	-1.2251	-0.3501	-3.6426	2.0673	*
S137	*	-1.5083	0.257	-2.0169	-0.9997	-4.3750	1.3584	*
S138	0.5306	1.8149	0.138	1.5419	2.0879	-1.0195	4.6493	-1.2843
S139	*	-0.6318	0.213	-1.0547	-0.2089	-3.4845	2.2210	*
S140	*	0.0858	0.182	-0.2750	0.4466	-2.7584	2.9300	*
S141	-2.4079	-0.0169	0.186	-0.3859	0.3522	-2.8621	2.8284	-2.3911
S142	-1.5141	1.5015	0.141	1.2220	1.7811	-1.3335	4.3366	-3.0156
S143	-1.2379	1.8277	0.138	1.5548	2.1005	-1.0067	4.6621	-3.0655

[a] Asterisks refer to the points with $Q_{7,10} = 0$

APPENDIX B

1. Coefficients of MRC's equations
2. 134 Pairs of Master Recession Curves (MRC's) for 134 Iowa Streams

Table 1. Coefficients of MRC's equations: T = A (log Q)**2 + B (log Q) + C

Assigned name	No of Rec segments	Coefficients of MRC's equations			No of Rec segments	Coefficients of MRC's equations		
	for winter				for summer			
		A	B	C		A	B	C
S1	16	4.62	-47.93	95.23	16	9.86	-75.33	133.18
S2	14	-10.33	24.19	12.80	21	8.64	-71.57	133.38
S3	21	6.44	-72.10	166.60	21	24.39	-171.28	292.39
S4	15	-7.81	-12.10	35.02	13	-4.65	-12.39	30.07
S5	11	9.89	-76.34	126.61	24	10.84	-73.07	117.62
S6	16	-2.77	-15.14	149.71	32	-4.64	5.46	99.31
S7	22	3.83	-42.38	86.84	26	6.91	-55.25	95.44
S8	4	-0.87	-14.56	54.44	8	9.94	-76.07	141.36
S9	36	1.27	-36.50	113.98	48	-0.06	-26.22	94.73
S10	27	2.94	-36.53	70.77	41	3.32	-36.54	69.98
S11	14	8.92	-62.15	106.11	16	10.15	-69.35	113.81
S12	17	32.23	-141.33	152.93	42	18.80	-87.32	99.51
S13	13	13.96	-112.42	209.44	18	32.57	-201.87	308.26
S15	32	7.32	-109.68	372.74	44	7.13	-111.55	388.99
S16	16	3.43	-34.15	56.94	41	5.29	-36.36	54.42
S17	25	9.28	-74.47	143.99	44	5.69	-51.59	106.05
S18	44	9.24	-87.92	200.24	44	10.77	-93.84	202.53
S19	6	5.99	-37.08	47.53	11	9.07	-38.75	36.29
S20	9	6.75	-41.38	60.88	20	3.00	-30.78	57.32
S21	13	6.57	-40.71	57.24	31	3.10	-29.04	54.51
S22	34	3.19	-38.60	87.09	45	5.16	-45.31	91.03
S23	25	1.94	-32.13	90.13	34	7.47	-65.71	139.69
S24	8	0.74	-13.07	22.99	16	1.62	-26.84	52.76
S25	14	-2.20	-12.30	31.98	14	-2.56	-11.52	34.76
S26	9	1.62	-27.67	54.31	8	3.24	-34.33	59.70
S27	7	1.78	-16.09	24.26	8	1.49	-20.17	31.41
S28	12	-1.30	-13.44	61.94	16	0.26	-21.66	71.73
S29	43	0.58	-29.83	75.80	41	3.70	-41.75	82.96
S30	10	3.08	-43.62	116.53	29	6.12	-66.61	167.73
S31	7	0.22	-11.73	20.30	23	0.15	-15.04	18.75
S32	7	-0.20	-18.45	41.13	11	2.33	-21.18	36.83
S33	18	8.36	-85.00	204.40	31	7.04	-70.21	165.23
S34	12	1.00	-13.21	11.06	15	1.49	-14.15	9.09
S35	6	0.47	-13.71	10.76	13	2.67	-15.91	14.30
S36	13	0.41	-16.83	43.40	14	1.22	-23.62	47.68
S37	28	1.81	-27.27	62.89	36	1.45	-24.73	59.69
S38	10	-2.60	-9.68	76.37	16	0.29	-25.79	98.07
S39	20	4.98	-54.04	126.08	31	12.50	-101.68	200.77
S40	18	2.89	-36.38	79.75	31	1.88	-27.54	58.63
S41	16	11.68	-92.45	180.27	20	10.03	-85.08	173.58
S42	19	2.33	-32.21	84.49	40	5.30	-50.49	110.67
S43	7	-0.32	-15.63	45.12	18	-2.72	-5.11	43.66
S44	28	0.18	-21.30	66.83	48	1.76	-27.01	68.51
S45	9	2.33	-30.44	73.73	15	-0.78	-15.29	58.80
S46	12	10.48	-96.38	212.17	39	4.00	-50.80	130.56
S47	29	6.27	-57.29	111.09	42	7.60	-64.56	119.44
S48	6	-1.57	-4.80	25.08	20	8.09	-52.22	78.76
S49	21	7.71	-79.66	197.90	30	8.62	-87.69	215.03
S50	4	11.20	-29.31	17.82	8	14.21	-40.14	26.75
S52	8	-5.80	-11.07	18.00	11	4.17	-30.33	29.90
S53	31	9.53	-98.72	247.46	47	13.31	-126.09	295.67

Table 1 continued

Assigned name	No of Rec segments (for winter)	Coefficients of MRC's equations for winter A	B	C	No of Rec segments (for summer)	Coefficients of MRC's equations for summer A	B	C
S54	8	-6.04	1.98	26.41	17	3.74	-35.93	61.79
S55	17	19.56	-184.73	433.57	41	16.79	-159.12	375.54
S56	12	9.05	-98.95	263.38	26	12.37	-126.40	313.10
S57	13	3.09	-30.26	64.93	30	1.76	-20.26	42.17
S58	11	2.44	-29.65	58.21	16	2.55	-25.77	49.80
S59	9	0.53	-20.85	63.86	19	2.69	-26.83	56.47
S60	9	3.47	-35.85	73.51	28	3.19	-34.10	70.31
S61	18	3.43	-49.28	124.14	36	8.61	-75.67	160.42
S62	9	2.10	-29.59	66.29	23	-4.05	-2.21	41.08
S63	15	3.31	-41.50	110.53	29	6.79	-66.64	154.56
S64	13	3.59	-33.62	62.17	17	6.23	-41.52	63.99
S65	27	0.60	-18.11	34.13	40	3.66	-26.40	39.88
S66	31	8.73	-80.20	180.24	38	6.69	-64.09	147.53
S67	9	-11.53	71.42	-63.12	22	0.62	-52.30	261.69
S69	9	12.95	-105.41	200.02	25	-9.72	29.74	18.96
S70	13	5.05	-49.44	111.06	39	4.21	-41.44	86.93
S71	9	1.77	-22.86	47.81	26	3.37	-28.63	53.60
S72	10	13.14	-118.13	259.18	22	8.01	-75.70	170.95
S73	13	3.25	-30.62	65.41	15	2.85	-28.78	64.58
S74	17	6.85	-76.94	196.46	37	5.69	-64.15	167.19
S76	15	-1.00	-13.51	41.21	37	-2.57	-6.04	32.99
S77	8	5.21	-56.88	138.08	21	5.60	-60.02	150.05
S78	16	-2.48	-7.75	29.42	40	1.27	-19.61	39.96
S79	8	2.22	-32.10	79.67	18	2.12	-25.16	57.17
S80	15	3.06	-34.53	84.79	32	4.94	-49.33	113.69
S81	8	4.14	-27.61	37.54	19	3.13	-20.22	24.60
S82	5	26.40	-153.79	216.94	10	8.04	-57.63	93.71
S83	9	6.22	-55.45	107.06	23	9.01	-70.27	128.56
S84	24	8.00	-75.75	171.28	35	5.31	-55.66	128.34
S85	5	10.66	-55.95	70.34	11	-2.24	-9.11	30.88
S86	11	7.74	-83.22	207.59	31	9.65	-95.63	223.96
S87	8	-2.05	-10.86	35.09	16	-2.84	-5.66	27.01
S88	15	1.86	-19.28	39.12	24	-1.50	-8.21	27.00
S89	18	-5.21	1.44	33.38	21	2.00	-26.82	58.95
S90	8	-0.62	-8.17	25.15	16	2.92	-22.04	36.54
S91	13	0.34	-14.56	31.96	23	2.15	-21.50	38.14
S92	19	-1.19	-10.55	34.76	16	1.48	-19.23	34.47
S93	16	5.08	-64.17	176.69	26	6.47	-73.26	191.17
S94	8	2.50	-22.29	38.24	17	-2.11	-5.49	22.43
S95	16	8.62	-87.81	214.32	33	6.91	-76.47	204.94
S96	14	5.56	-63.14	166.11	32	8.41	-88.62	222.29
S97	11	1.43	-15.94	23.29	13	1.74	-16.67	22.55
S98	9	4.33	-20.80	21.79	16	2.05	-13.08	16.56
S99	9	2.39	-20.94	34.48	17	2.89	-17.59	23.26
S100	13	4.11	-38.10	67.04	18	7.79	-52.77	83.33
S101	11	2.05	-21.86	47.28	25	4.28	-39.26	79.35
S103	12	4.14	-44.65	107.70	26	4.08	-48.43	116.27
S104	7	26.00	-257.94	632.83	15	9.13	-123.54	378.81
S105	7	12.08	-36.40	25.34	9	1.22	-11.36	12.57
S106	12	1.91	-20.32	34.76	16	1.76	-16.95	25.64
S107	7	-1.14	-10.01	20.59	19	-2.99	-6.80	23.18

Table 1 continued

Assigned name	No of Rec segments	Coefficients of equations		MRC's	No of Rec segments	Coefficients of equations		MRC's
	for winter				for summer			
		A	B	C		A	B	C
S108	10	5.11	-40.46	70.50	15	5.76	-49.36	92.22
S109	8	6.00	-44.39	67.68	12	8.17	-55.19	85.07
S110	20	-2.33	-8.79	63.20	17	2.48	-36.65	100.74
S111	6	3.96	-33.64	65.39	13	3.26	-33.62	72.20
S112	10	2.98	-41.03	100.42	19	4.79	-49.30	112.90
S113	12	5.85	-57.36	117.53	17	5.98	-58.32	127.28
S114	11	12.94	-102.52	196.20	24	5.84	-58.10	129.37
S115	13	6.80	-60.18	122.59	20	3.23	-47.69	119.29
S116	6	-3.78	-11.78	26.62	12	8.37	-48.47	56.88
S117	7	-3.15	-0.06	20.54	16	-1.83	-7.95	42.79
S118	9	-1.53	-8.15	48.73	17	-1.32	-9.68	58.45
S119	9	4.26	-37.38	62.28	11	-4.24	-13.38	67.46
S120	14	-4.05	-2.96	36.08	17	-7.51	7.04	37.33
S123	4	2.40	-16.95	11.50	6	-7.23	-10.91	28.65
S124	5	-1.99	-9.38	17.51	9	2.01	-13.93	12.12
S126	13	-2.08	-11.14	45.54	17	-4.19	-8.46	54.89
S128	11	6.42	-56.45	116.06	17	5.60	-55.95	117.47
S129	10	2.63	-14.45	15.16	10	8.23	-37.72	40.87
S130	10	4.99	-36.04	58.25	18	-2.00	-12.50	48.88
S131	13	4.87	-52.66	119.33	23	3.36	-41.20	93.76
S132	11	3.72	-40.60	94.43	15	3.06	-36.26	84.73
S133	5	1.43	-21.08	31.09	11	-1.40	-12.88	27.80
S134	12	5.03	-40.72	69.14	26	2.39	-29.86	64.36
S135	10	-1.09	-11.66	28.79	25	1.35	-19.03	36.27
S136	5	-3.63	-7.44	22.57	7	4.67	-23.58	25.42
S137	14	-0.73	-8.61	15.52	14	0.84	-11.43	14.44
S138	36	2.08	-22.65	46.24	28	2.88	-26.99	52.09
S139	17	2.20	-16.47	23.44	28	1.28	-11.01	16.39
S140	18	2.24	-16.20	25.41	34	1.31	-11.16	17.96
S141	17	1.28	-12.56	21.36	26	1.02	-11.18	17.33
S142	14	2.85	-21.29	37.32	33	0.62	-11.01	26.86
S143	21	2.83	-23.28	43.39	39	1.64	-15.55	30.79

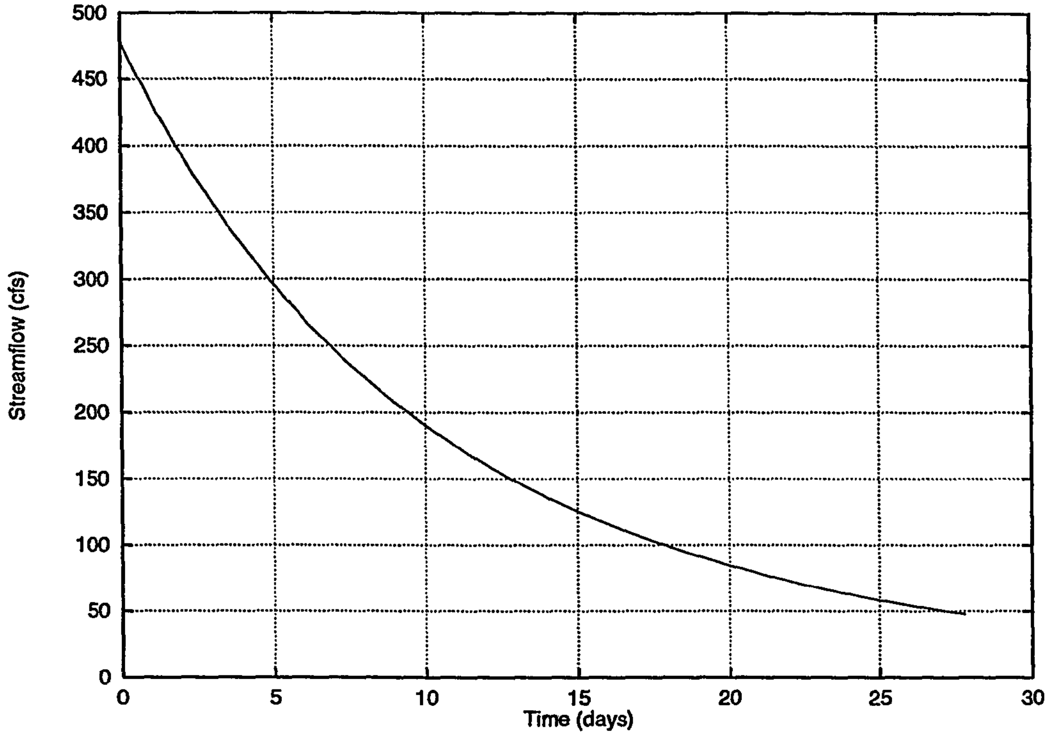

Figure 1.1: MRC of Upper Iowa River at Decorah (for winter), ID# 05387500

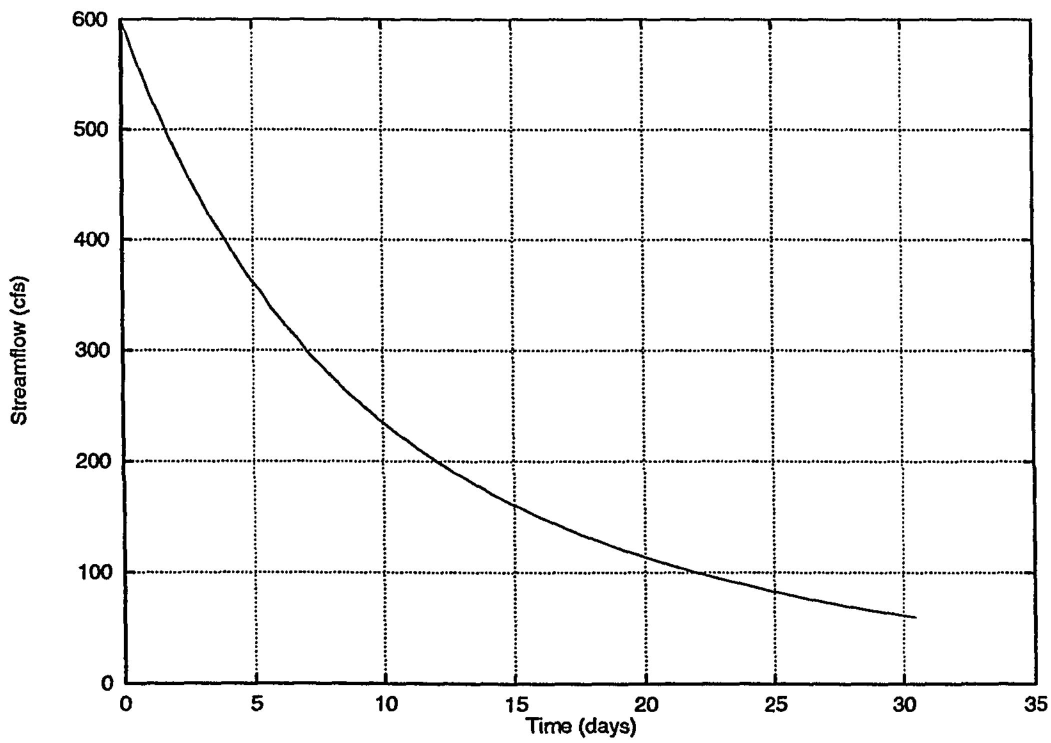

Figure 1.2: MRC of Upper Iowa River at Decorah (for summer), ID# 05387500

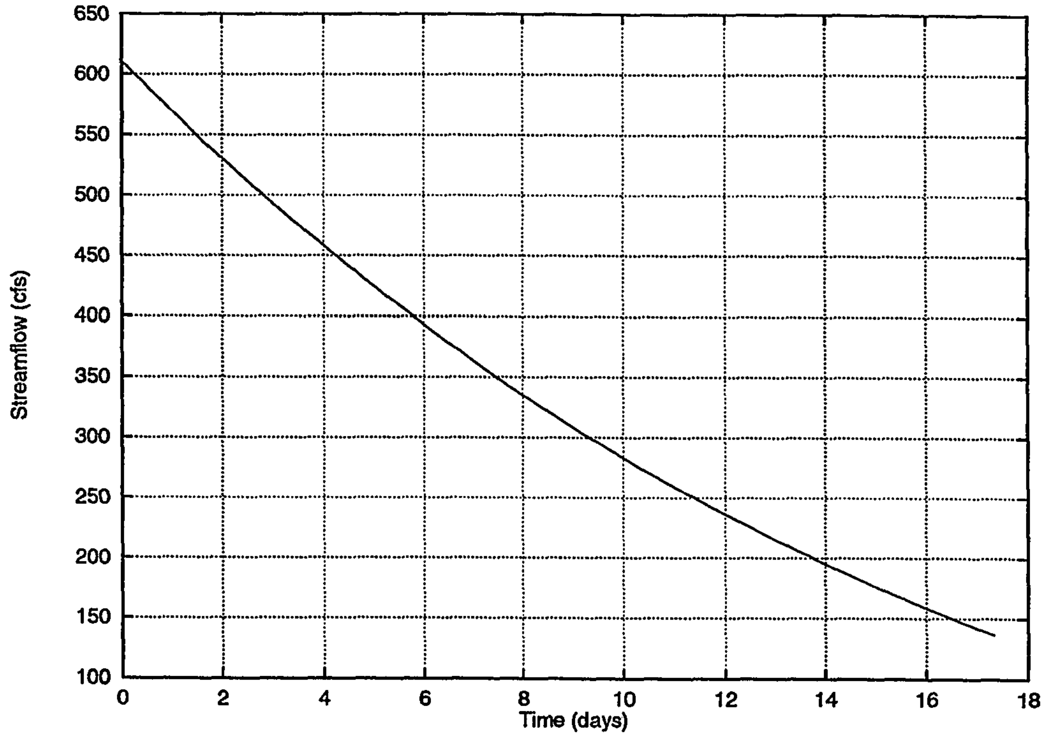

Figure 2.1: MRC of Upper Iowa River near Decorah (for winter), ID# 05388000

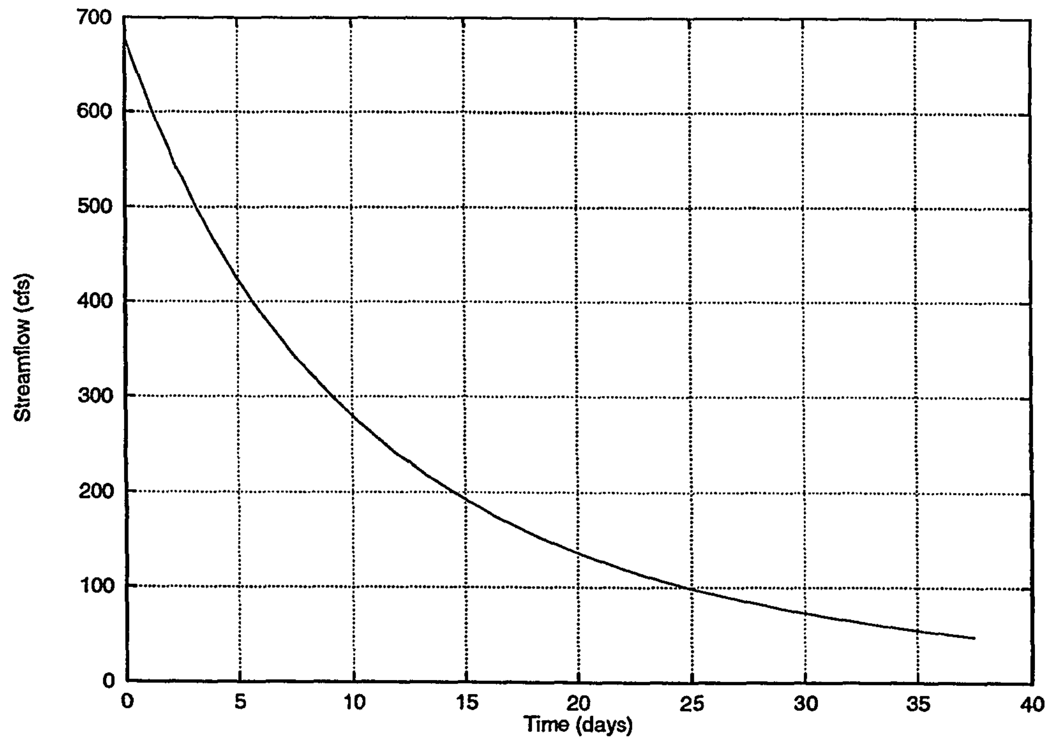

Figure 2.2: MRC of Upper Iowa River near Decorah (for summer), ID# 05388000

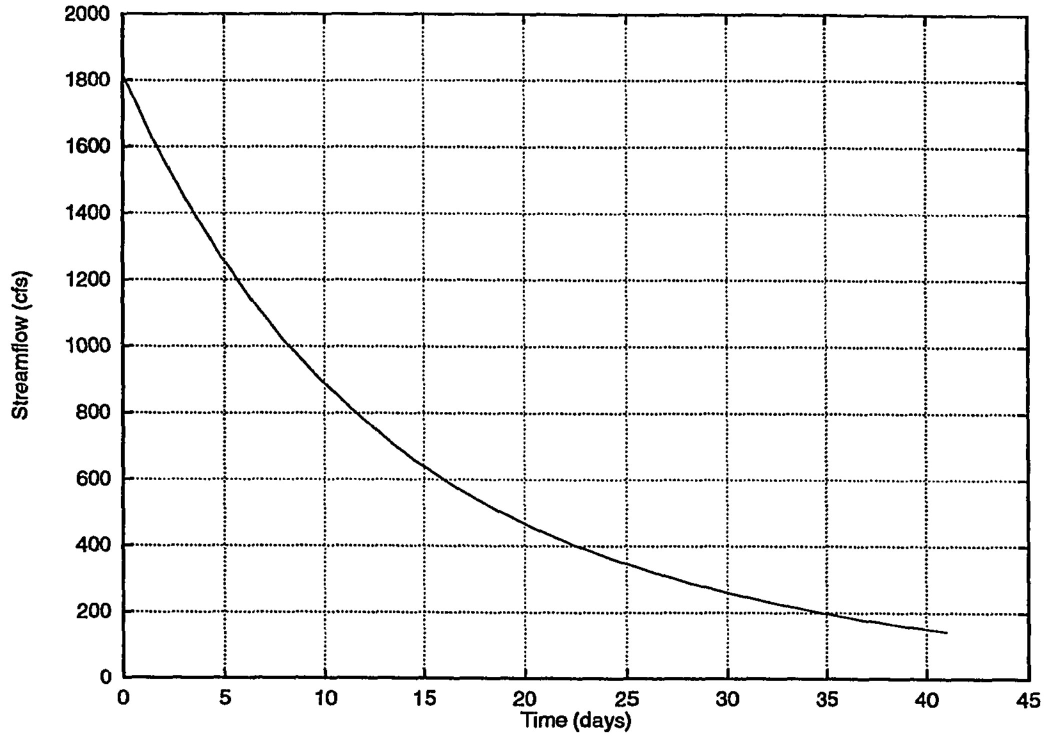

Figure 3.1: MRC of Upper Iowa River near Dorchester (for winter)

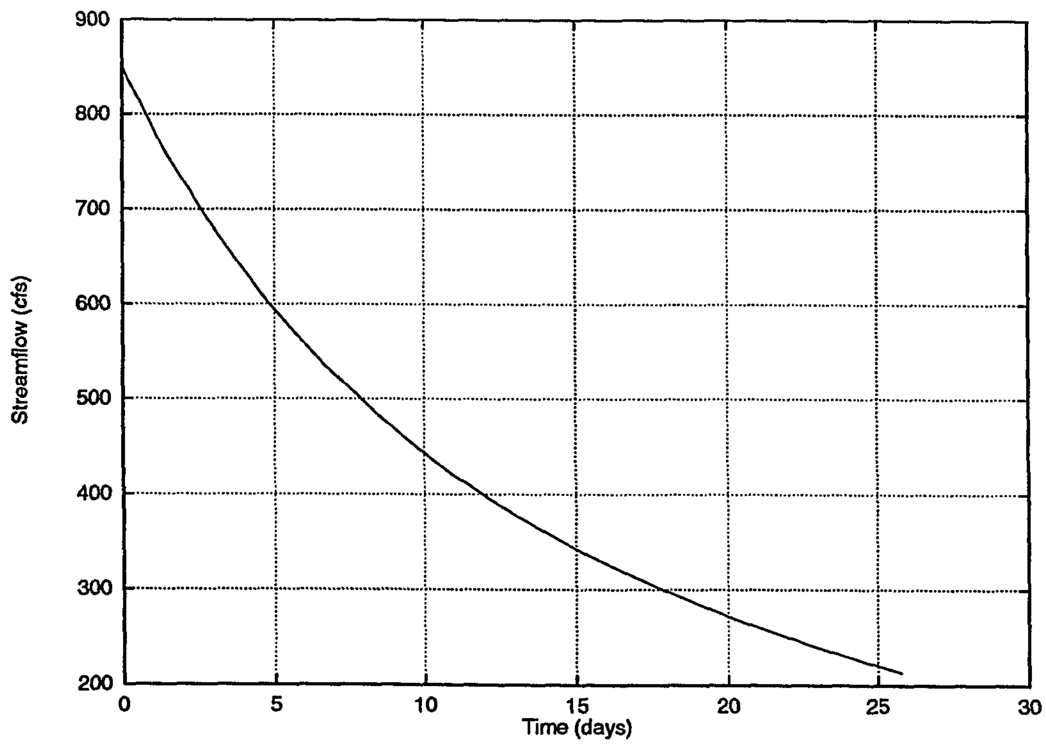

Figure 3.2: MRC of Upper Iowa River near Dorchester (for summer), ID# 05388250

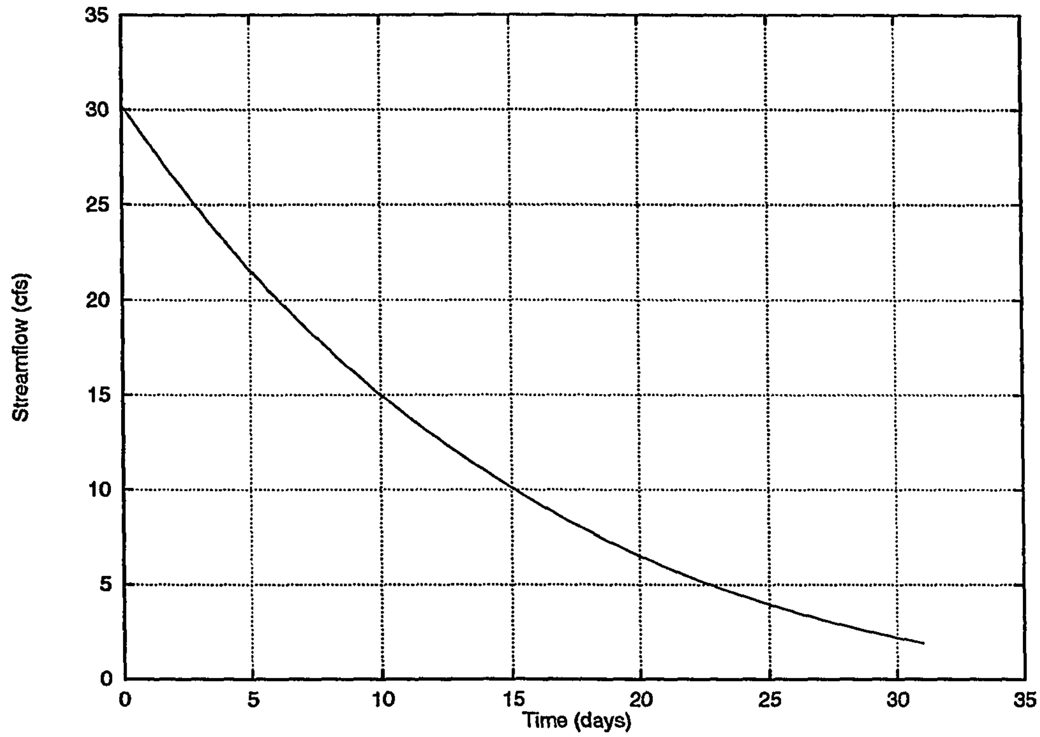

Figure 4.1: MRC of Paint Creek at Waterville (for winter), ID# 05388500

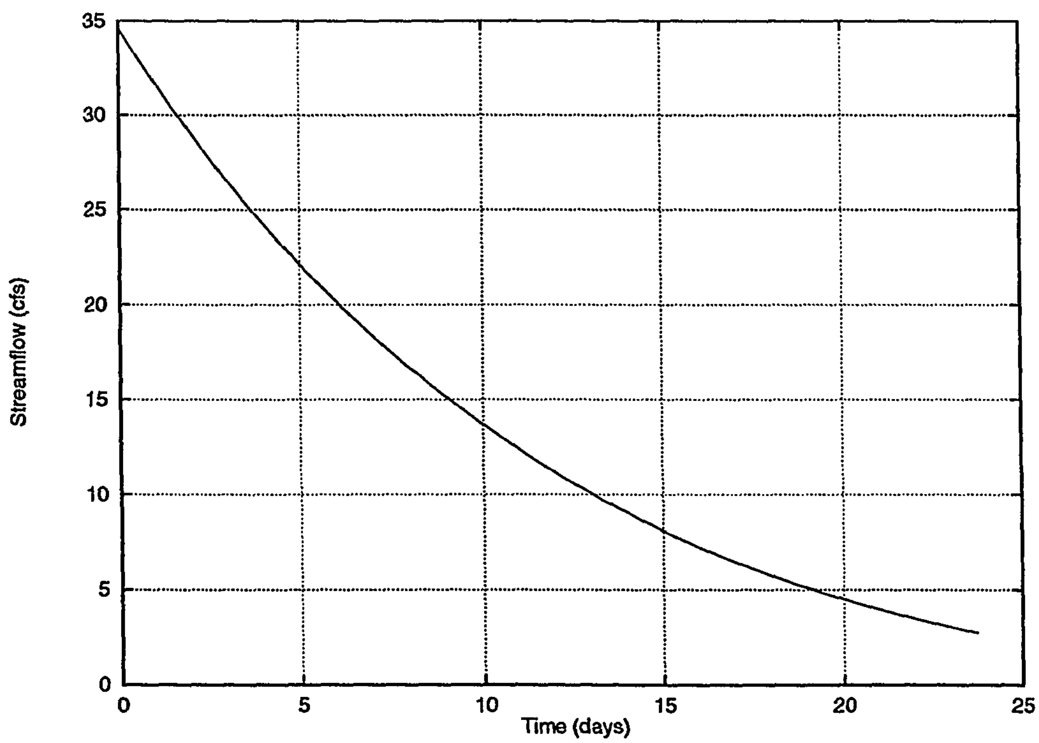

Figure 4.2: MRC of Paint Creek at Waterville (for summer), ID# 05388500

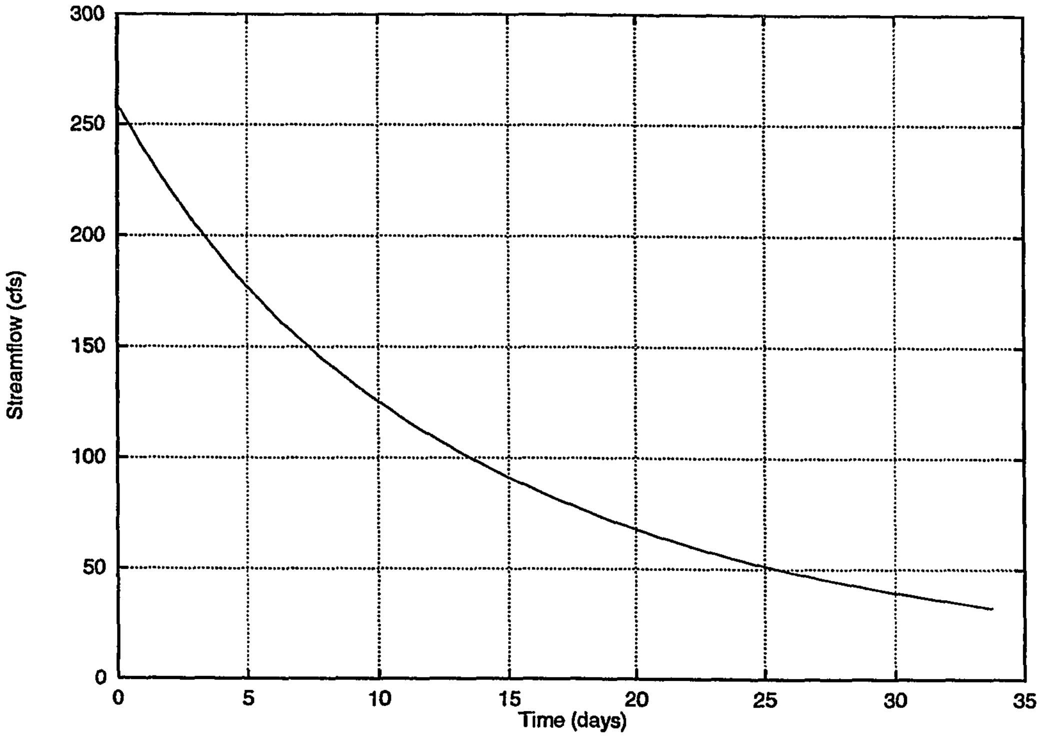

Figure 5.1: MRC of Yellow River at Ion (for winter), ID# 05389000

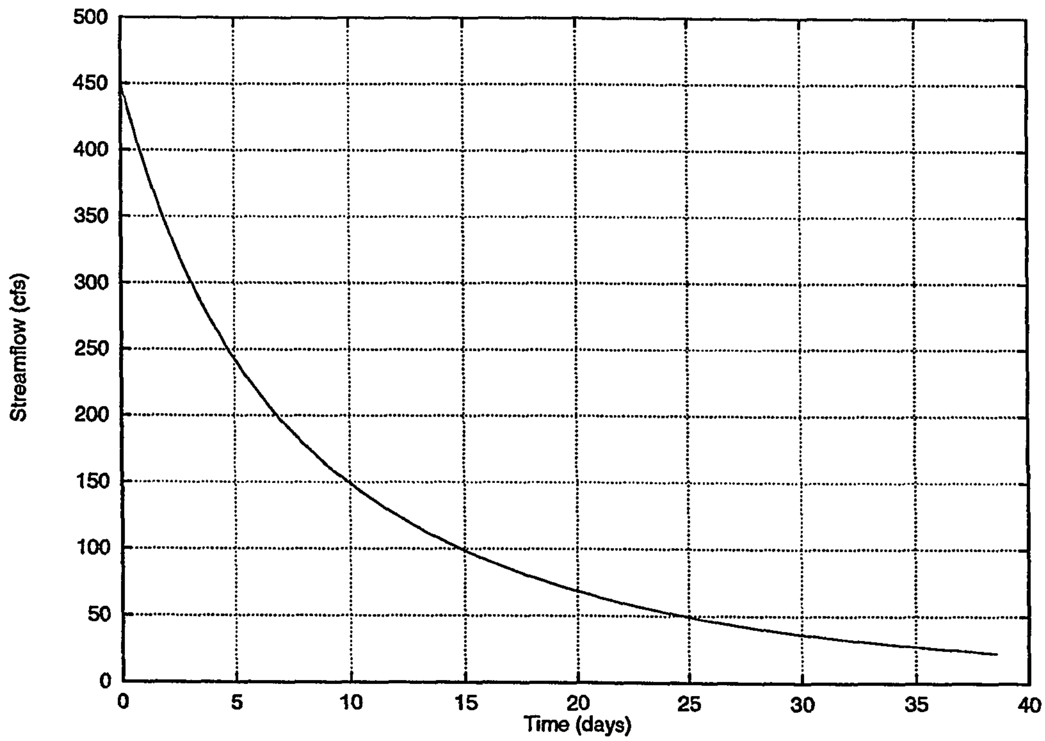

Figure 5.2: MRC of Yellow River at Ion (for summer), ID# 05389000

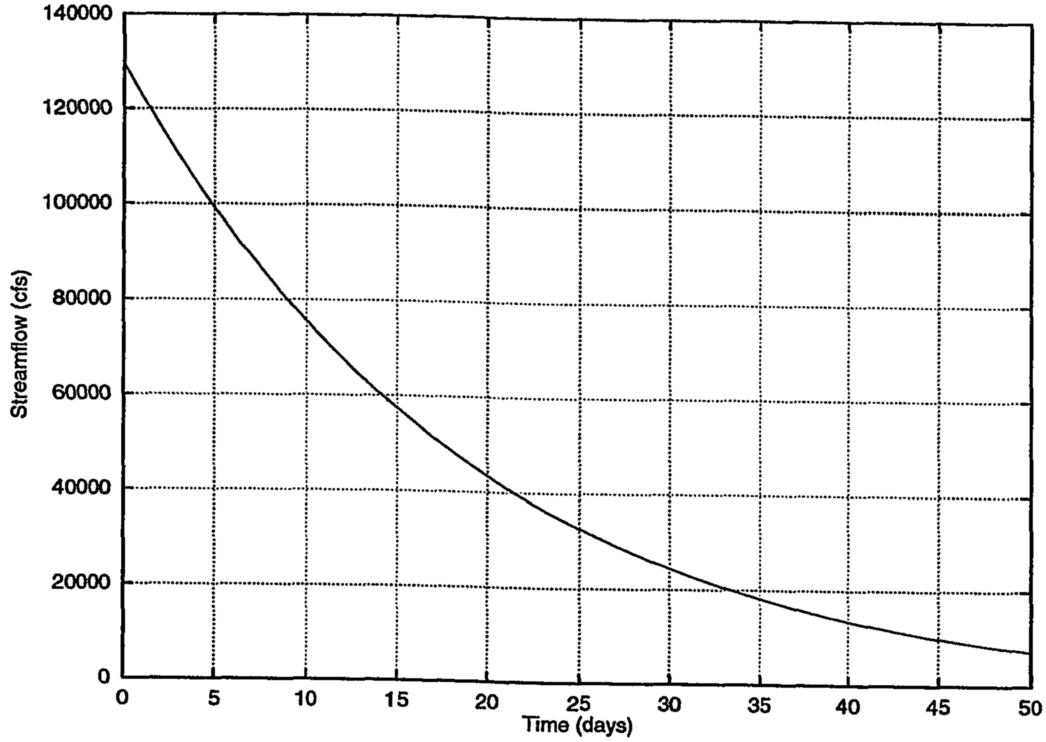

Figure 6.1: MRC of Mississippi River at McGregor (for winter), ID# 05389500

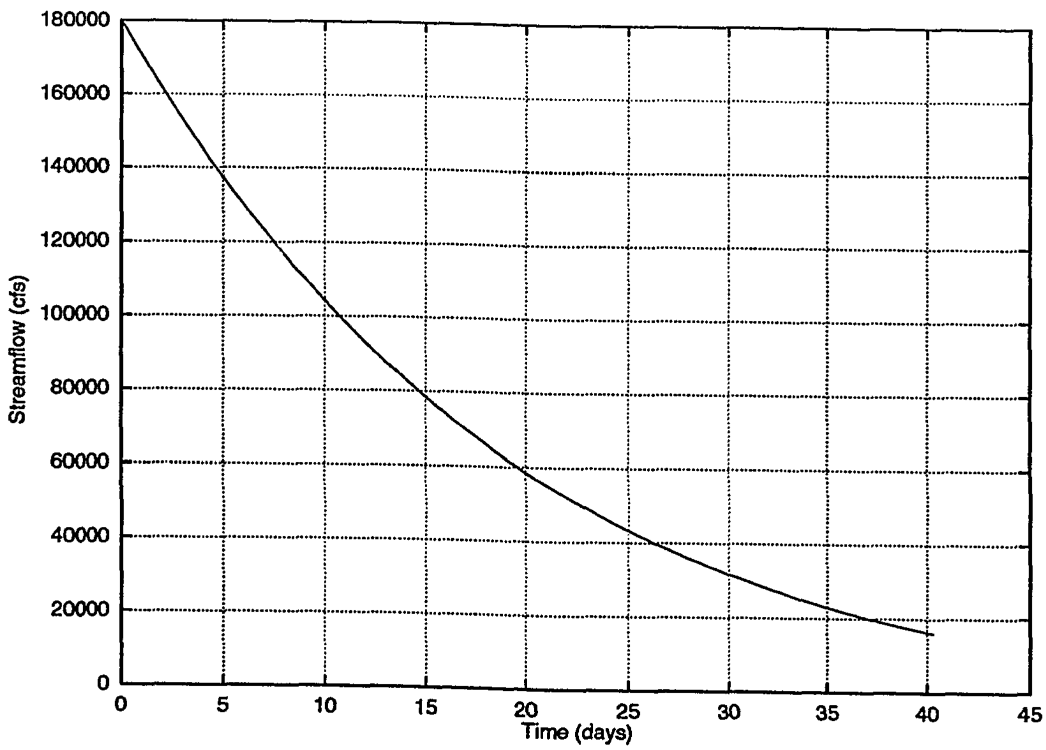

Figure 6.2: MRC of Mississippi River at McGregor (for summer), ID# 05389500

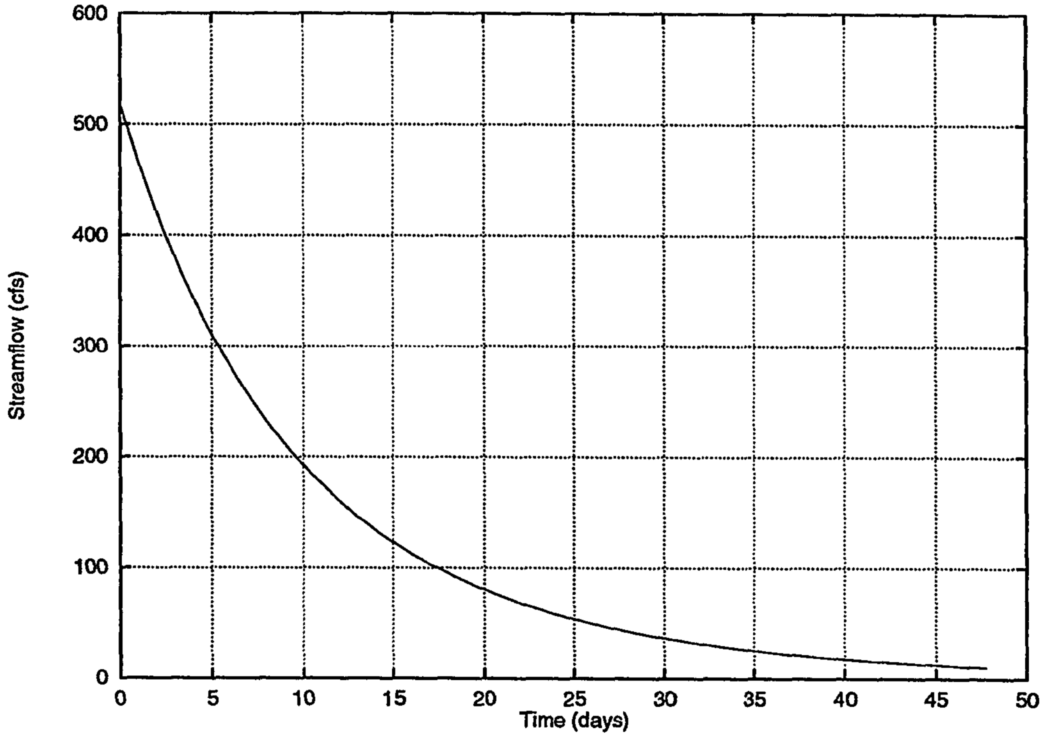

Figure 7.1: MRC of Turkey River at Spillville (for winter), ID# 05411600

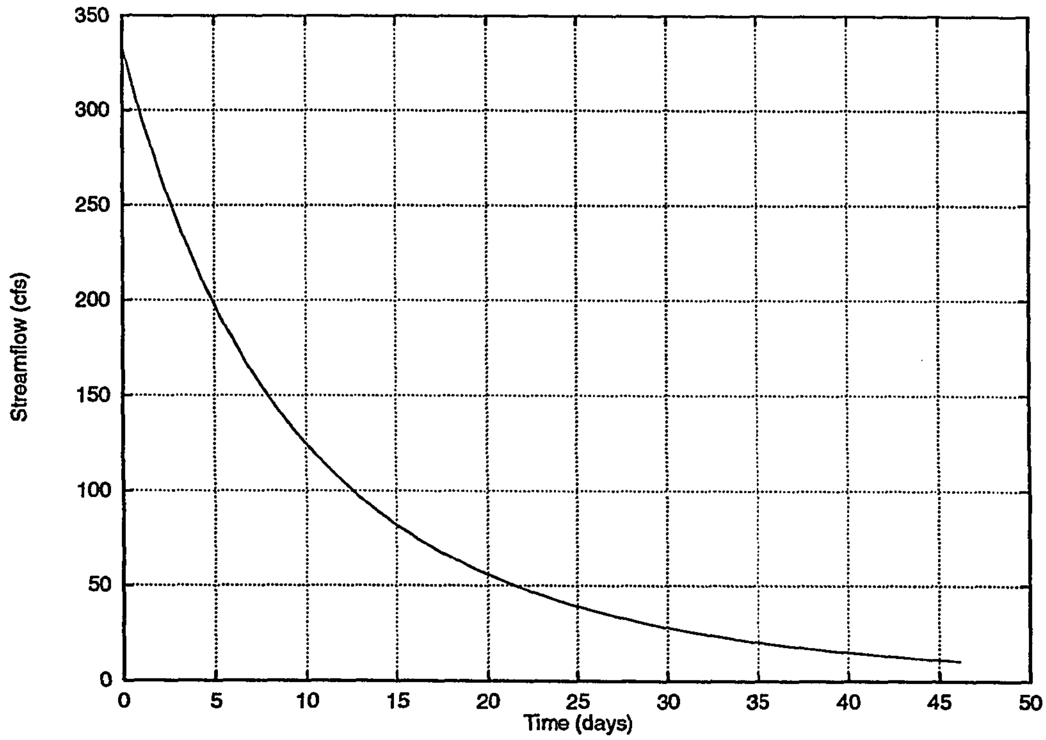

Figure 7.2: MRC of Turkey River at Spillville (for summer), ID# 05411600

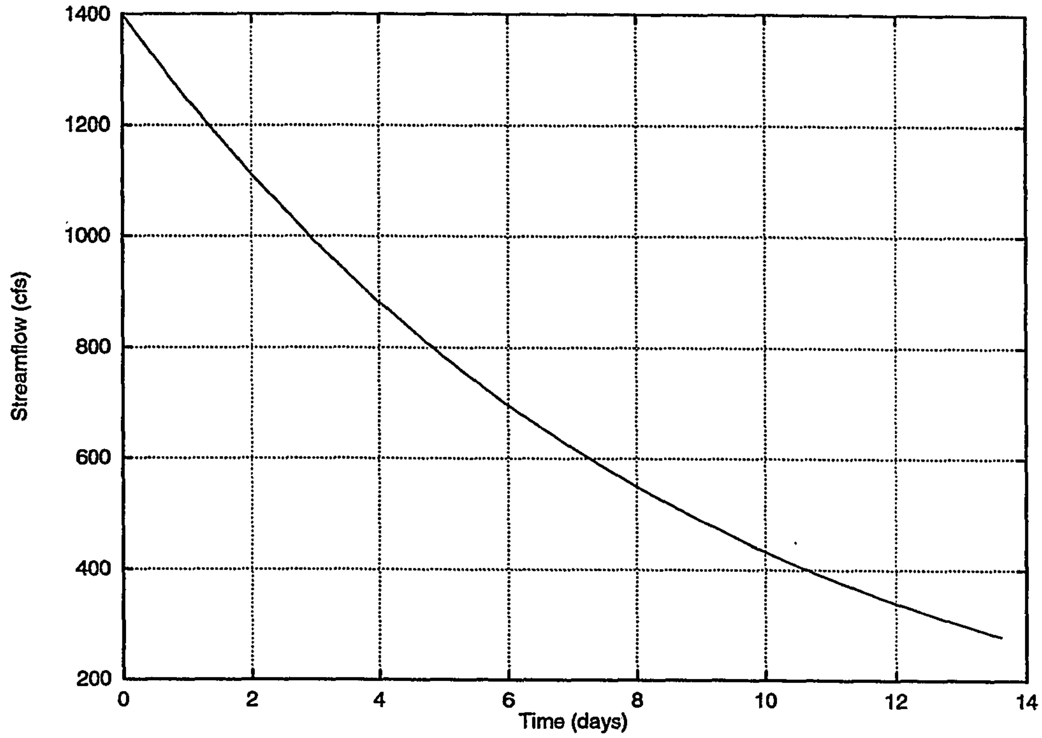

Figure 8.1: MRC of Turkey River at Elkader (for winter), ID# 05412000

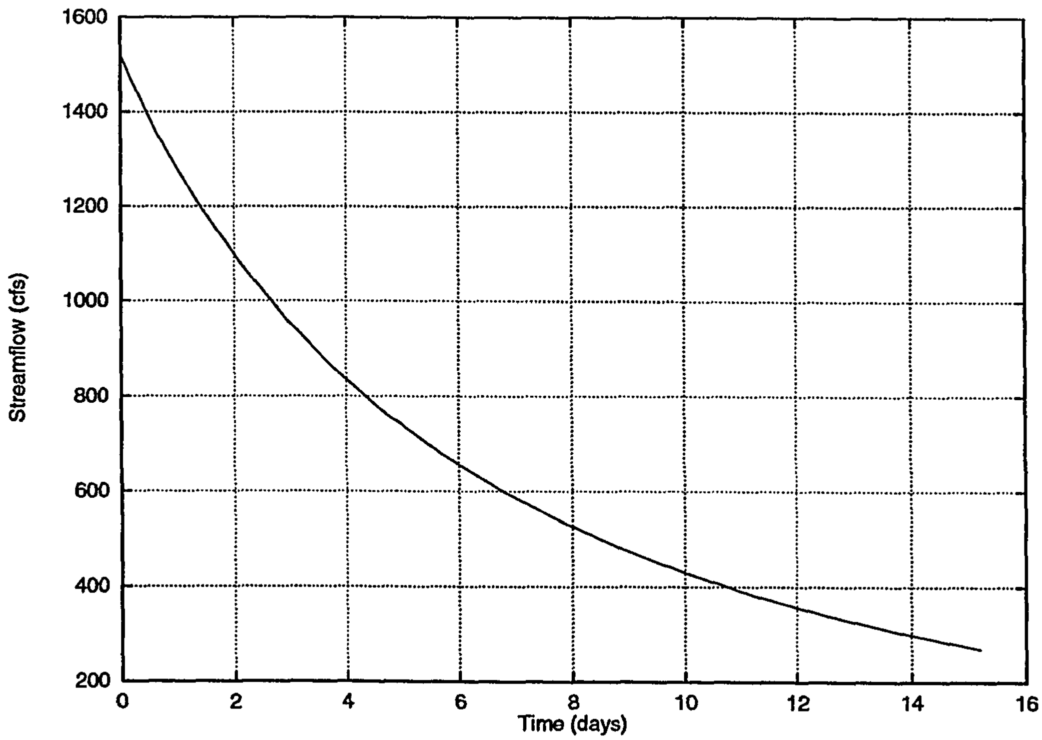

Figure 8.2: MRC of Turkey River at Elkader (for summer), ID# 05412000

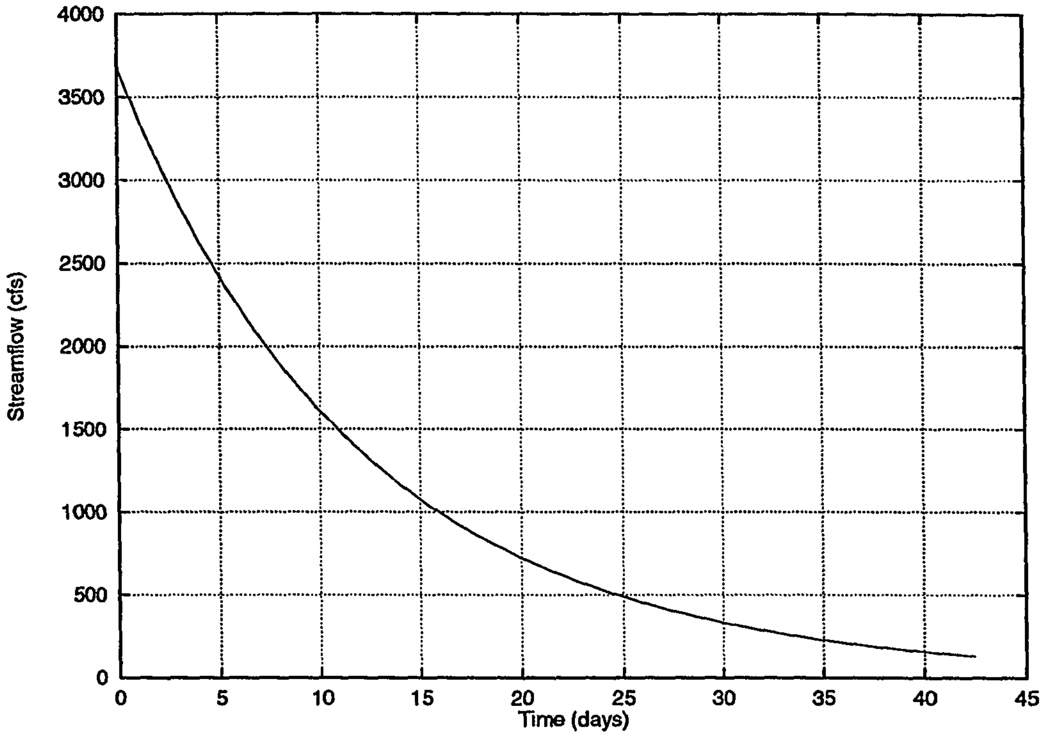

Figure 9.1: MRC of Turkey River at Garber (for winter), ID# 05412500

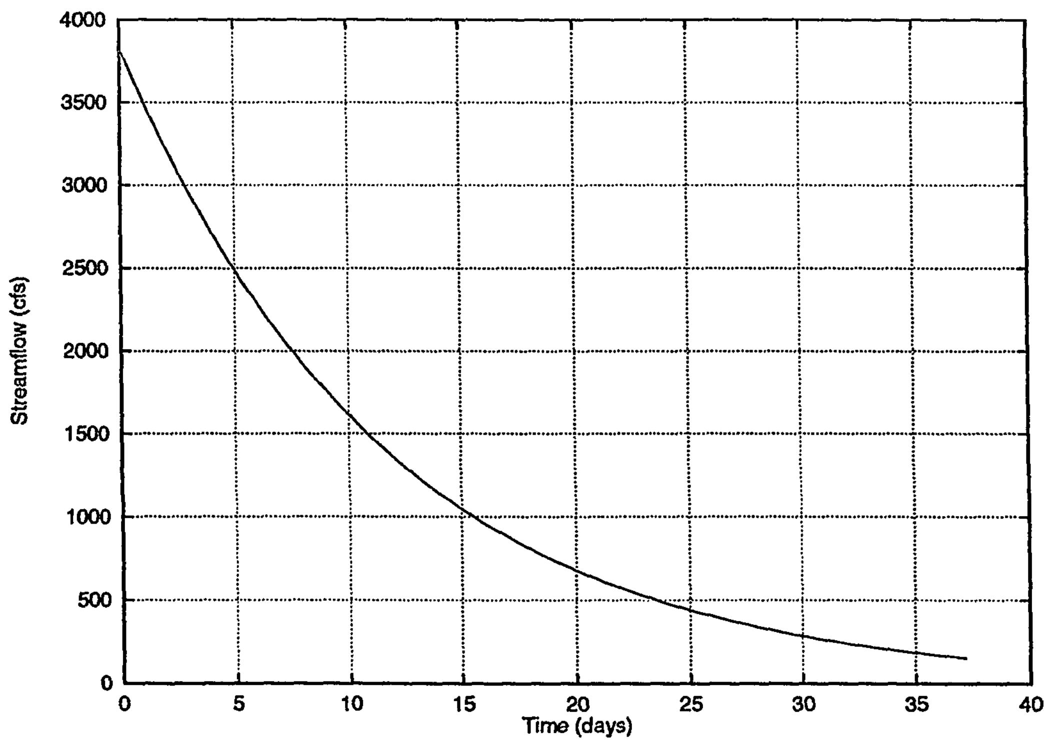

Figure 9.2: MRC of Turkey River at Garber (for summer), ID# 05412500

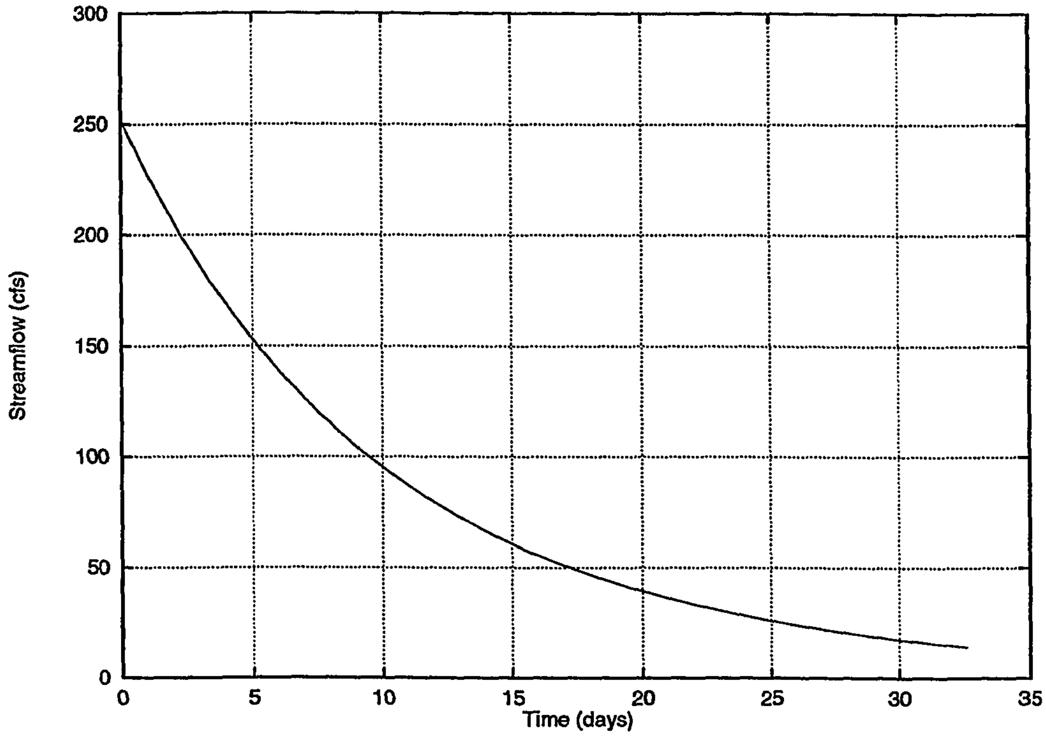

Figure 10.1: MRC of Little Maquoketa River near Durango (for winter), ID# 05414500

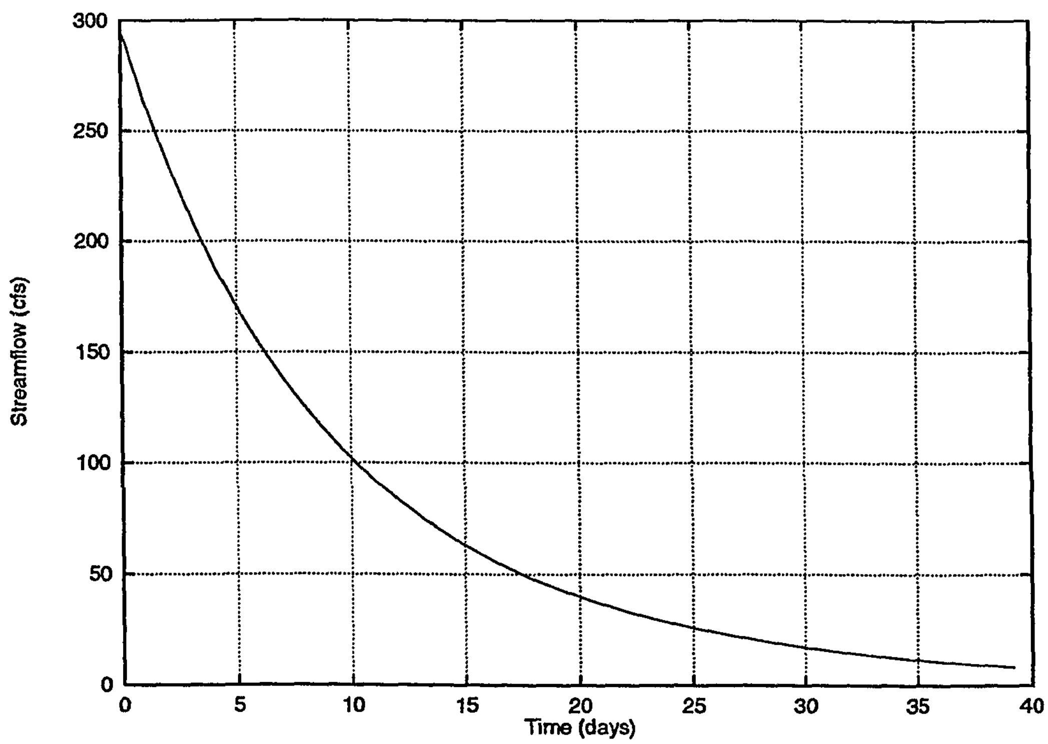

Figure 10.2: MRC of Little Maquoketa River near Durango (for summer), ID# 05414500

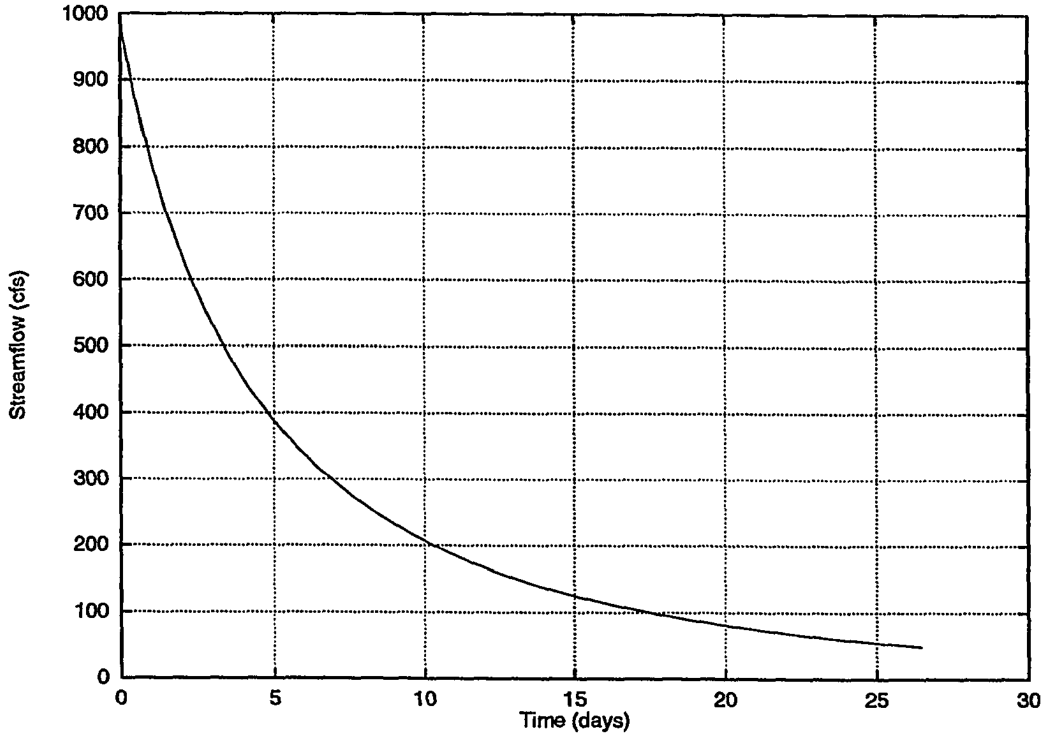

Figure 11.1: MRC of Maquoketa River near Manchester (for winter), ID# 05417000

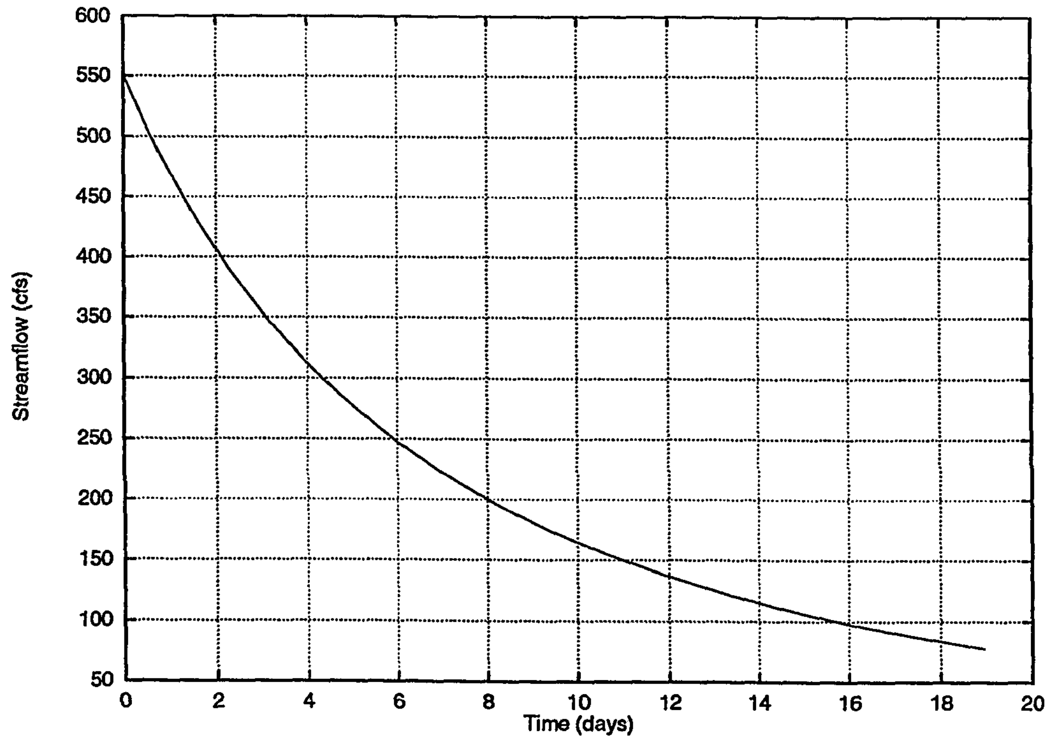

Figure 11.2: MRC of Maquoketa River near Manchester (for summer), ID# 05417000

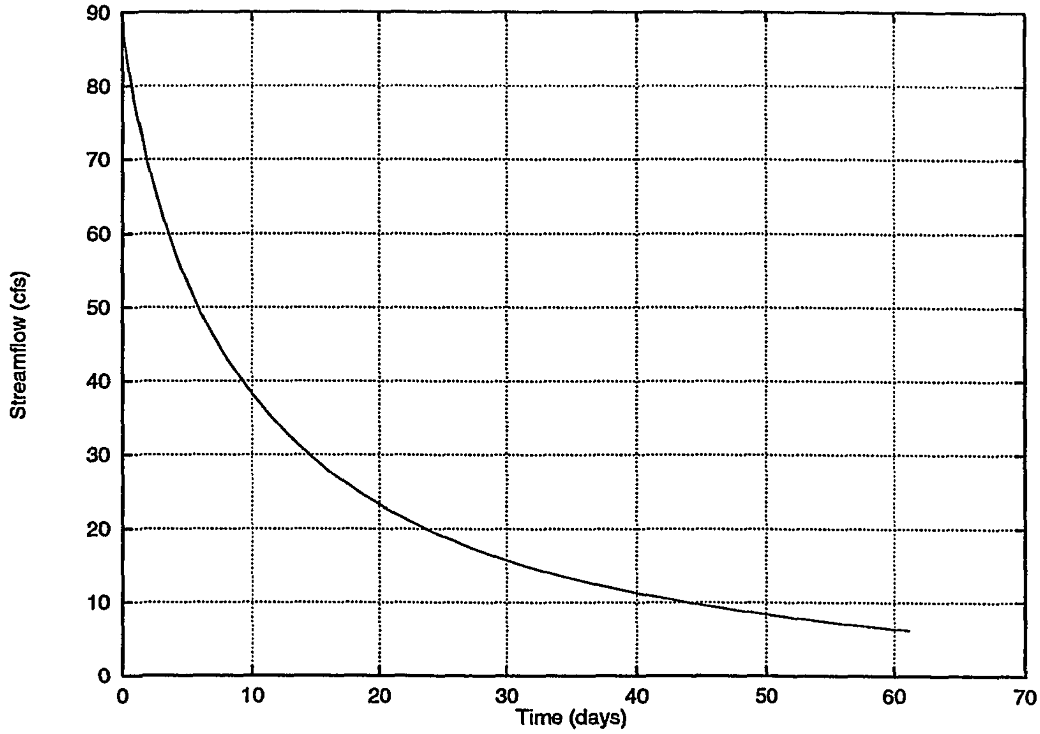

Figure 12.1: MRC of Bear Creek near Monmouth (for winter), ID# 05417700

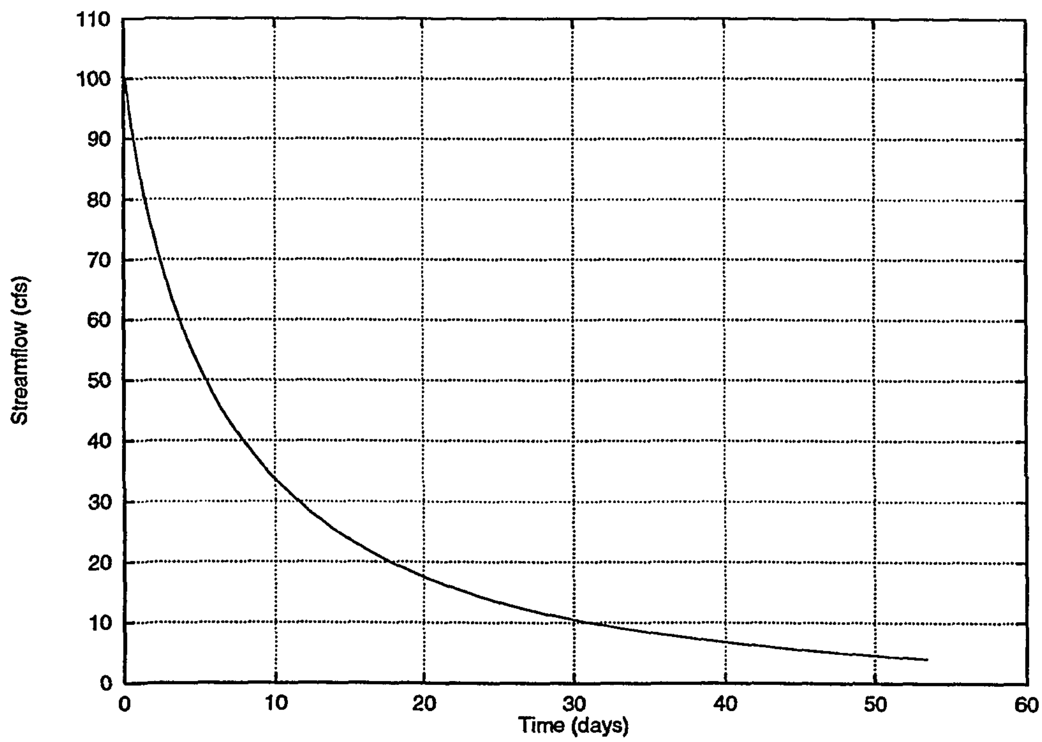

Figure 12.2: MRC of Bear Creek near Monmouth (for summer), ID# 05417700

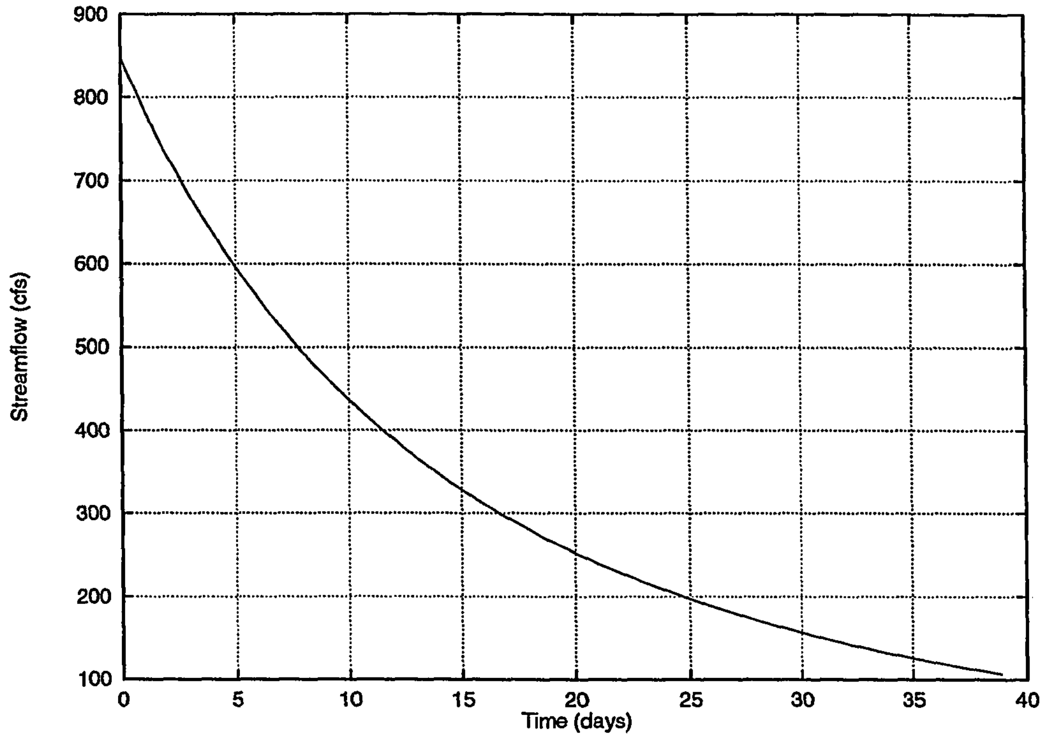

Figure 13.1: MRC of North Fork Maquoketa River at Fulton (for winter), ID# 05418450

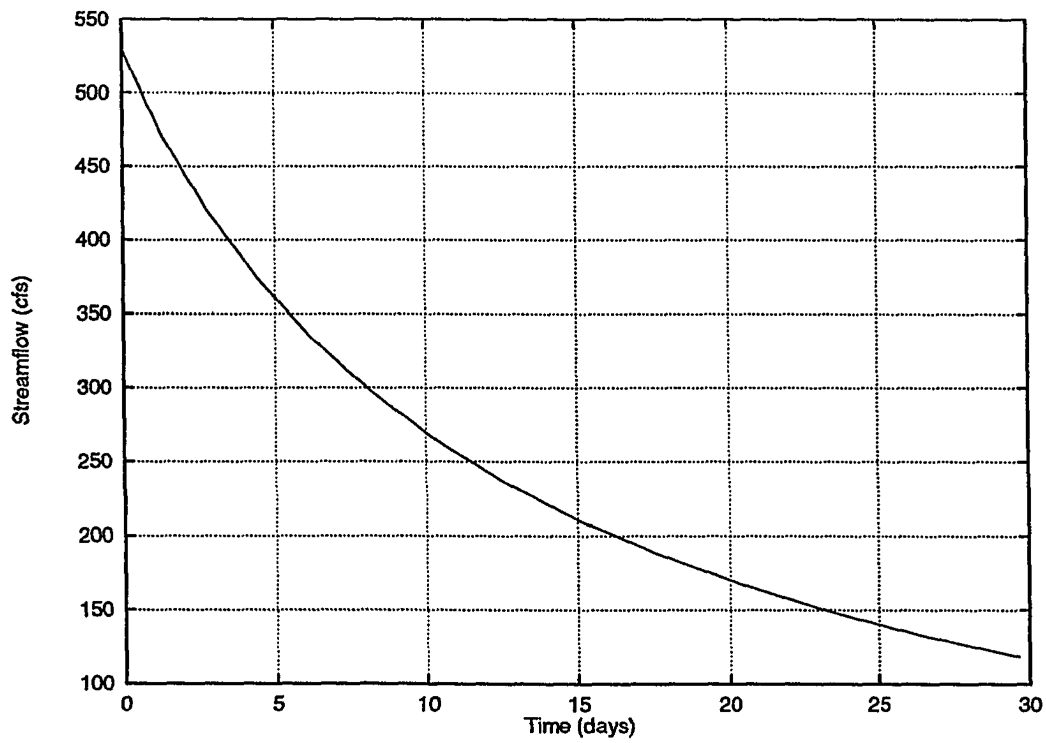

Figure 13.2: MRC of North Fork Maquoketa River at Fulton (for summer), ID# 05418450

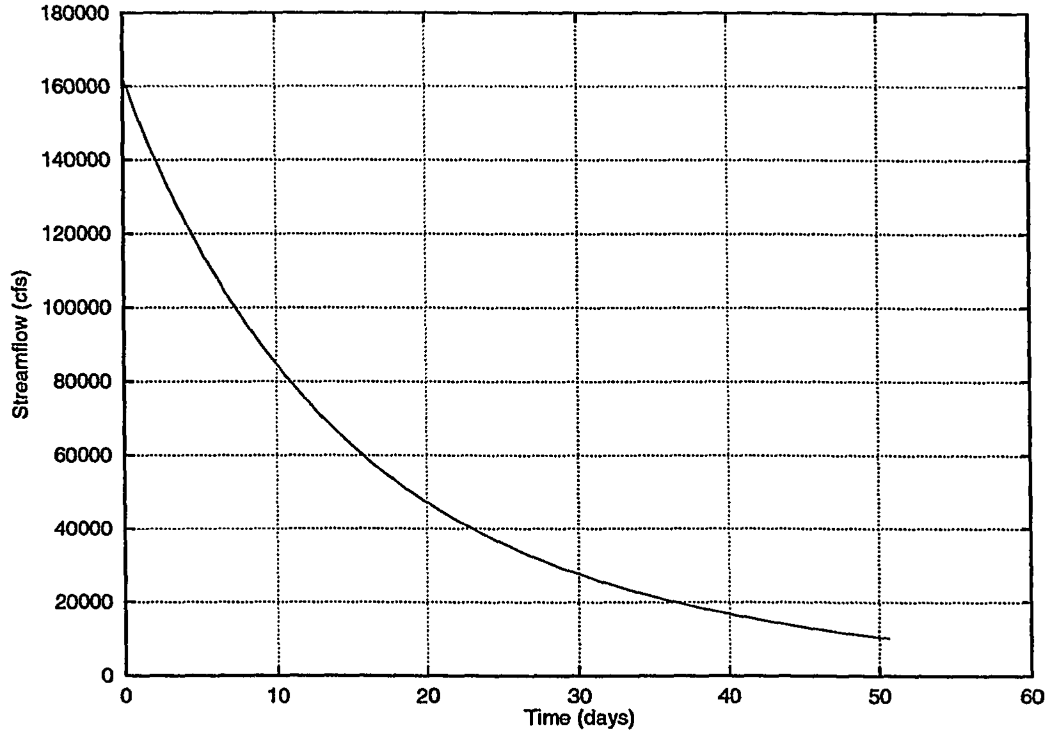

Figure 14.1: MRC of Mississippi River at Clinton (for winter), ID# 05420500

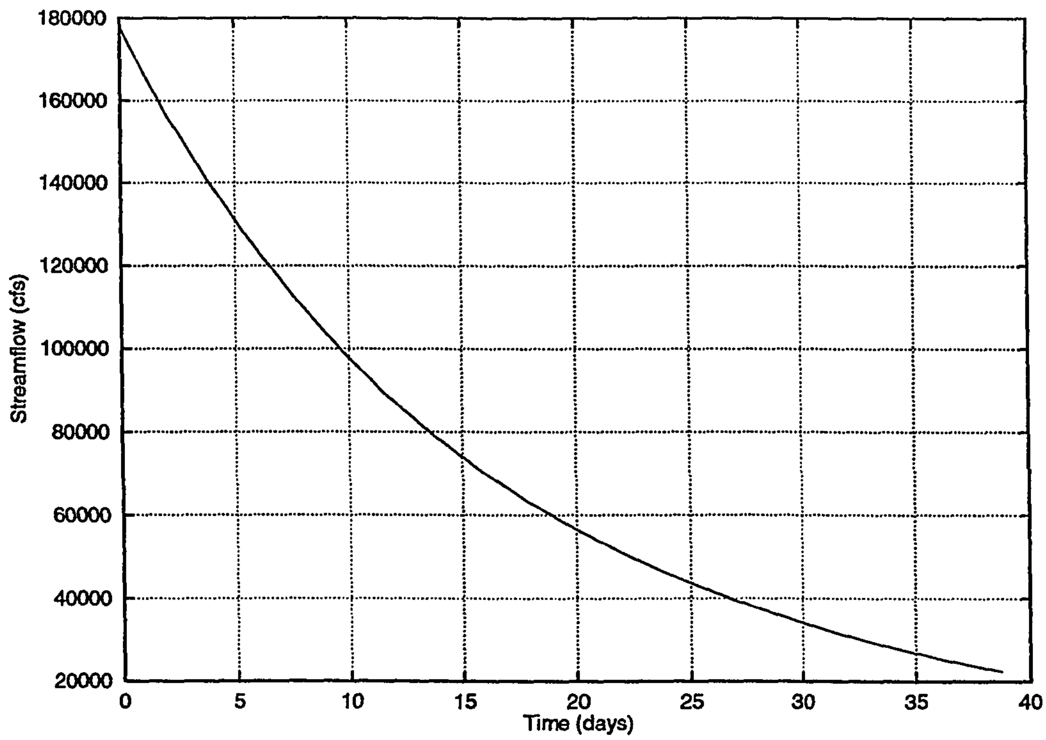

Figure 14.2: MRC of Mississippi River at Clinton (for summer), ID# 05420500

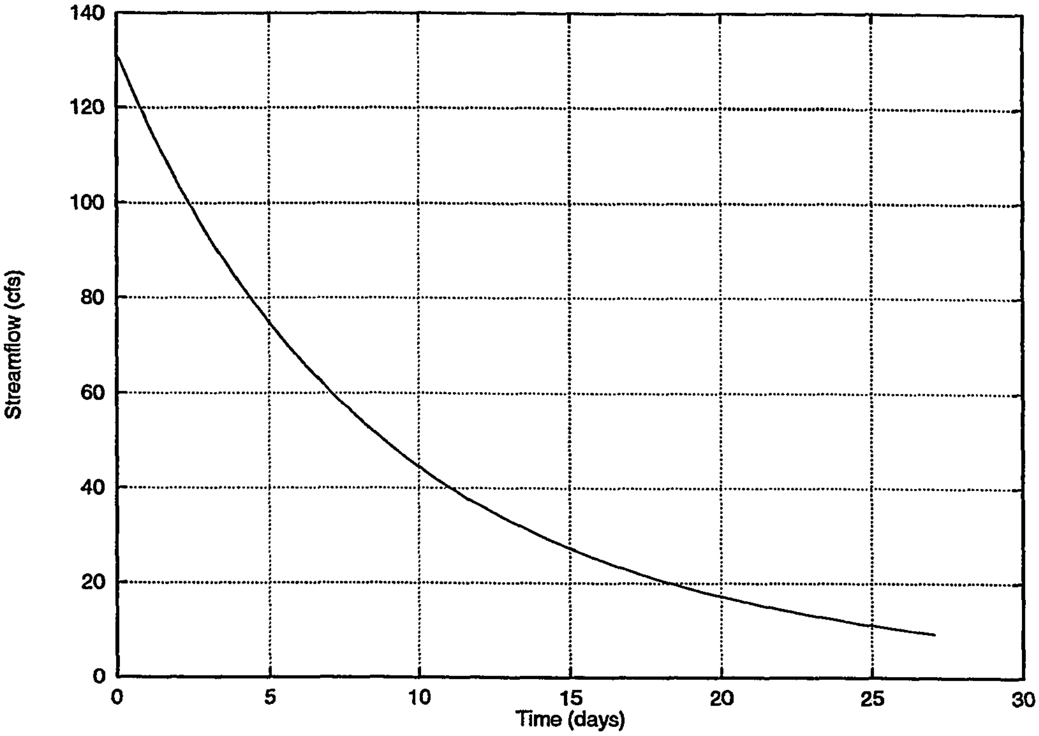

Figure 15.1: MRC of Wapsipinicon River near Elma (for winter), ID# 05420560

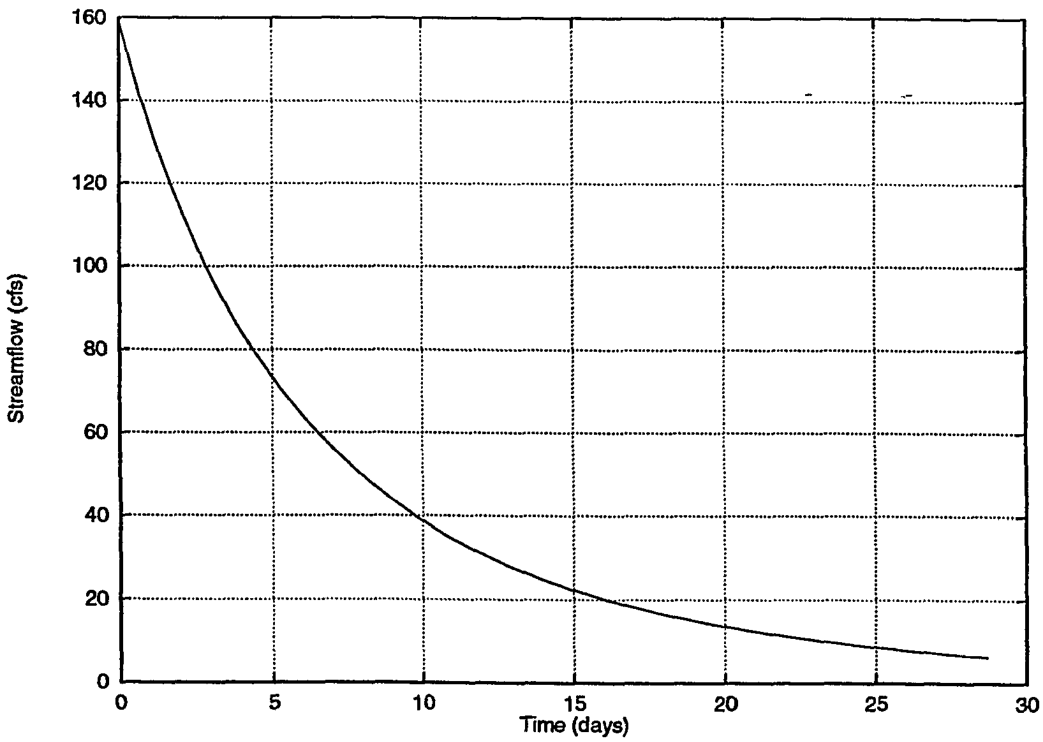

Figure 15.2: MRC of Wapsipinicon River near Elma (for summer), ID# 05420560

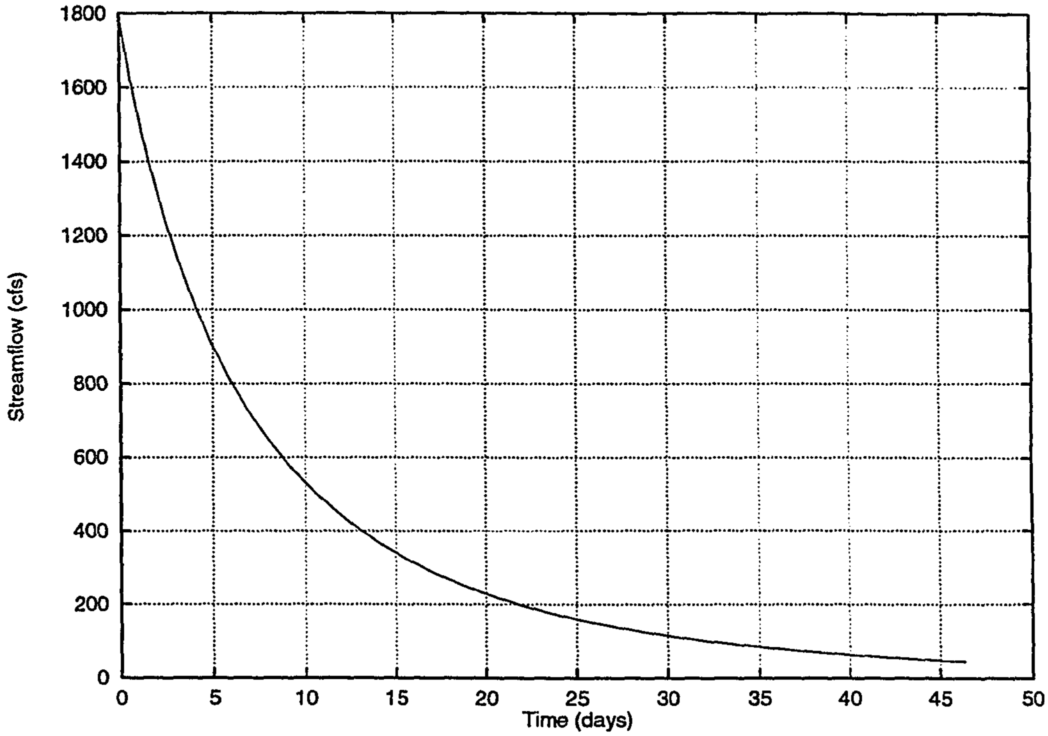

Figure 16.1: MRC of Wapsipinicon River at Independence (for winter), ID# 05421000

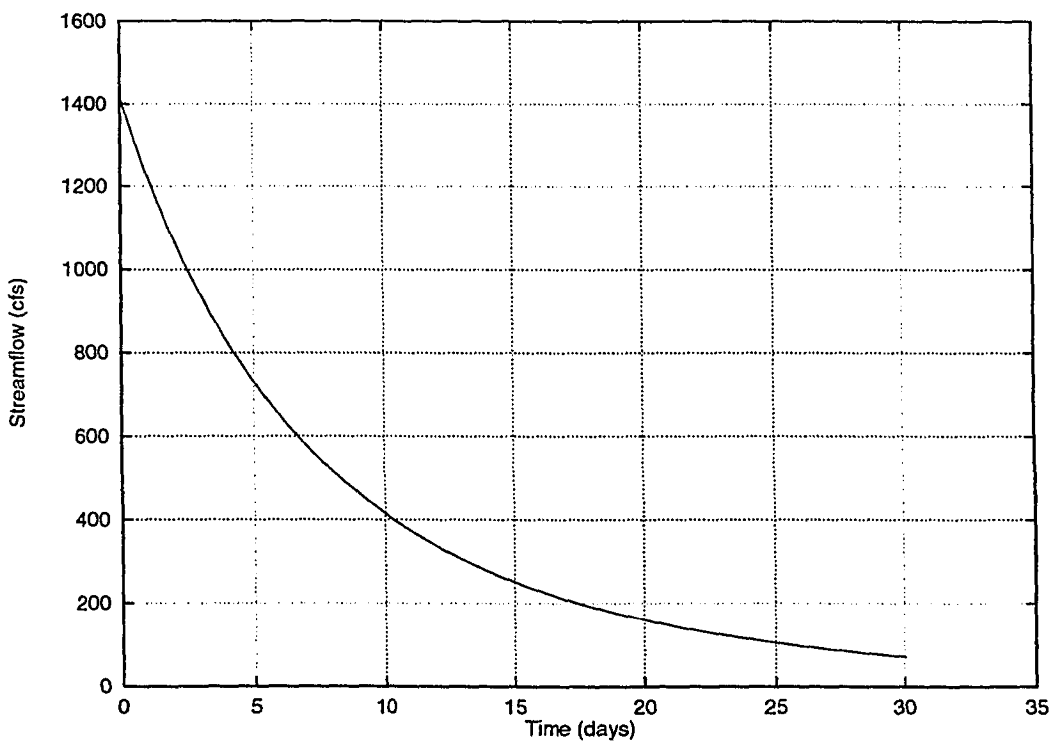

Figure 16.2: MRC of Wapsipinicon River at Independence (for summer), ID# 05421000

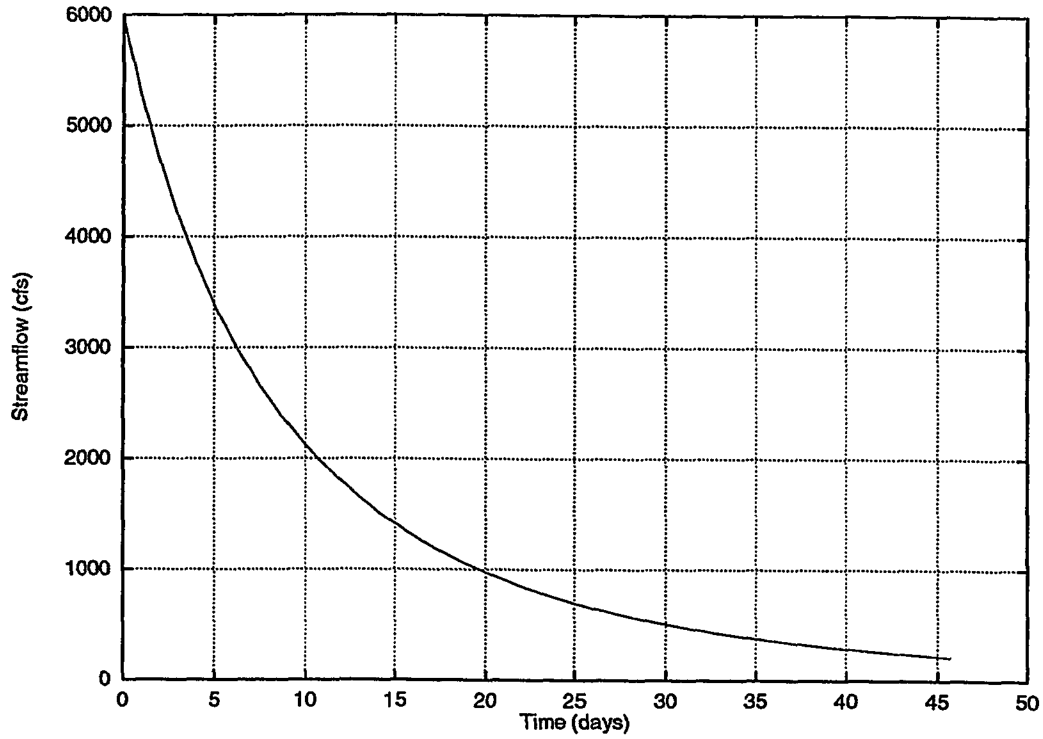

Figure 17.1: MRC of Wapsipinicon River near Dewitt (for winter), ID# 05422000

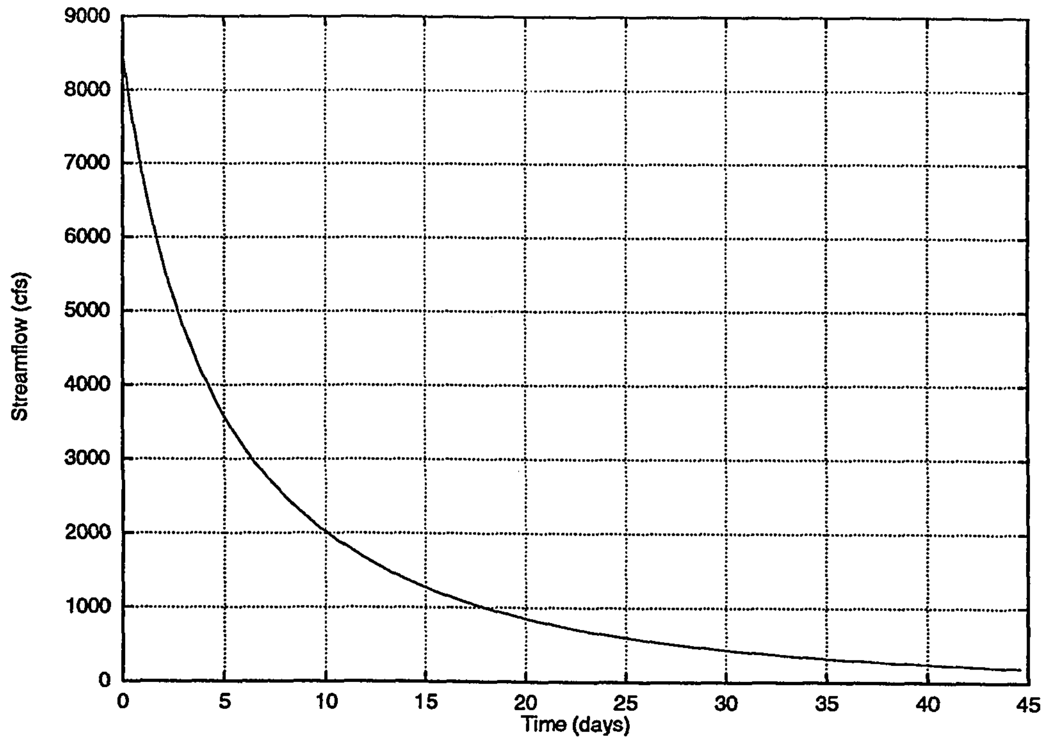

Figure 17.2: MRC of Wapsipinicon River near Dewitt (for summer), ID# 05422000

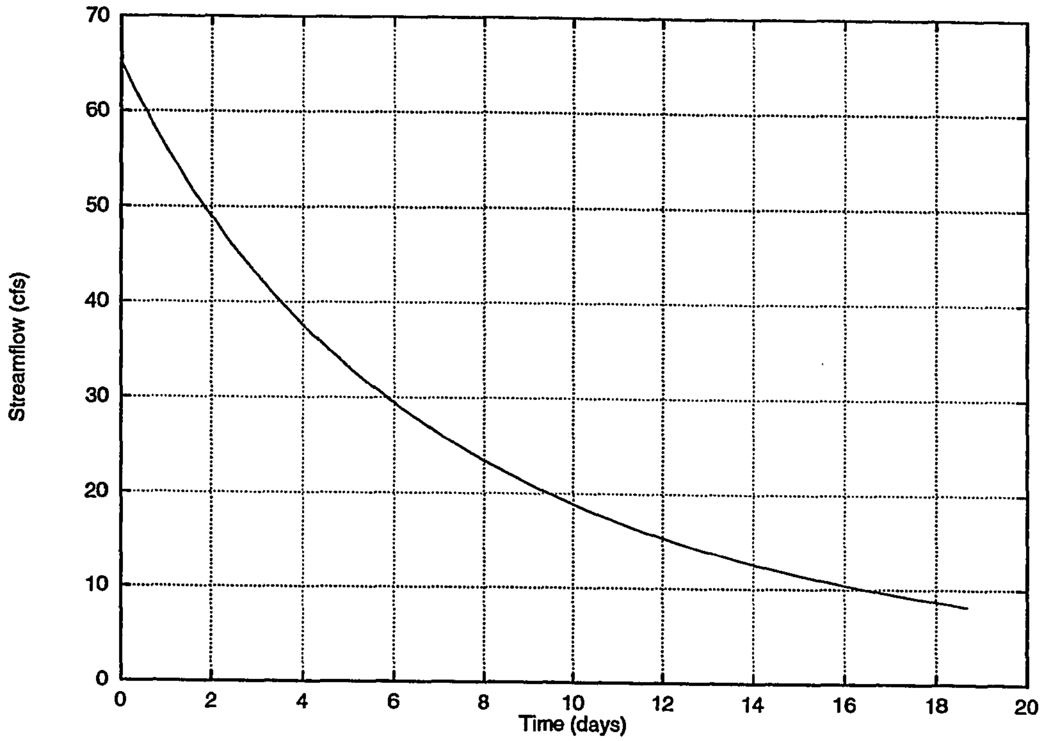

Figure 18.1: MRC of Crow Creek at Bettendorf (for winter), ID# 05422470

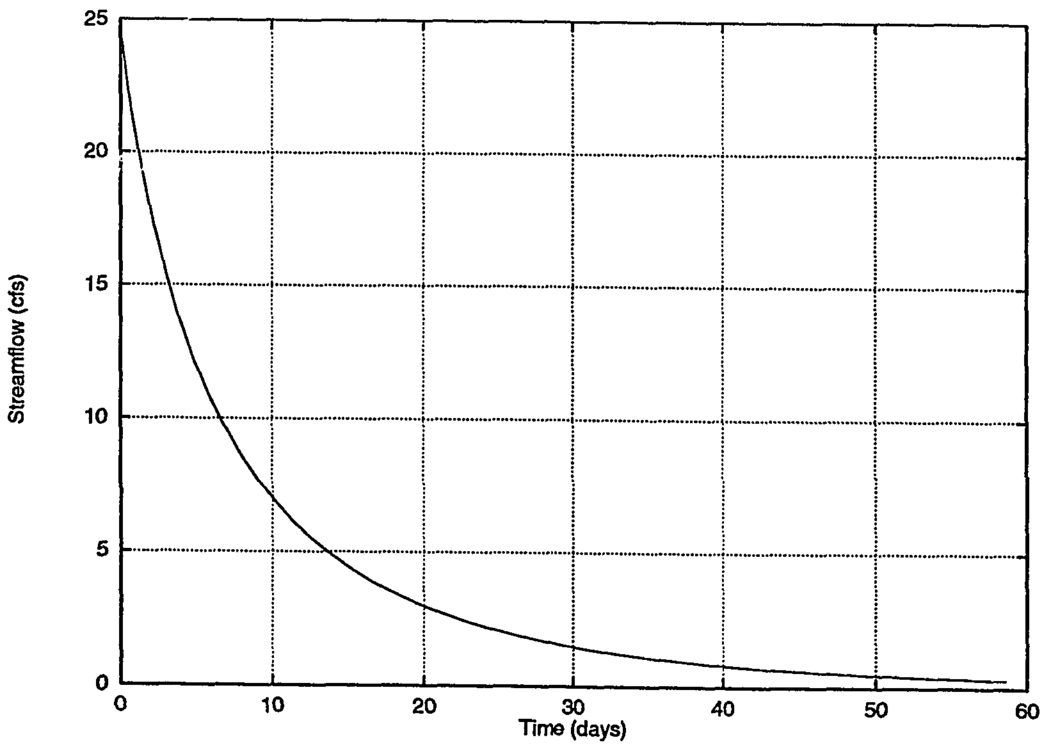

Figure 18.2: MRC of Crow Creek at Bettendorf (for summer), ID# 05422470

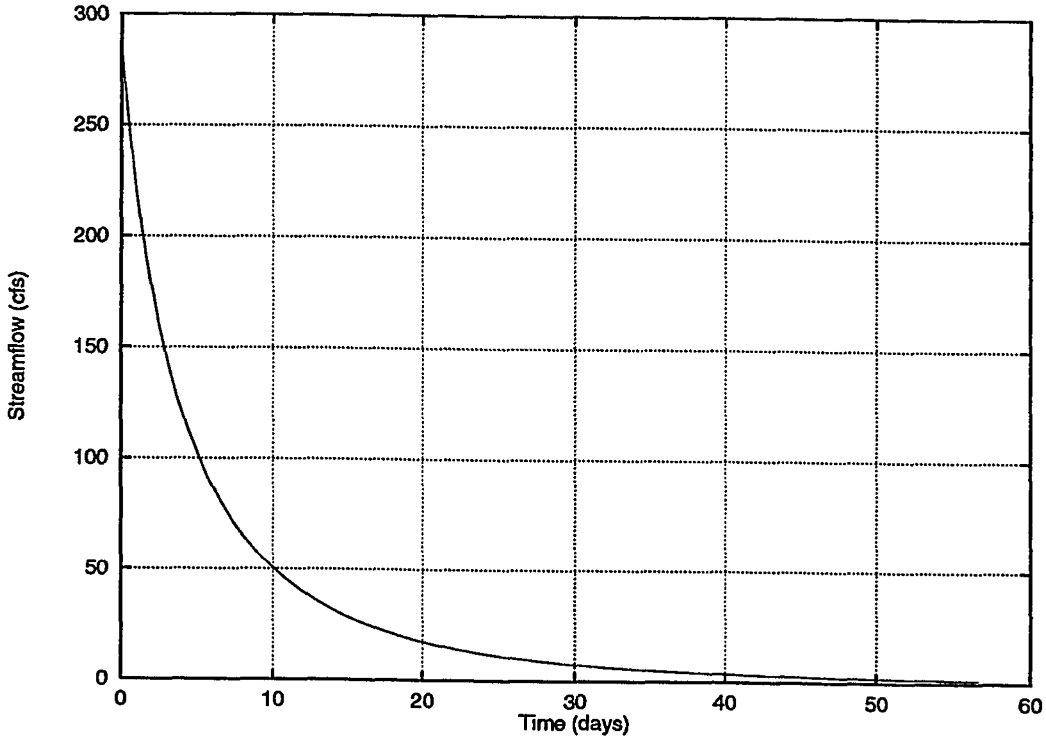

Figure 19.1: MRC of West Branch Iowa River near Klemme (for winter), ID# 05448500

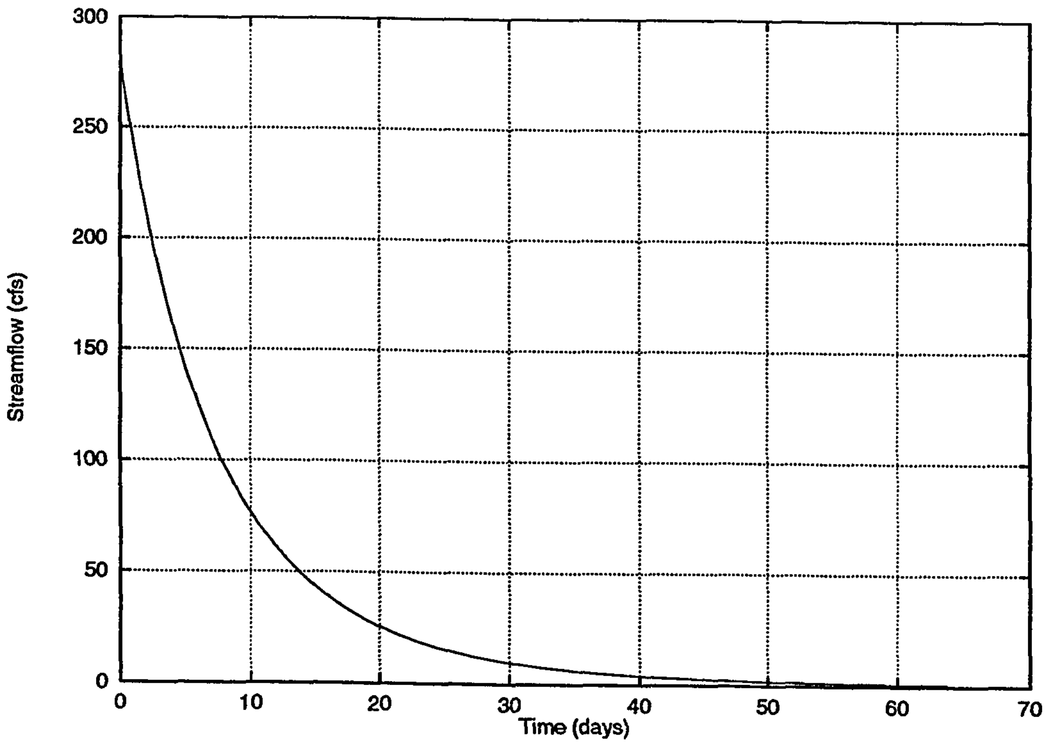

Figure 19.2: MRC of West Branch Iowa River near Klemme (for summer), ID# 05448500

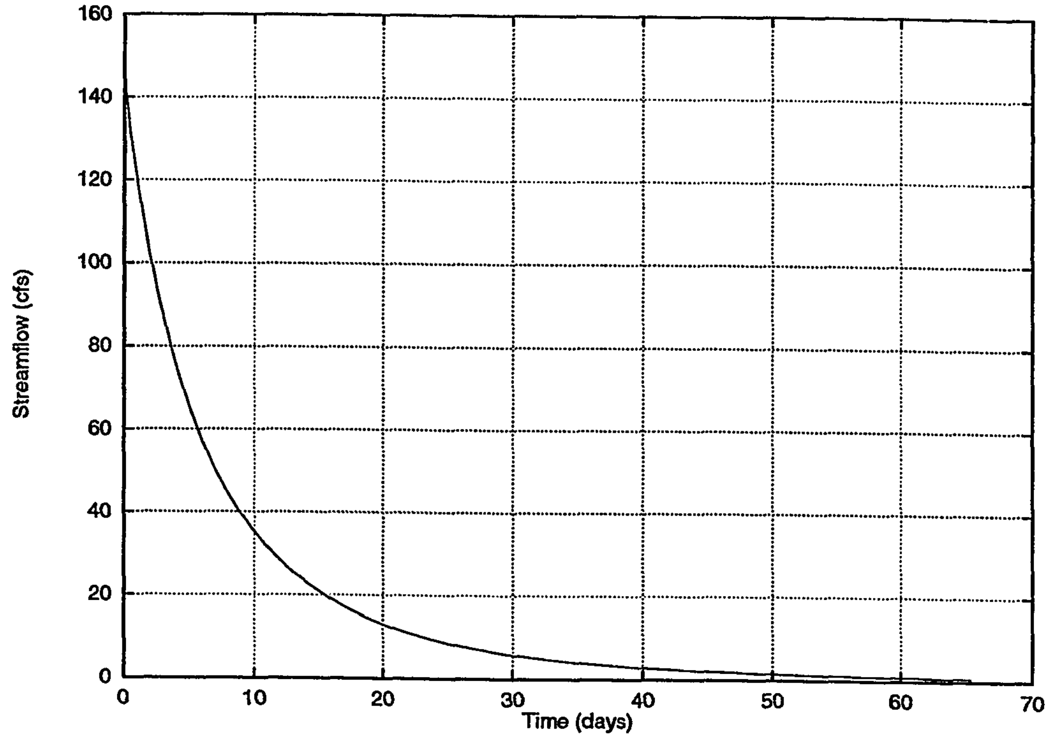

Figure 20.1: MRC of East Branch Iowa River near Klemme (for winter), ID# 05449000

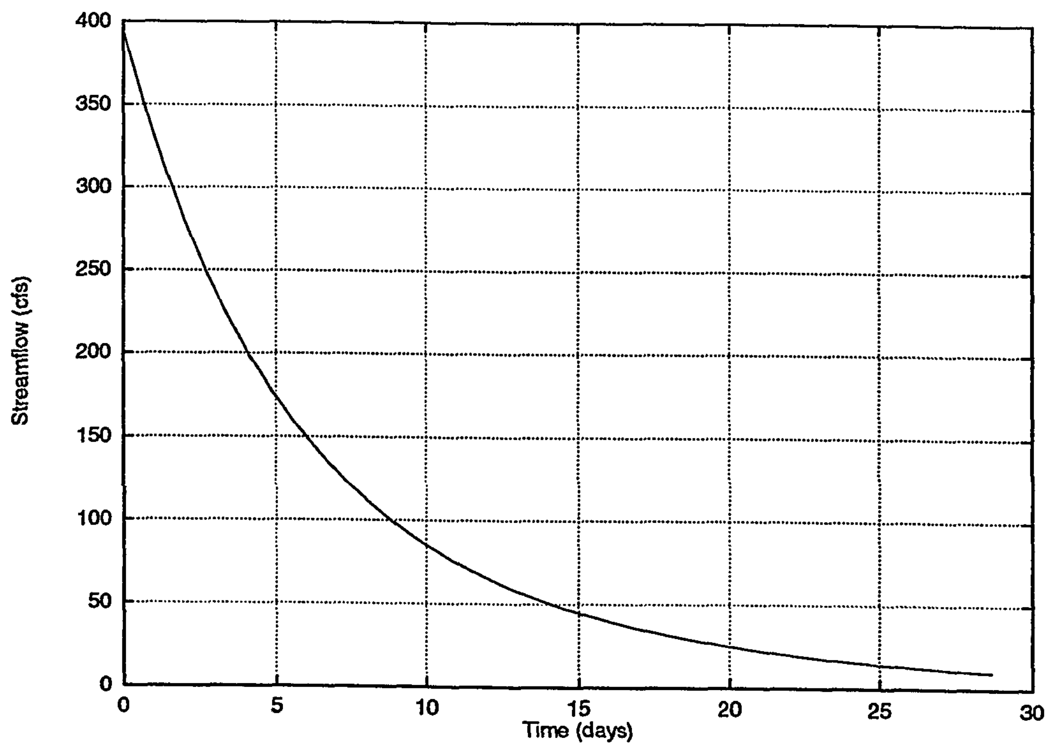

Figure 20.2: MRC of East Branch Iowa River near Klemme (for summer), ID# 05449000

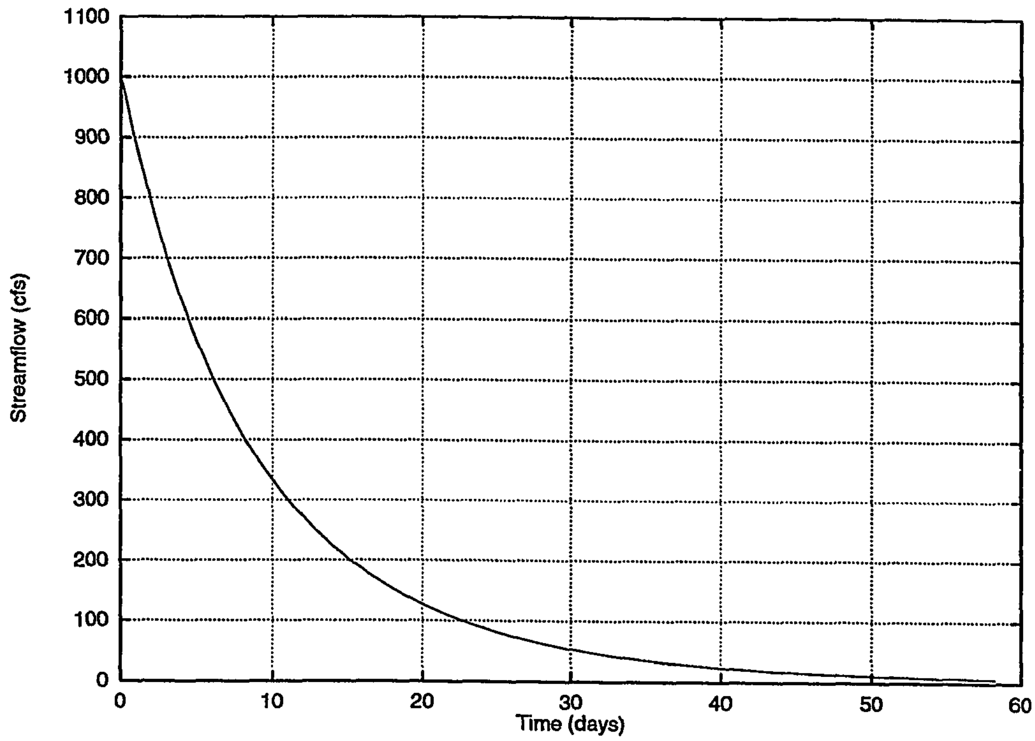

Figure 21.1: MRC of Iowa River near Rowan (for winter), ID# 05449500

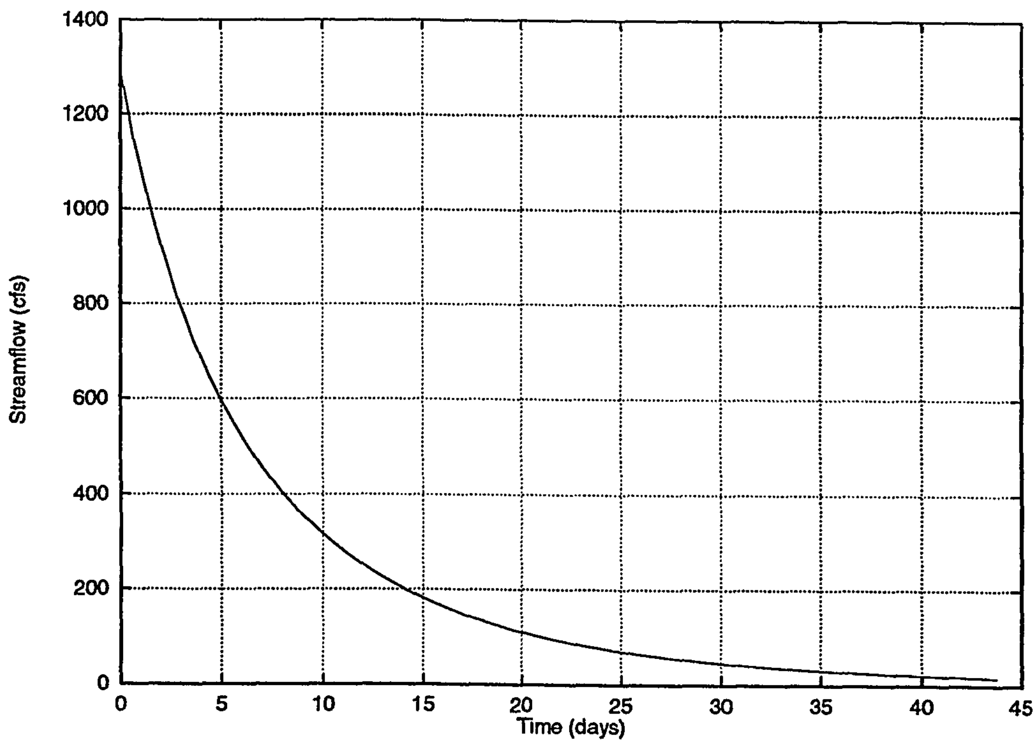

Figure 21.2: MRC of Iowa River near Rowan (for summer), ID# 05449500

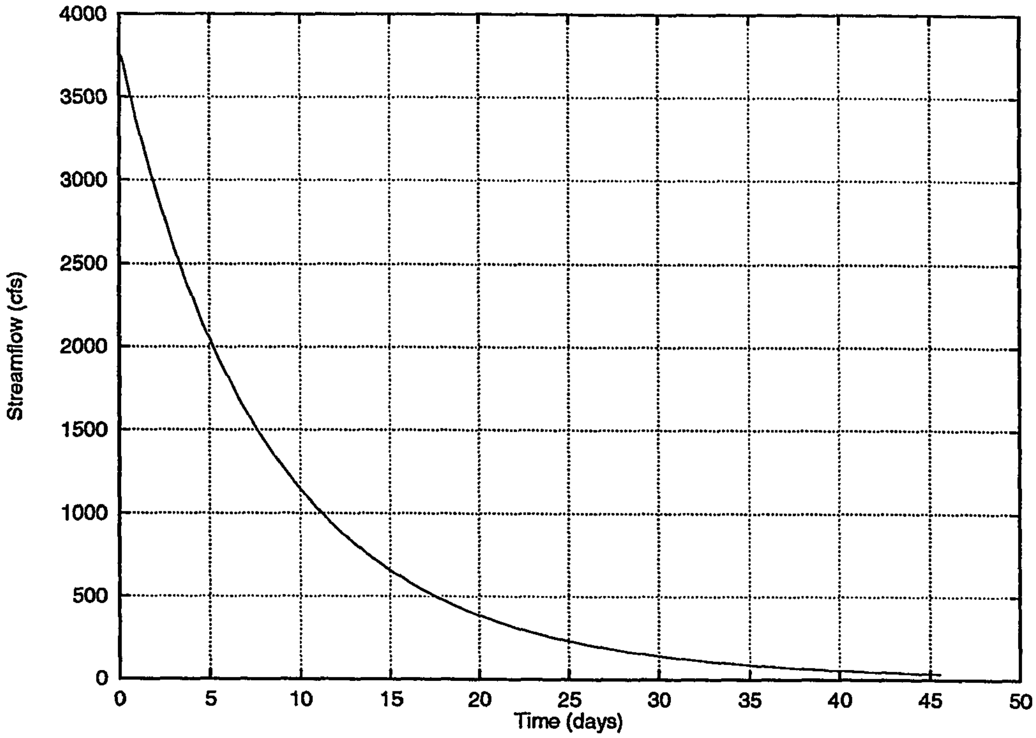

Figure 22.1: MRC of Iowa River at Marshalltown (for winter), ID# 05451500

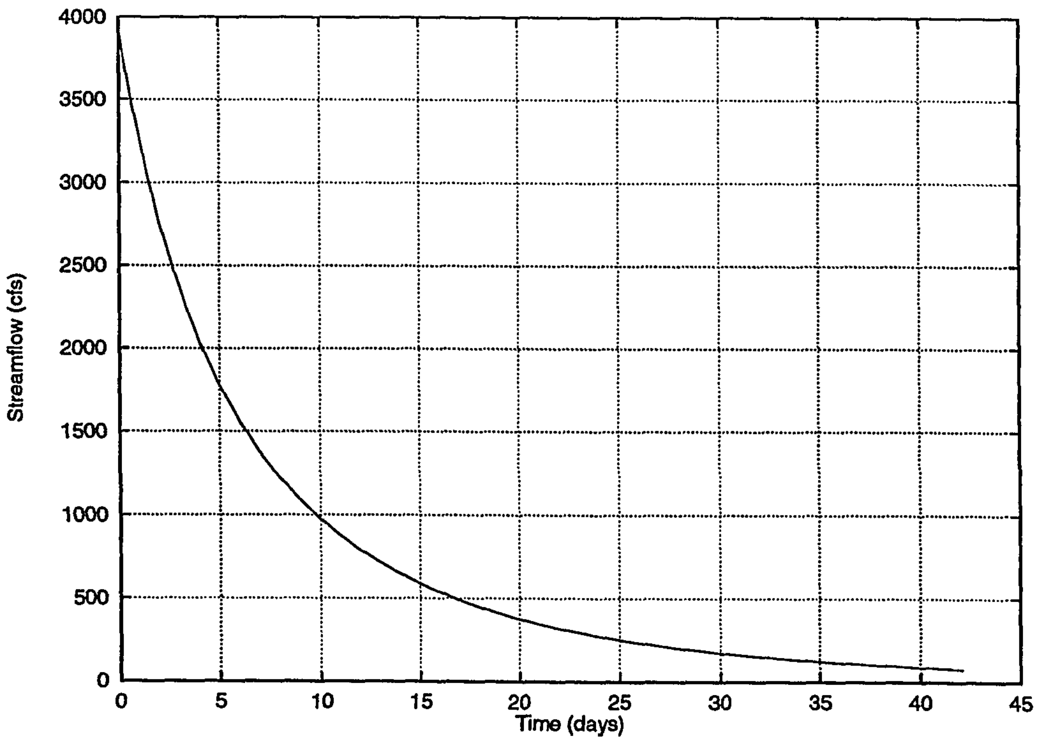

Figure 22.2: MRC of Iowa River at Marshalltown (for summer), ID# 05451500

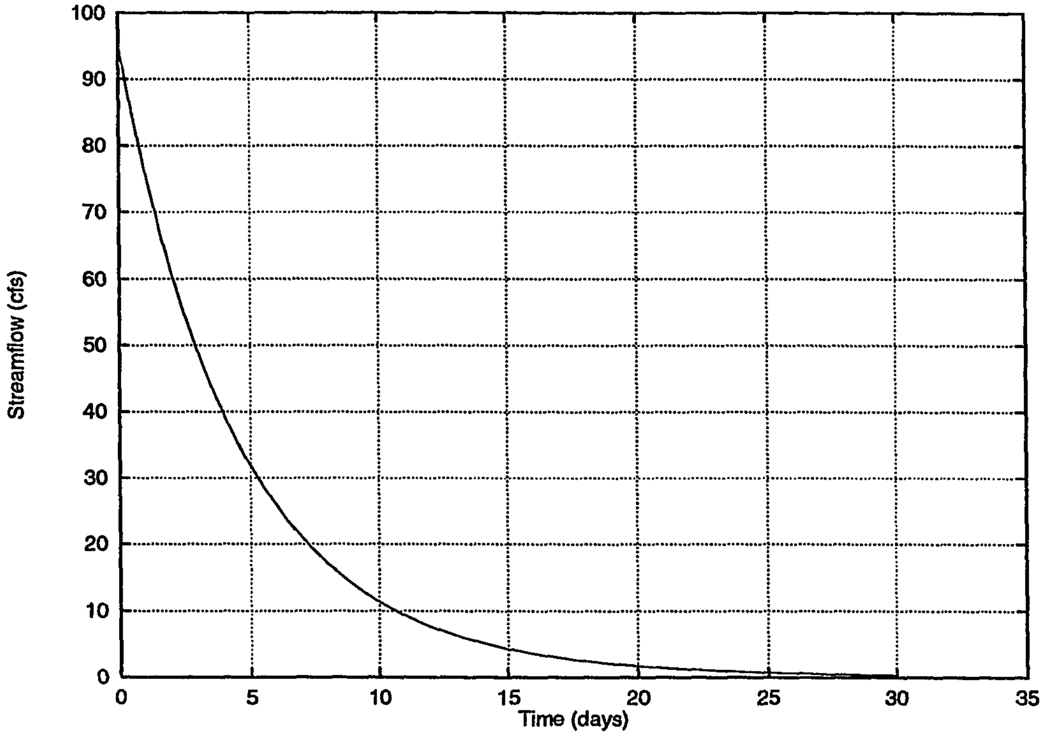

Figure 23.1: MRC of Timber Creek near Marshalltown (for winter), ID# 05451700

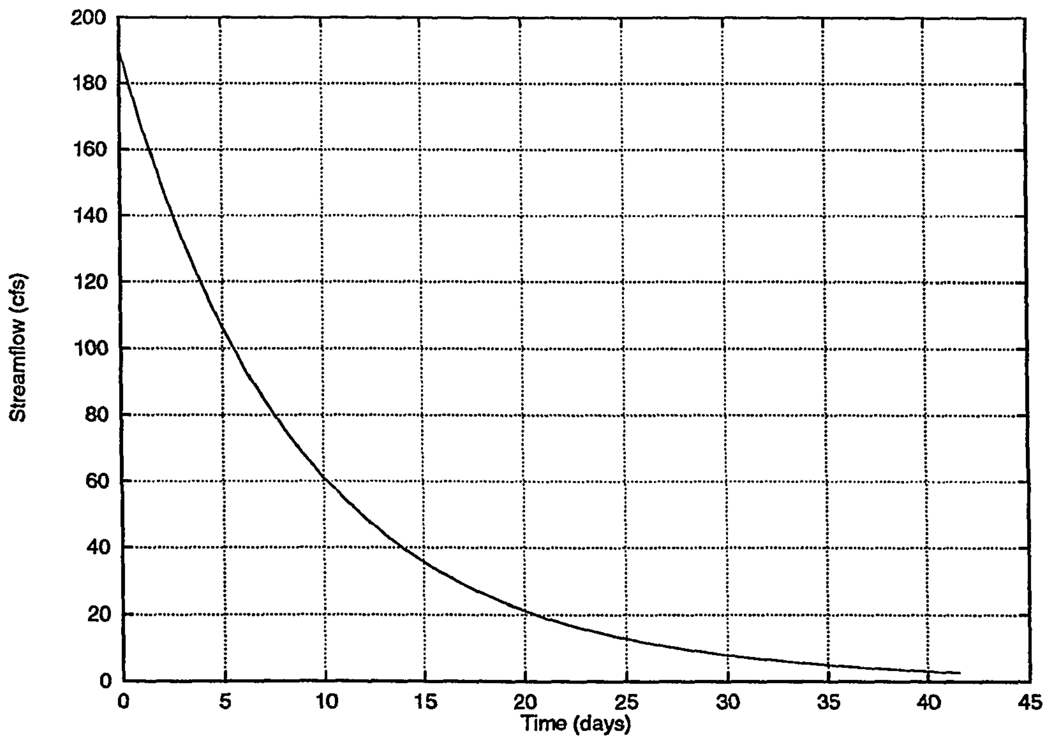

Figure 23.2: MRC of Timber Creek near Marshalltown (for summer), ID# 05451700

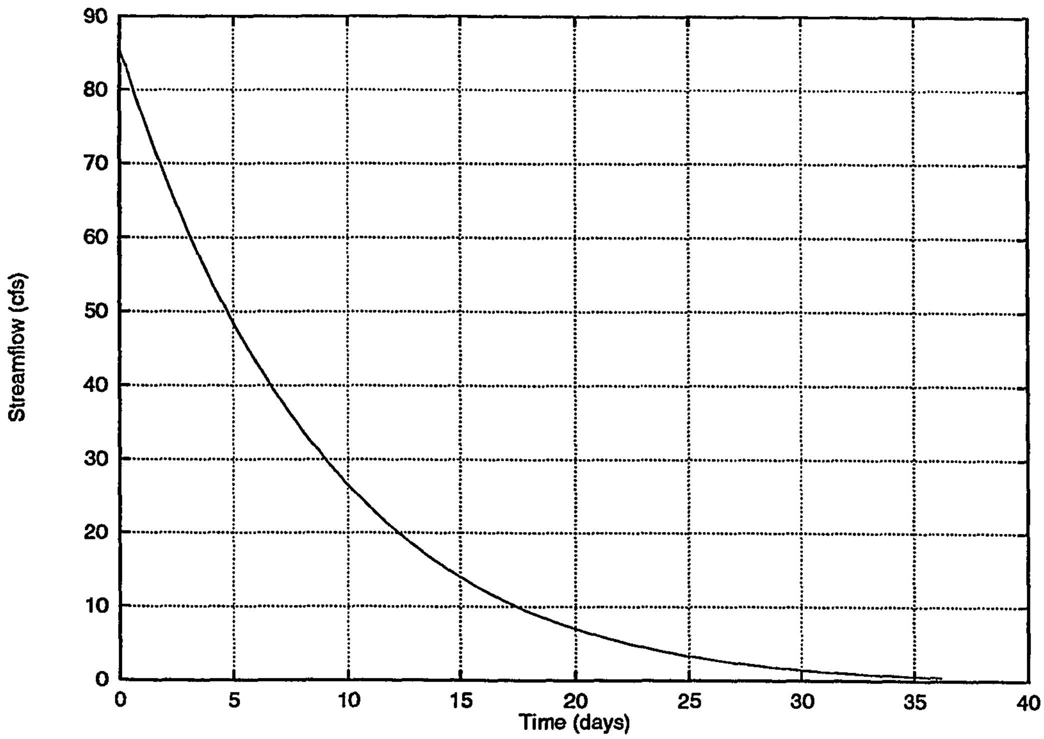

Figure 24.1: MRC of Richland Creek near Haven (for winter), ID# 05451900

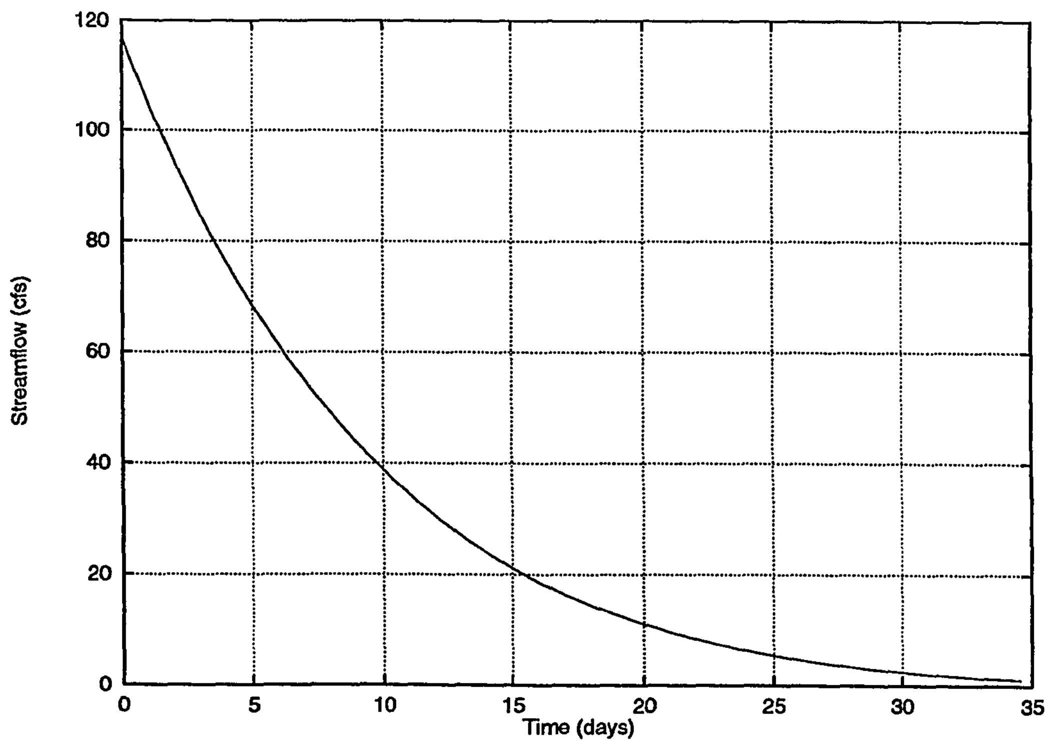

Figure 24.2: MRC of Richland Creek near Haven (for summer), ID# 05451900

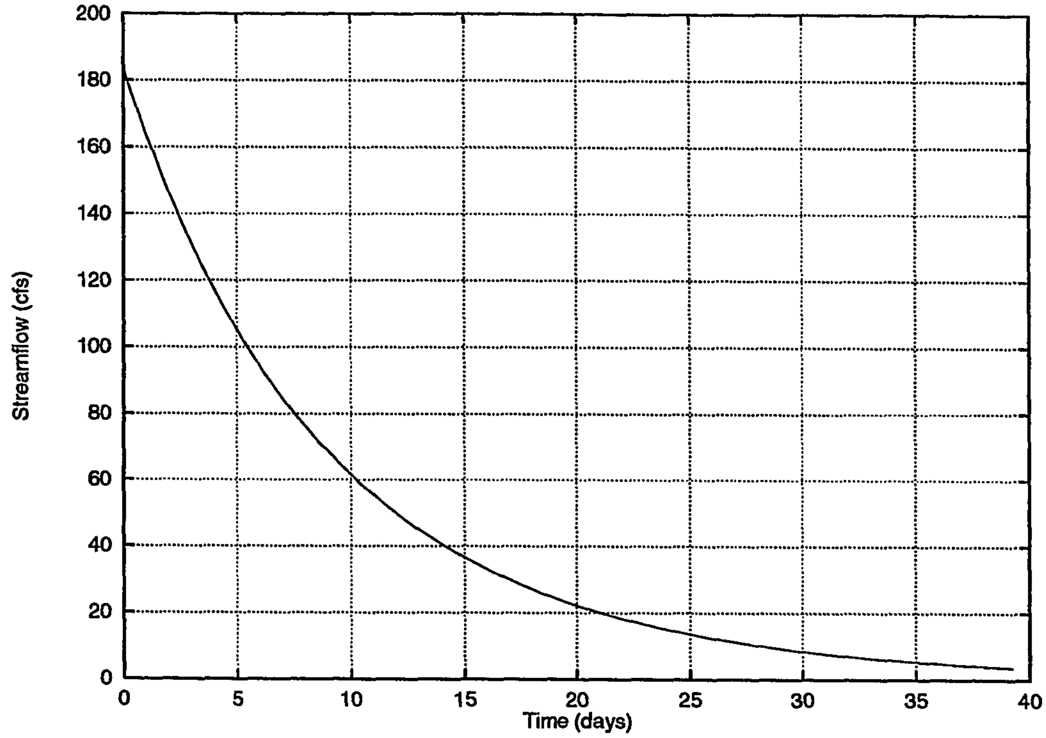

Figure 25.1: MRC of Salt Creek near Elberon (for winter), ID# 05452000

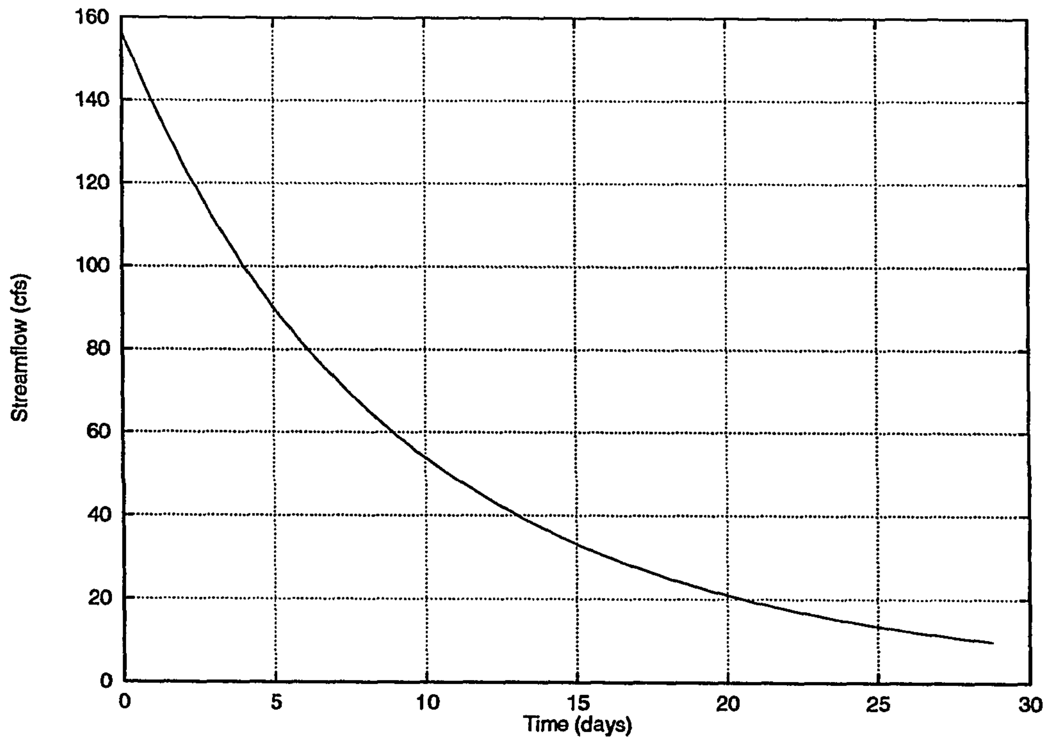

Figure 25.2: MRC of Salt Creek near Elberon (for summer), ID# 05452000

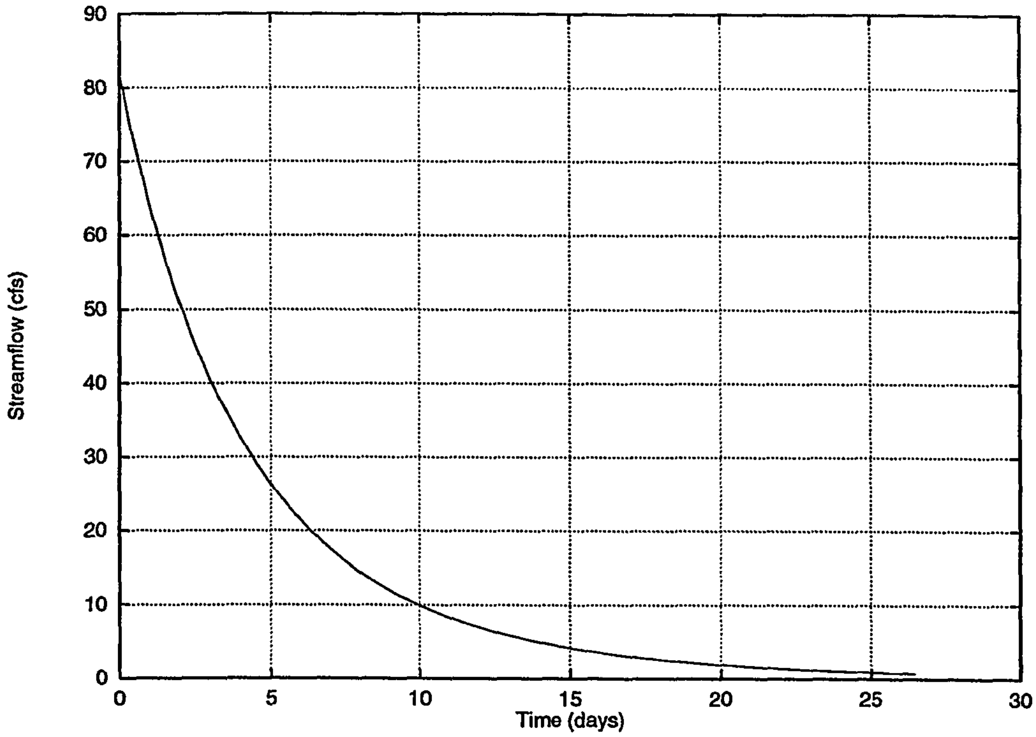

Figure 26.1: MRC of Walnut Creek near Hartwick (for winter), ID# 05452200

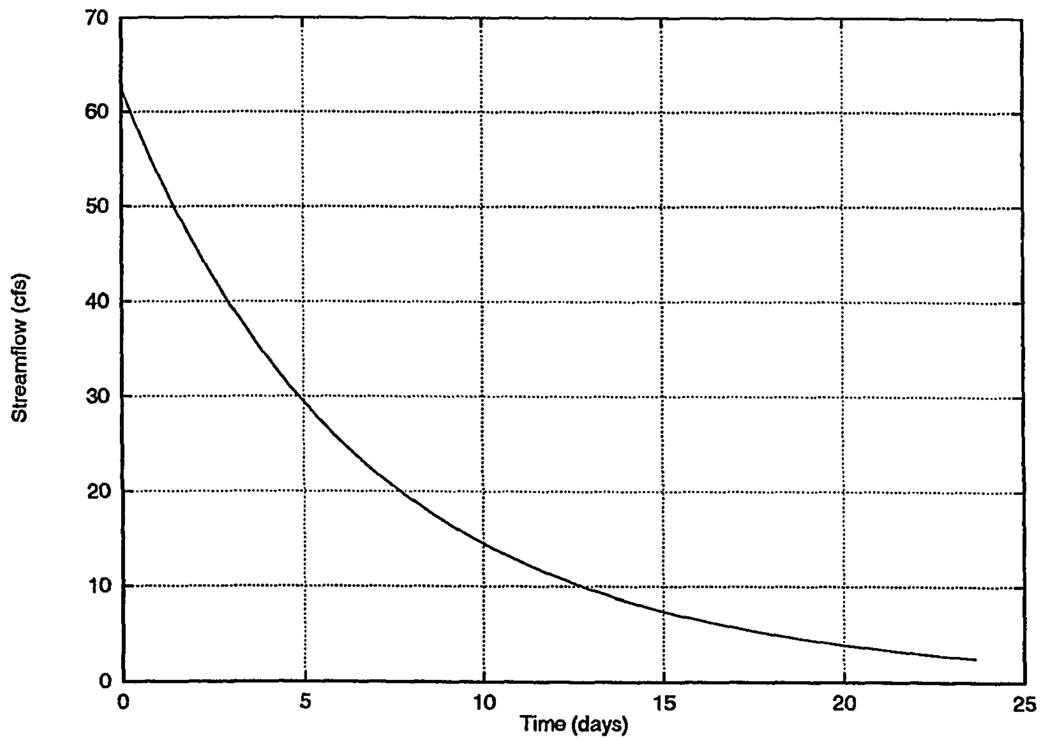

Figure 26.2: MRC of Walnut Creek near Hartwick (for summer), ID# 05452200

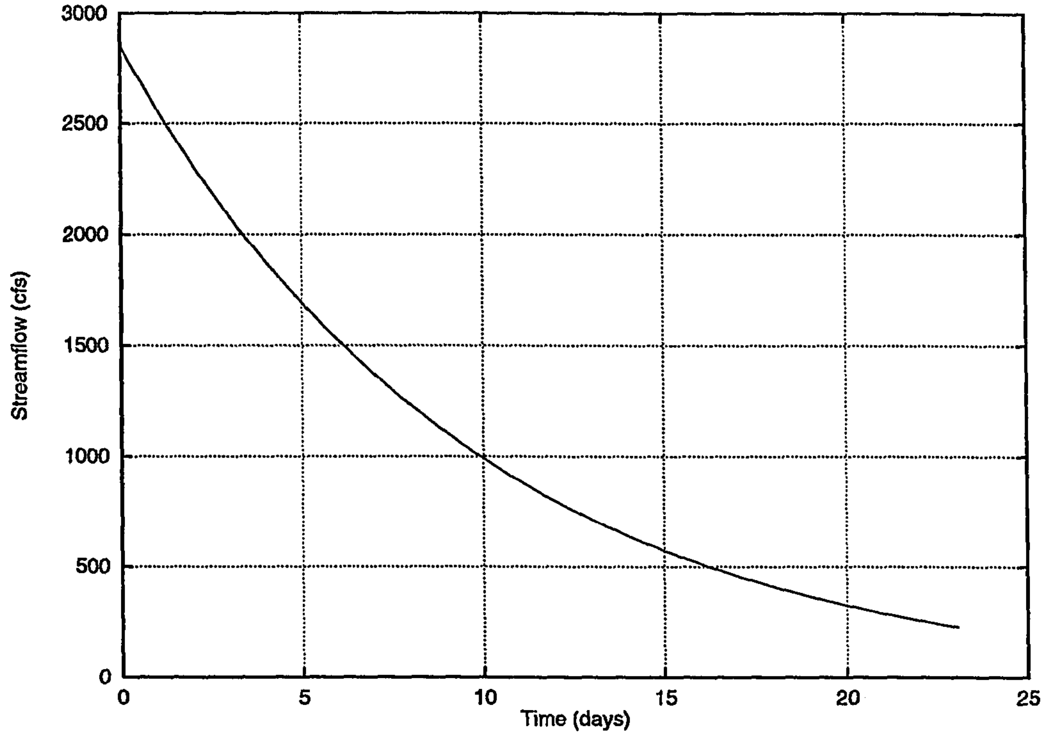

Figure 27.1: MRC of Iowa River near Belle Plaine (for winter), ID# 05452500

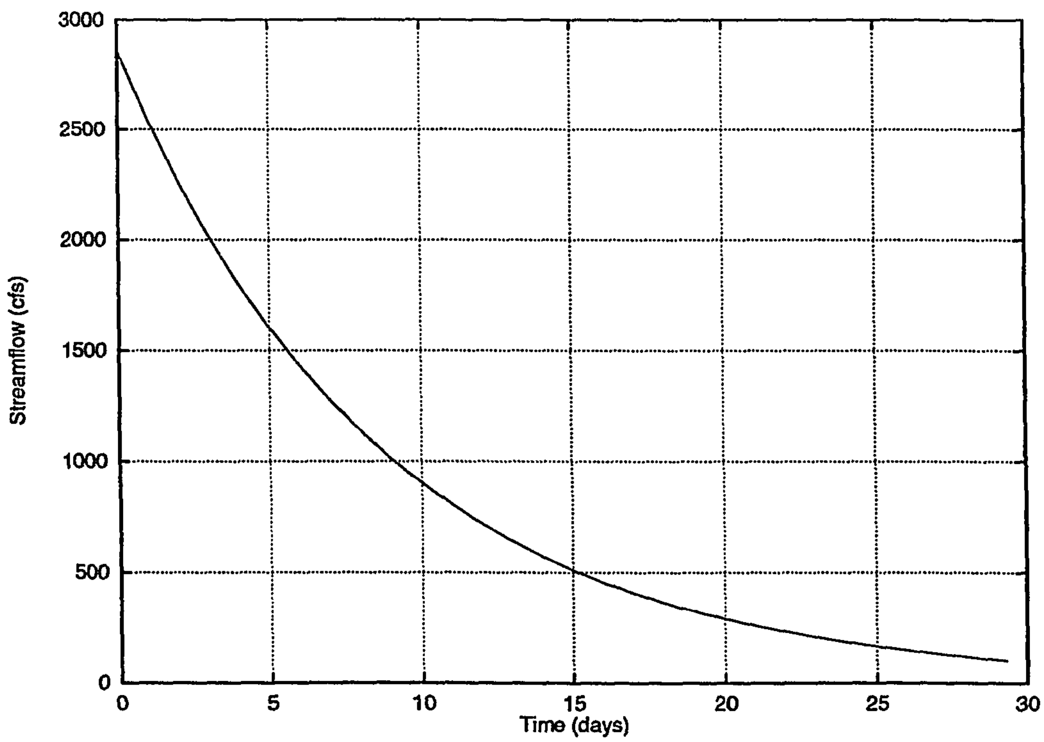

Figure 27.2: MRC of Iowa River near Belle Plaine (for summer), ID# 05452500

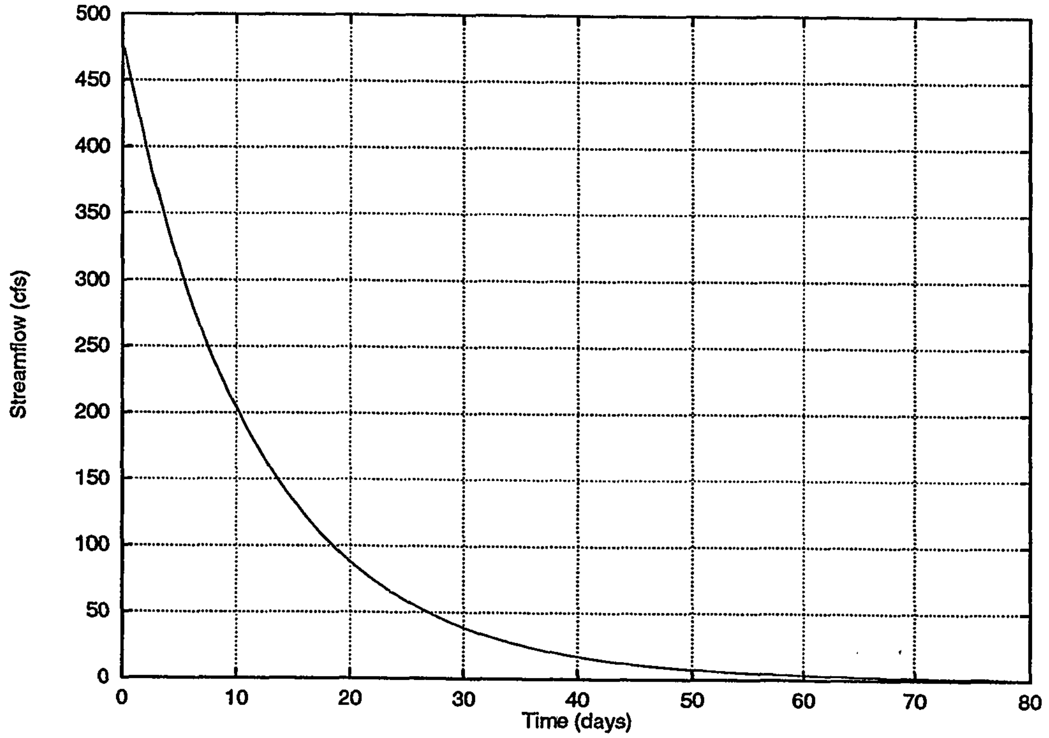

Figure 28.1: MRC of Big Bear Creek at Ladora (for winter), ID# 05453000

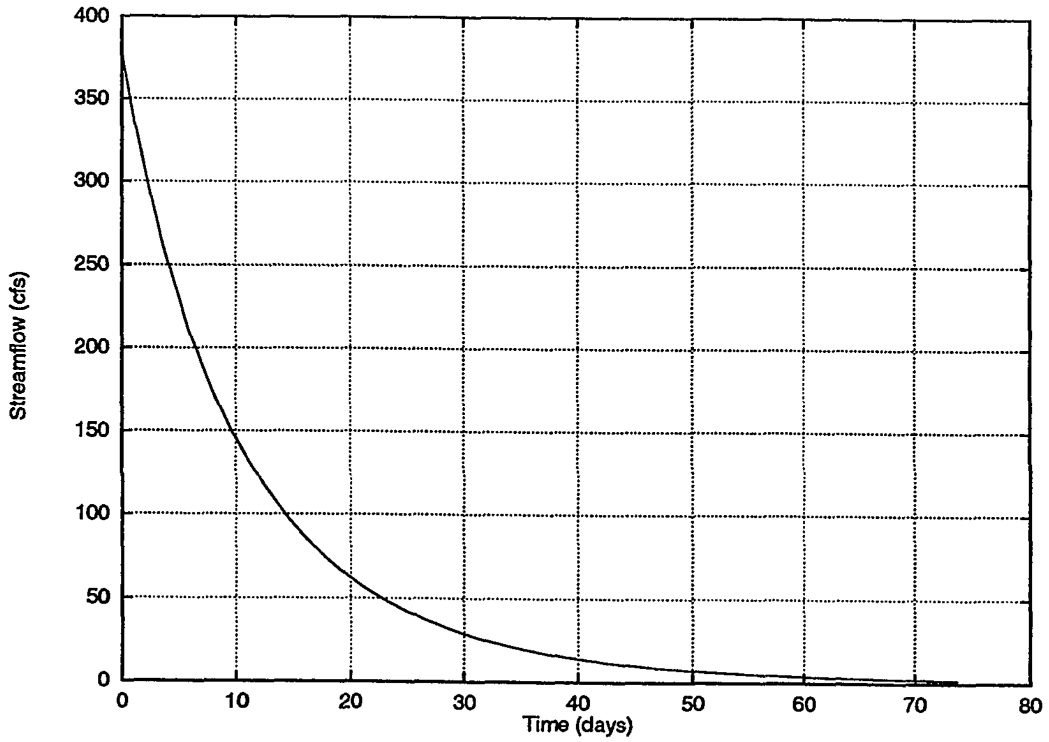

Figure 28.2: MRC of Big Bear Creek at Ladora (for summer), ID# 05453000

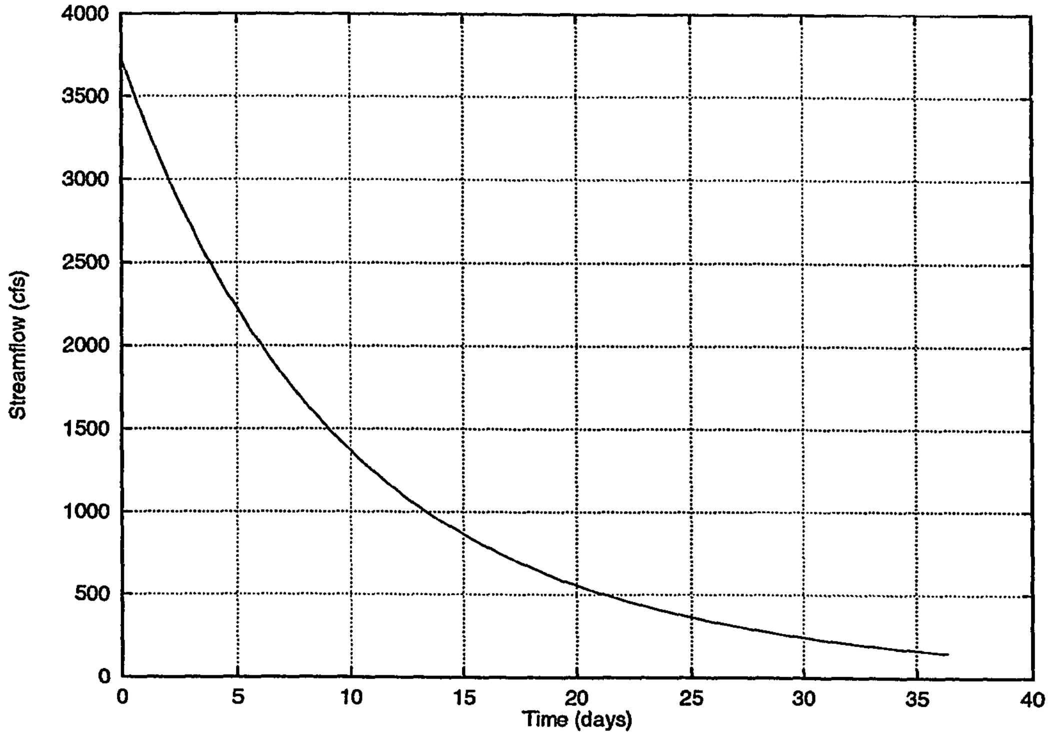

Figure 29.1: MRC of Iowa River at Marengo (for winter), ID# 05453100

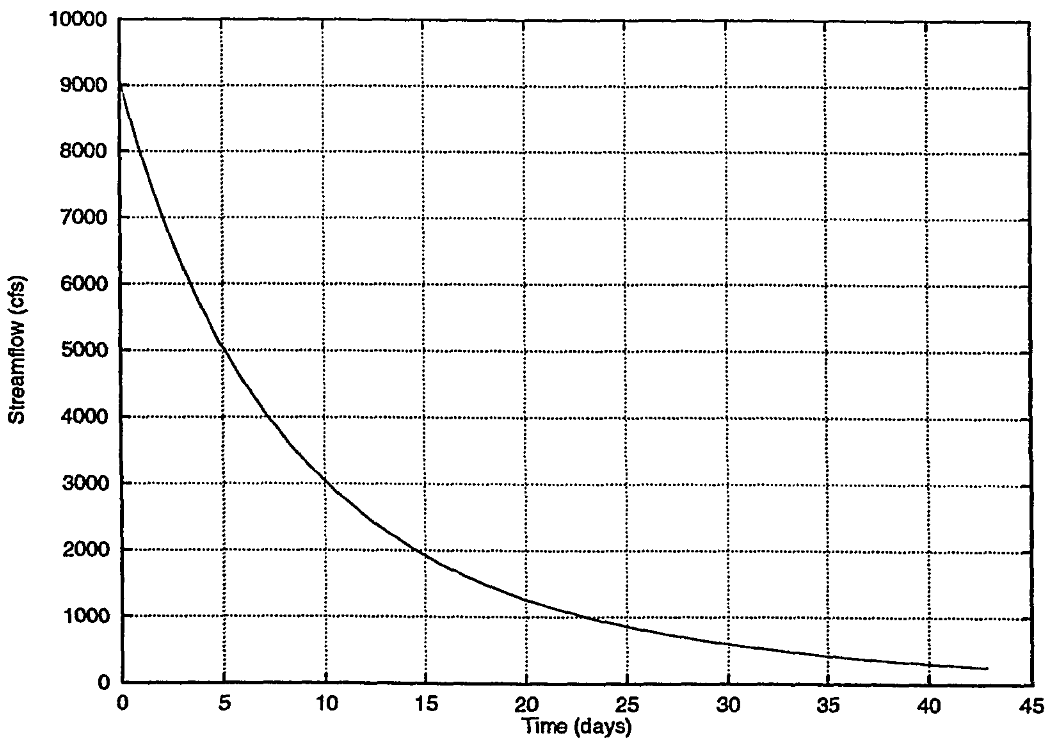

Figure 29.2: MRC of Iowa River at Marengo (for summer), ID# 05453100

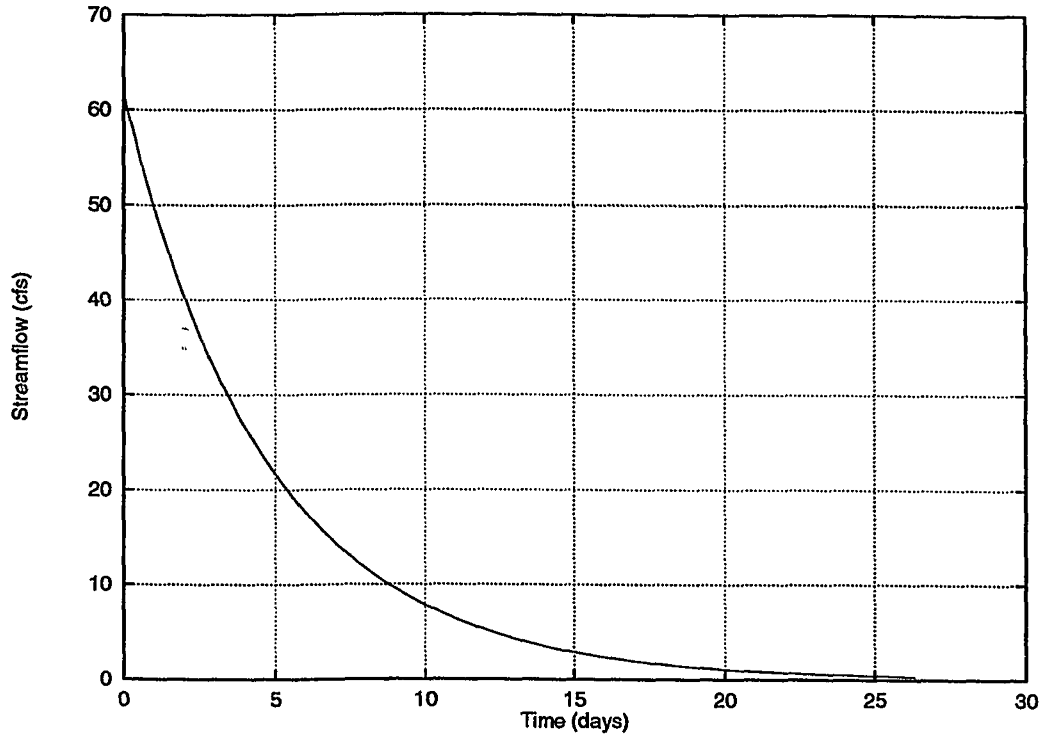

Figure 30.1: MRC of Rapid Creek near Iowa City (for winter), ID# 05454000

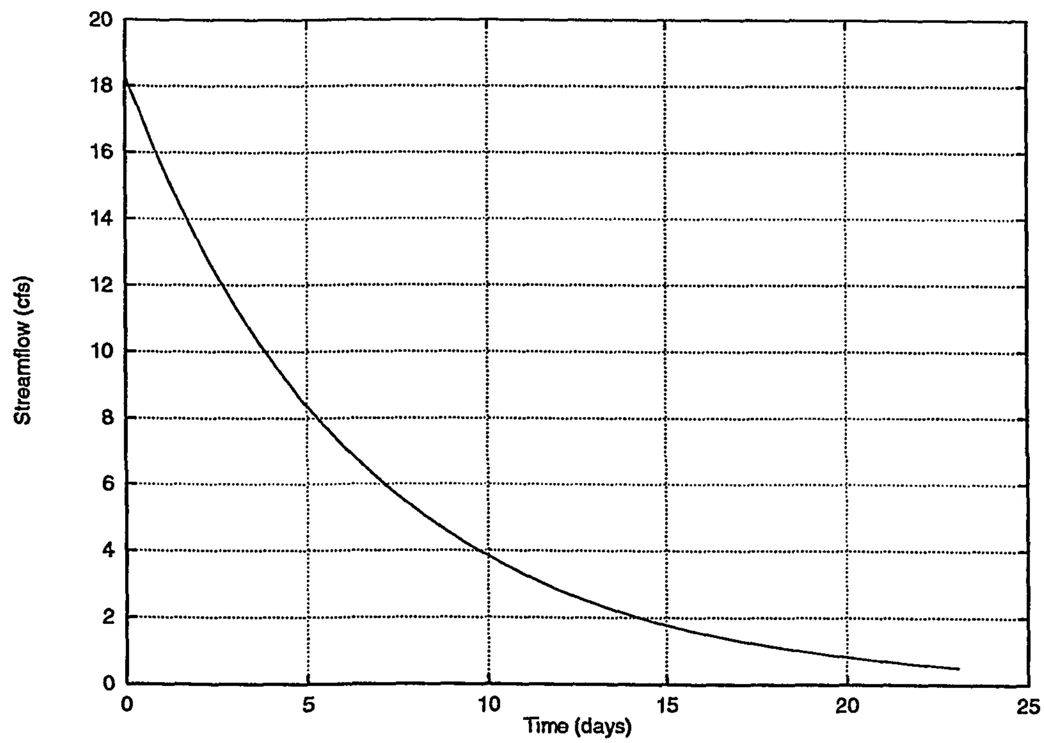

Figure 30.2: MRC of Rapid Creek near Iowa City (for summer), ID# 05454000

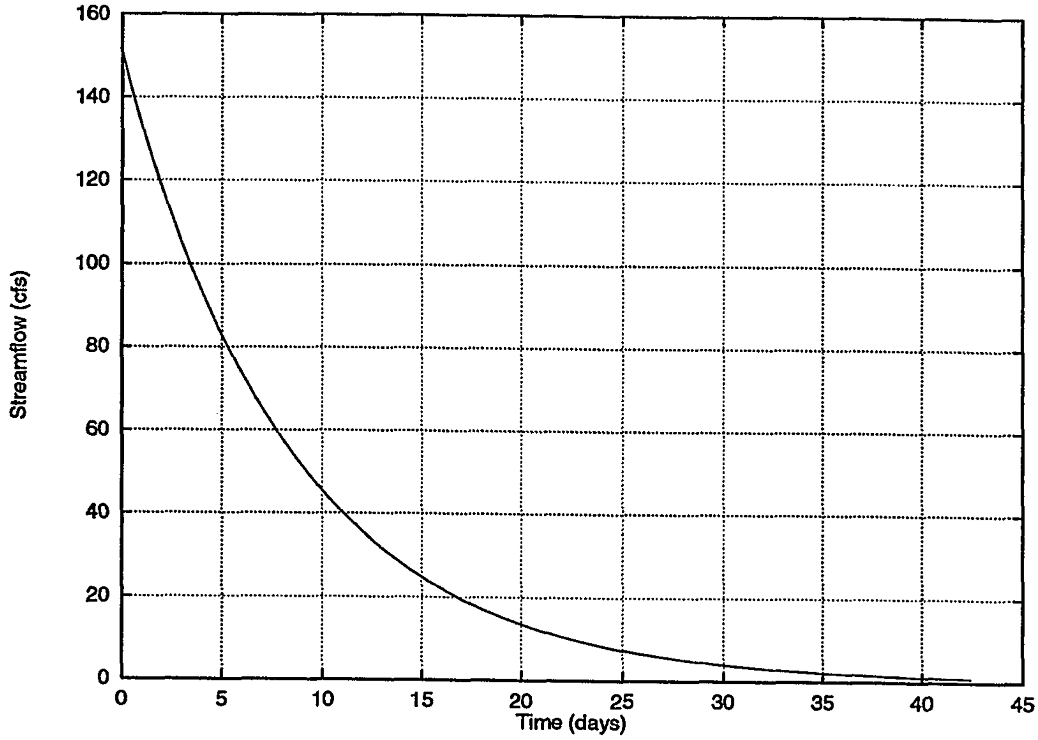

Figure 31.1: MRC of Clear Creek near Coralville (for winter), ID# 05454300

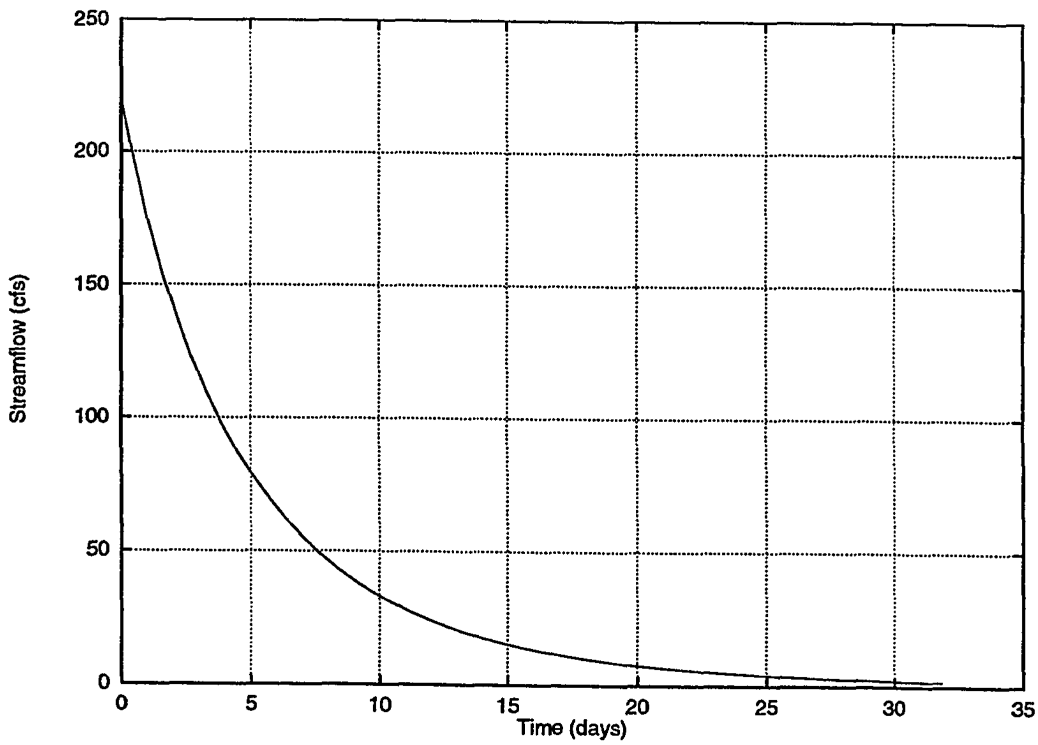

Figure 31.2: MRC of Clear Creek near Coralville (for summer), ID# 05454300

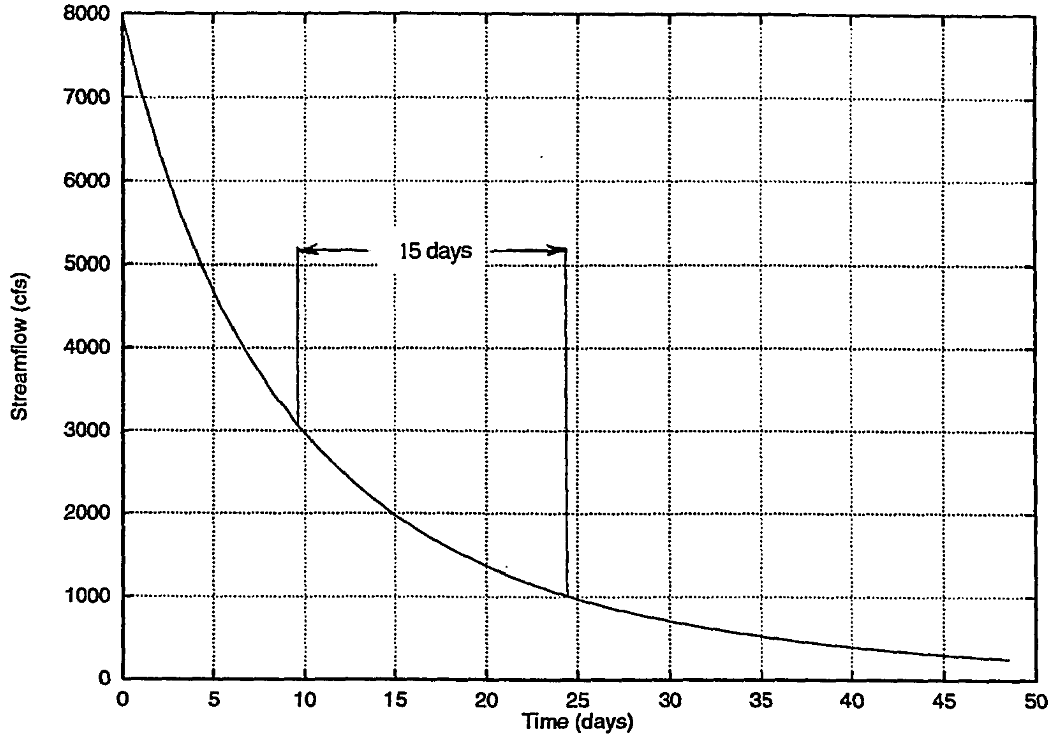

Figure 32.1: MRC of Iowa River at Iowa City (for winter), ID# 05454500

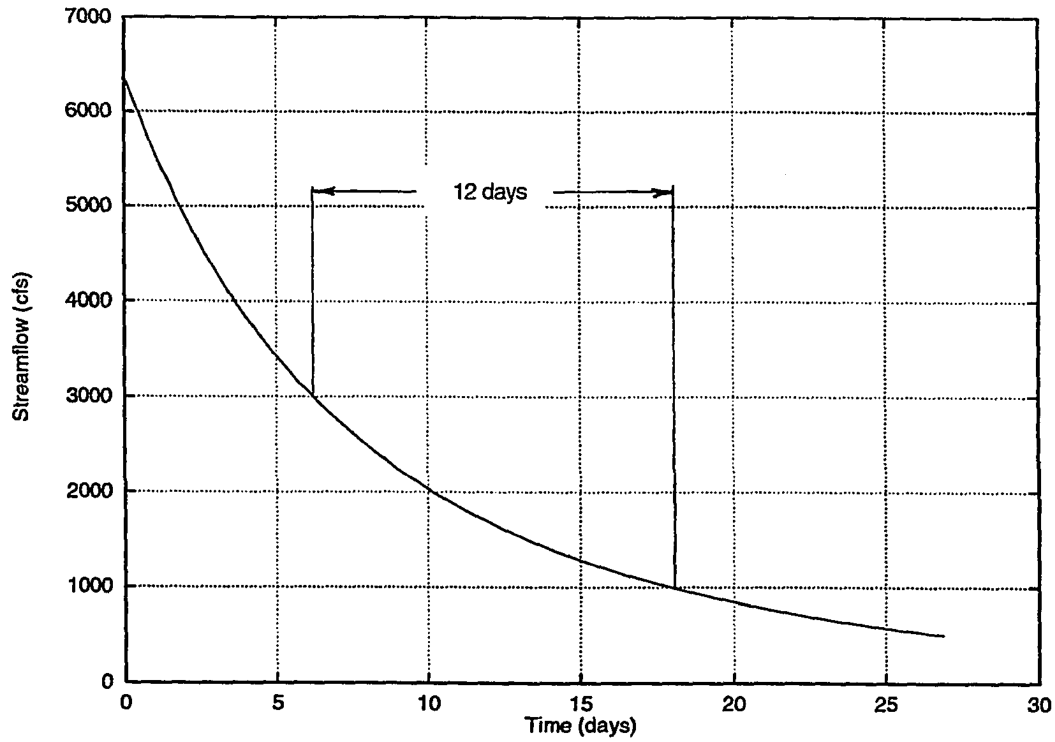

Figure 32.2: MRC of Iowa River at Iowa City (for summer), ID# 05454500

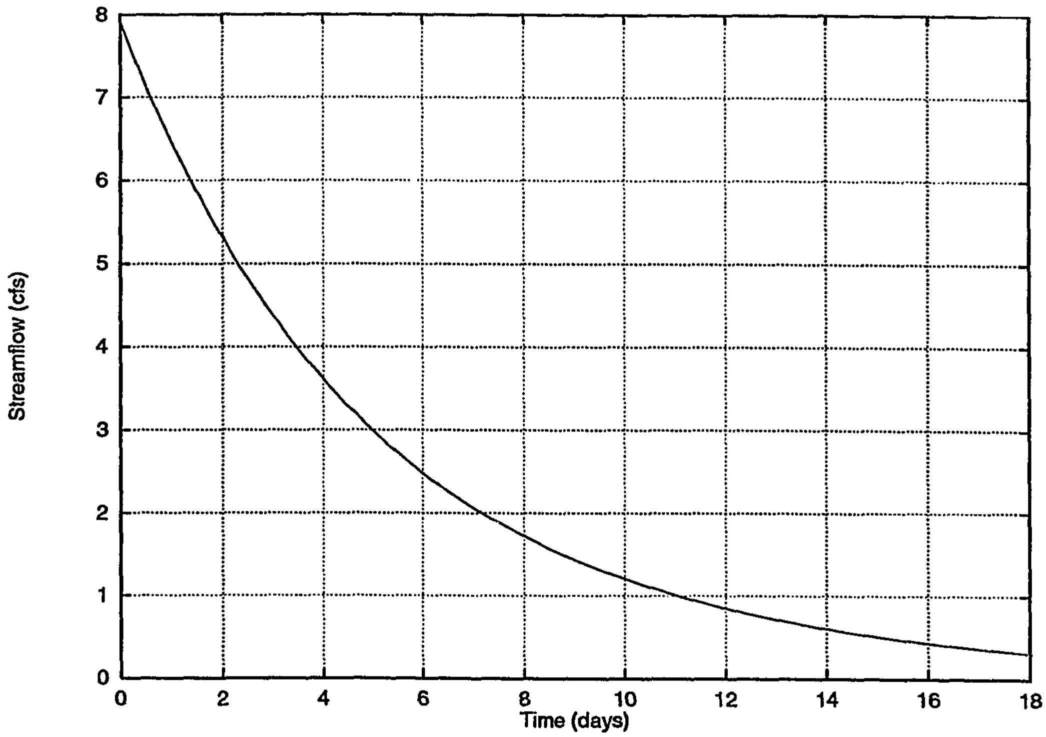

Figure 33.1: MRC of Ralston Creek at Iowa City (for winter), ID# 05455000

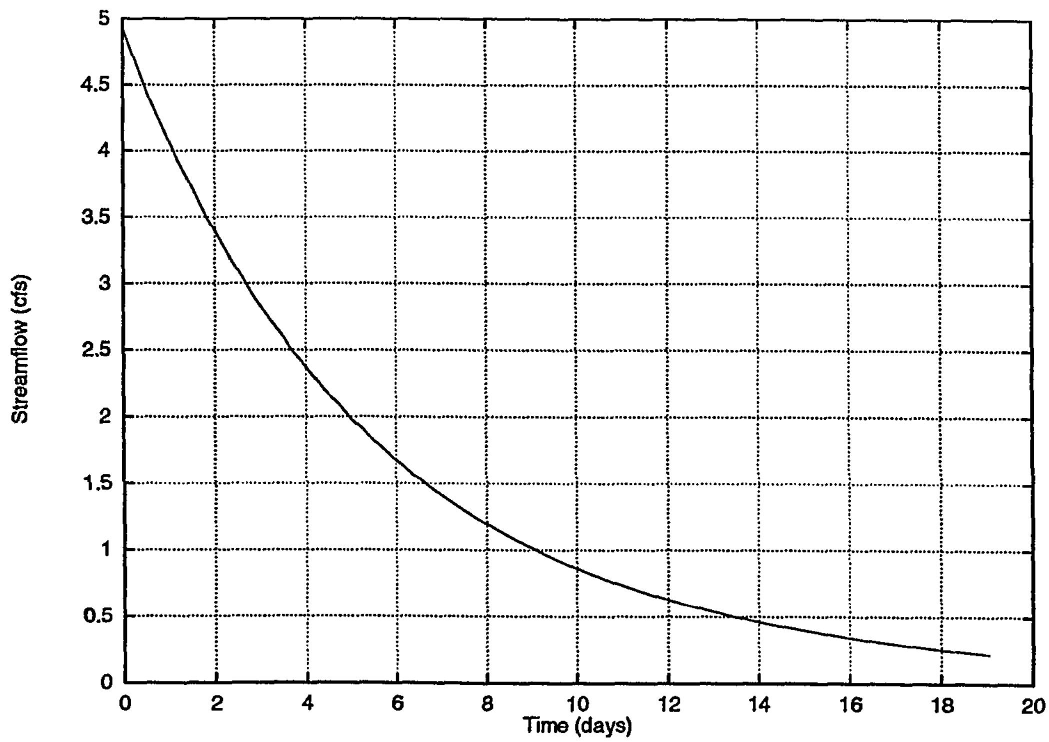

Figure 33.2: MRC of Ralston Creek at Iowa City (for summer), ID# 05455000

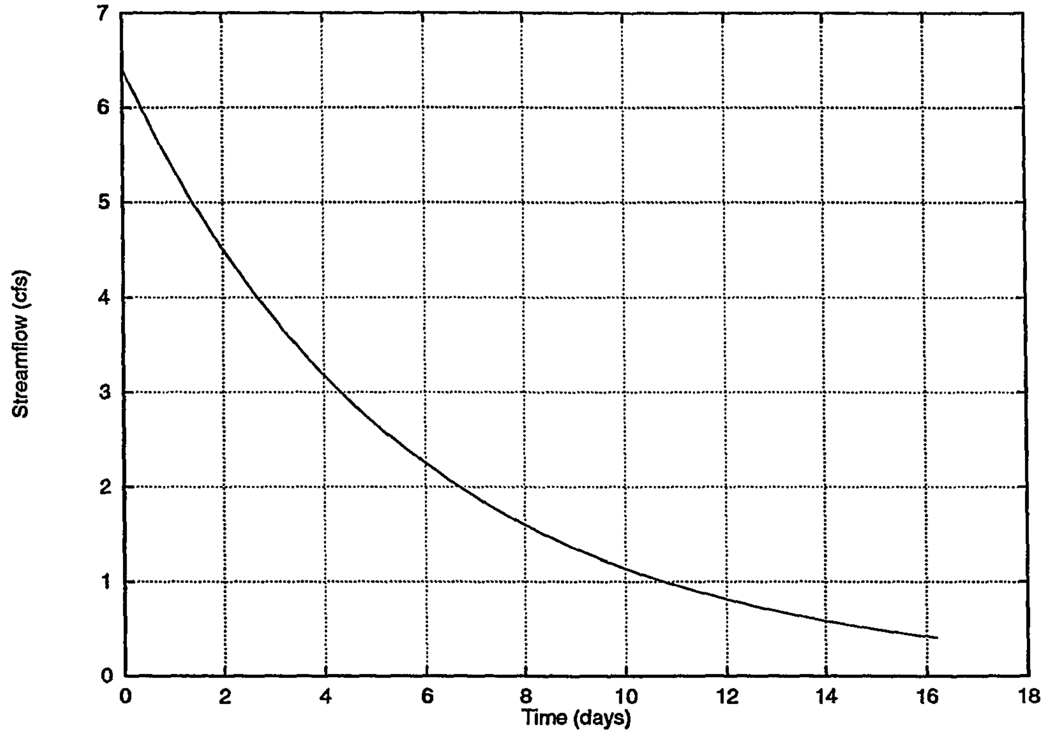

Figure 34.1: MRC of South Branch Ralston Creek at Iowa City (for winter), ID# 05455010

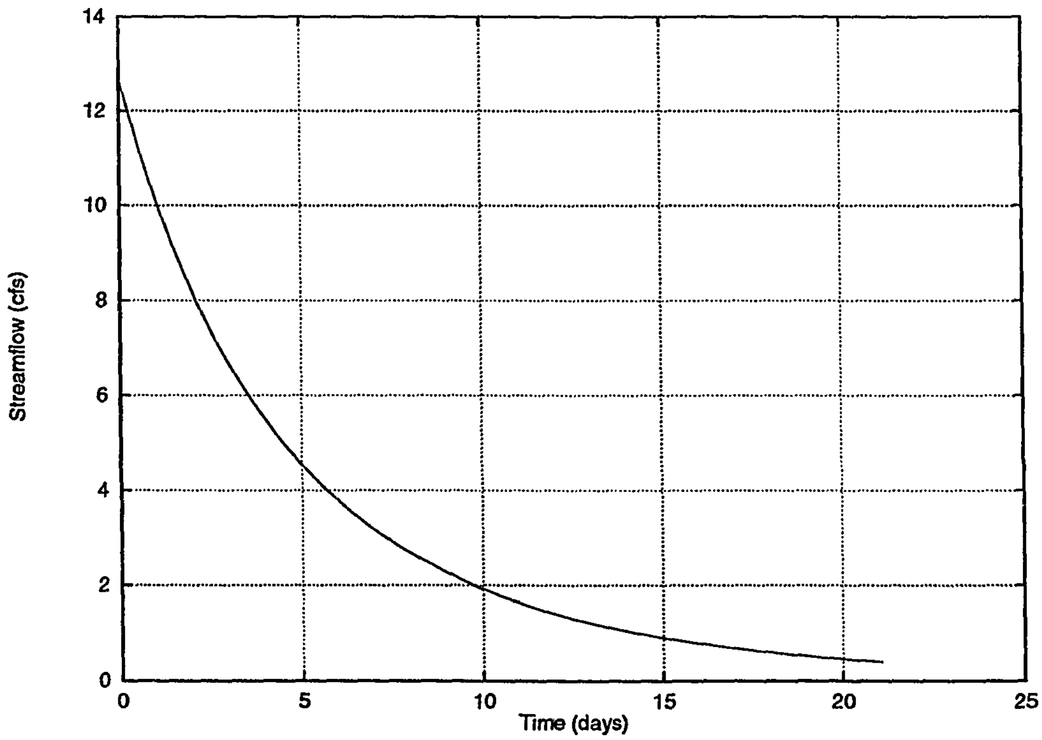

Figure 34.2: MRC of South Branch Ralston Creek at Iowa City (for summer), ID# 05455010

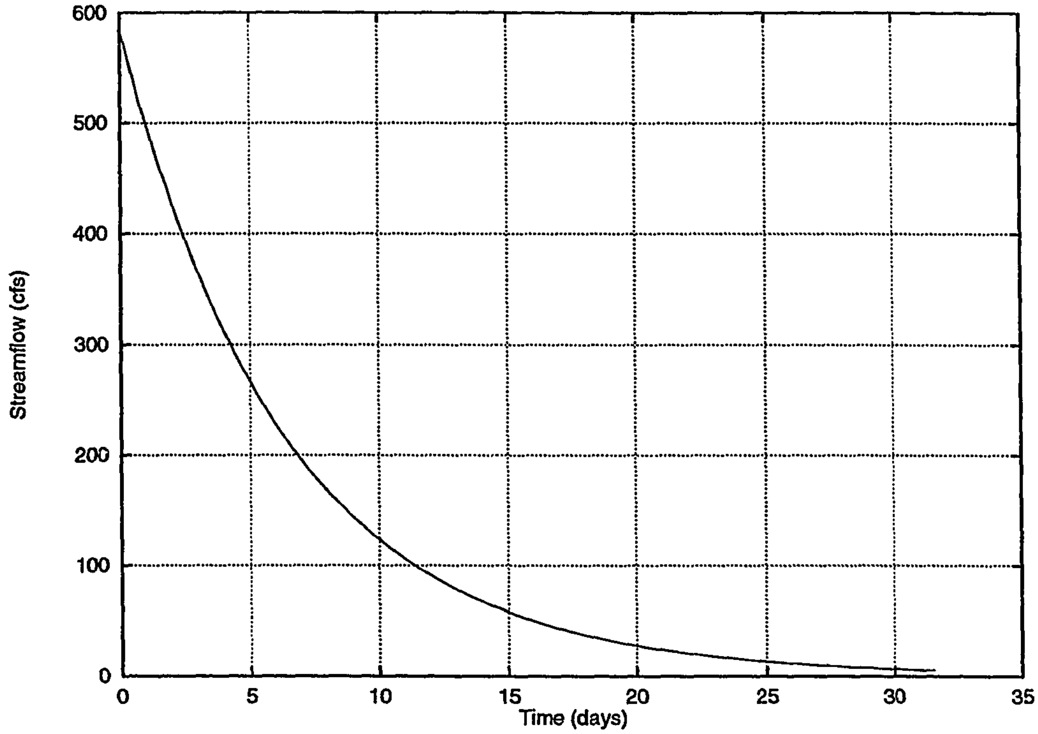

Figure 35.1: MRC of Old Mans Creek near Iowa City (for winter), ID# 05455100

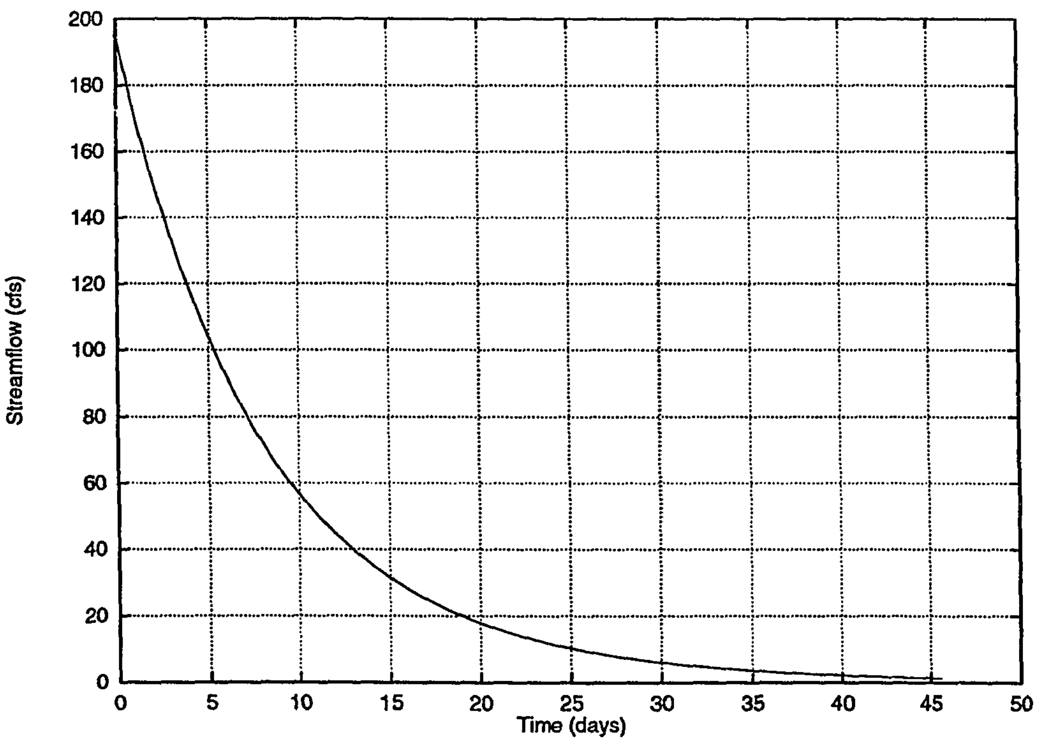

Figure 35.2: MRC of Old Mans Creek near Iowa City (for summer), ID# 05455100

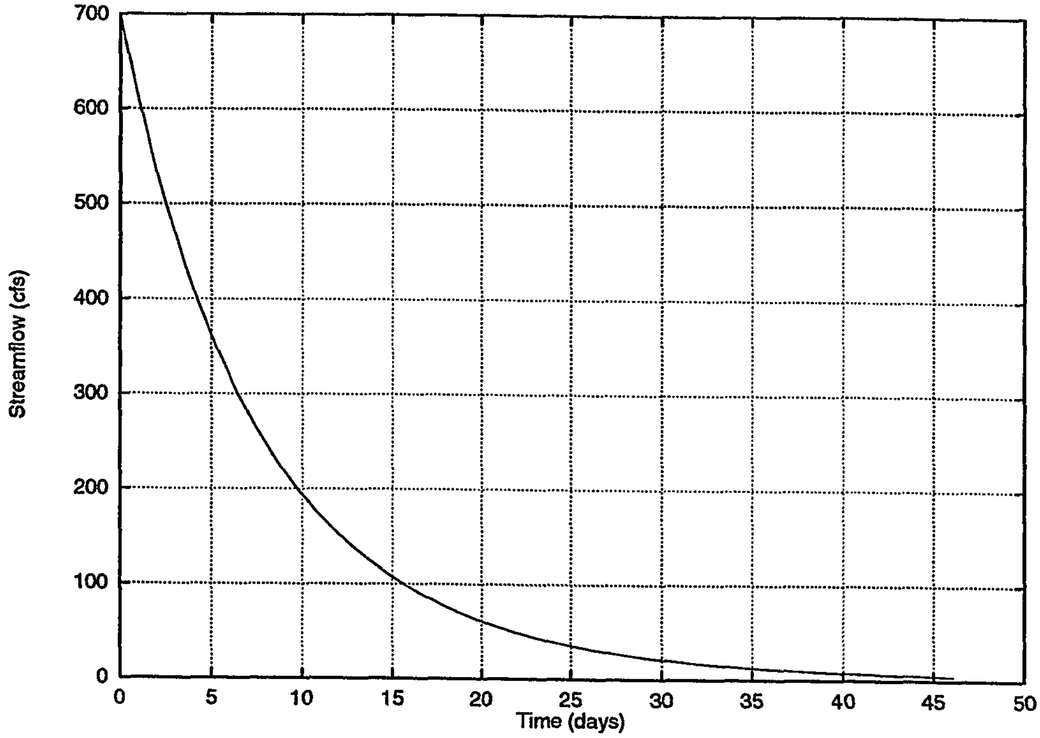

Figure 36.1: MRC of English River at Kalona (for winter), ID# 05455500

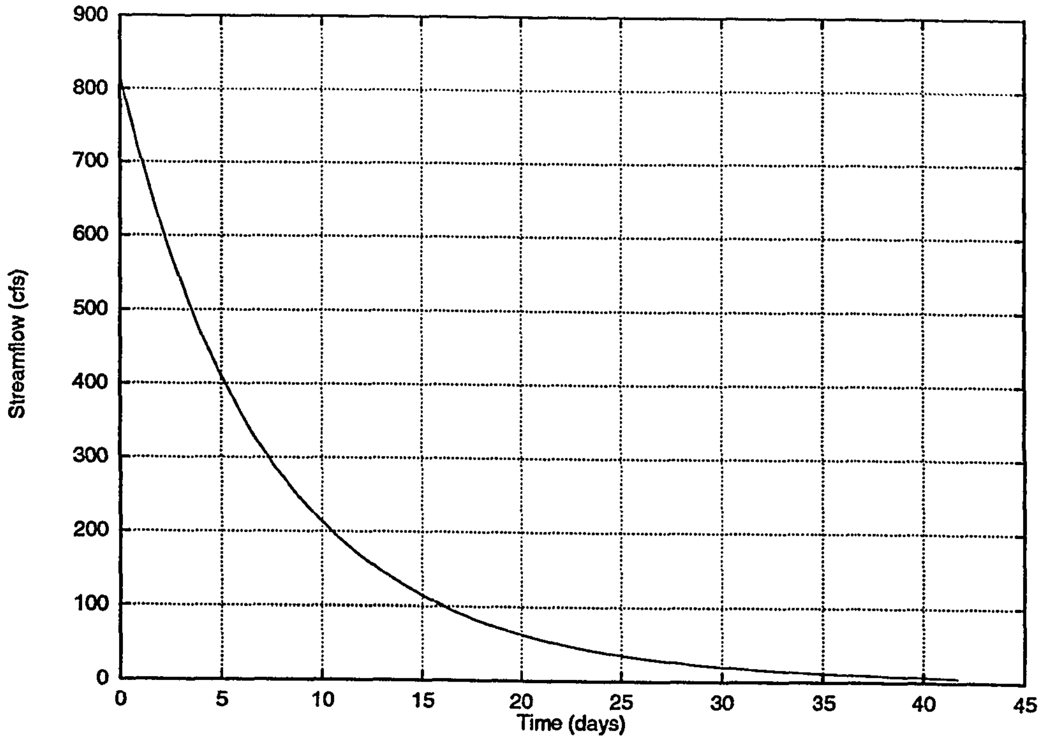

Figure 36.2: MRC of English River at Kalona (for summer), ID# 05455500

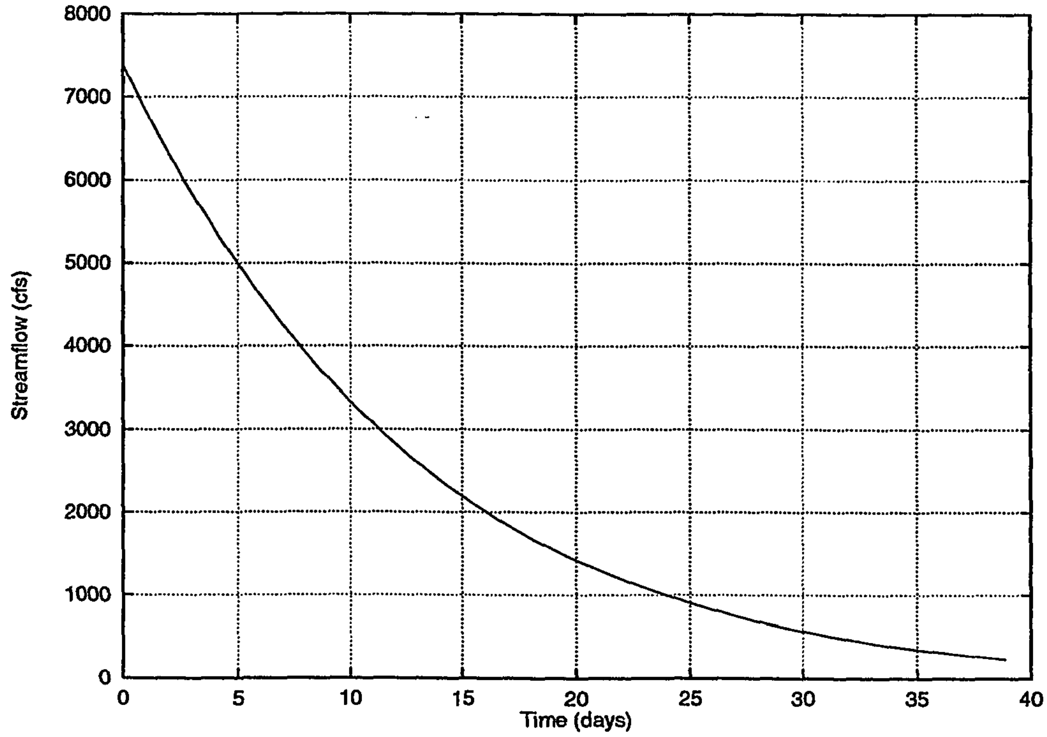

Figure 37.1: MRC of Iowa River near Lone Tree (for winter), ID# 05455700

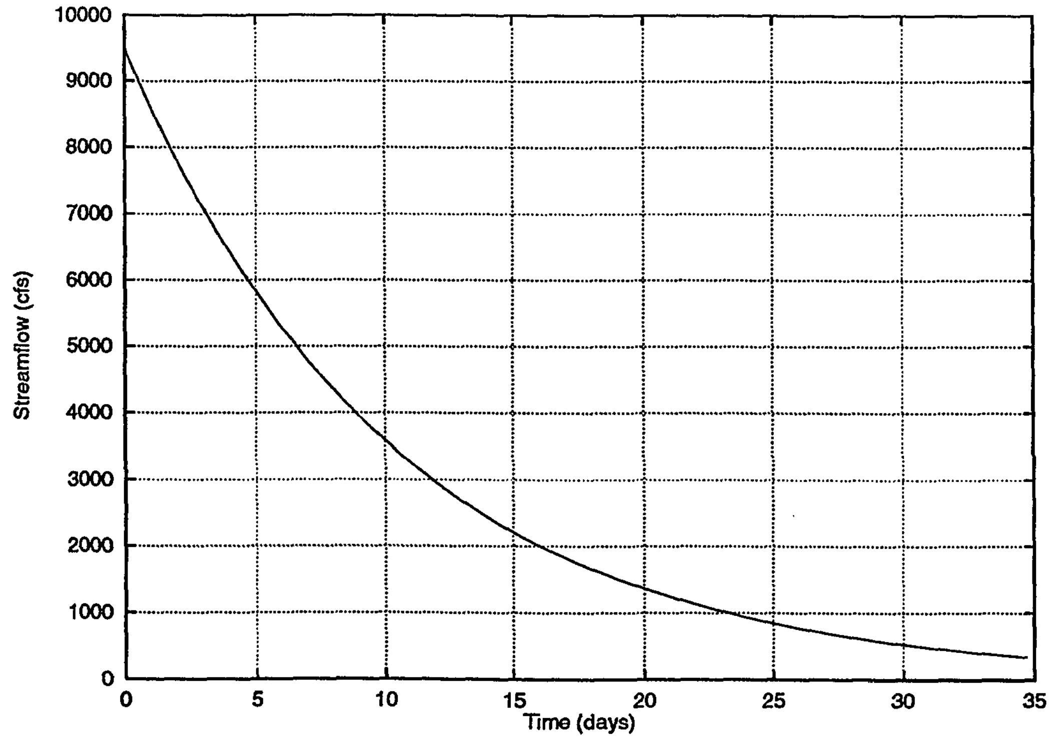

Figure 37.2: MRC of Iowa River near Lone Tree (for summer), ID# 05455700

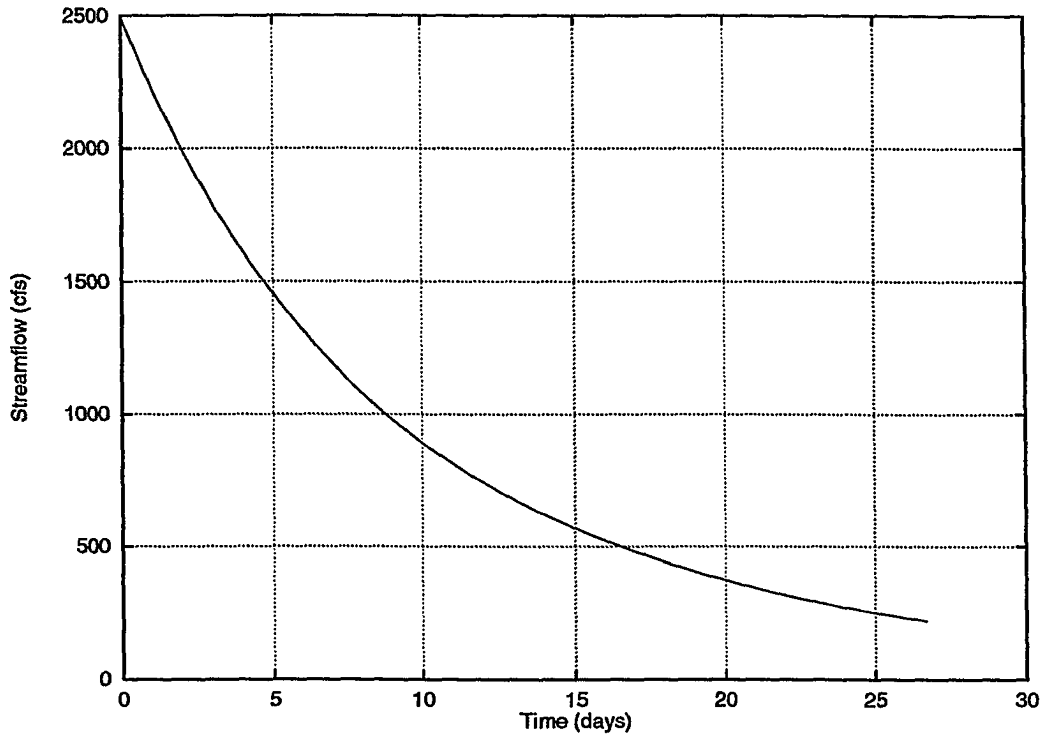

Figure 38.1: MRC of Cedar River at Charles City (for winter), ID# 05457700

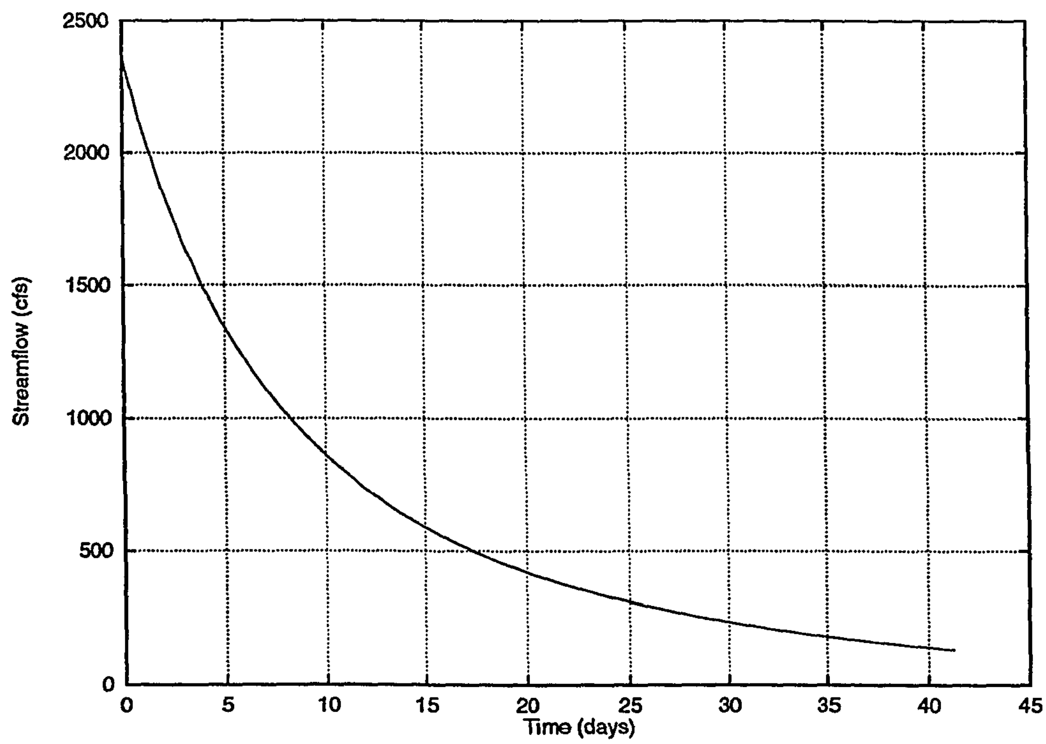

Figure 38.2: MRC of Cedar River at Charles City (for summer), ID# 05457700

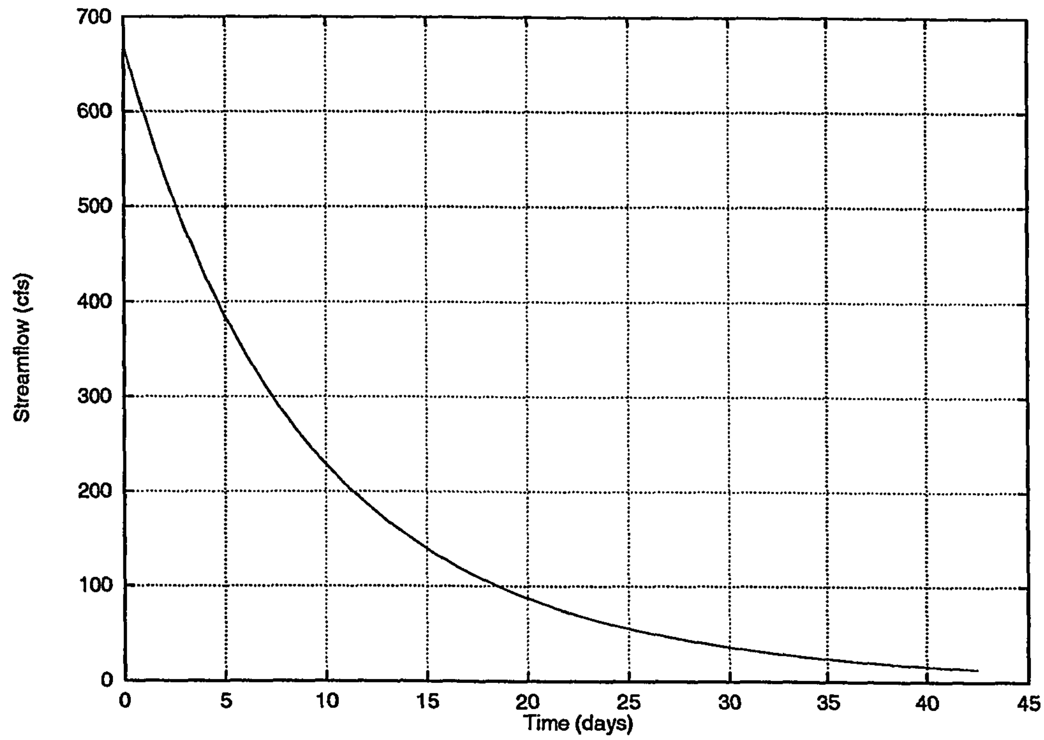

Figure 39.1: MRC of Little Cedar River near Ionia (for winter), ID# 05458000

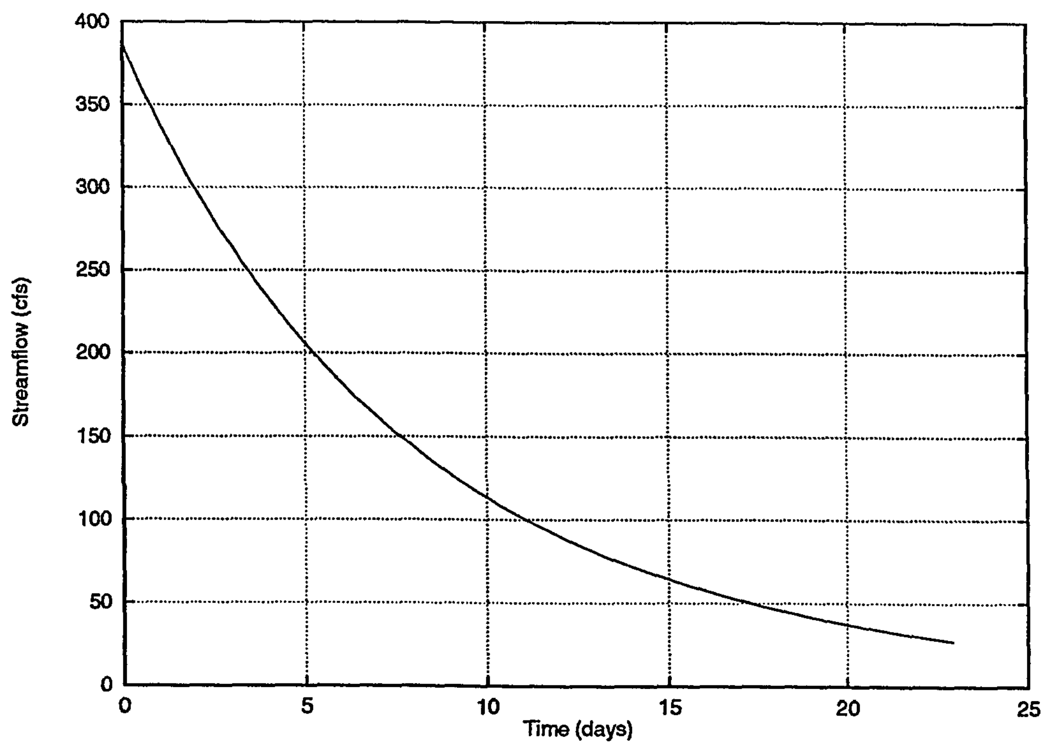

Figure 39.2: MRC of Little Cedar River near Ionia (for summer), ID# 05458000

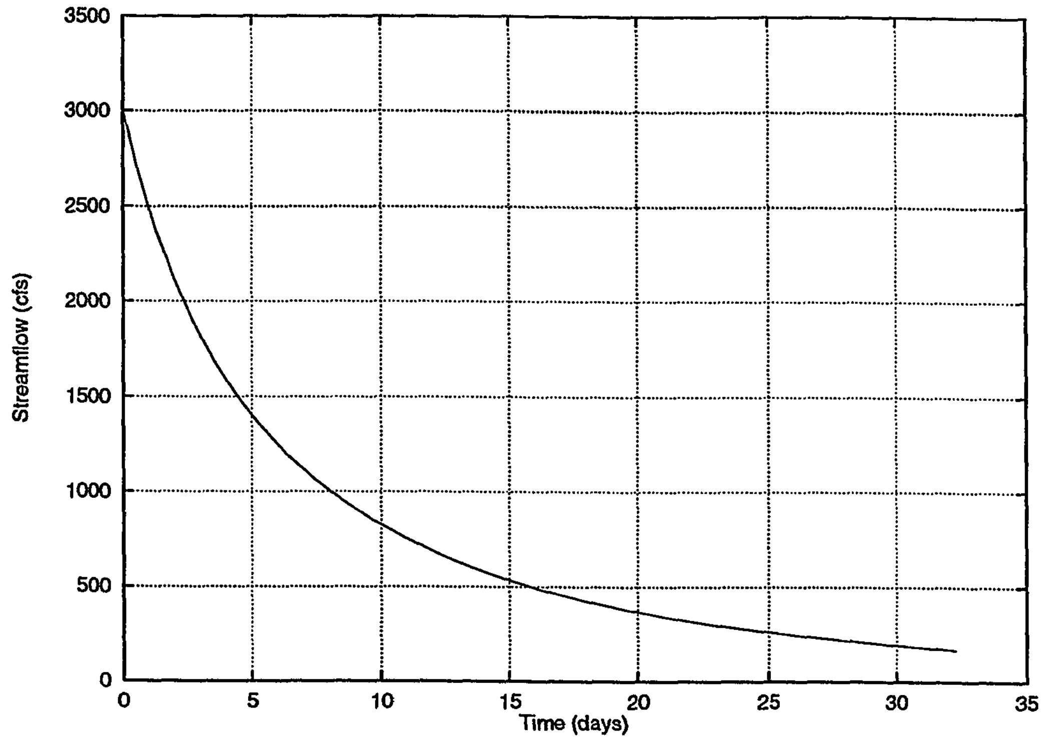

Figure 40.1: MRC of Cedar River at Janesville (for winter), ID# 05458500

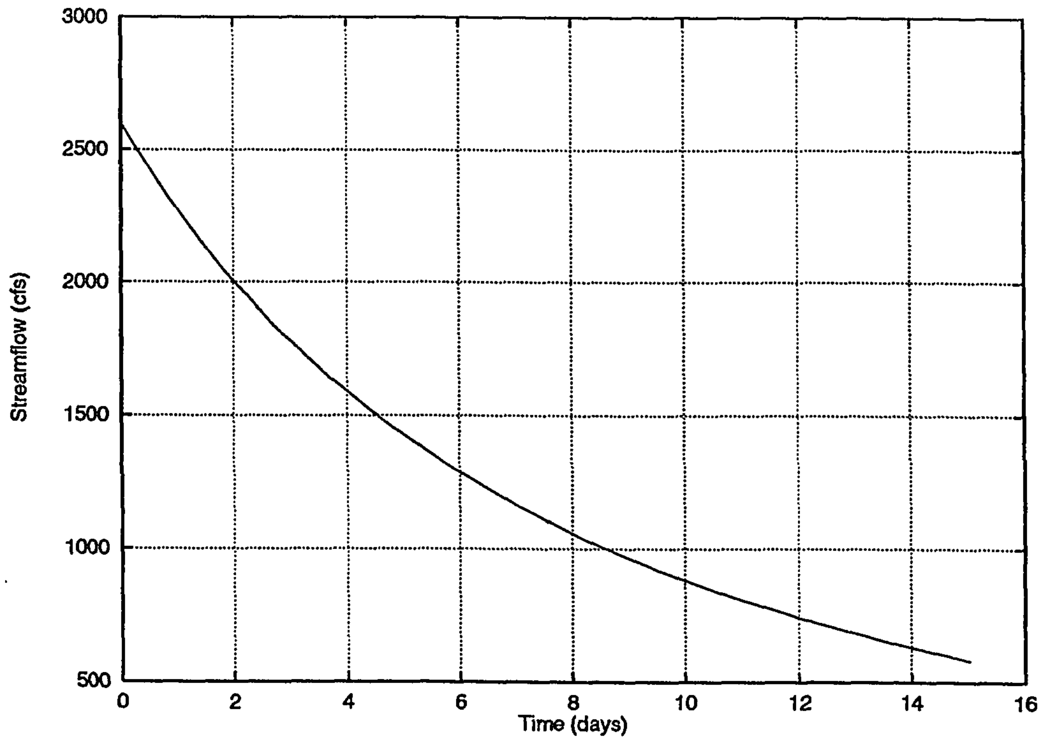

Figure 40.2: MRC of Cedar River at Janesville (for summer), ID# 05458500

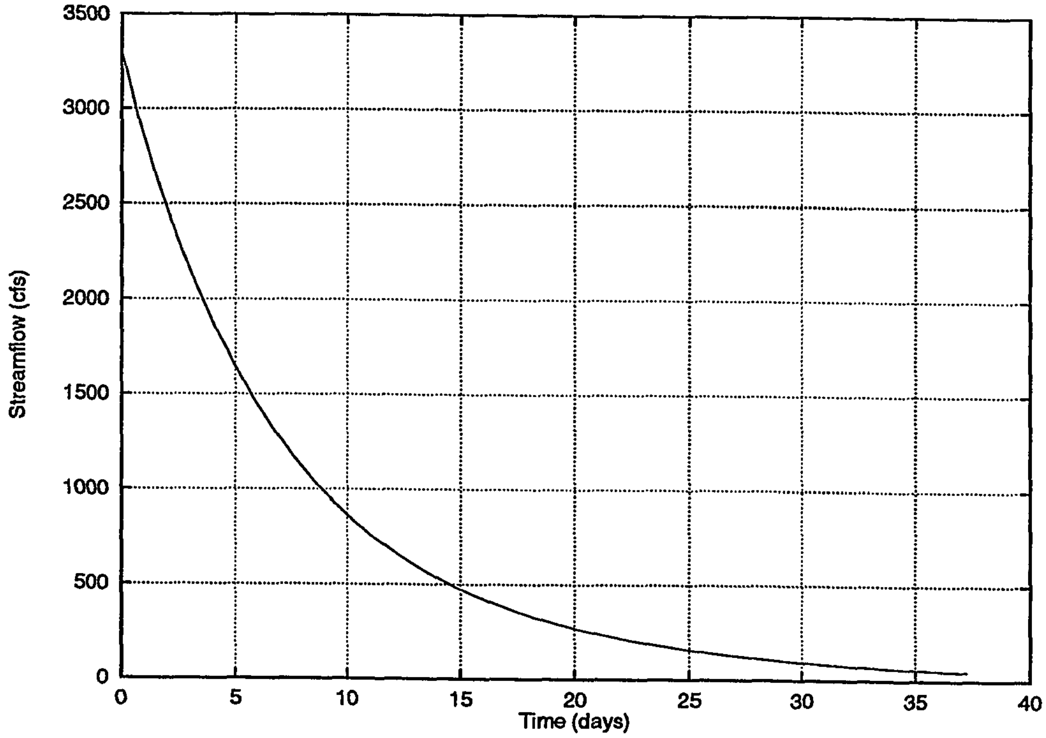

Figure 41.1: MRC of West Fork Cedar River at Finchford (for winter), ID# 05458900

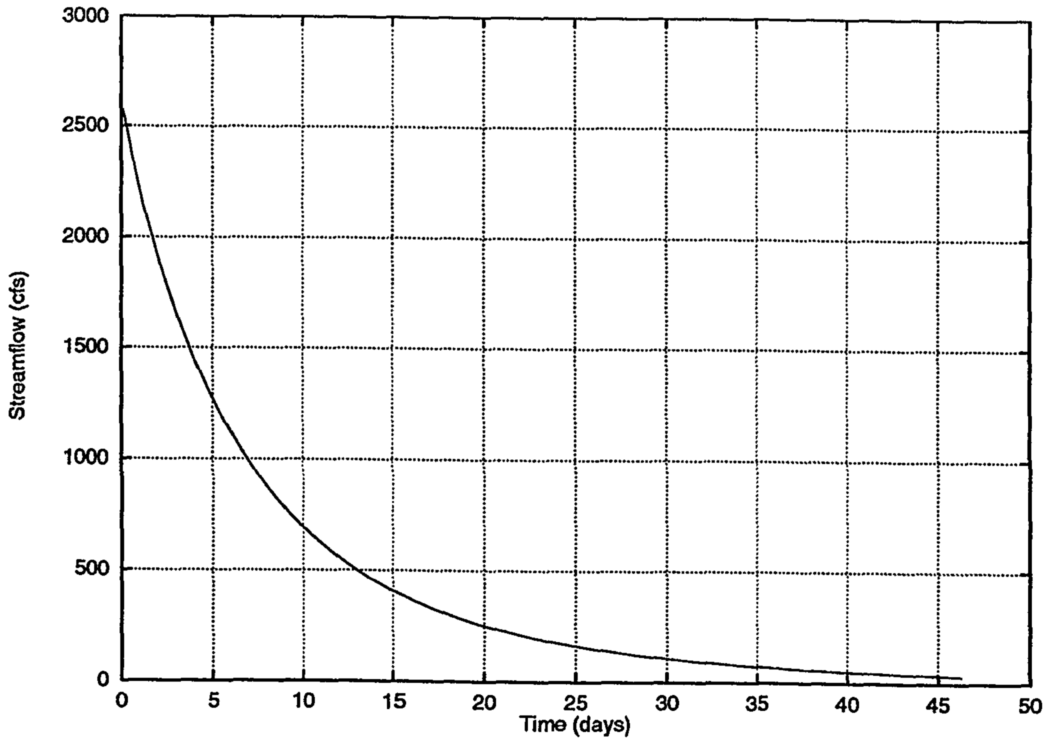

Figure 41.2: MRC of West Fork Cedar River at Finchford (for summer), ID# 05458900

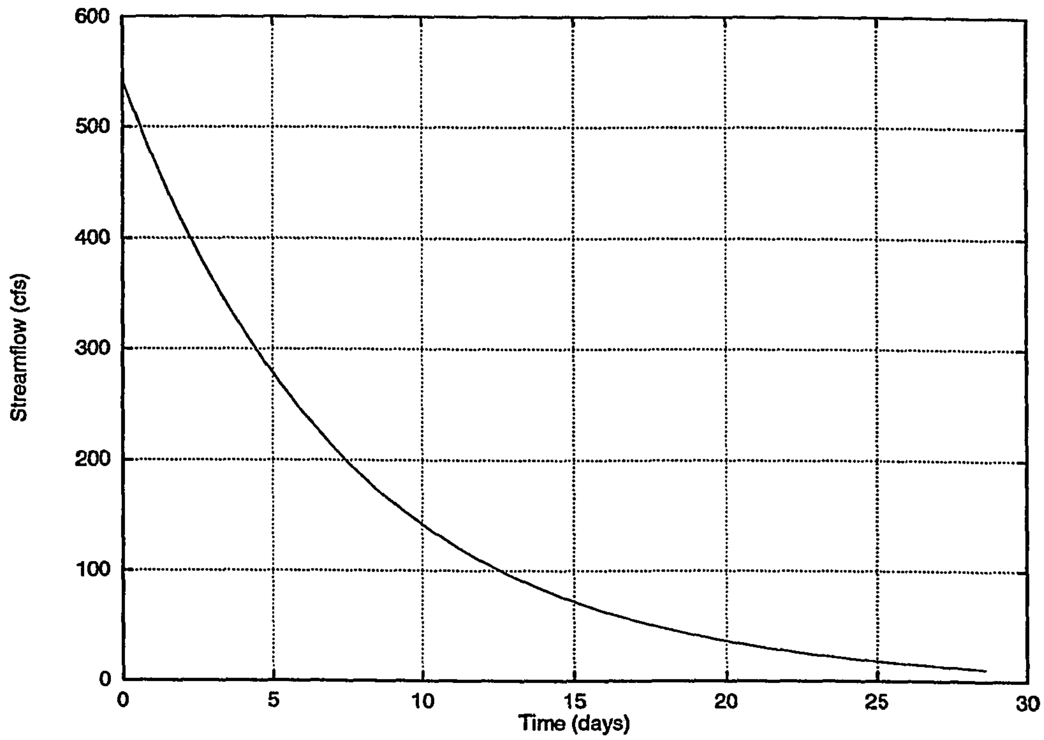

Figure 42.1: MRC of Shell Rock River near Northwood (for winter), ID# 05459000

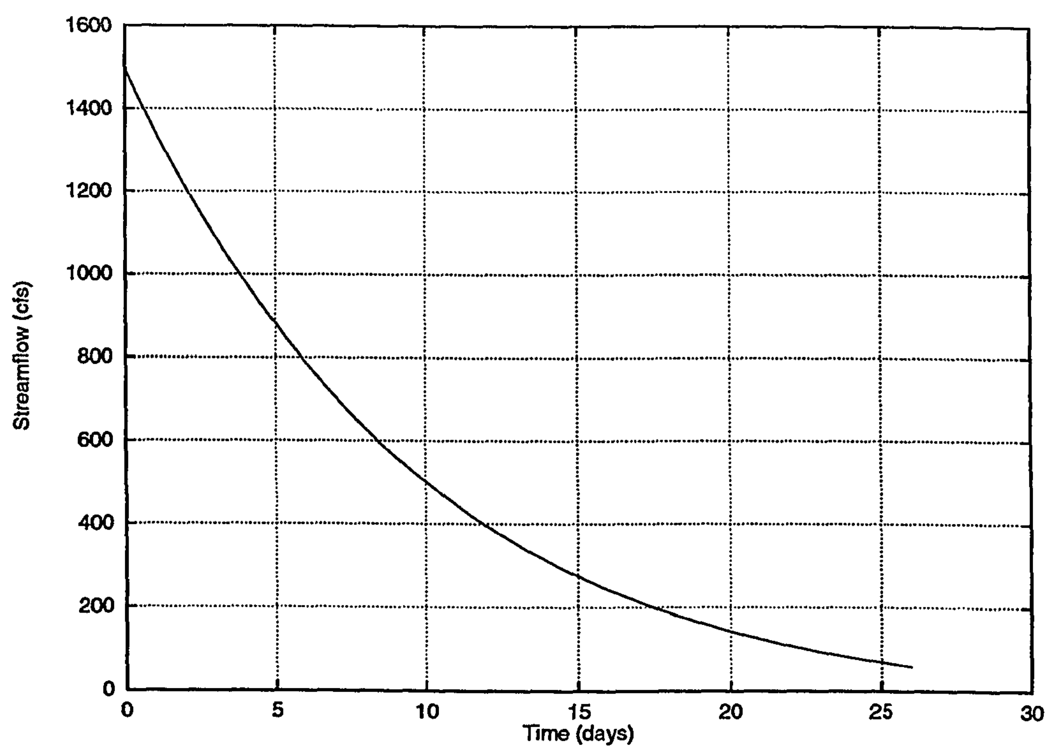

Figure 42.2: MRC of Shell Rock River near Northwood (for summer), ID# 05459000

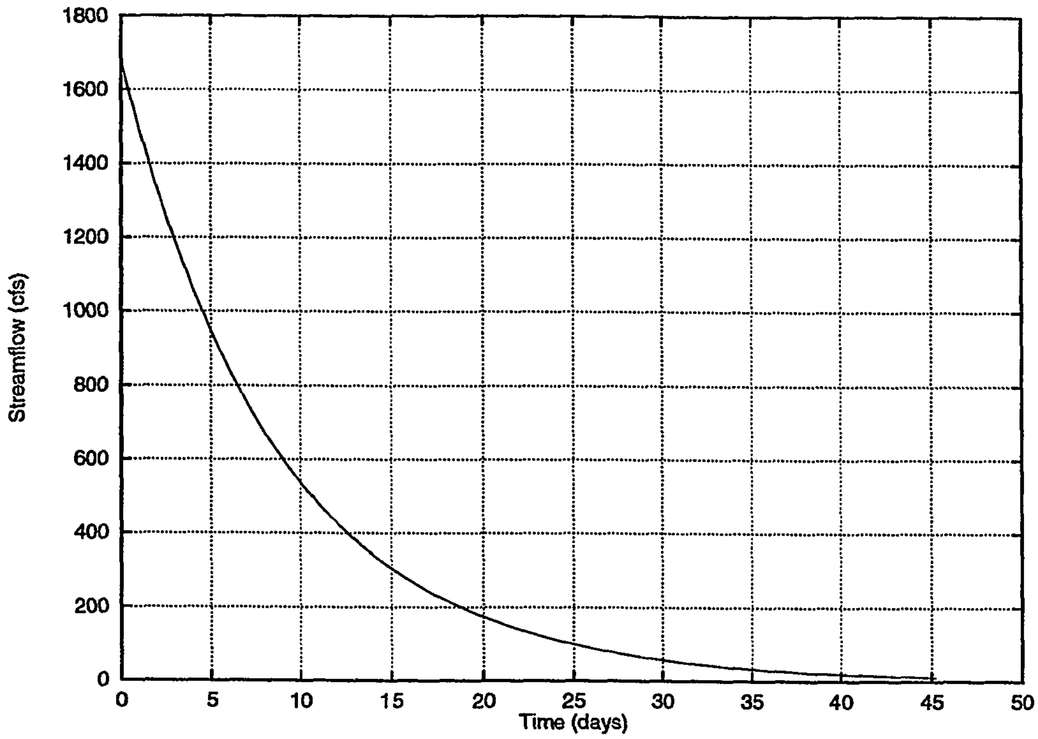

Figure 43.1: MRC of Winnebago River at Mason City (for winter), ID# 05459500

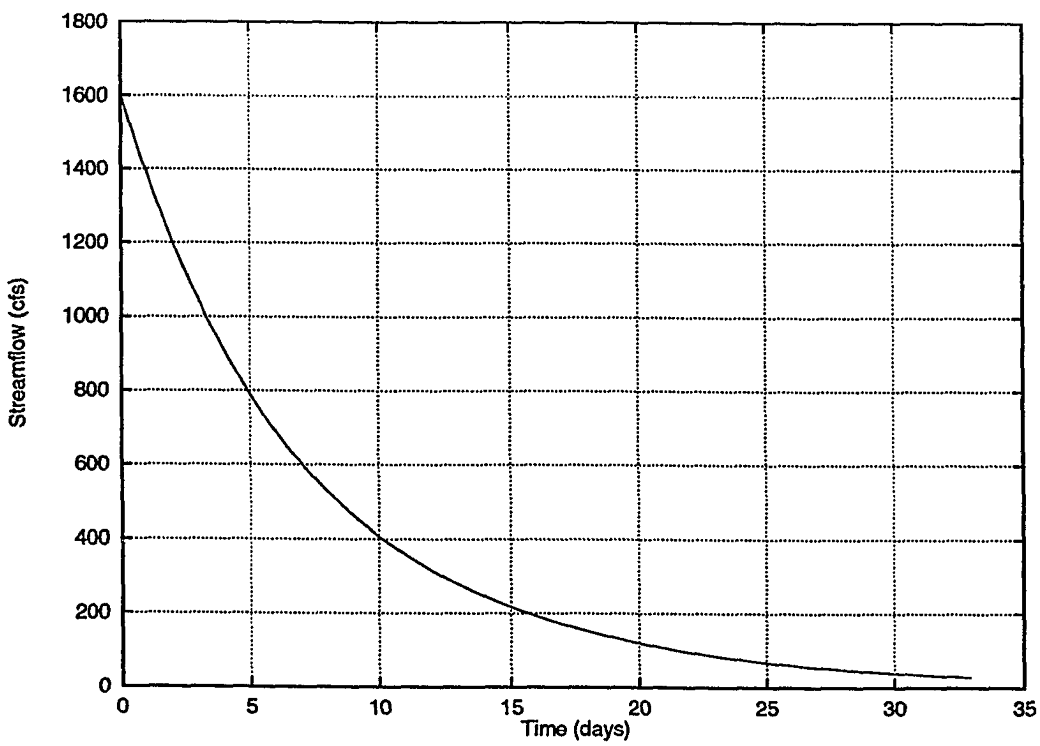

Figure 43.2: MRC of Winnebago River at Mason City (for summer), ID# 05459500

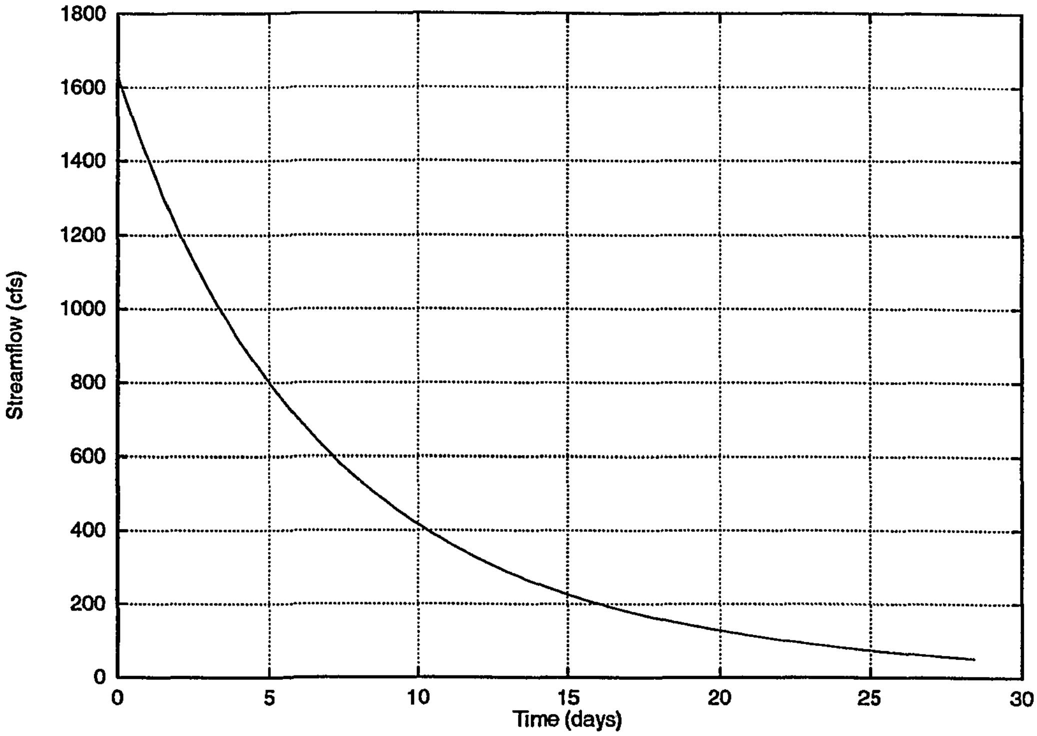

Figure 44.1: MRC of Shell Rock River at Marble Rock (for winter), ID# 05460500

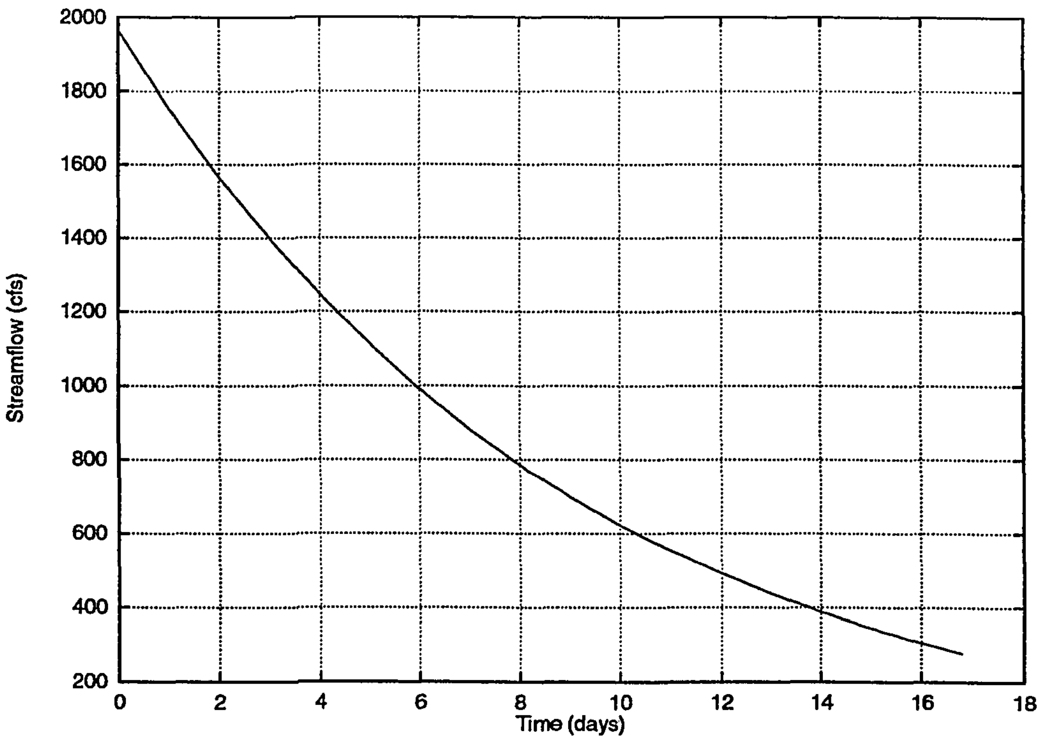

Figure 44.2: MRC of Shell Rock River at Marble Rock (for summer), ID# 05460500

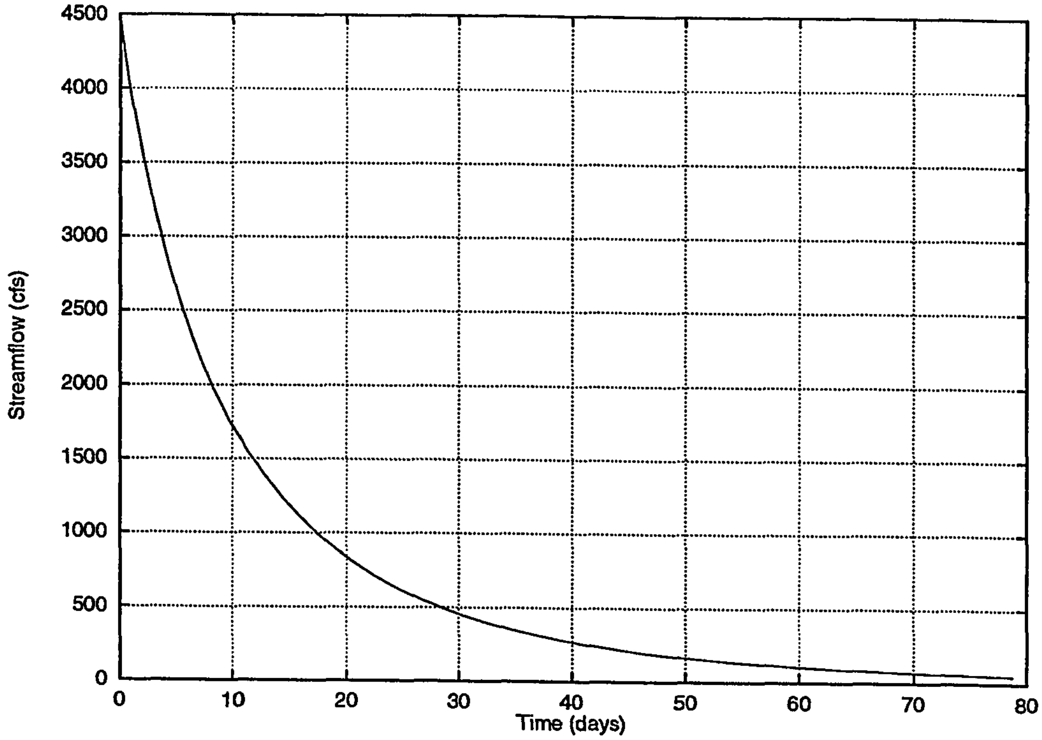

Figure 45.1: MRC of Shell Rock River at Shell Rock (for winter), ID# 05462000

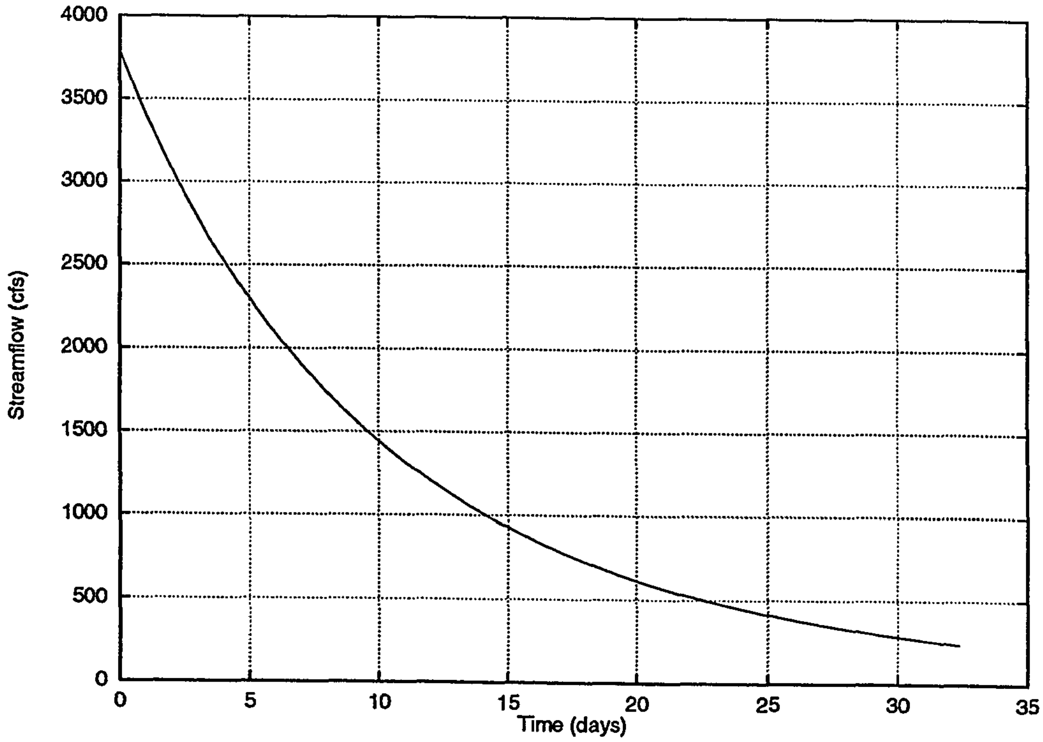

Figure 45.2: MRC of Shell Rock River at Shell Rock (for summer), ID# 05462000

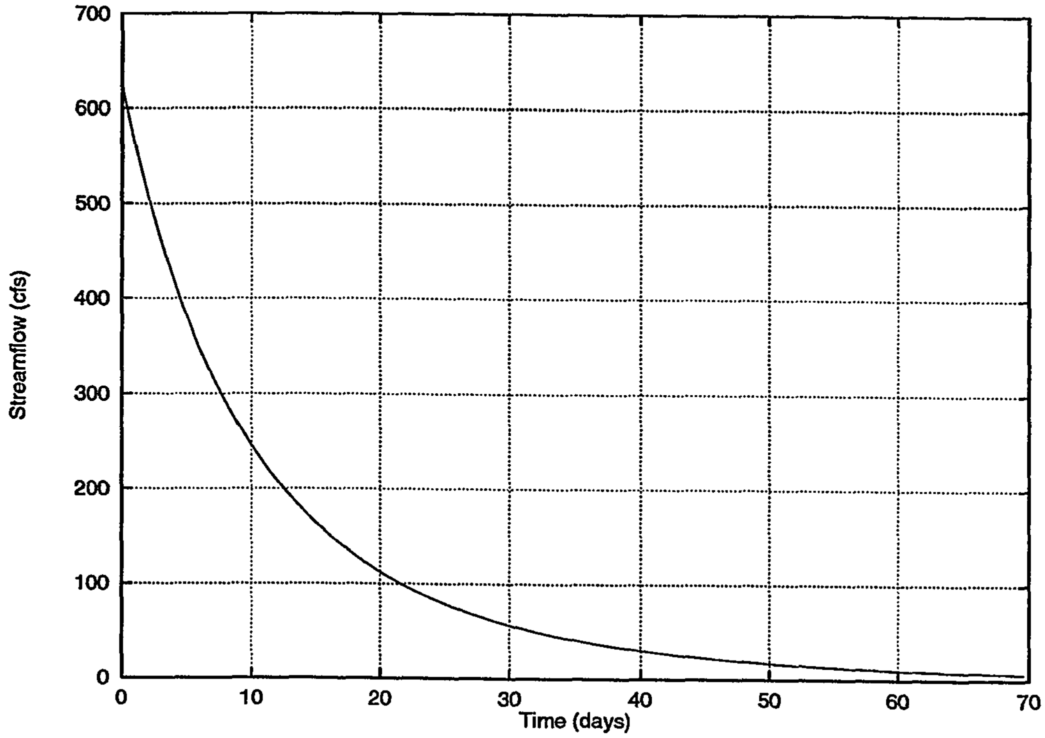

Figure 46.1: MRC of Beaver Creek at New Hartford (for winter), ID# 05463000

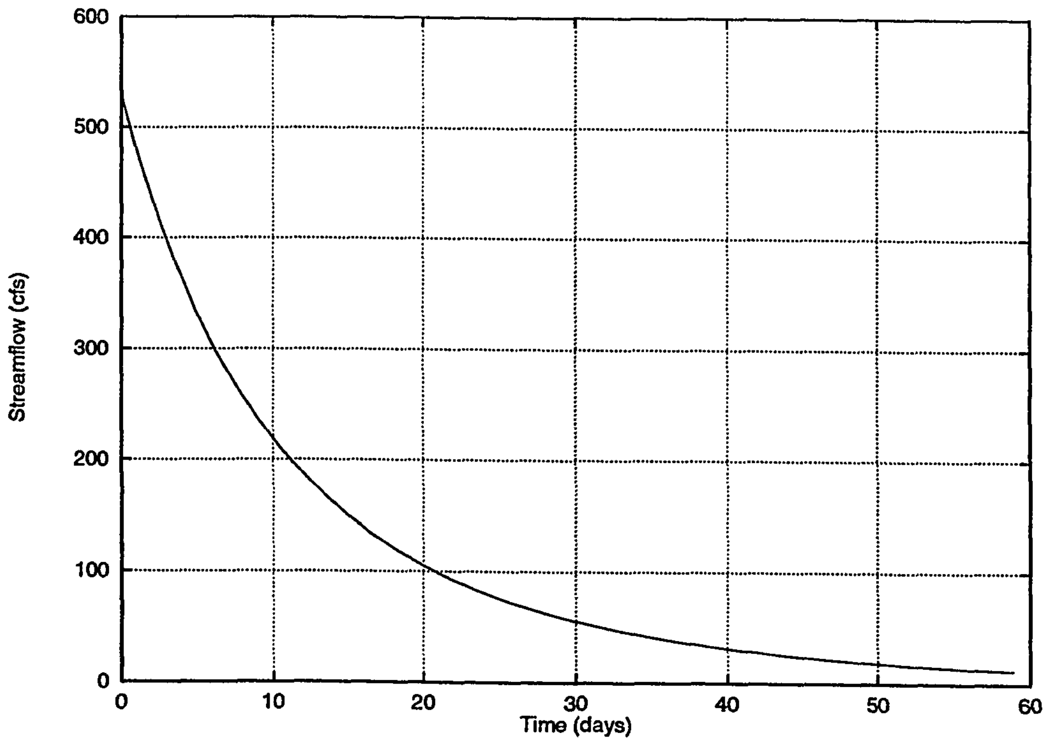

Figure 46.2: MRC of Beaver Creek at New Hartford (for summer), ID# 05463000

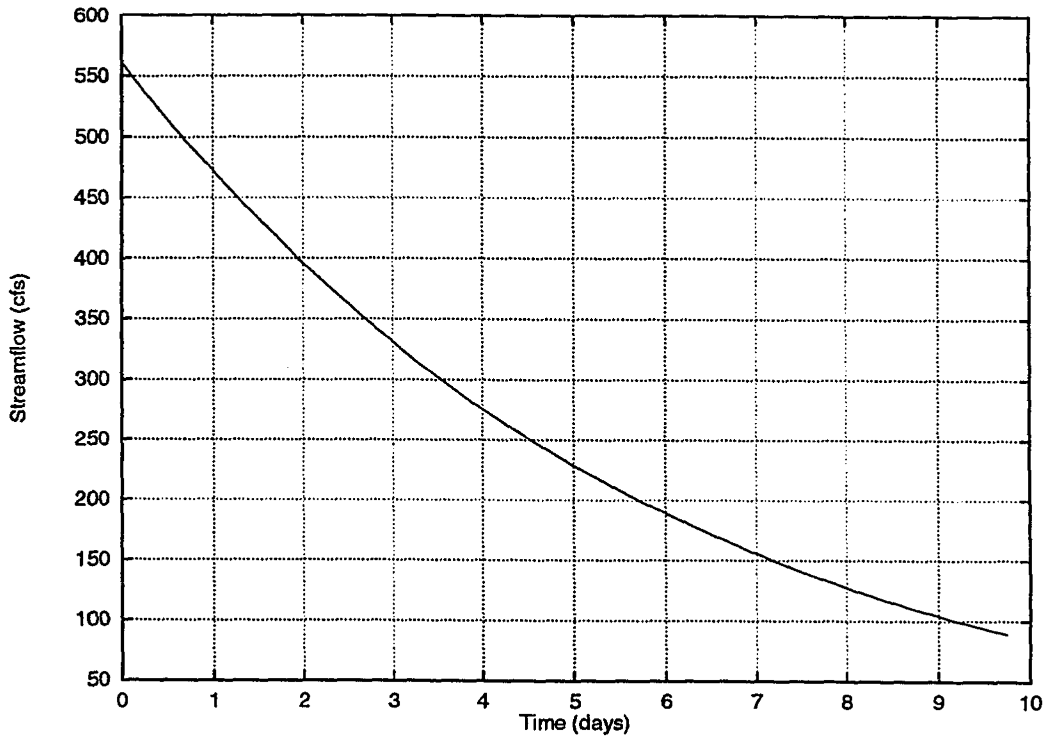

Figure 47.1: MRC of Black Hawk Creek at Hudson (for winter), ID# 05463500

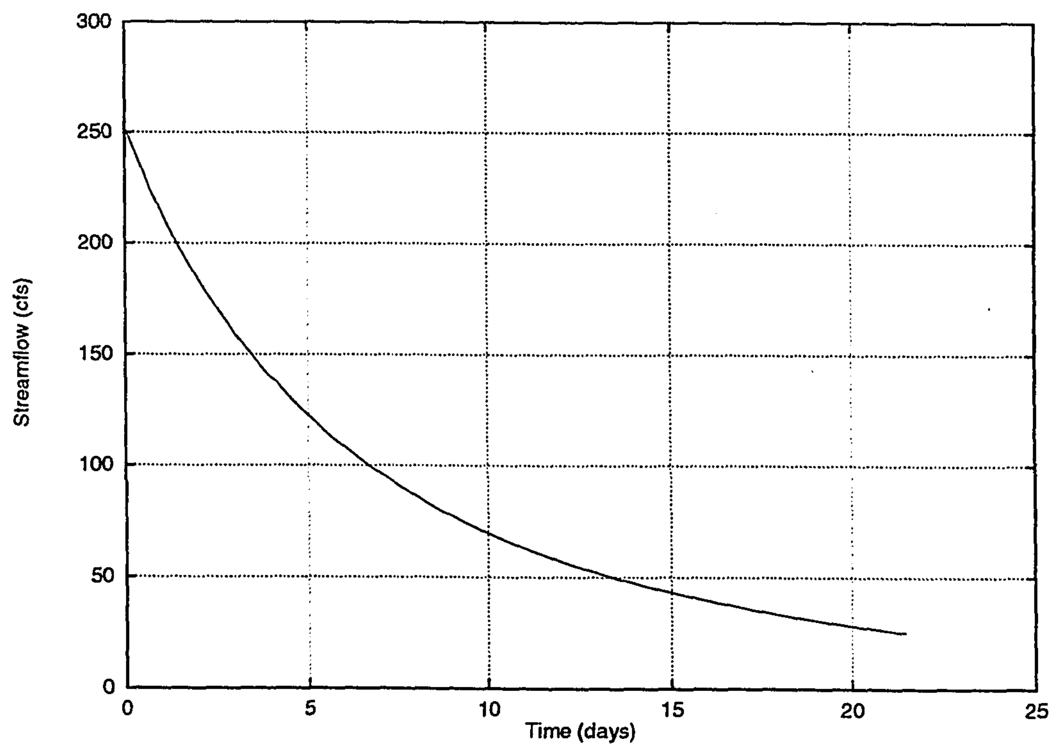

Figure 47.2: MRC of Black Hawk Creek at Hudson (for summer), ID# 05463500

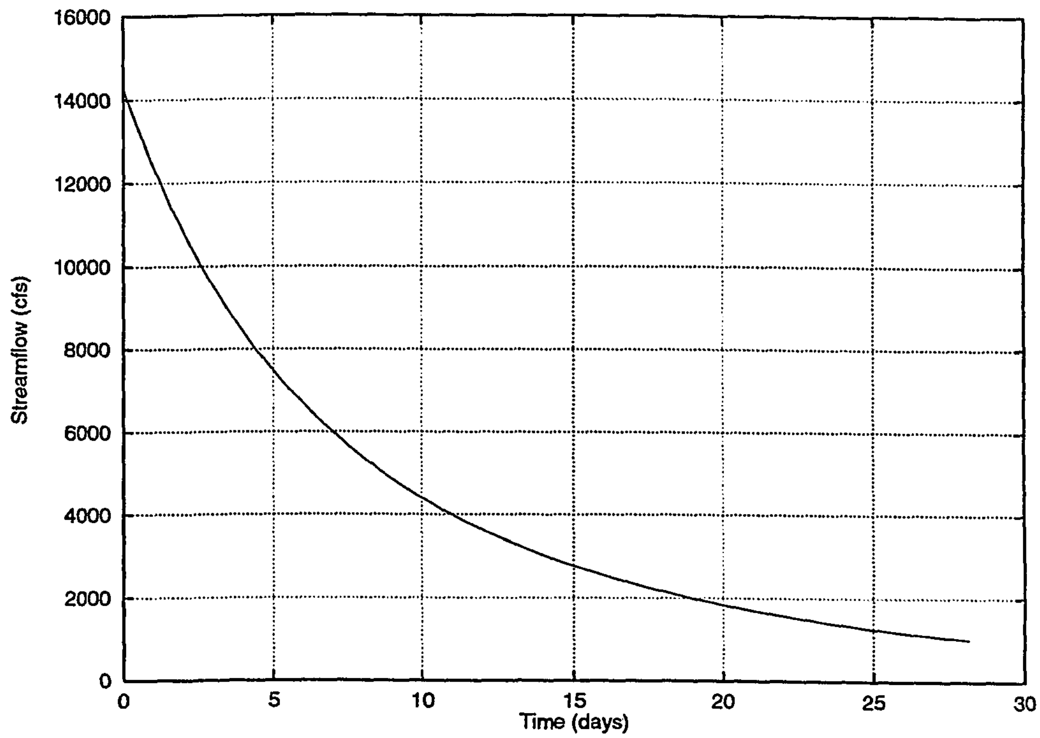

Figure 48.1: MRC of Cedar River at Waterloo (for winter), ID# 05464000

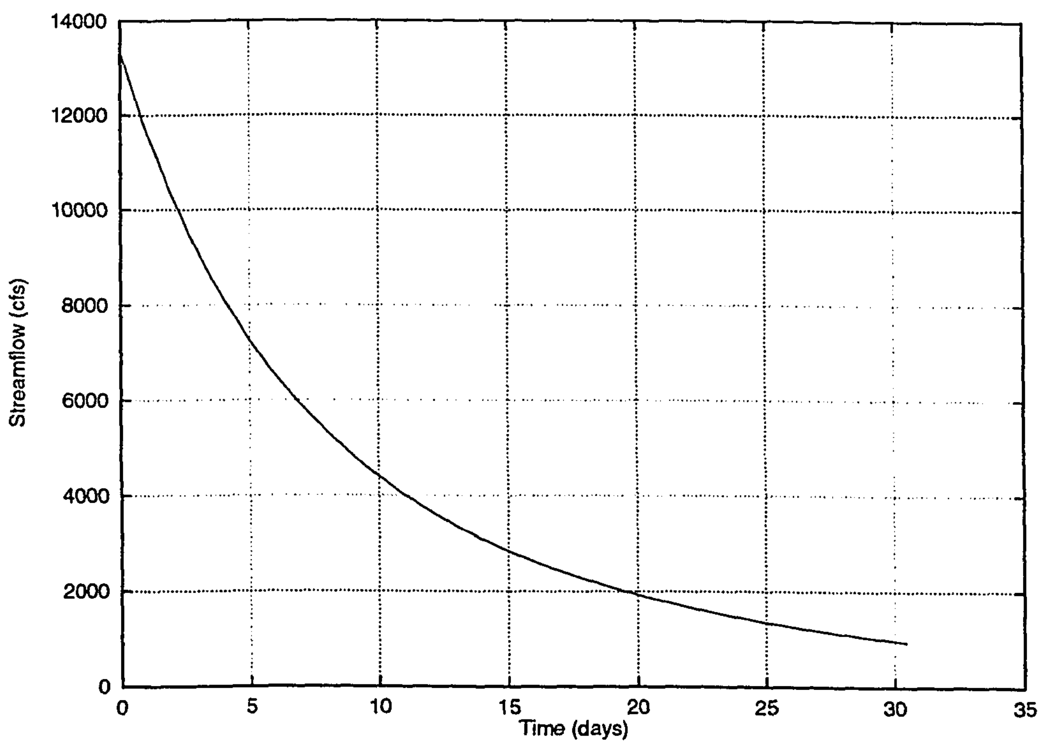

Figure 48.2: MRC of Cedar River at Waterloo (for summer), ID# 05464000

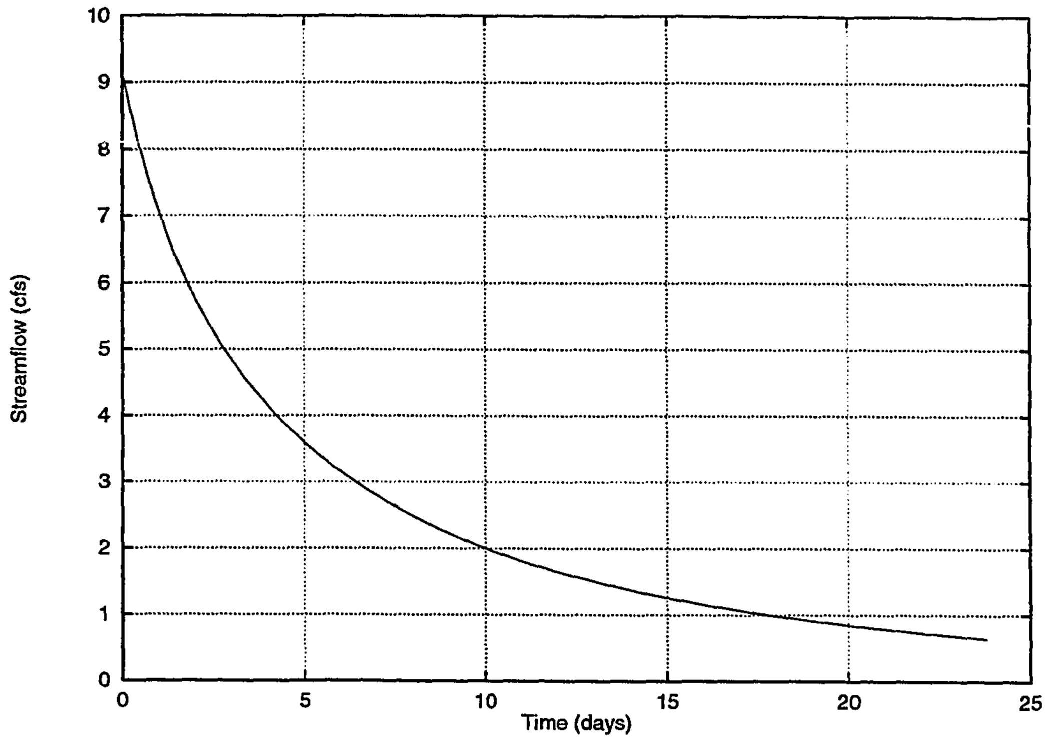

Figure 49.1: MRC of Fourmile Creek near Lincoln (for winter), ID# 05464130

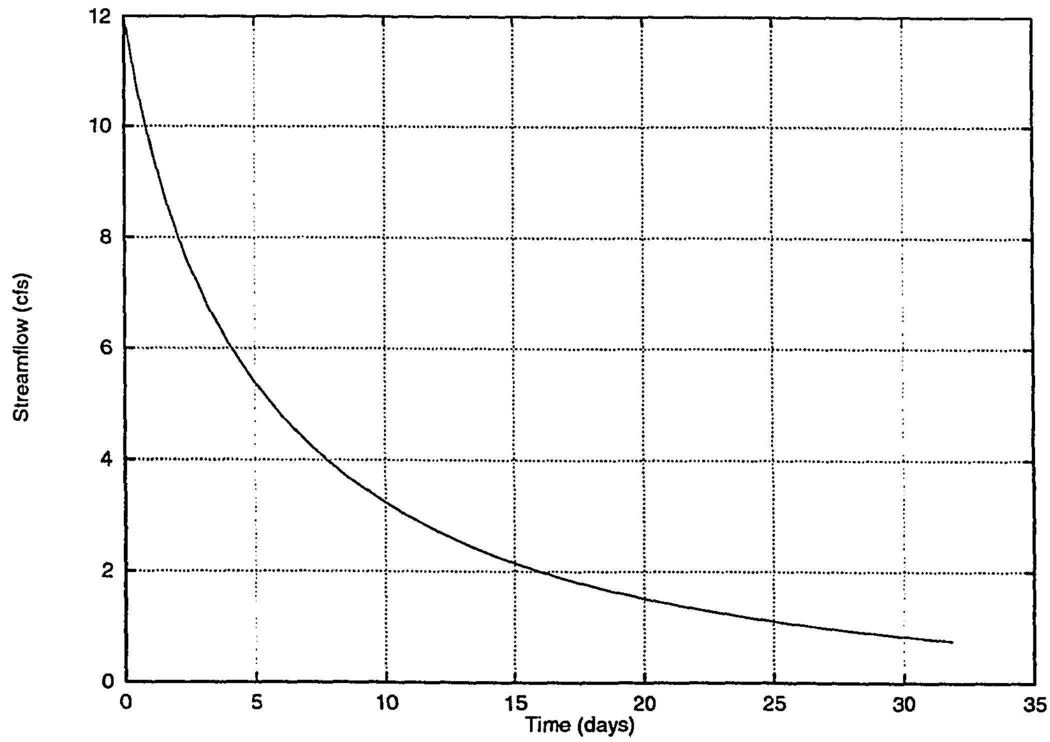

Figure 49.2: MRC of Fourmile Creek near Lincoln (for summer), ID# 05464130

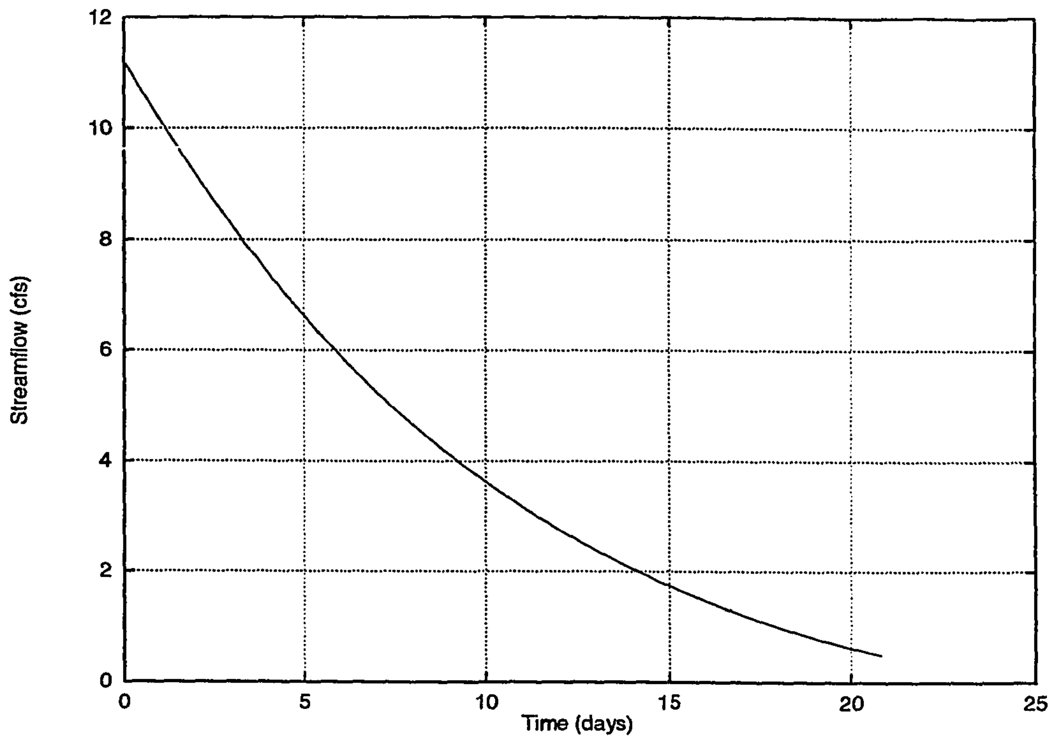

Figure 50.1: MRC of Fourmile Creek near Traer (for winter), ID# 05464137

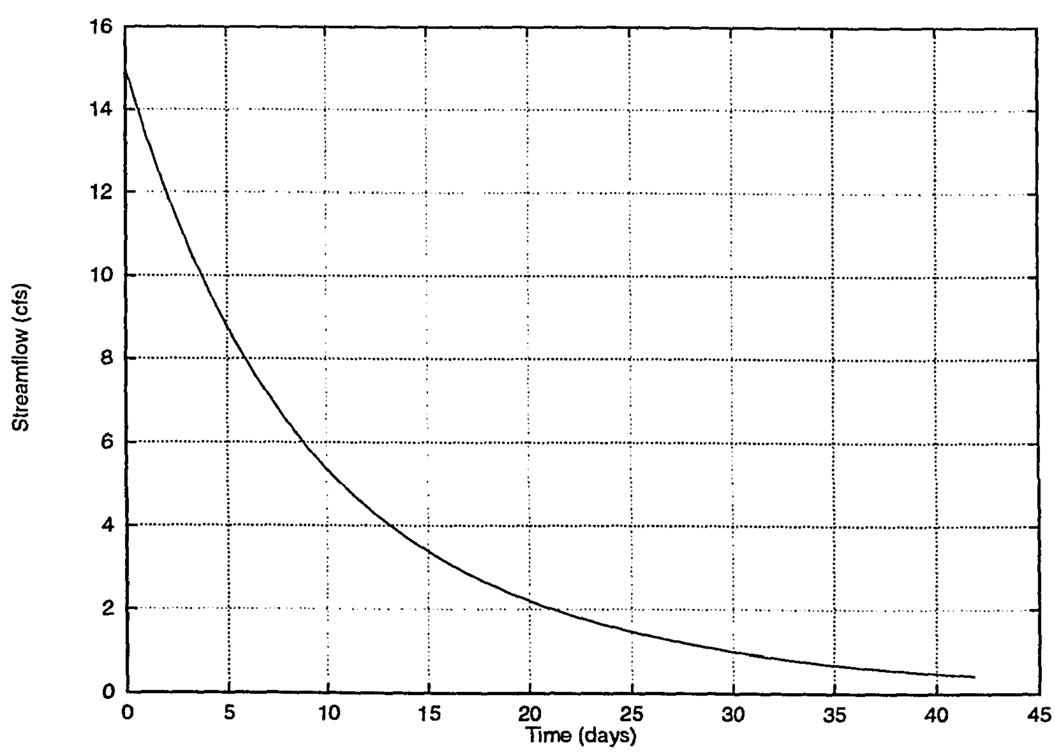

Figure 50.2: MRC of Fourmile Creek near Traer (for summer), ID# 05464137

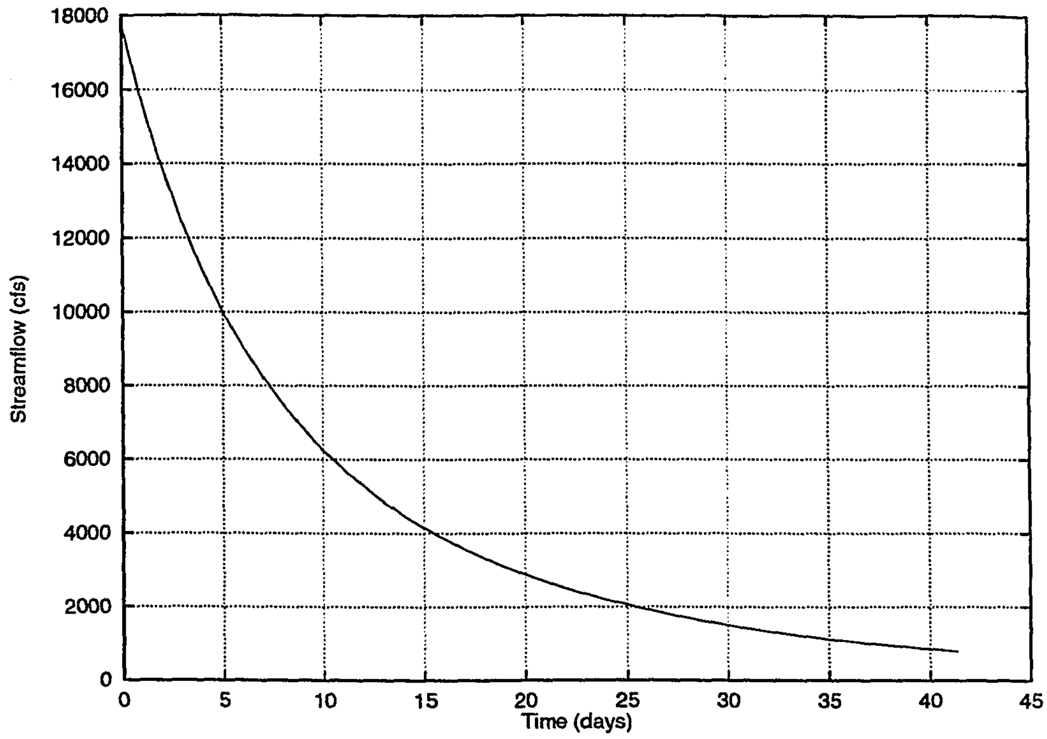

Figure 51.1: MRC of Cedar River at Cedar Rapids (for winter), ID# 05464500

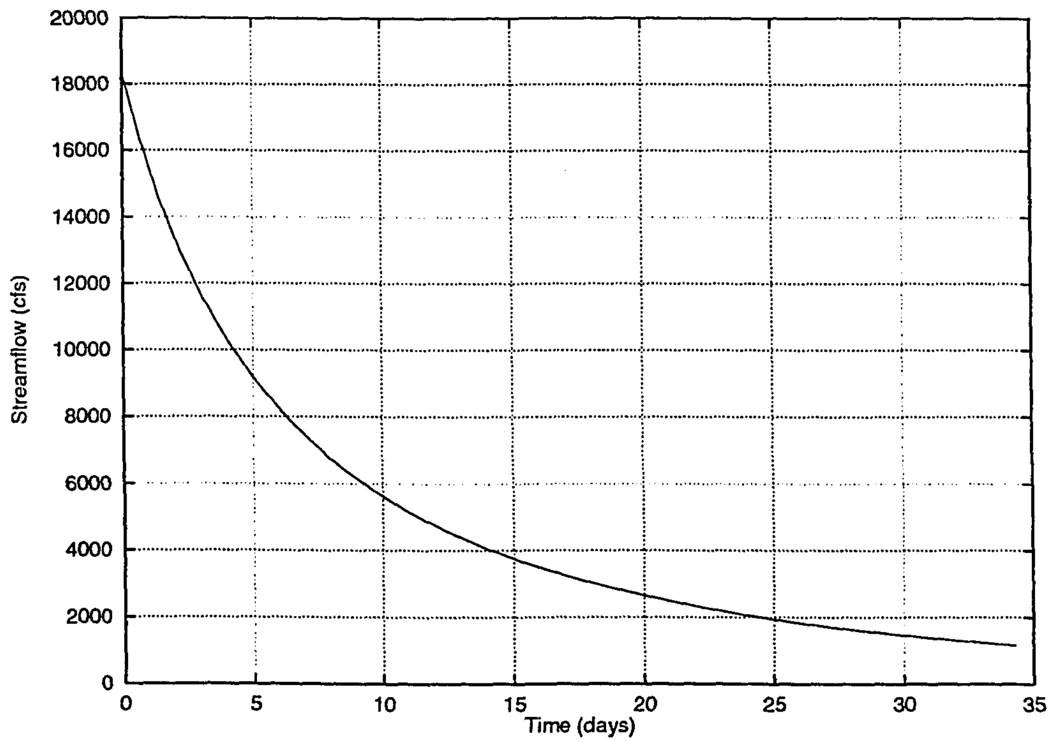

Figure 51.2: MRC of Cedar River at Cedar Rapids (for summer), ID# 05464500

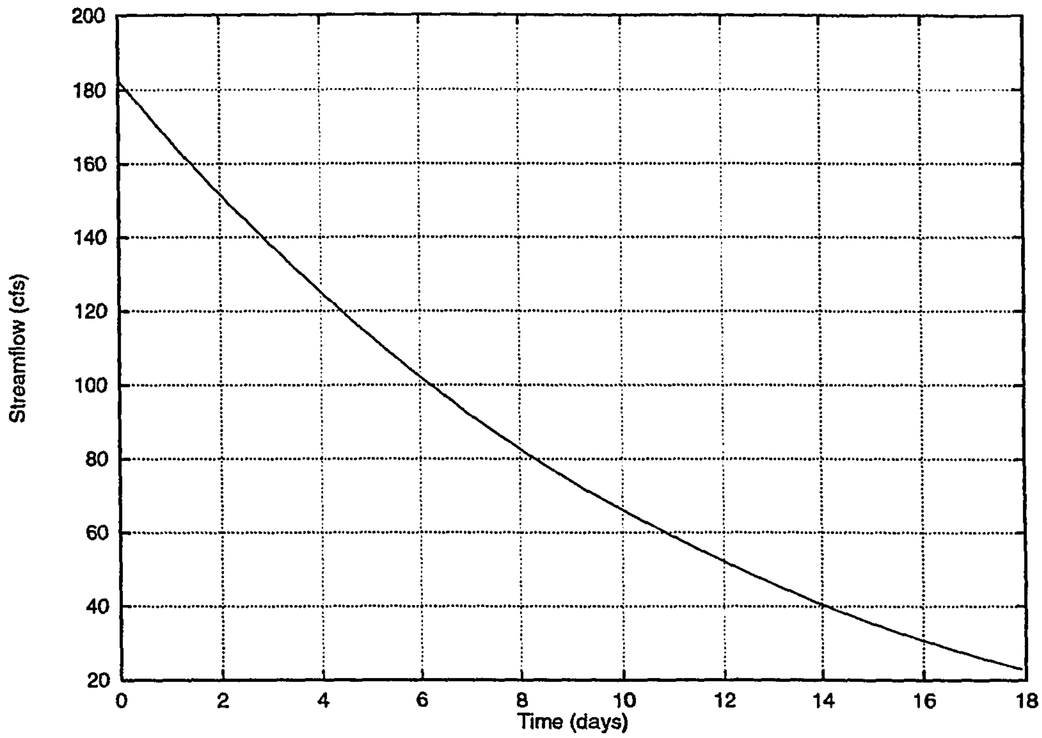

Figure 52.1: MRC of Prairie Creek at fairfax (for winter), ID# 05464640

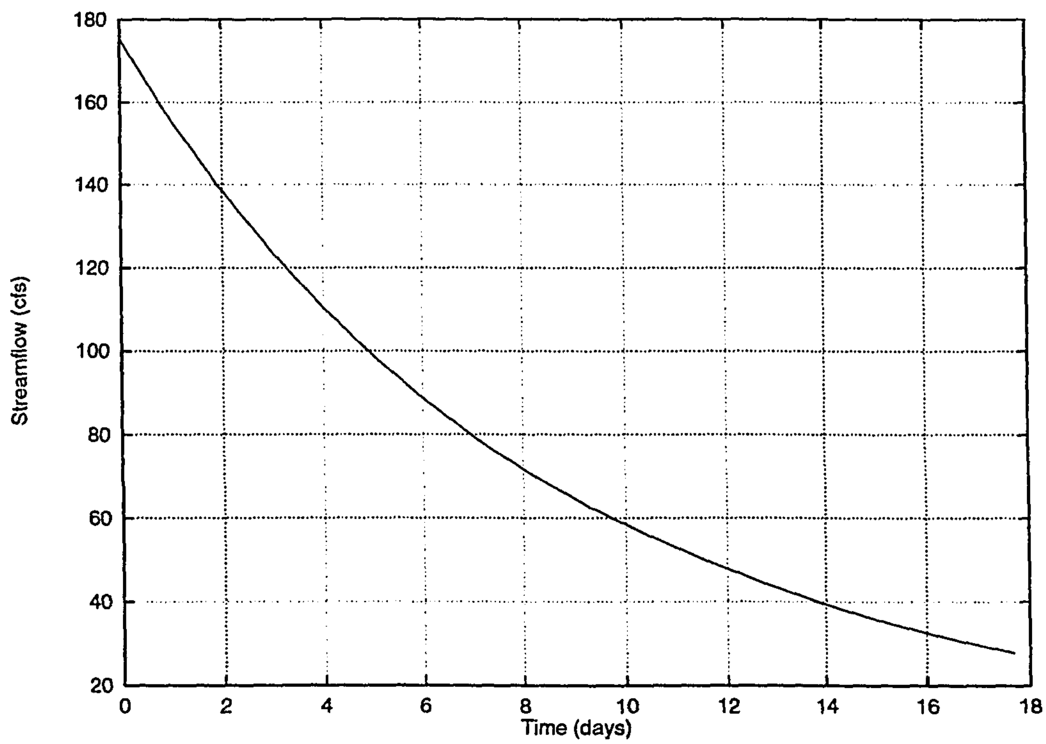

Figure 52.2: MRC of Prairie Creek at fairfax (for summer), ID# 05464640

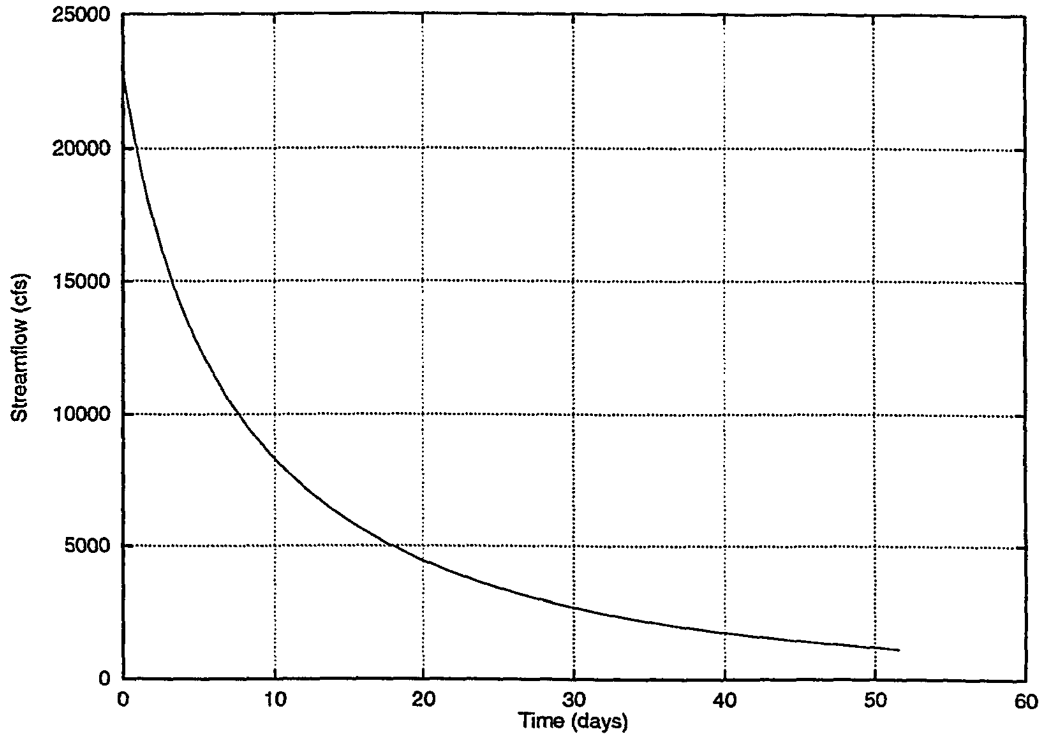

Figure 53.1: MRC of Cedar River near Conesville (for winter), ID# 05465000

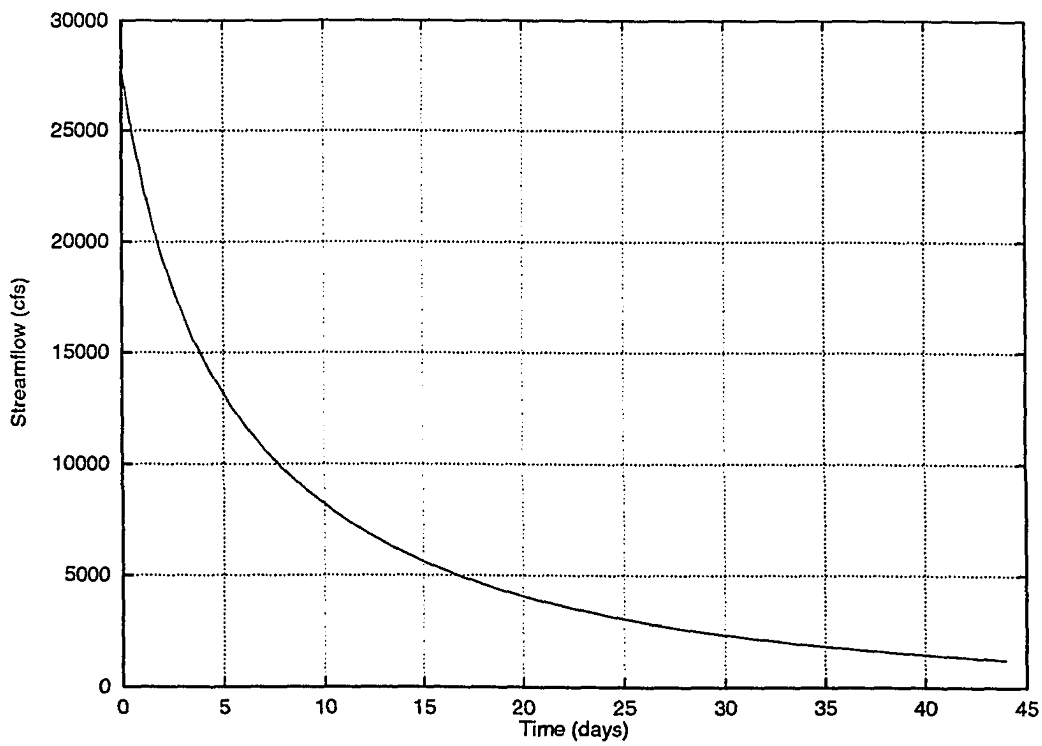

Figure 53.2: MRC of Cedar River near Conesville (for summer), ID# 05465000

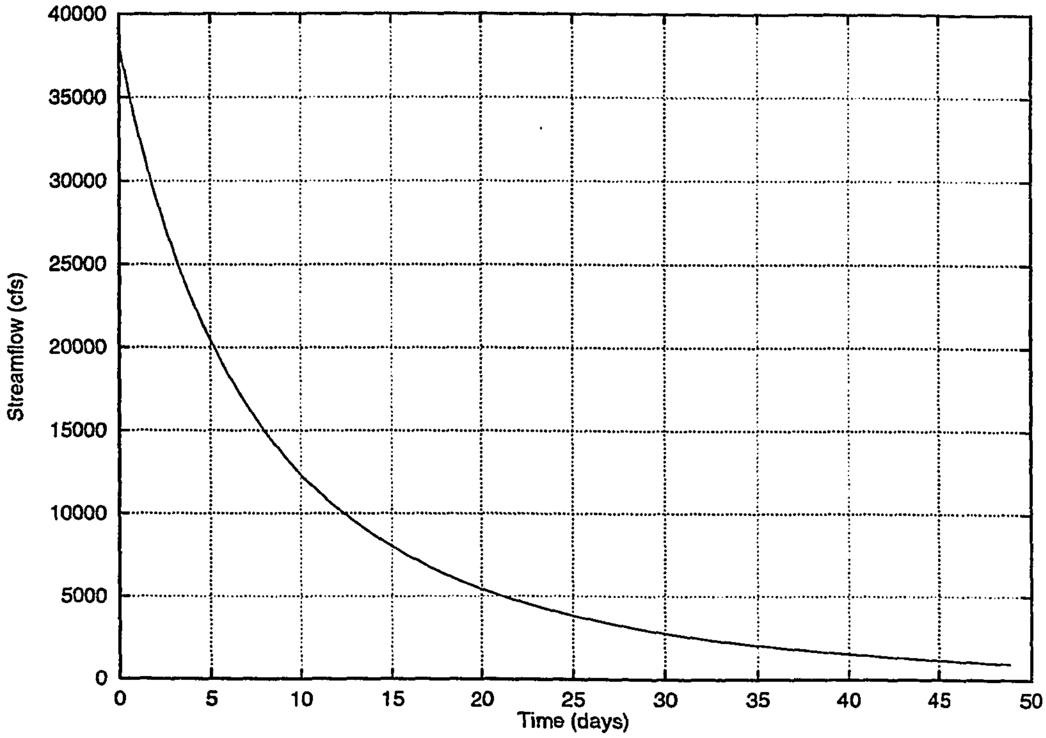

Figure 54.1: MRC of Iowa River at Wapello (for winter), ID# 05465500

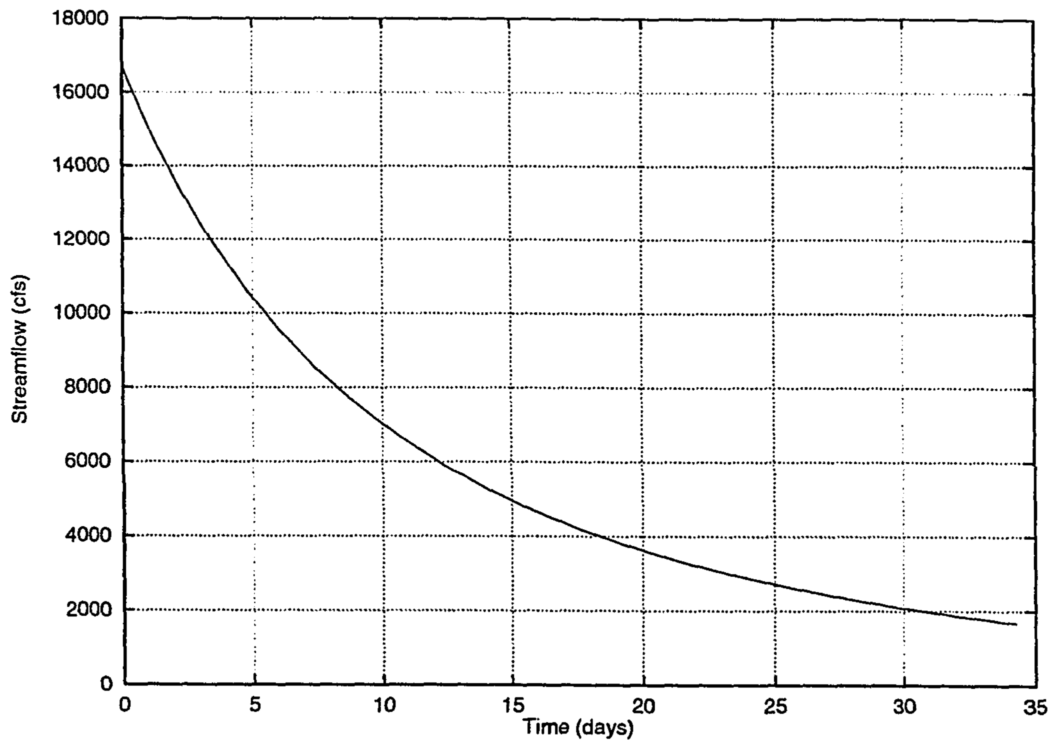

Figure 54.2: MRC of Iowa River at Wapello (for summer), ID# 05465500

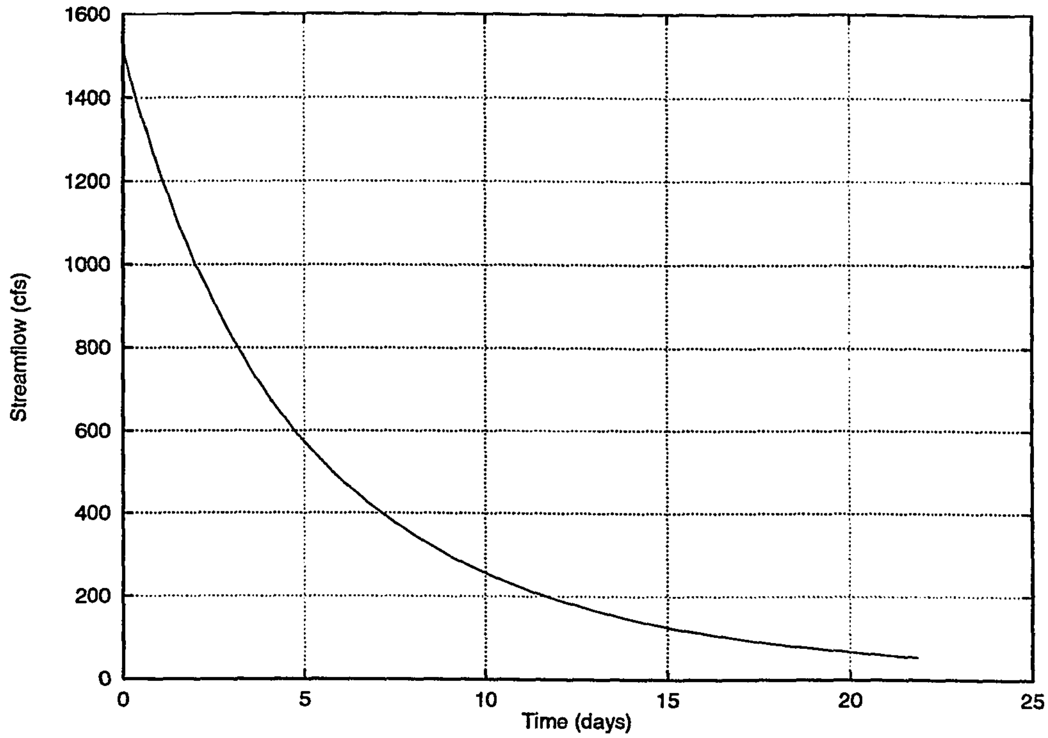

Figure 55.1: MRC of South Skunk River near Ames (for winter), ID# 05470000

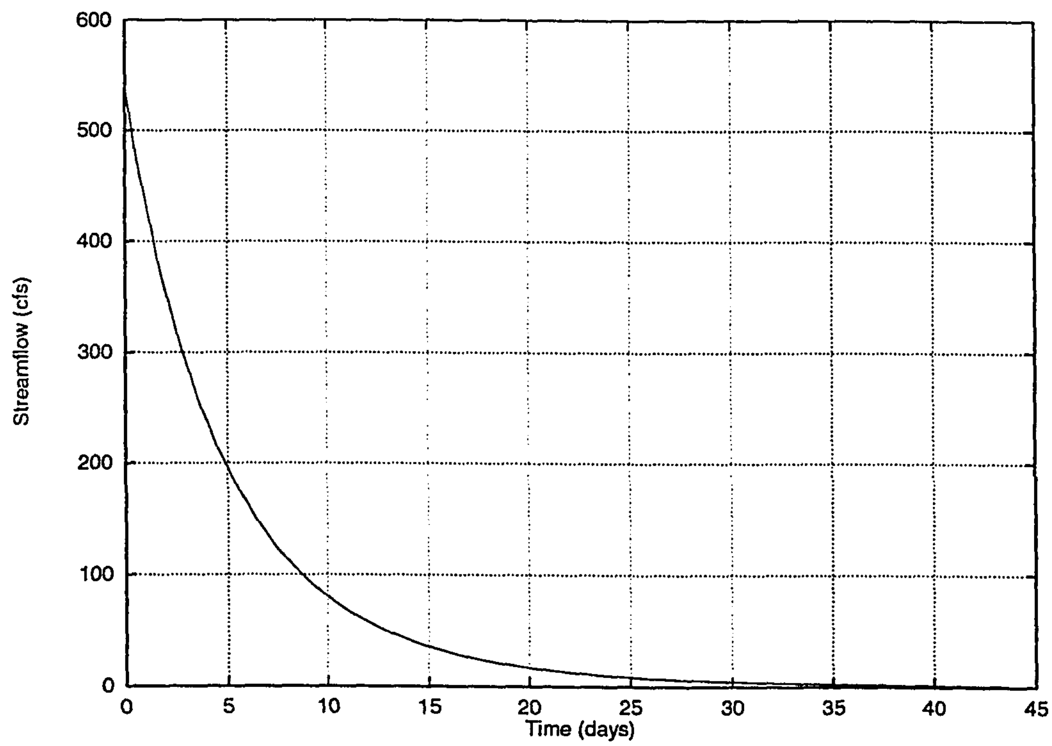

Figure 55.2: MRC of South Skunk River near Ames (for summer), ID# 05470000

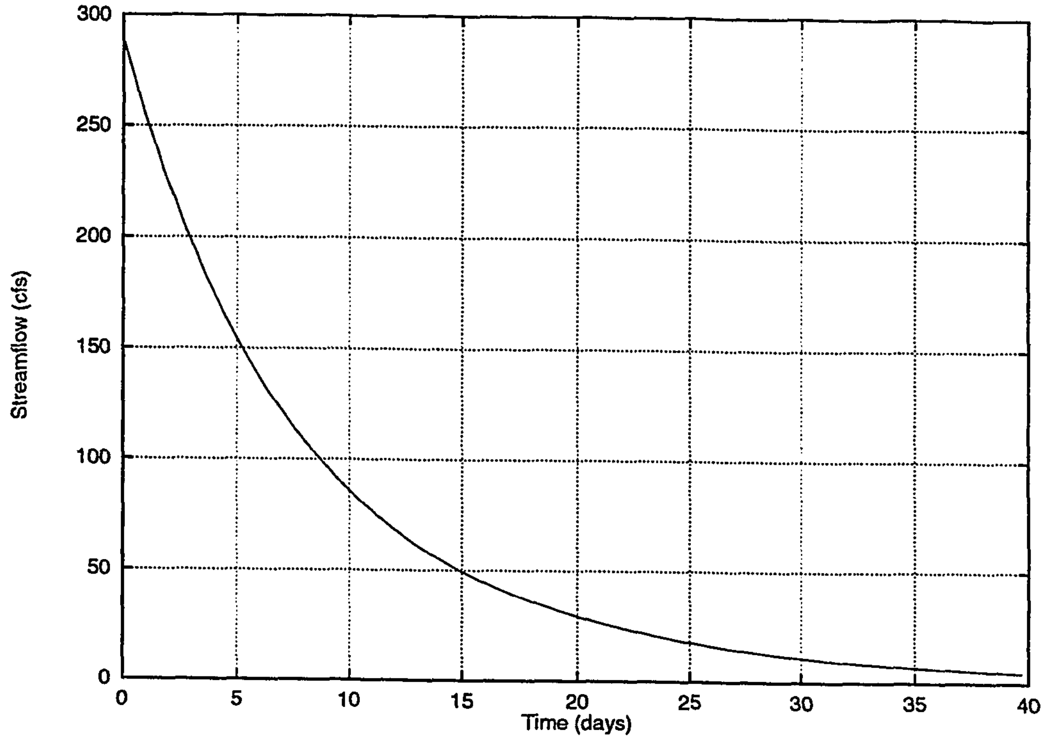

Figure 56.1: MRC of Squaw Creek at Ames (for winter), ID# 05470500

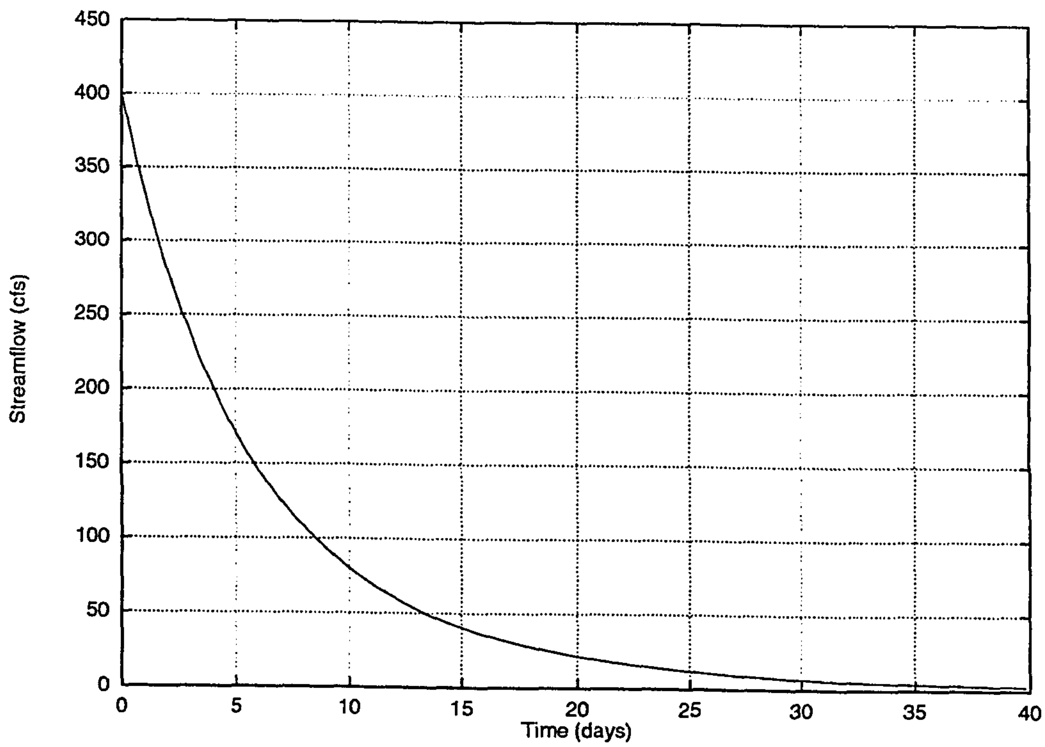

Figure 56.2: MRC of Squaw Creek at Ames (for summer), ID# 05470500

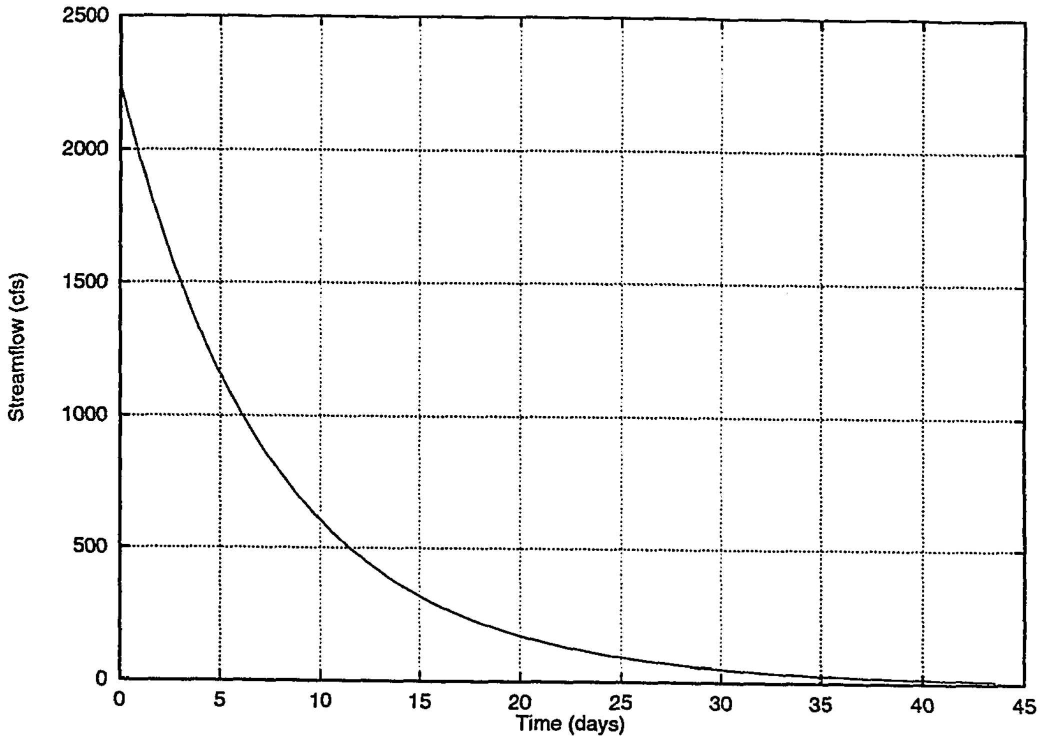

Figure 57.1: MRC of South Skunk River below Squaw Creek near Ames (for winter), ID# 05471000

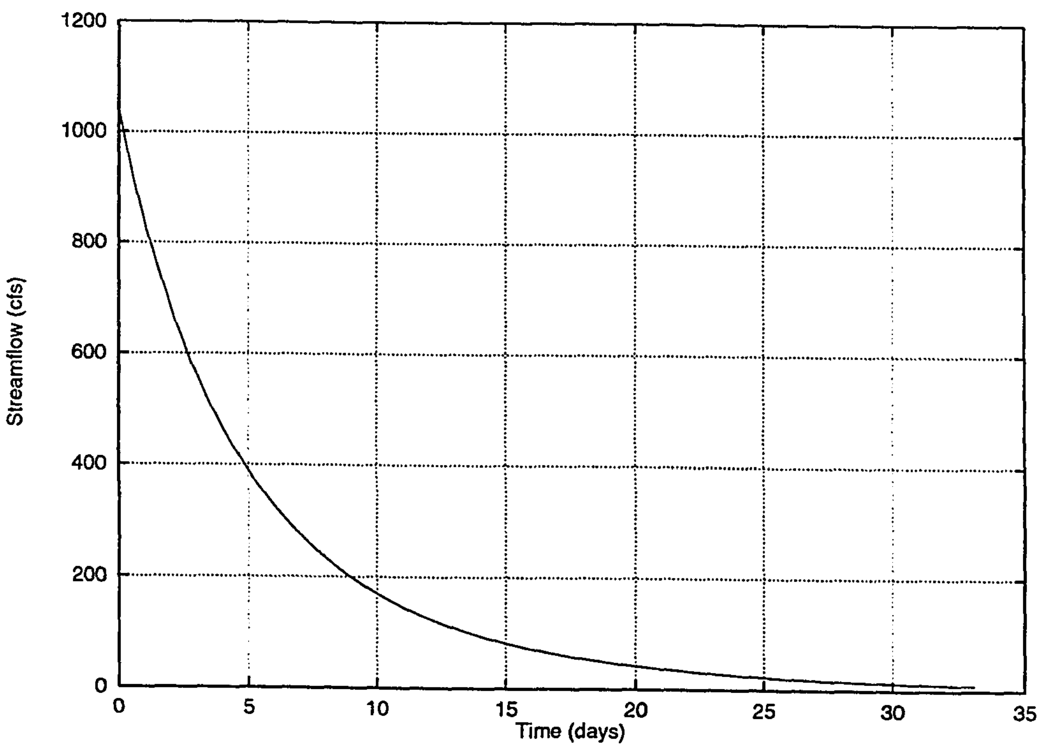

Figure 57.2: MRC of South Skunk River below Squaw Creek near Ames (for summer), ID# 05471000

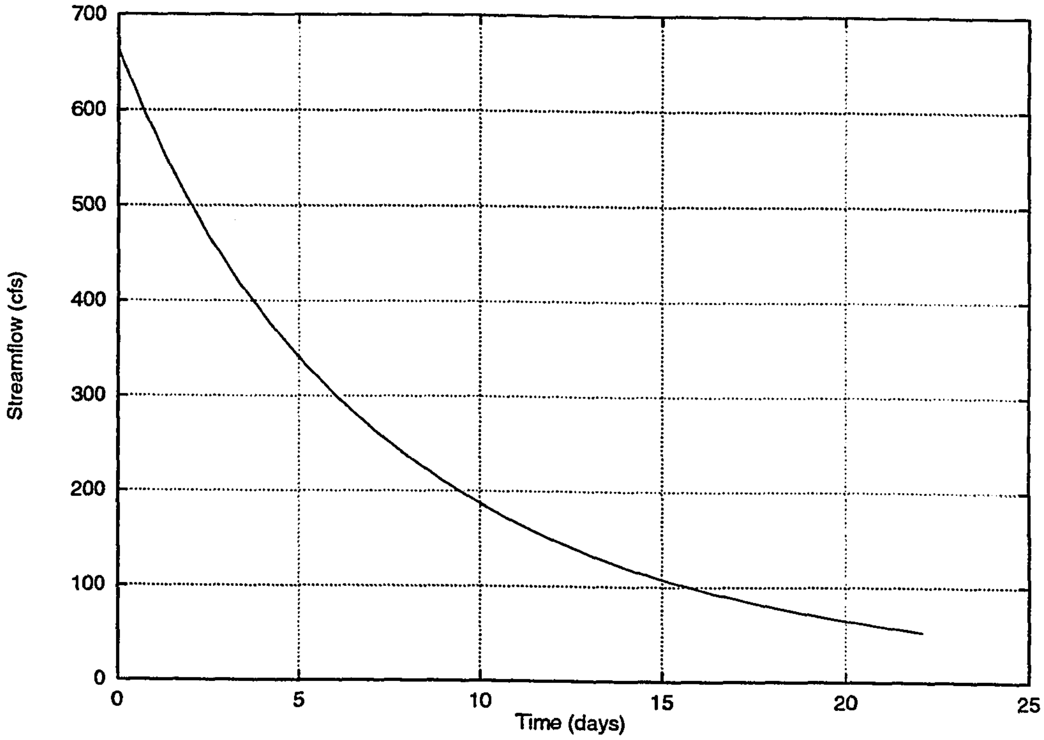

Figure 58.1: MRC of Indian Creek near Mingo (for winter), ID# 05471200

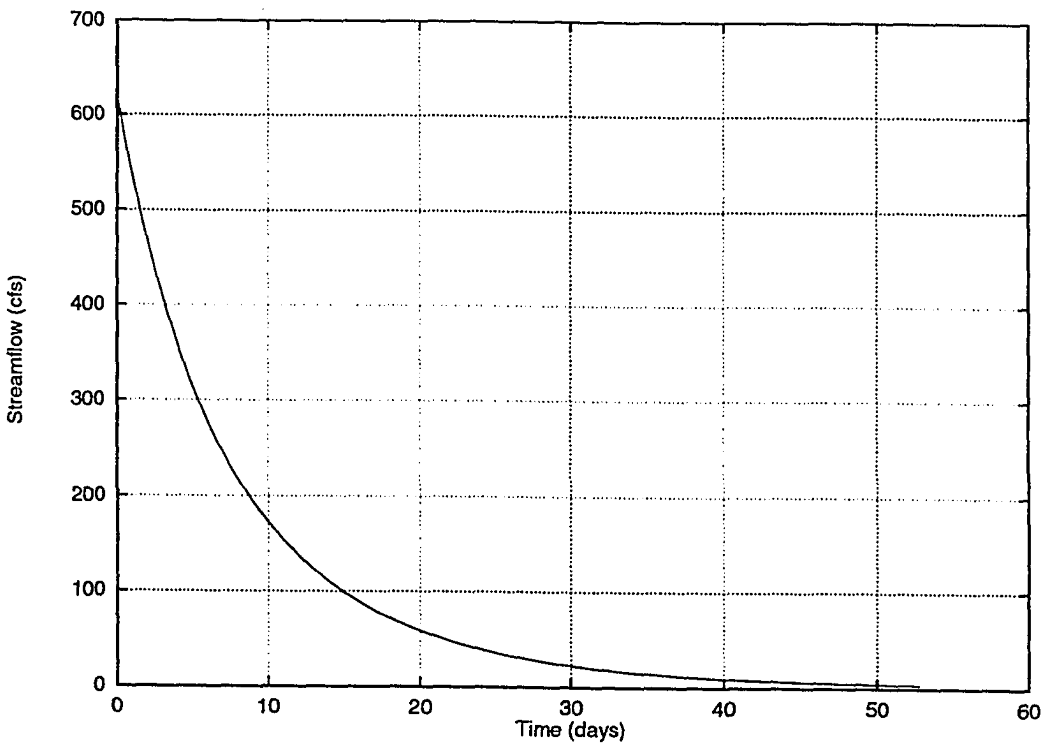

Figure 58.2: MRC of Indian Creek near Mingo (for summer), ID# 05471200

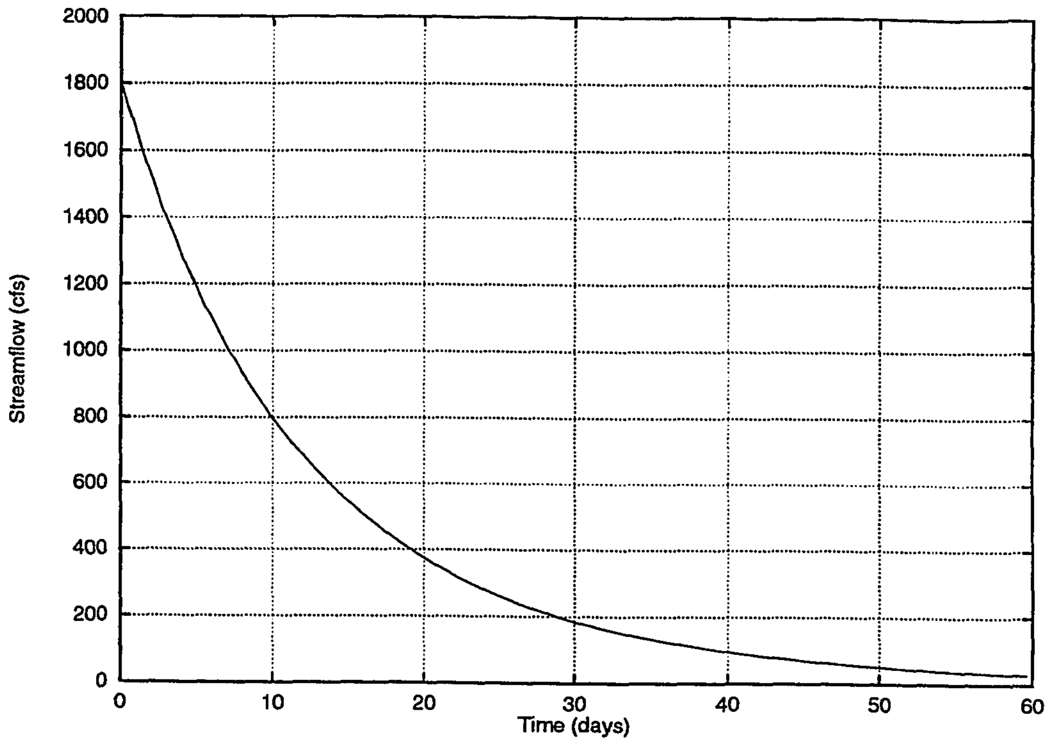

Figure 59.1: MRC of South Skunk River near Oskaloosa (for winter), ID# 05471500

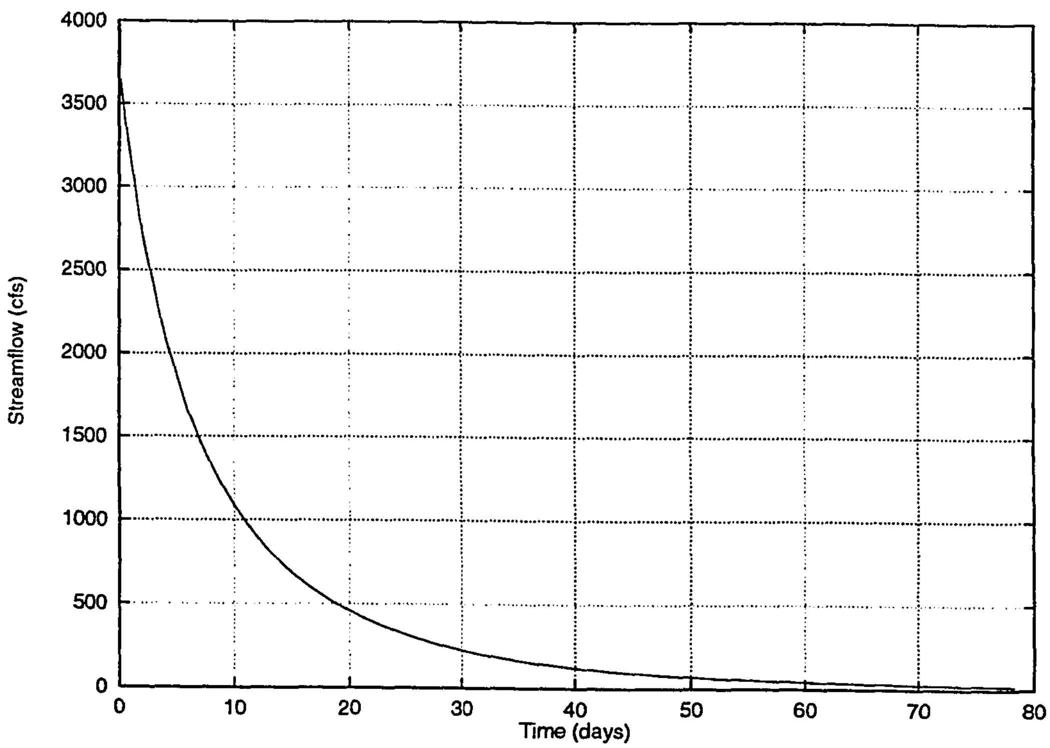

Figure 59.2: MRC of South Skunk River near Oskaloosa (for summer), ID# 05471500

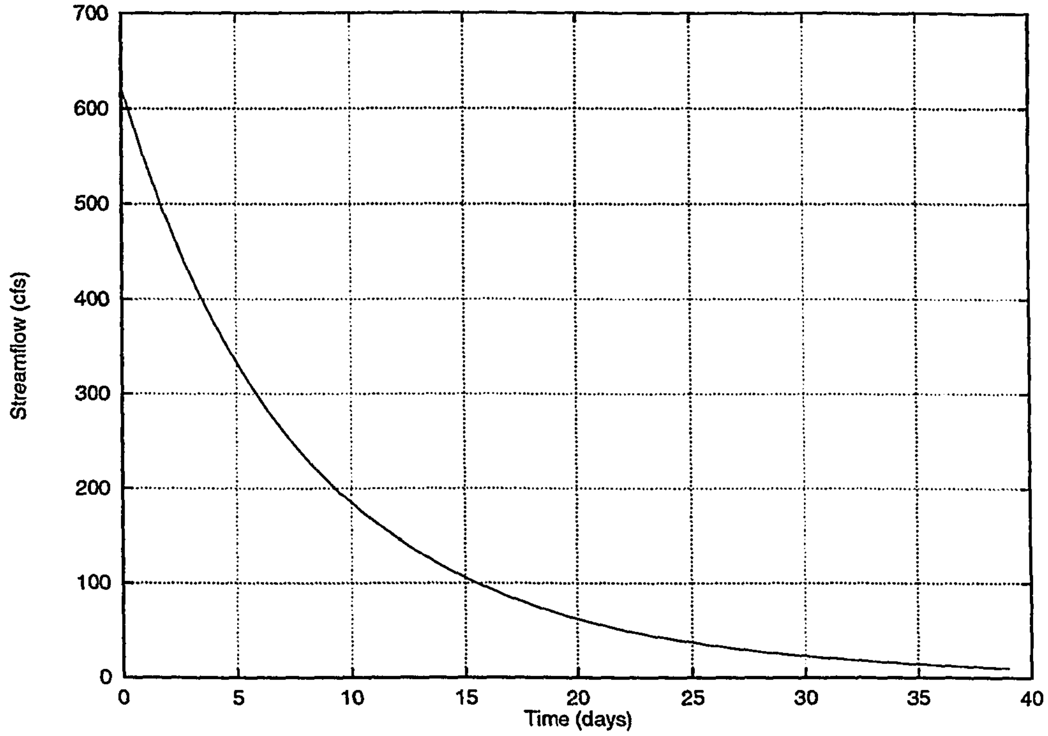

Figure 60.1: MRC of North Skunk River near Sigourney (for winter), ID# 05472500

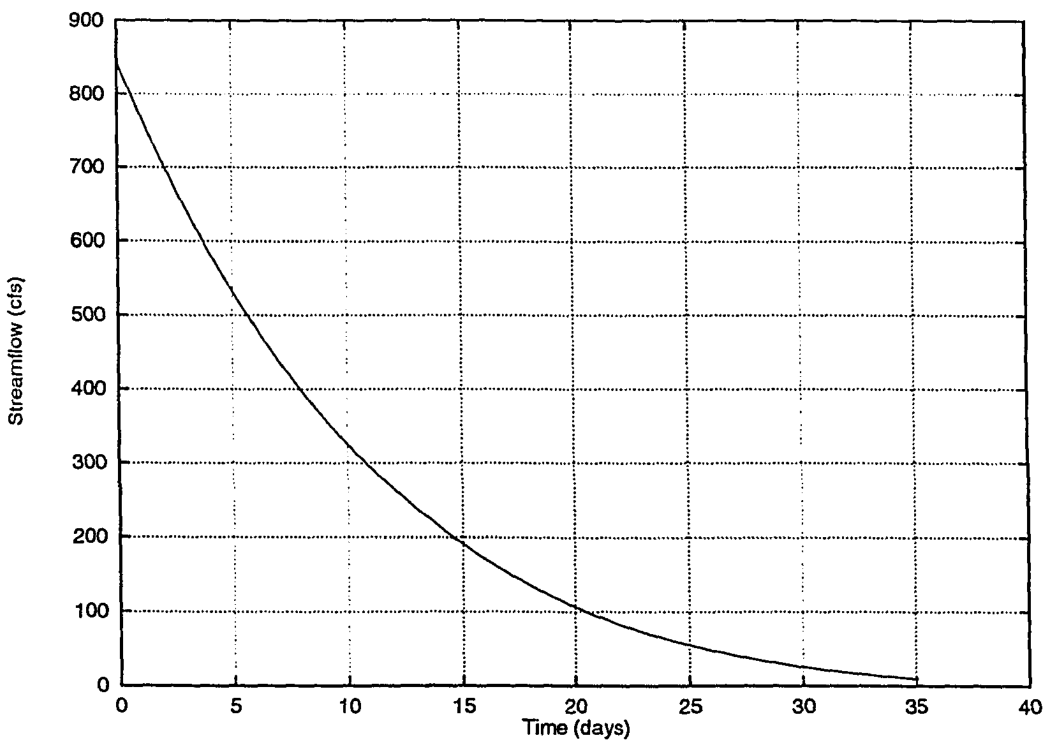

Figure 60.2: MRC of North Skunk River near Sigourney (for summer), ID# 05472500

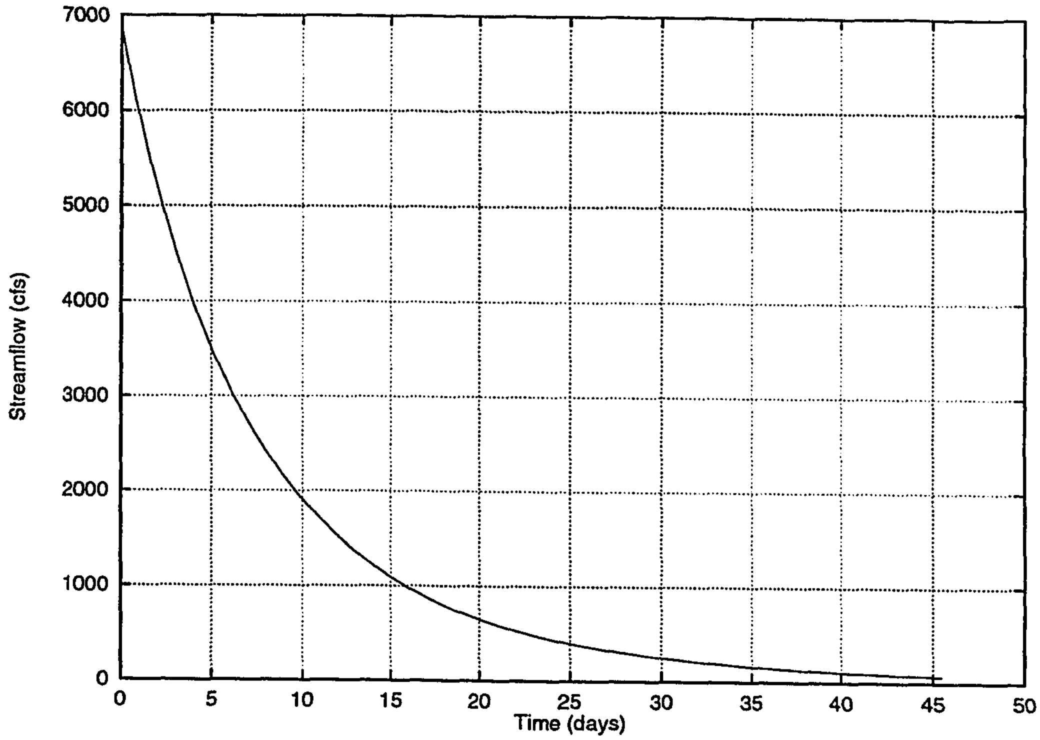

Figure 61.1: MRC of Skunk River at Coppock (for winter), ID# 05473000

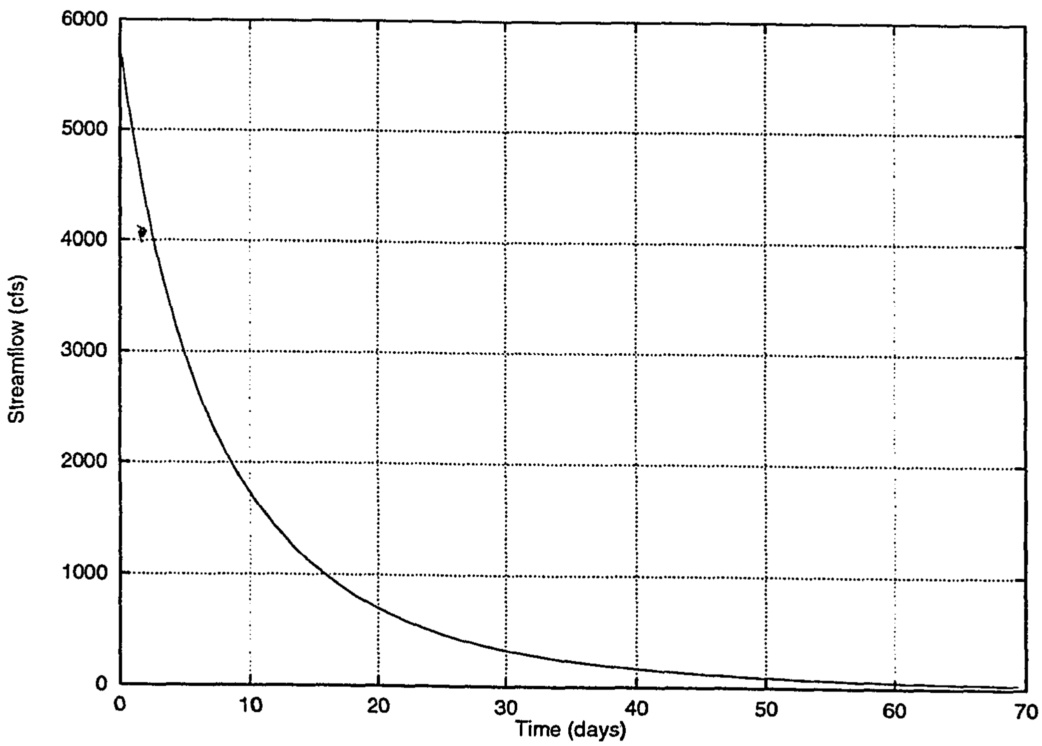

Figure 61.2: MRC of Skunk River at Coppock (for summer), ID# 05473000

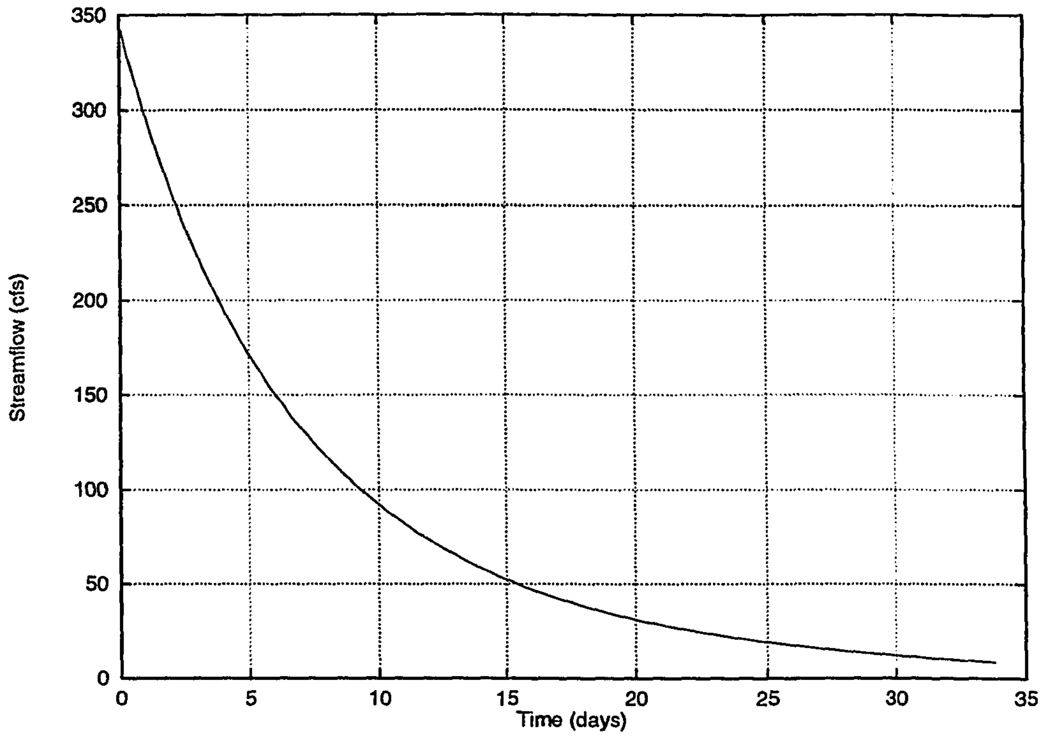

Figure 62.1: MRC of Cedar Creek near Oakland Mills (for winter), ID# 05473400

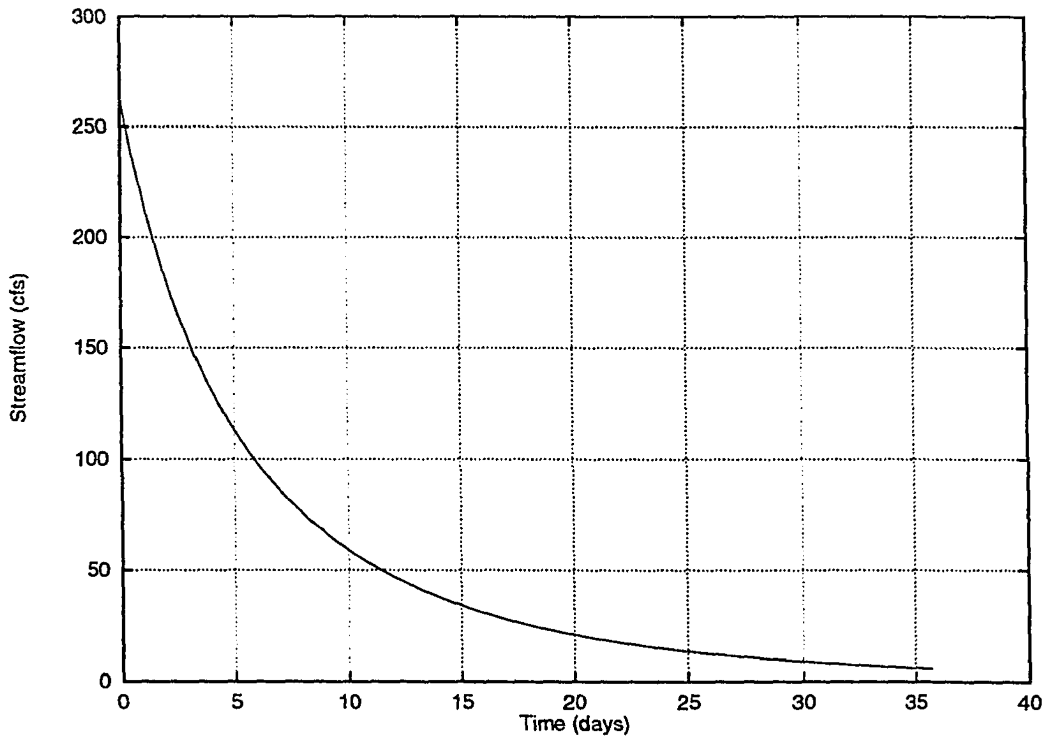

Figure 62.2: MRC of Cedar Creek near Oakland Mills (for summer), ID# 05473400

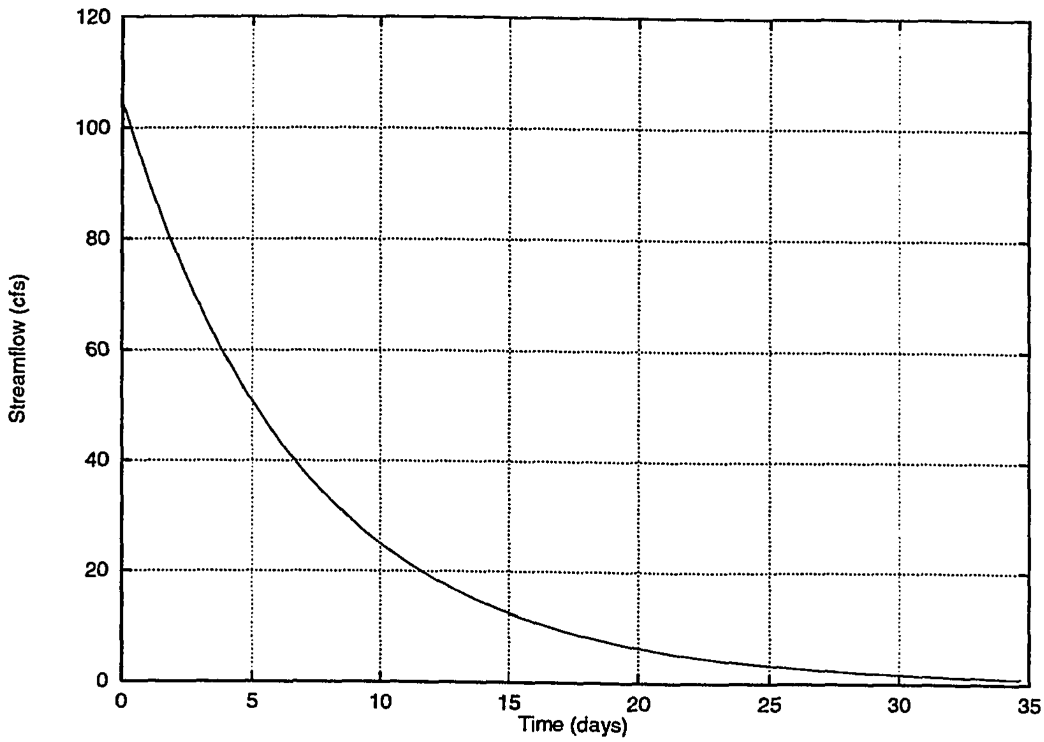

Figure 63.1: MRC of Big Creek near Mount Pleasant (for winter), ID# 05473500

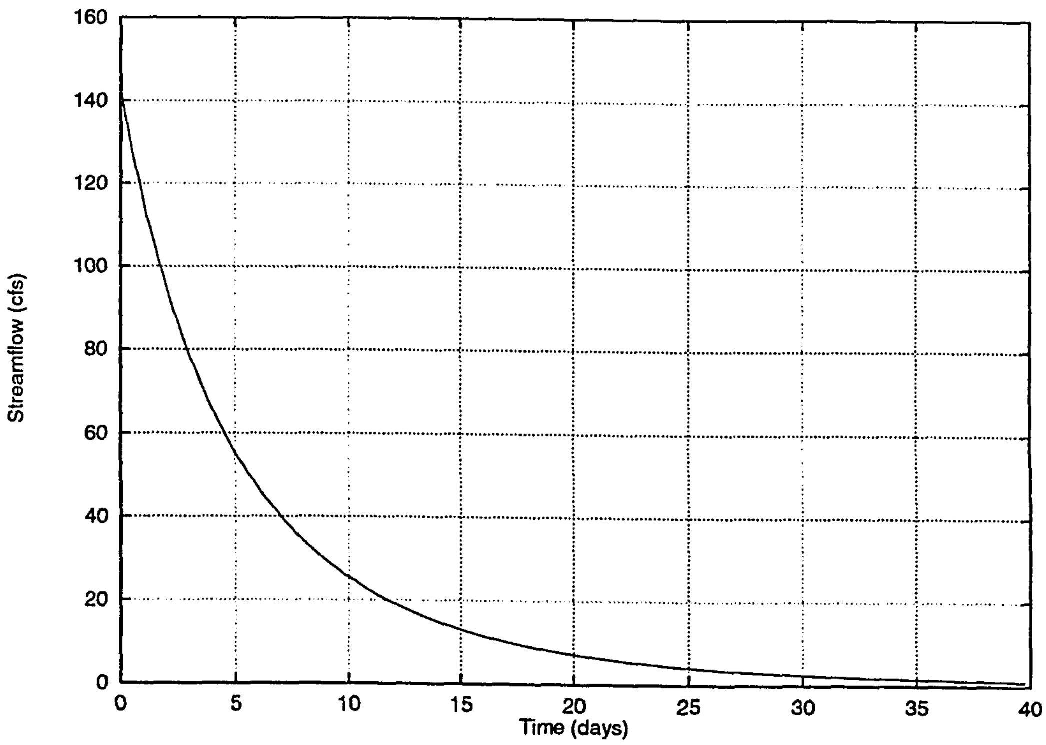

Figure 63.2: MRC of Big Creek near Mount Pleasant (for summer), ID# 05473500

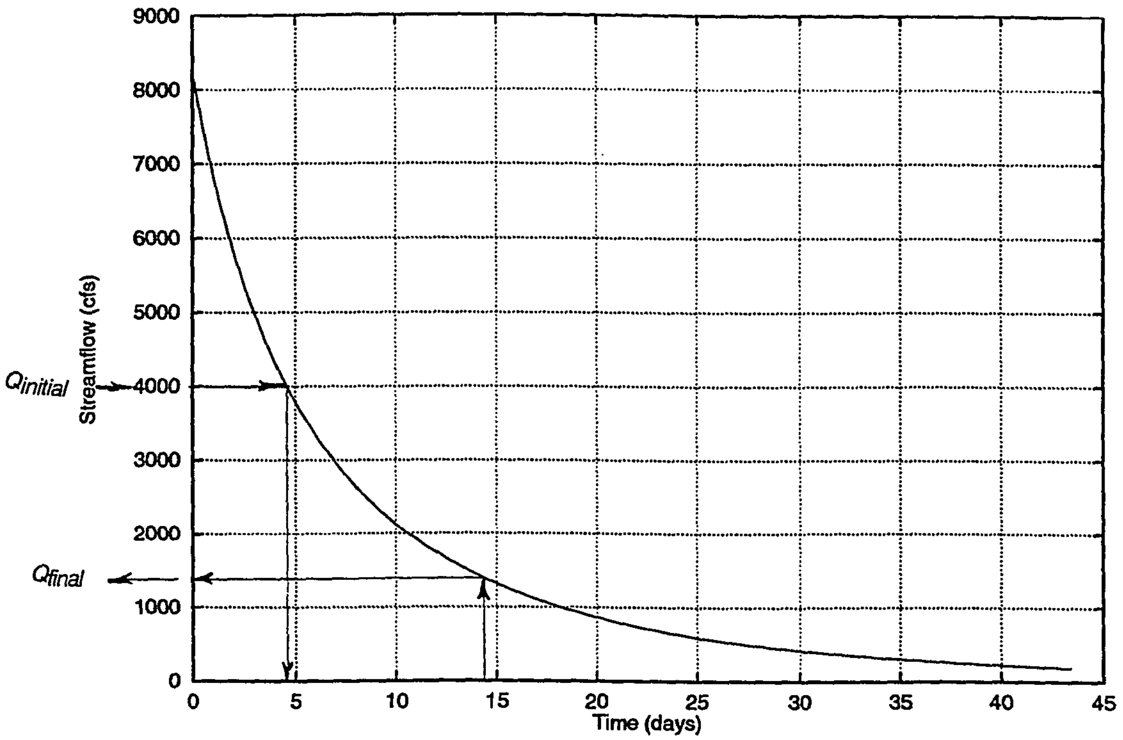

Figure 64.1: MRC of Skunk River at Augusta (for winter), ID# 05474000

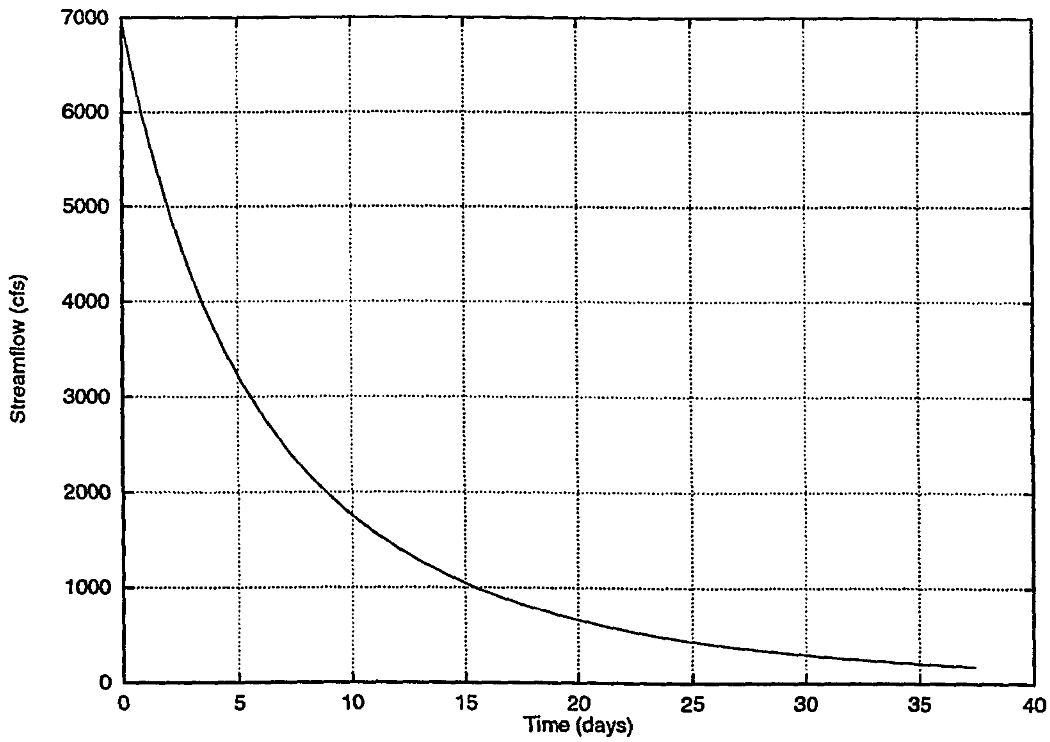

Figure 64.2: MRC of Skunk River at Augusta (for summer), ID# 05474000

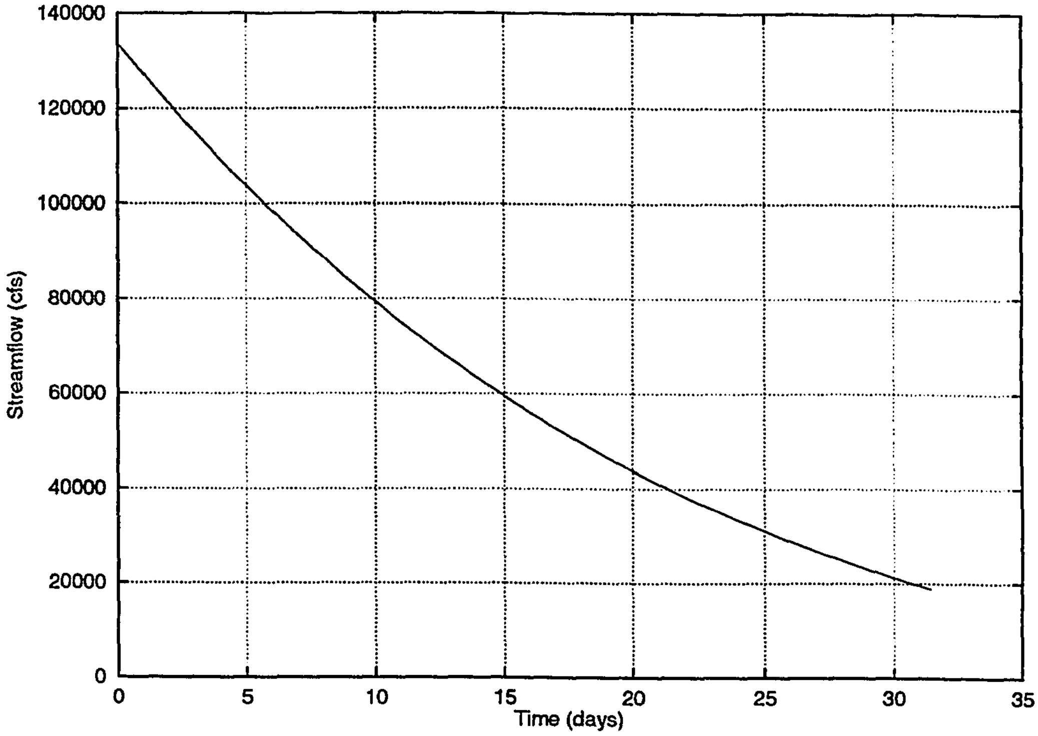

Figure 65.1: MRC of Mississippi River at Keokuk (for winter), ID# 05474500

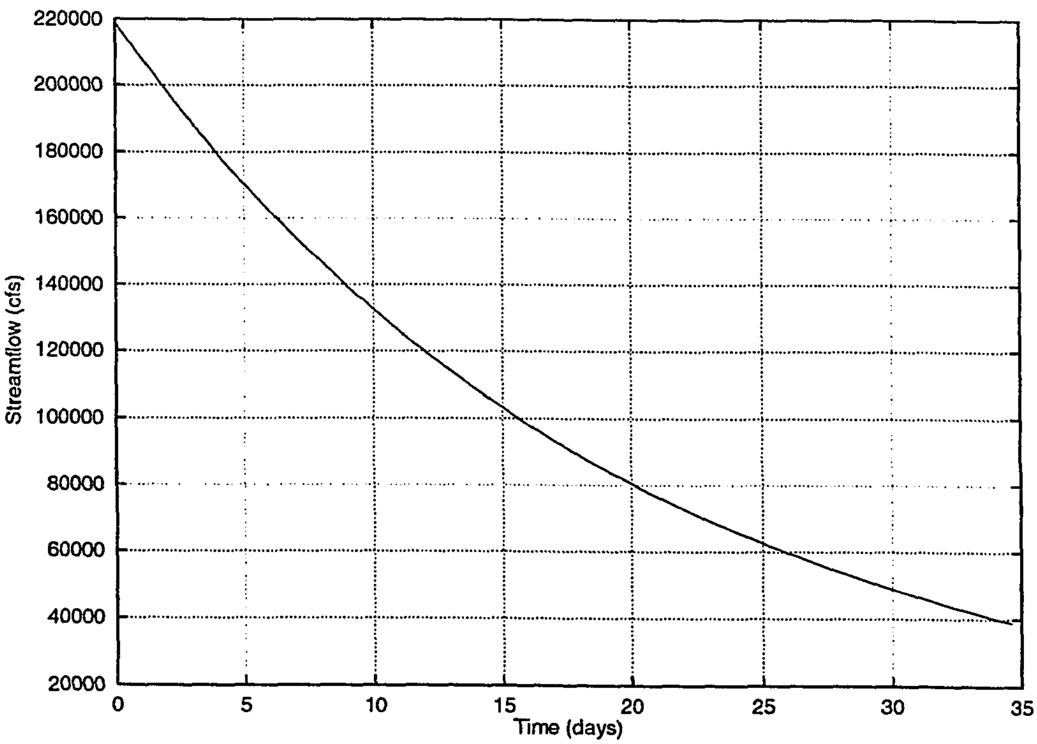

Figure 65.2: MRC of Mississippi River at Keokuk (for summer), ID# 05474500

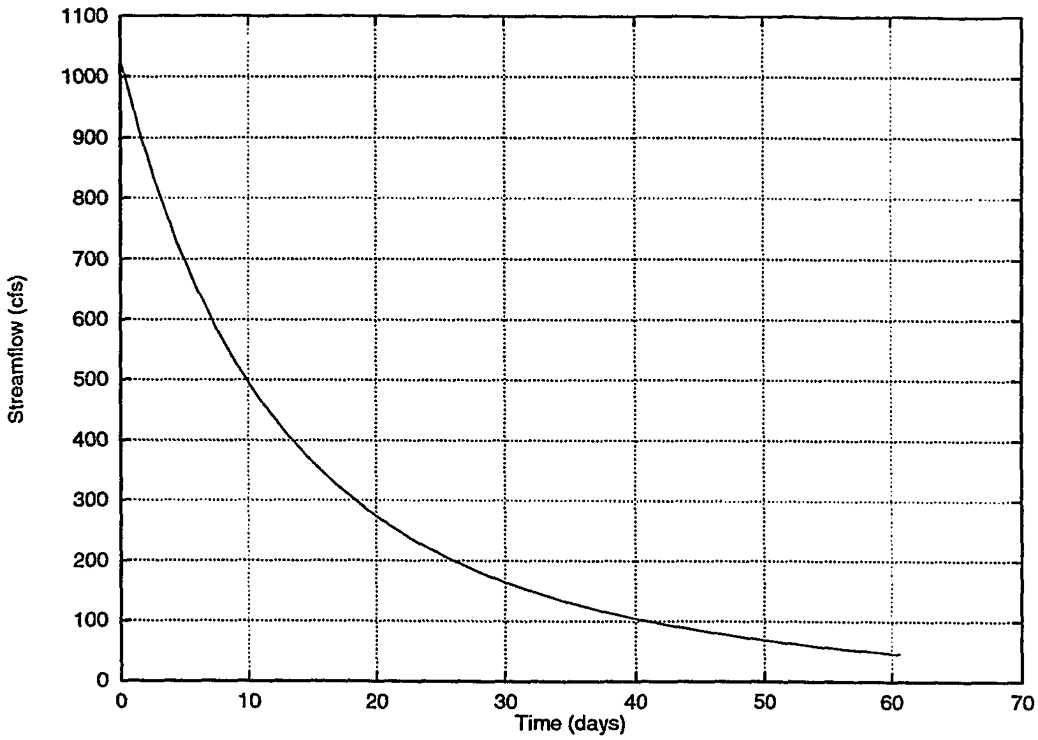

Figure 66.1: MRC of Des Moines River at Humboldt (for winter), ID# 05476750

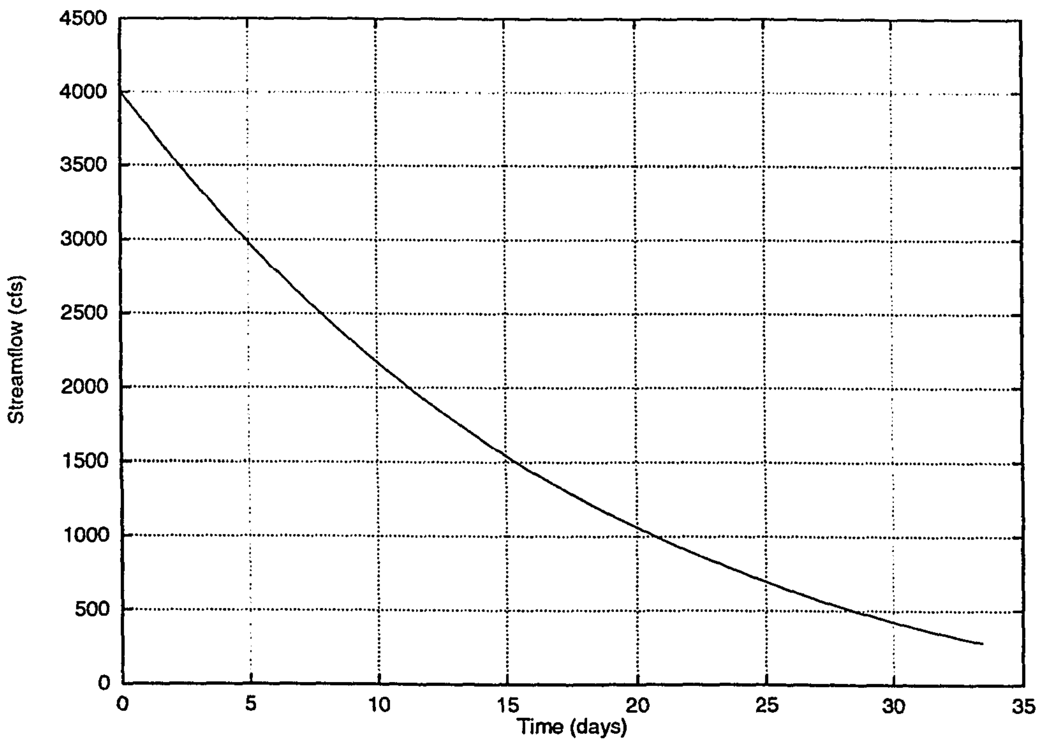

Figure 66.2: MRC of Des Moines River at Humboldt (for summer), ID# 05476750

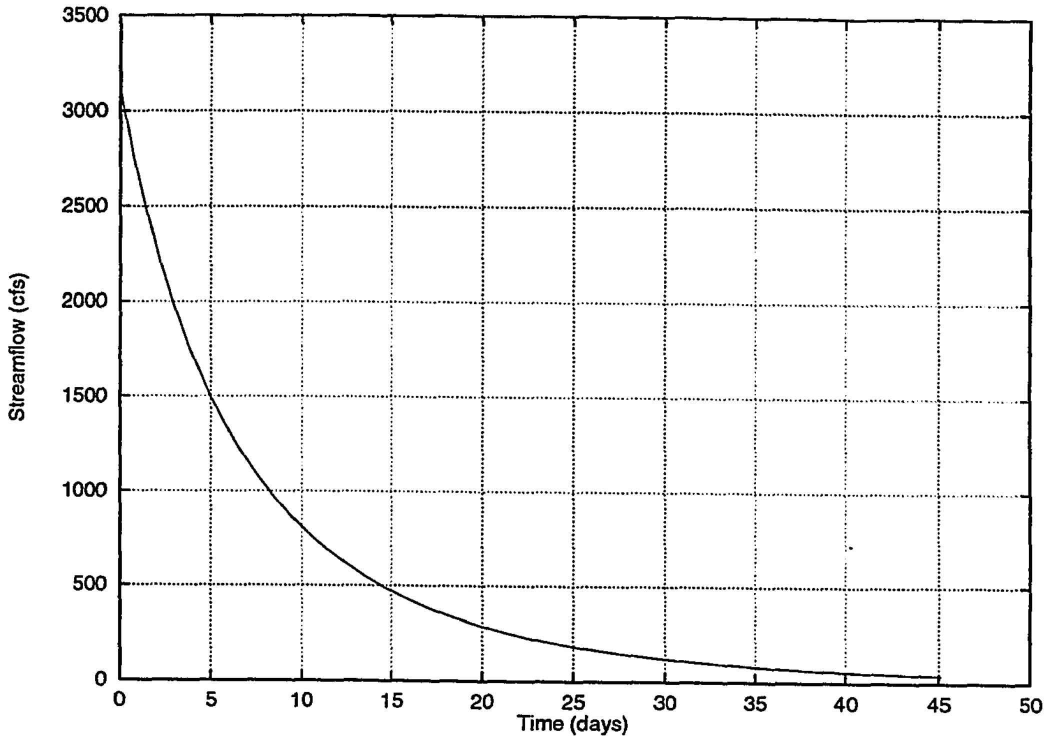

Figure 67.1: MRC of East Fork Des Moines River at Dakota City (for winter), ID# 05479000

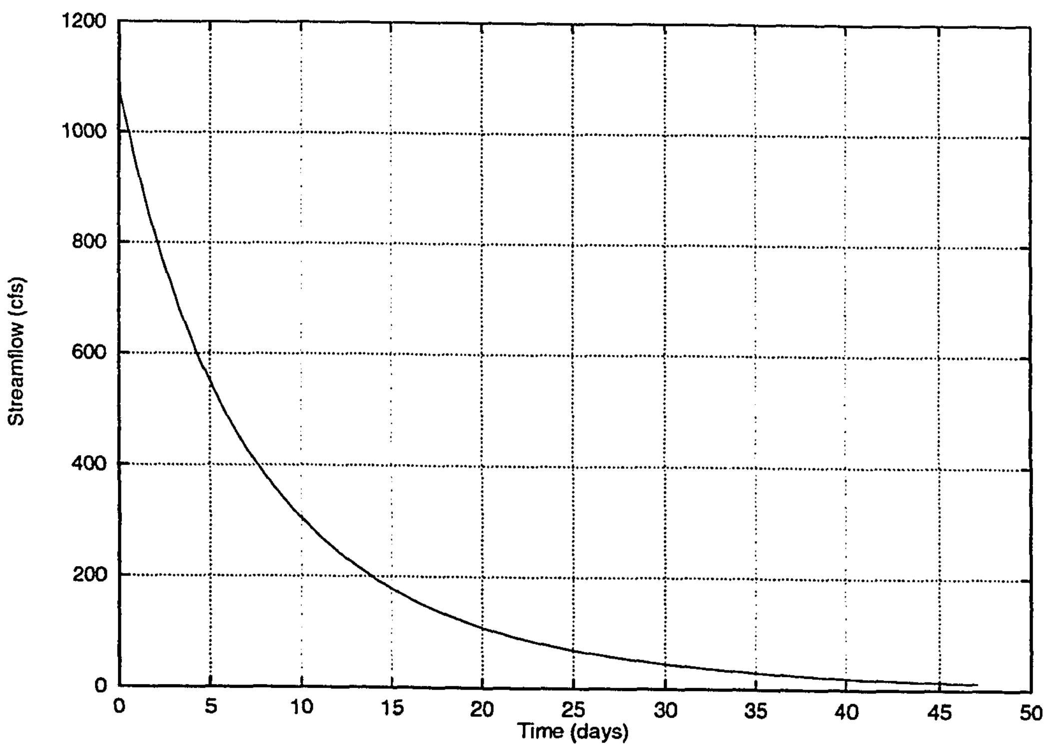

Figure 67.2: MRC of East Fork Des Moines River at Dakota City (for summer), ID# 05479000

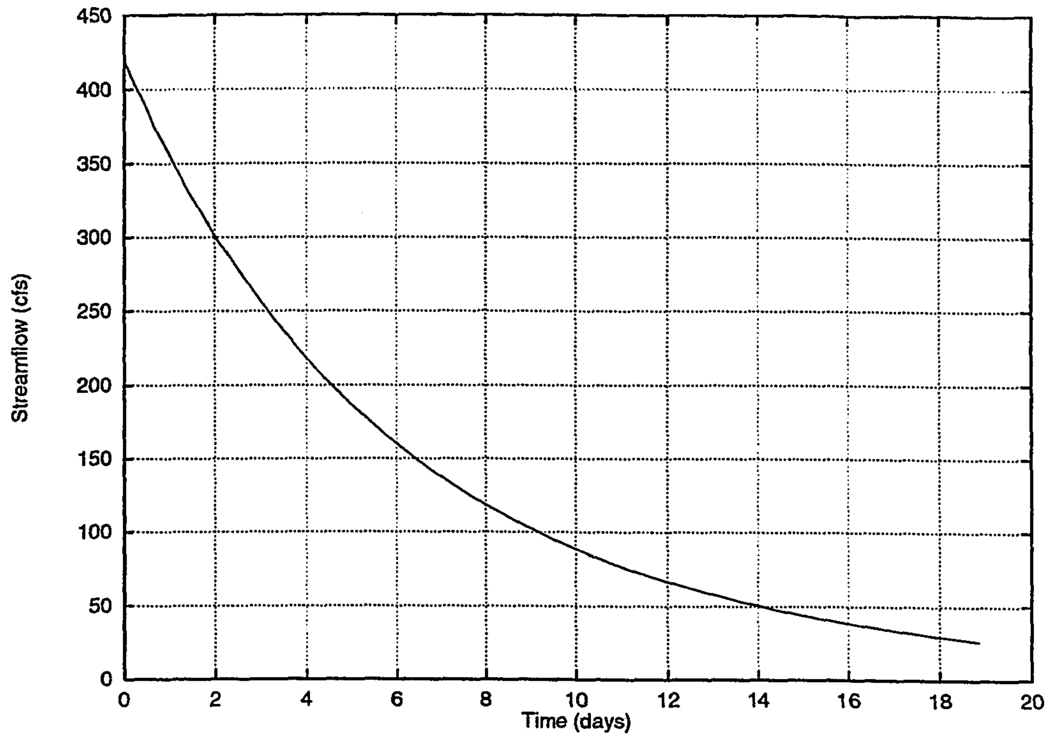

Figure 68.1: MRC of Lizard Creek near Clare (for winter), ID# 05480000

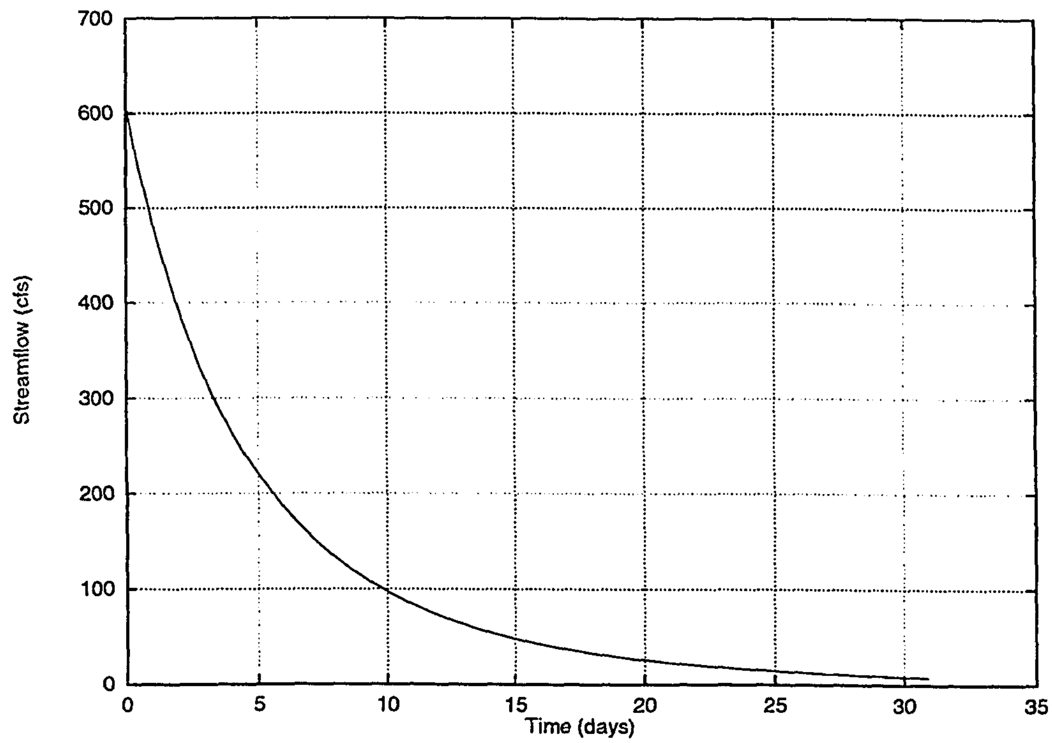

Figure 68.2: MRC of Lizard Creek near Clare (for summer), ID# 05480000

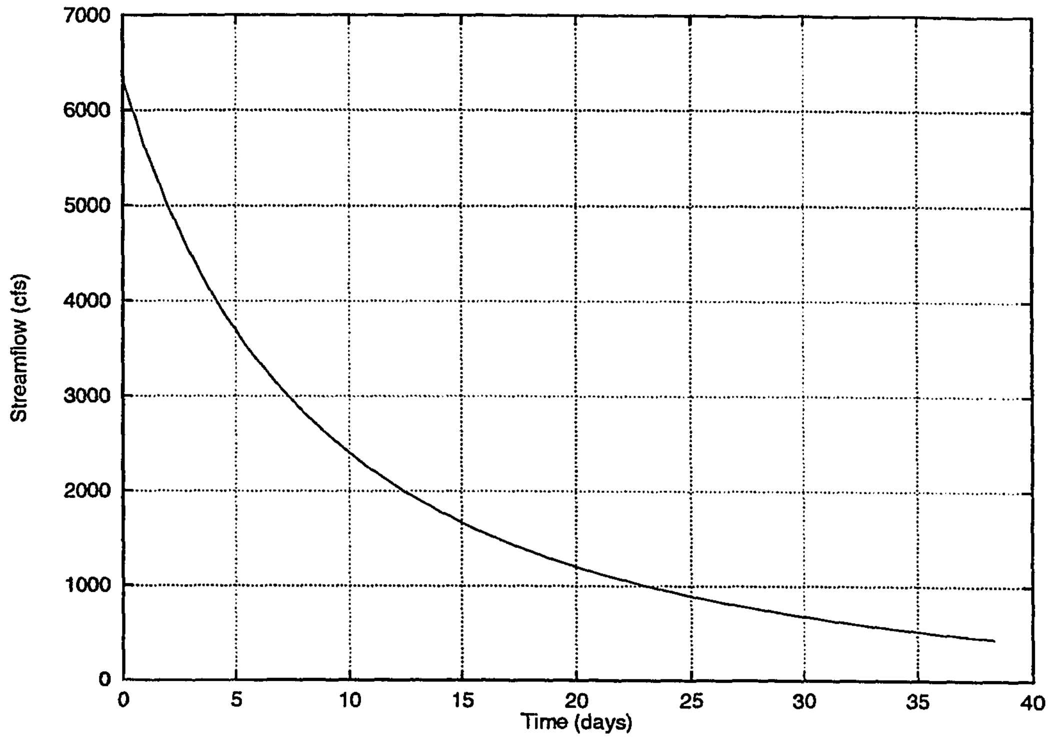

Figure 69.1: MRC of Des Moines River at Fort Dodge (for winter), ID# 05480500

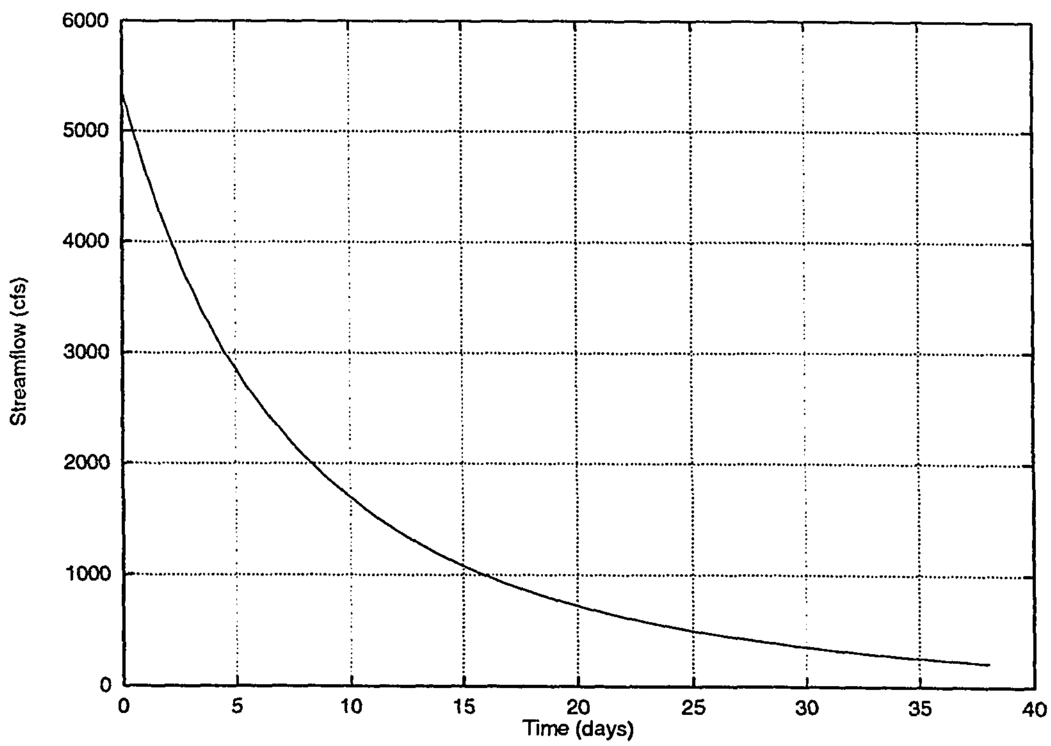

Figure 69.2: MRC of Des Moines River at Fort Dodge (for summer), ID# 05480500

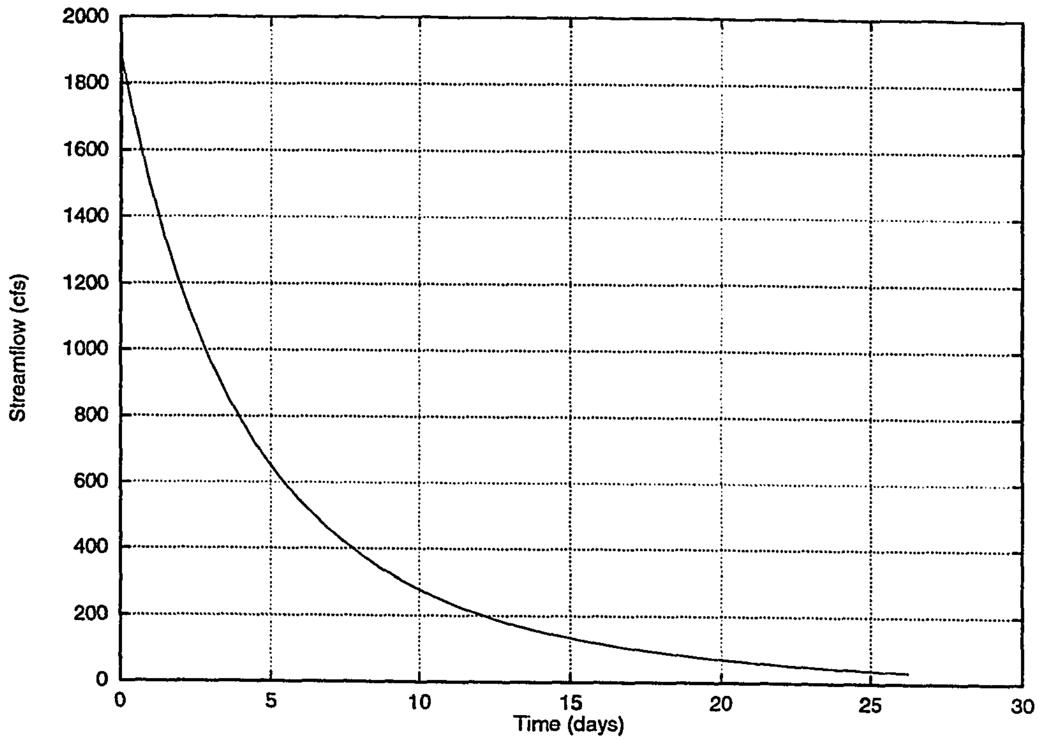

Figure 70.1: MRC of Boone River near Webster City (for winter), ID# 05481000

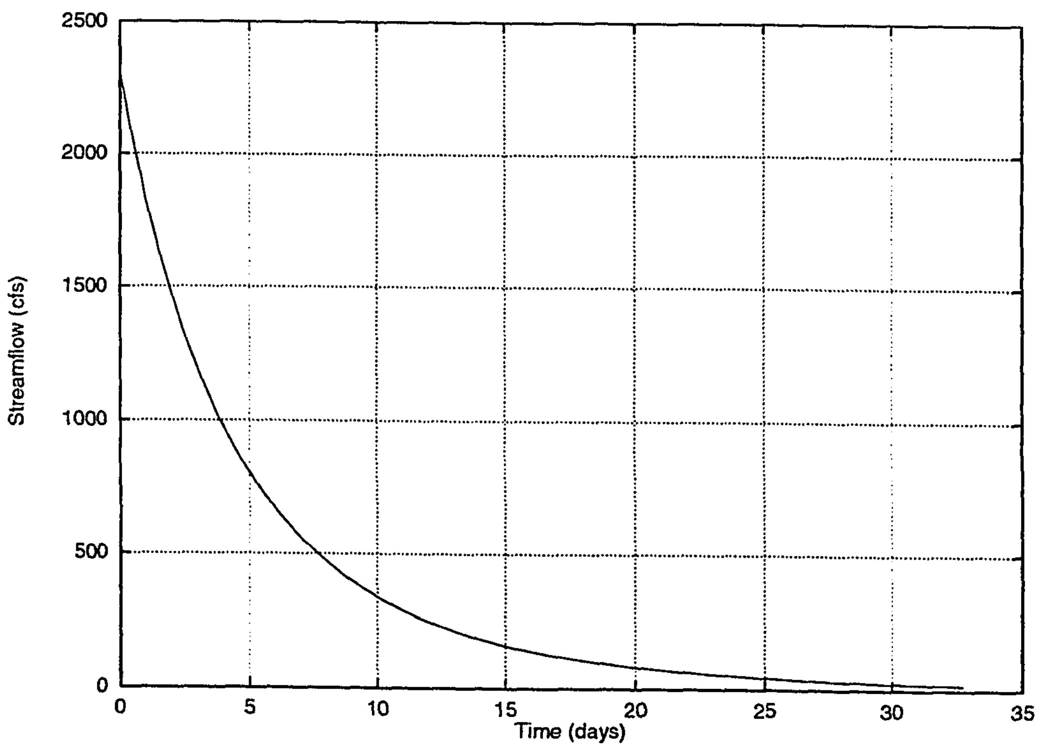

Figure 70.2: MRC of Boone River near Webster City (for summer), ID# 05481000

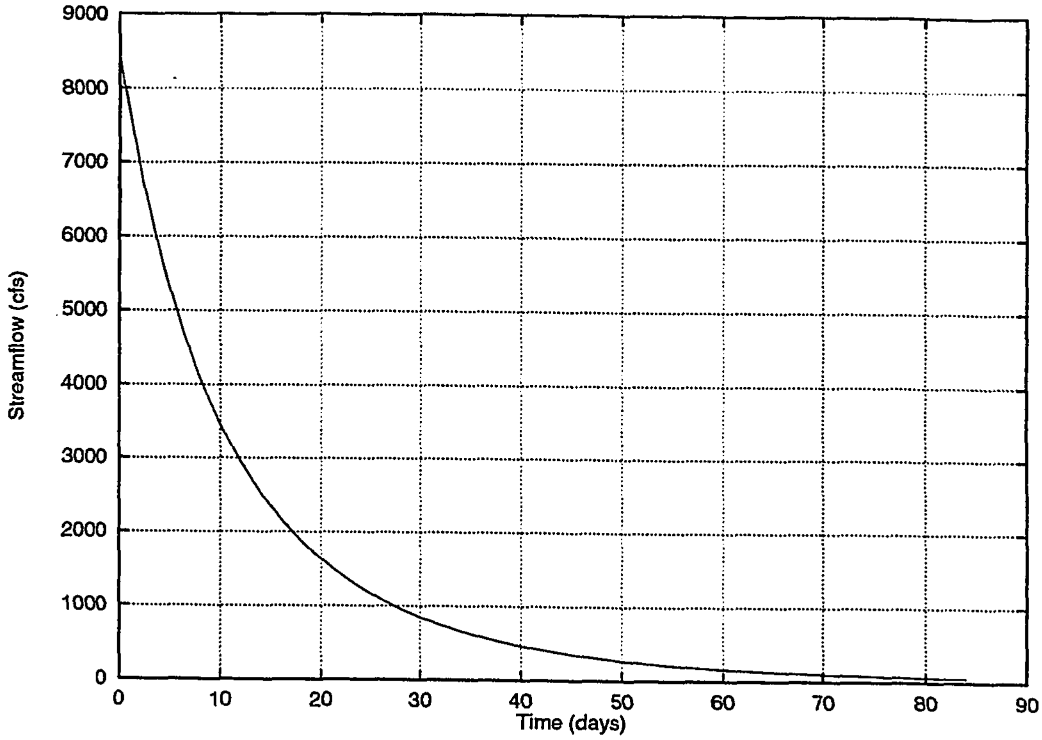

Figure 71.1: MRC of Des Moines River near Stratford (for winter), ID# 05481300

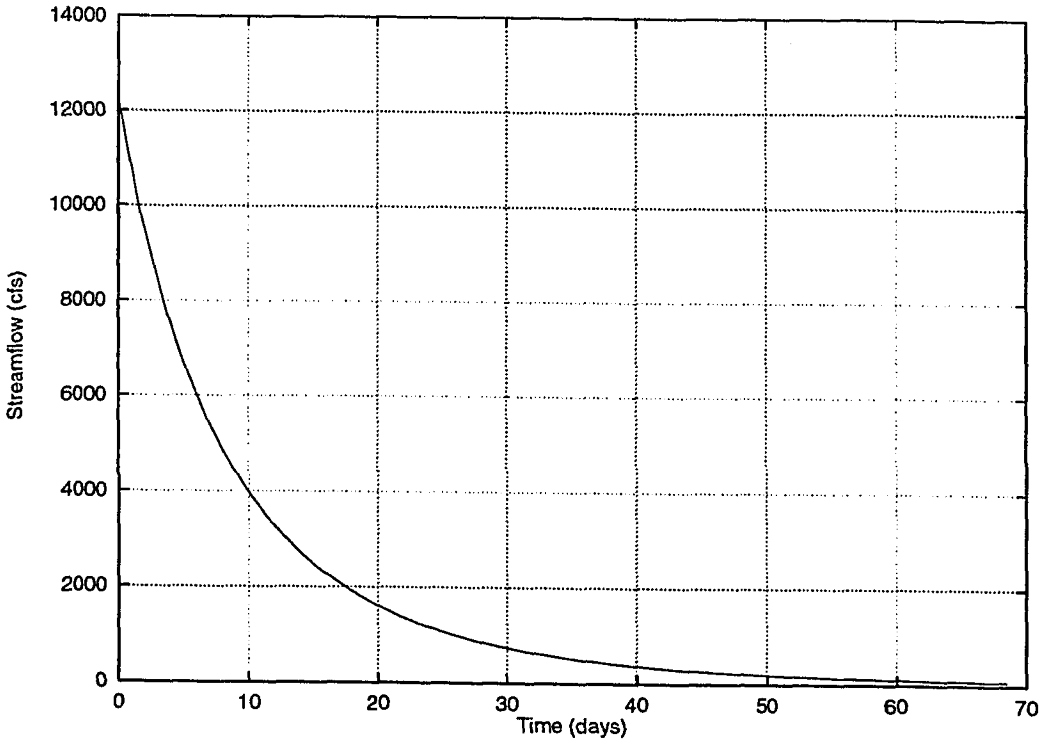

Figure 71.2: MRC of Des Moines River near Stratford (for summer), ID# 05481300

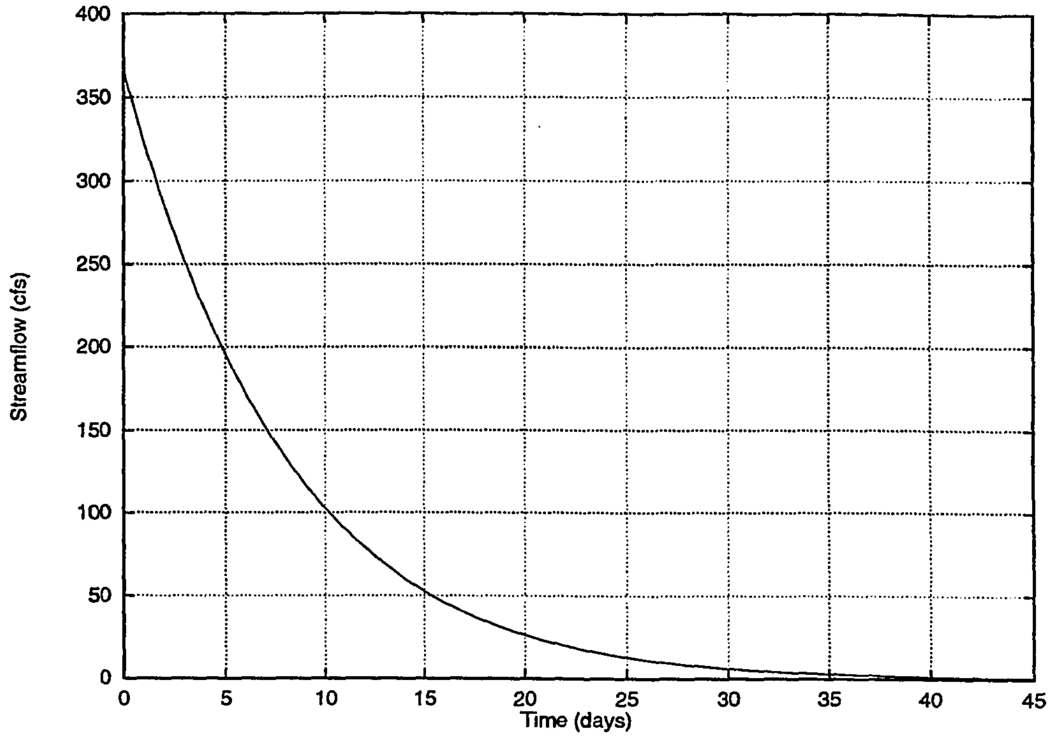

Figure 72.1: MRC of Beaver Creek near Grimes (for winter), ID# 05481950

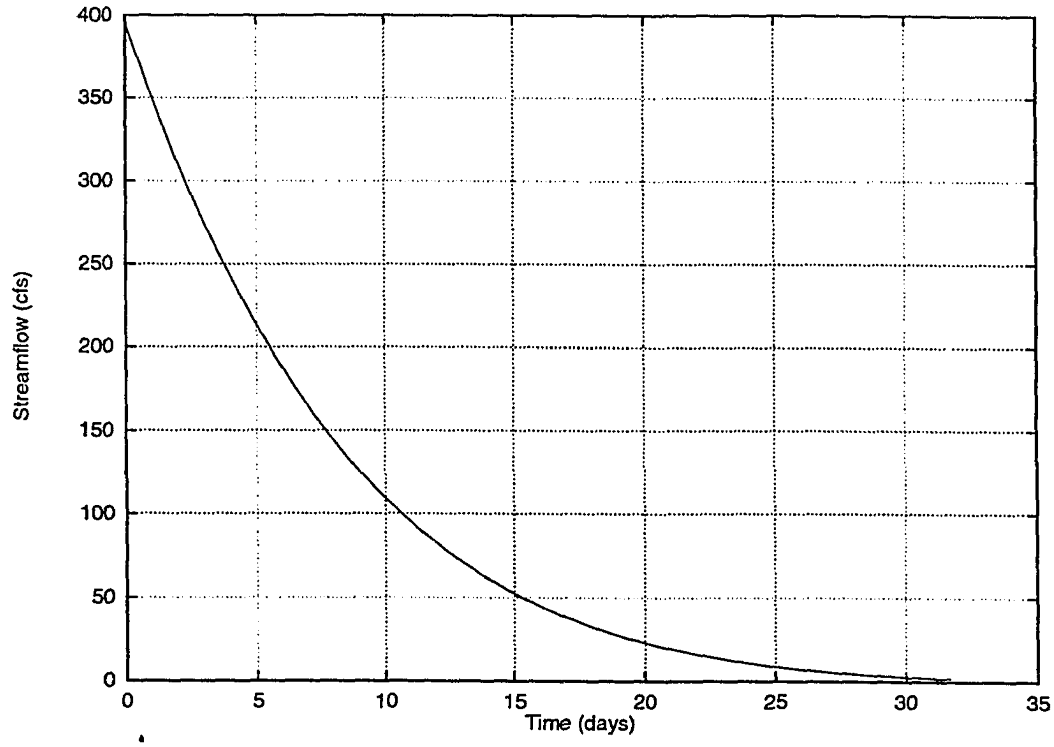

Figure 72.2: MRC of Beaver Creek near Grimes (for summer), ID# 05481950

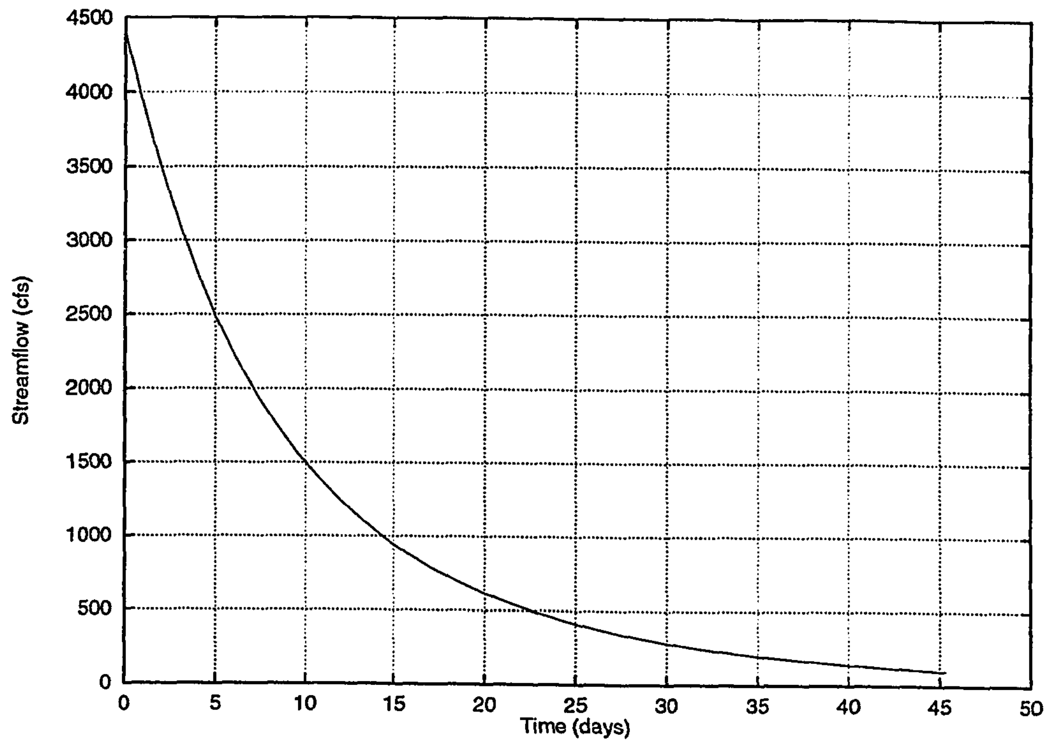

Figure 73.1: MRC of Des Moines River at Des Moines (for winter), ID# 05482000

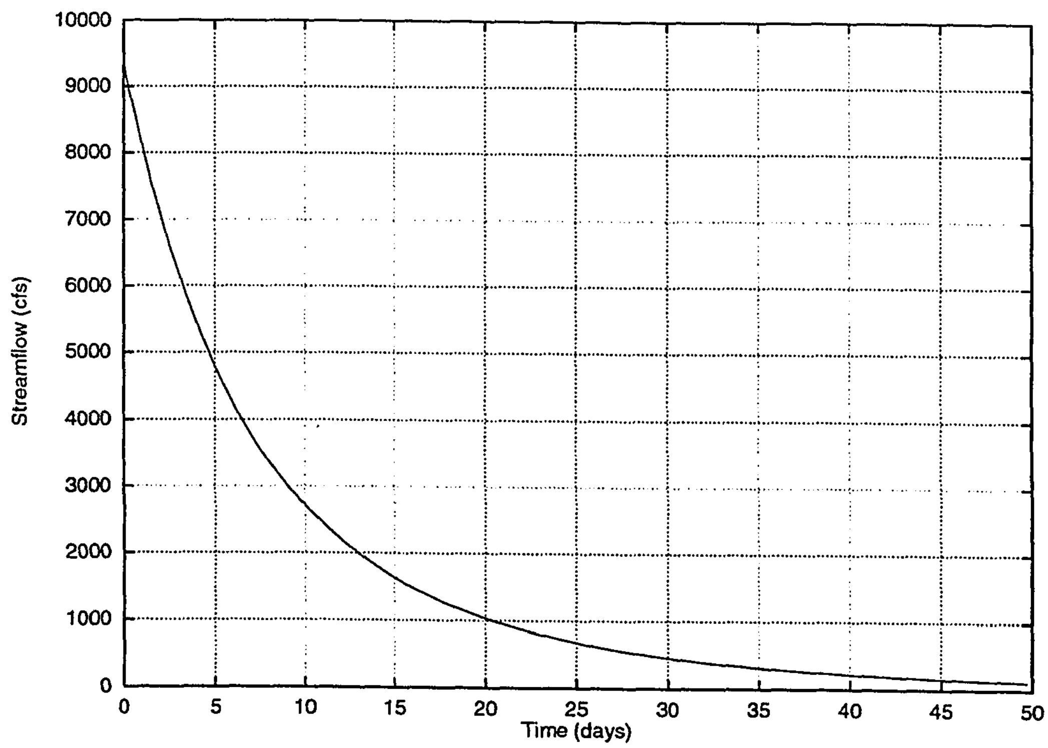

Figure 73.2: MRC of Des Moines River at Des Moines (for summer), ID# 05482000

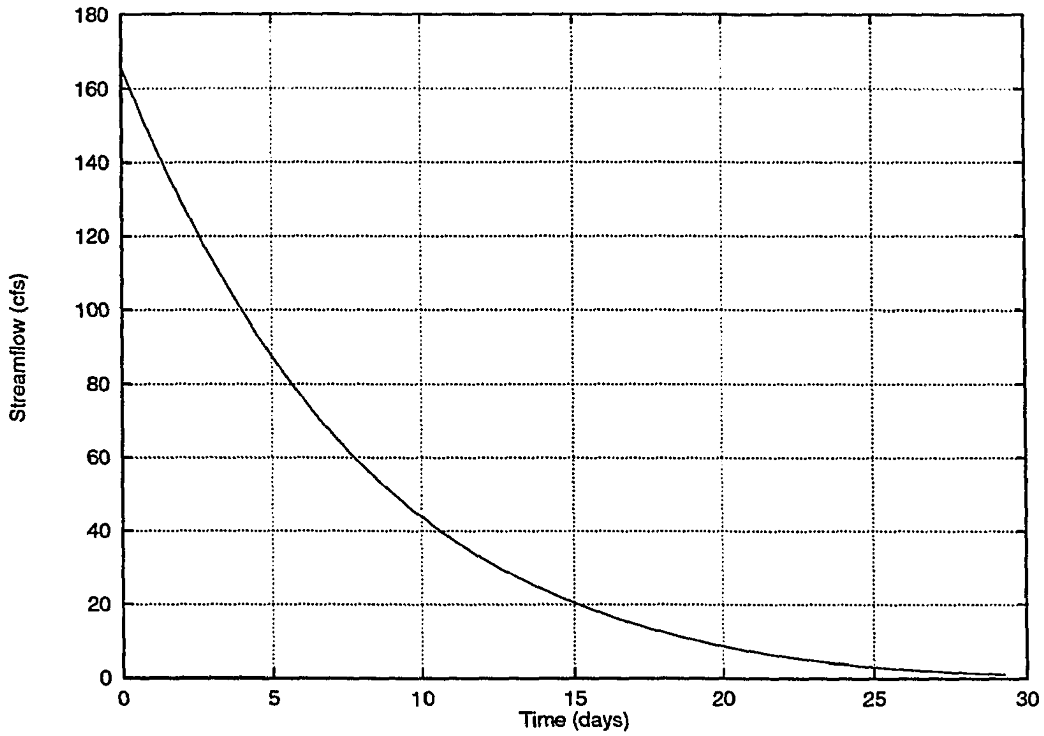

Figure 74.1: MRC of Big Cedar Creek near Varina (for winter), ID# 05482170

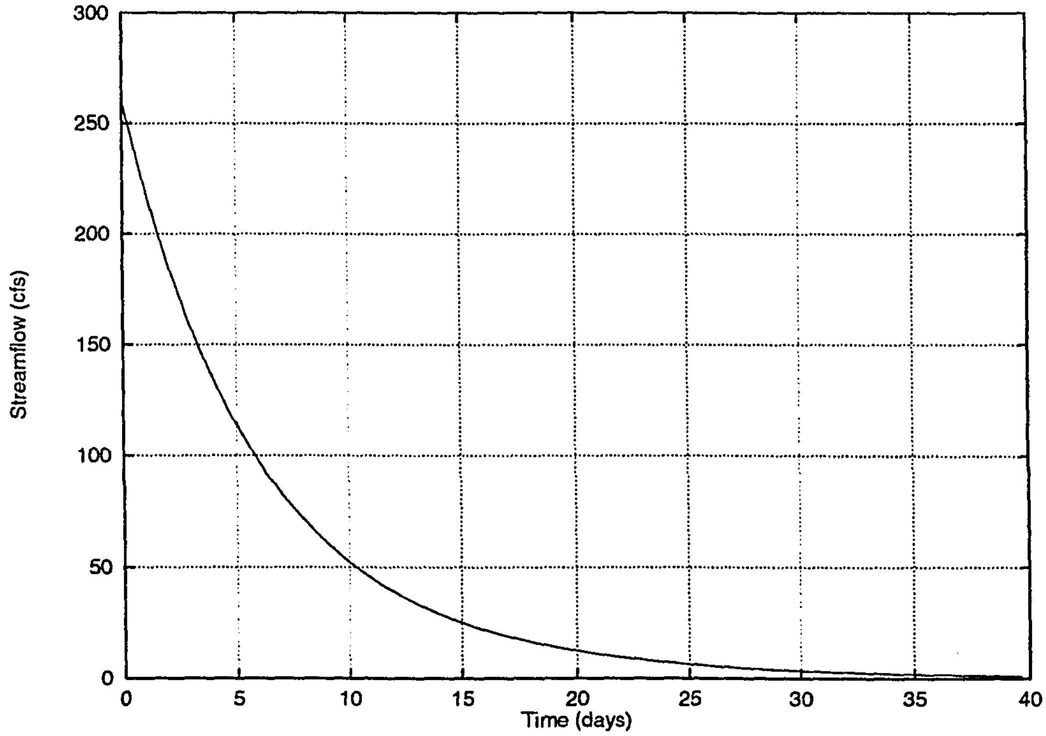

Figure 74.2: MRC of Big Cedar Creek near Varina (for summer), ID# 05482170

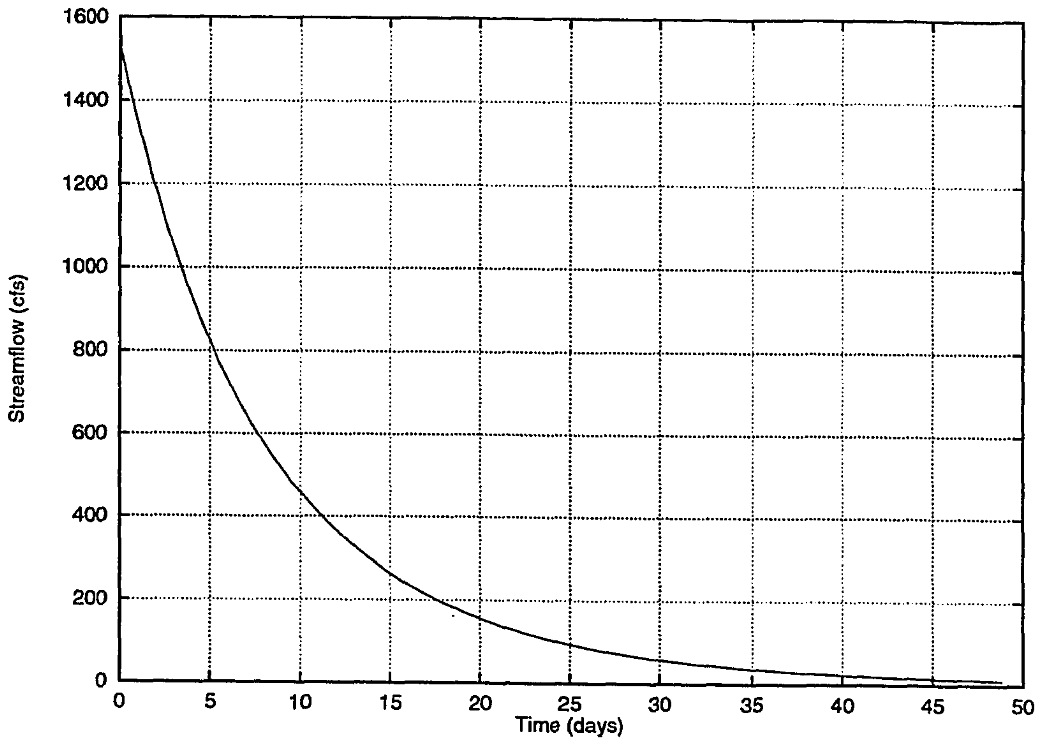

Figure 75.1: MRC of North Raccoon River near Sac City (for winter), ID# 05482300

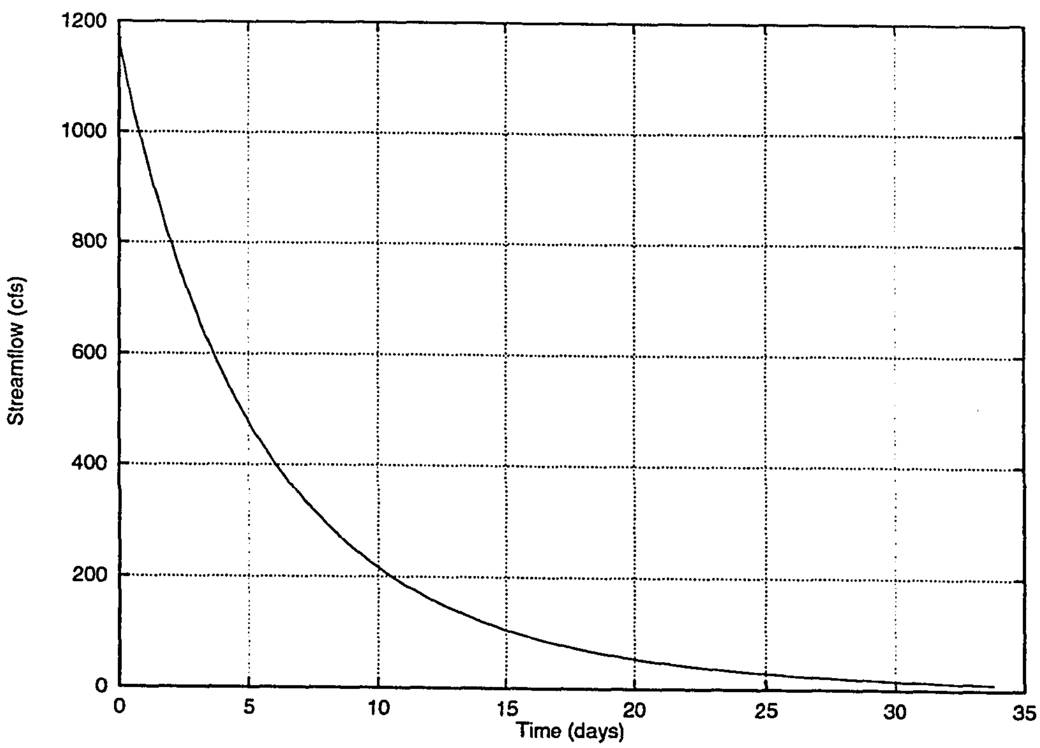

Figure 75.2: MRC of North Raccoon River near Sac City (for summer), ID# 05482300

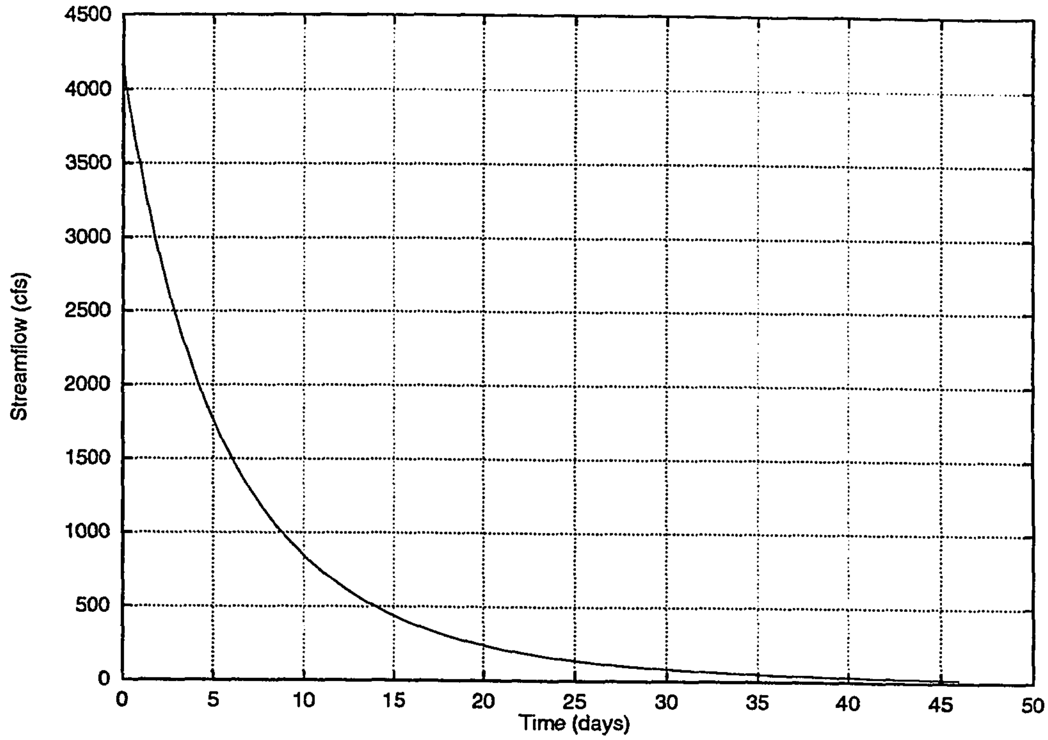

Figure 76.1: MRC of North Raccoon River near Jefferson (for winter), ID# 05482500

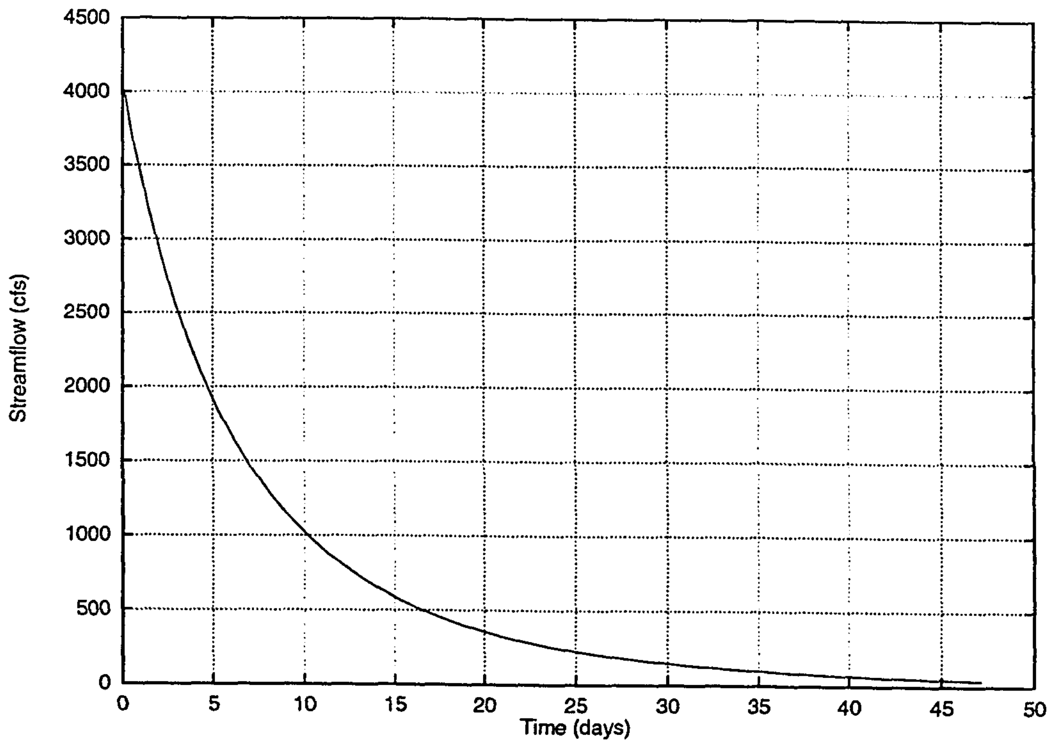

Figure 76.2: MRC of North Raccoon River near Jefferson (for summer), ID# 05482500

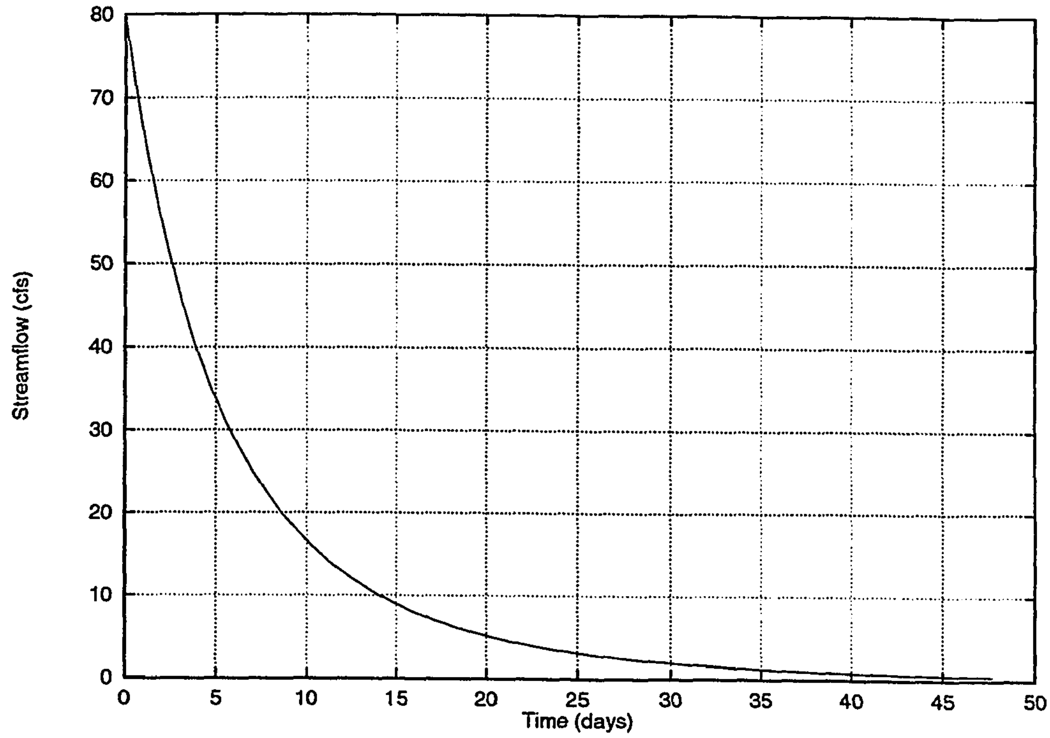

Figure 77.1: MRC of East Fork Hardin Creek near Churdan (for winter), ID# 05483000

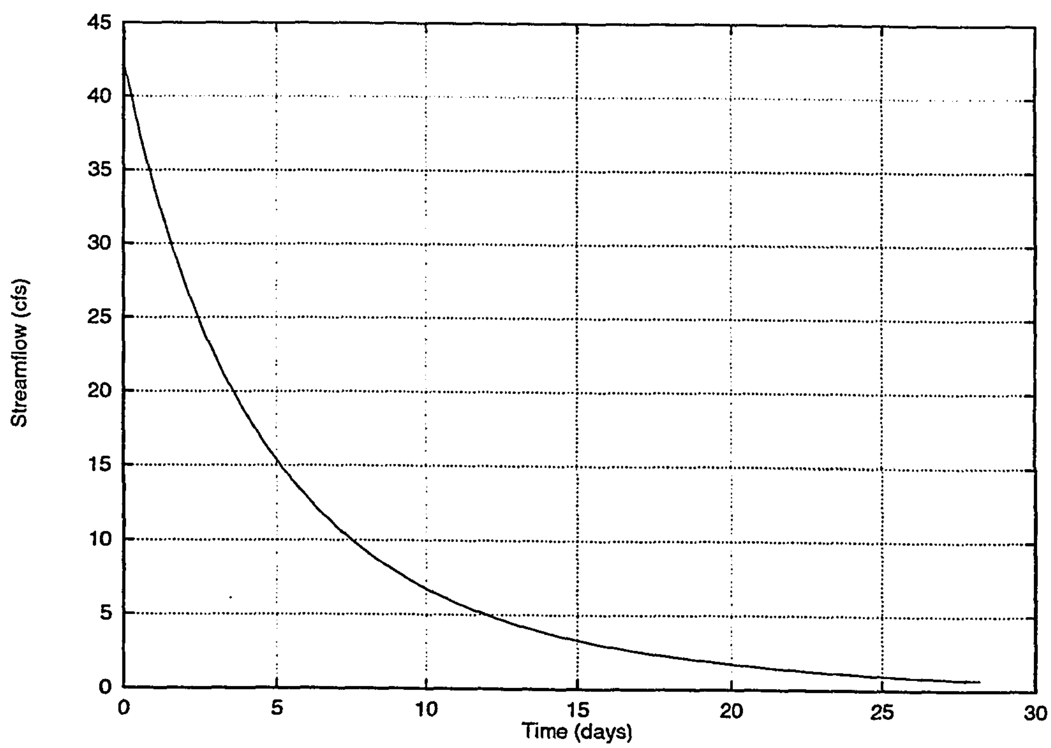

Figure 77.2: MRC of East Fork Hardin Creek near Churdan (for summer), ID# 05483000

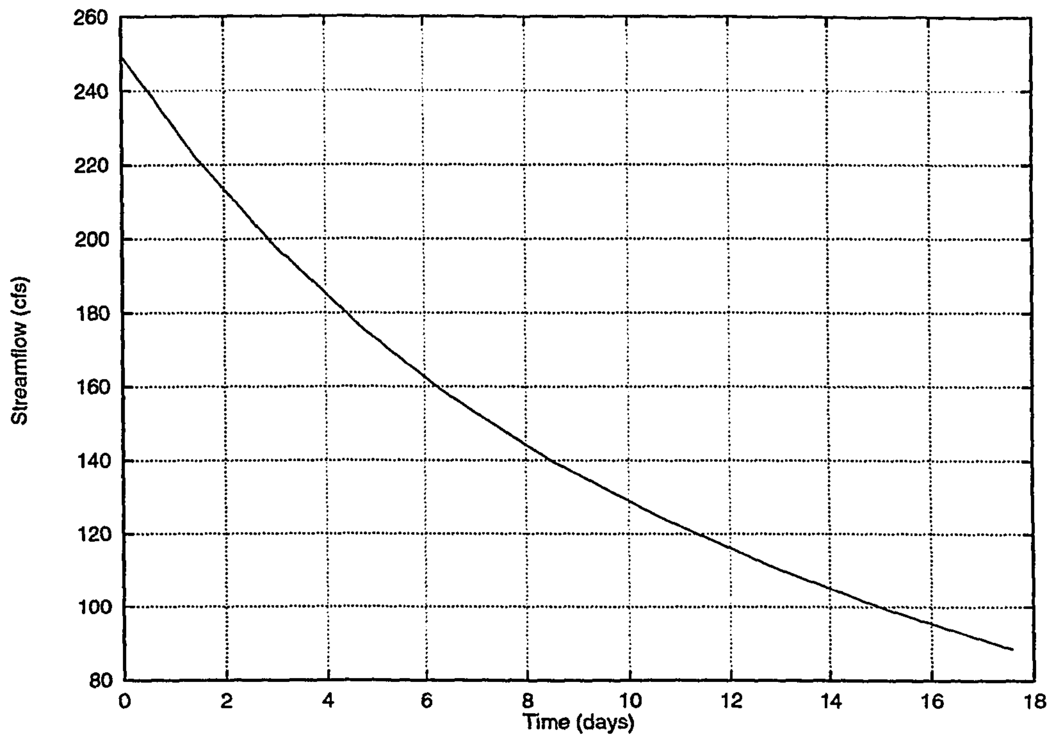

Figure 78.1: MRC of Middle Raccoon River at Panora (for winter), ID# 05483600

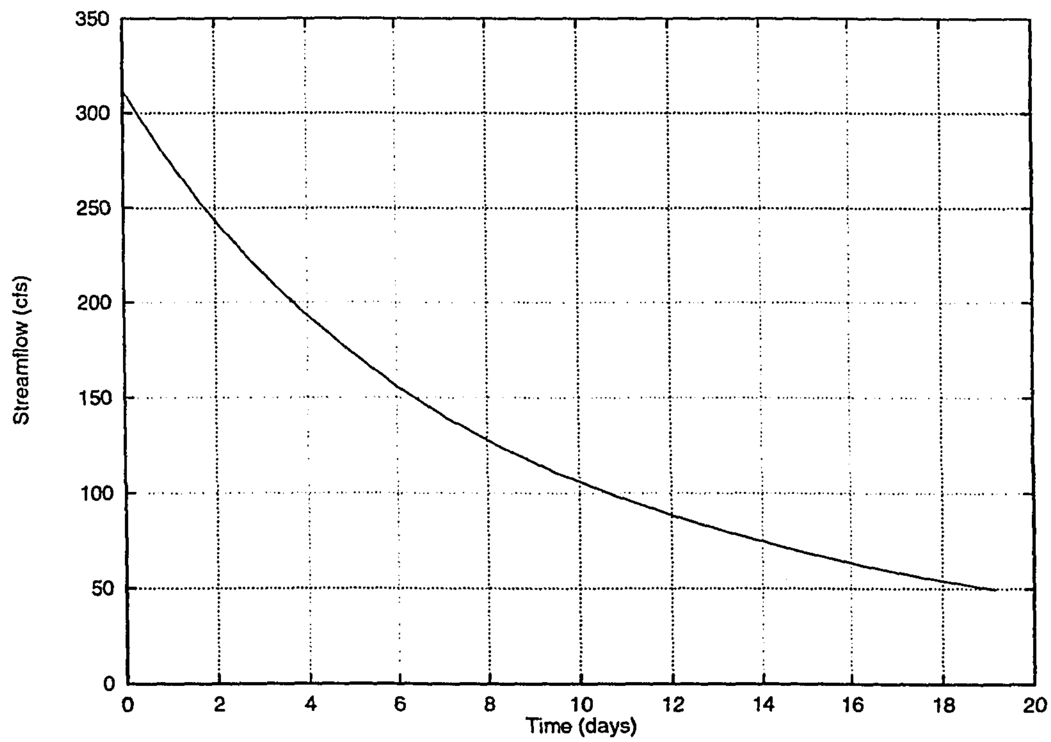

Figure 78.2: MRC of Middle Raccoon River at Panora (for summer), ID# 05483600

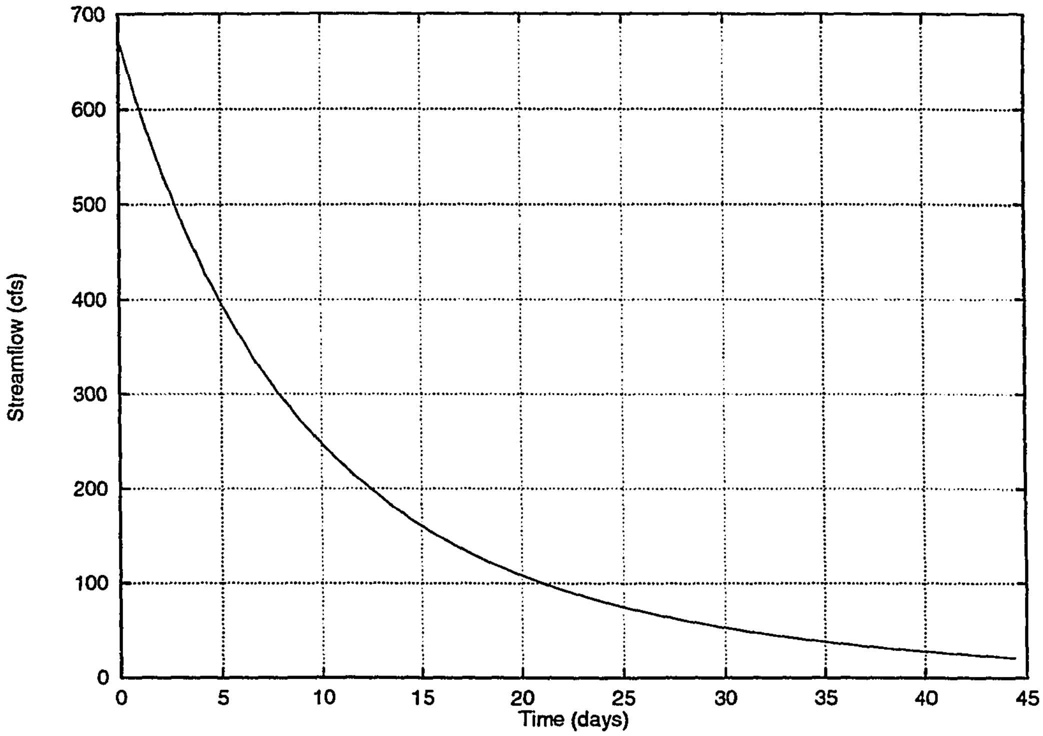

Figure 79.1: MRC of South Raccoon River at Redfield (for winter), ID# 05484000

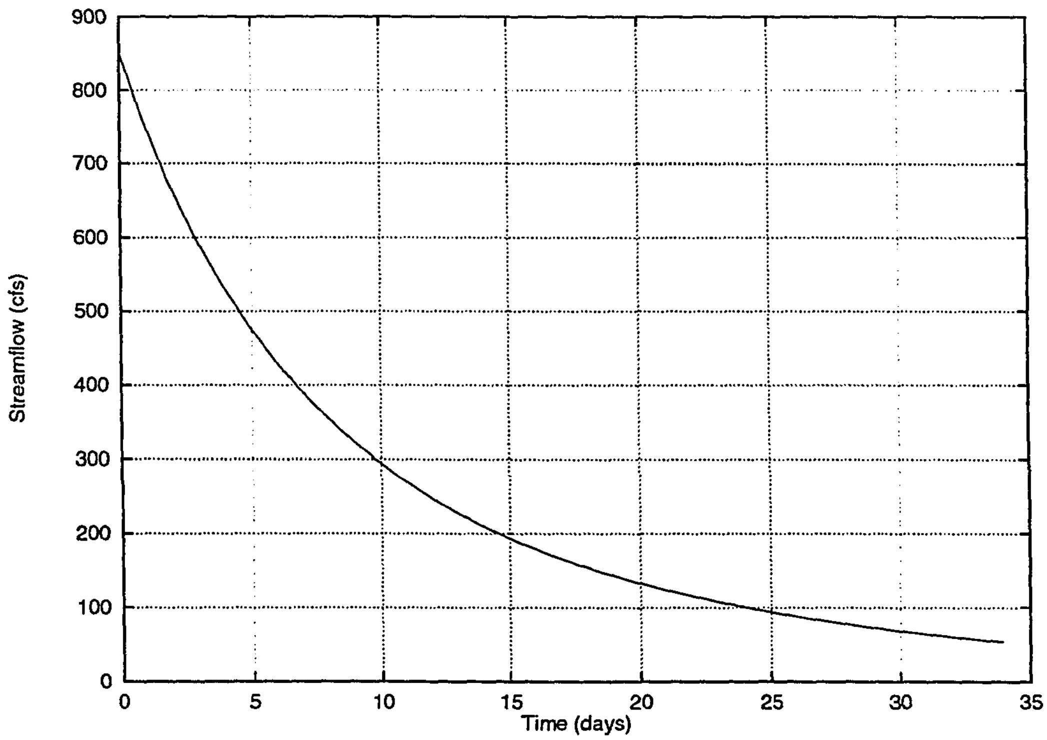

Figure 79.2: MRC of South Raccoon River at Redfield (for summer), ID# 05484000

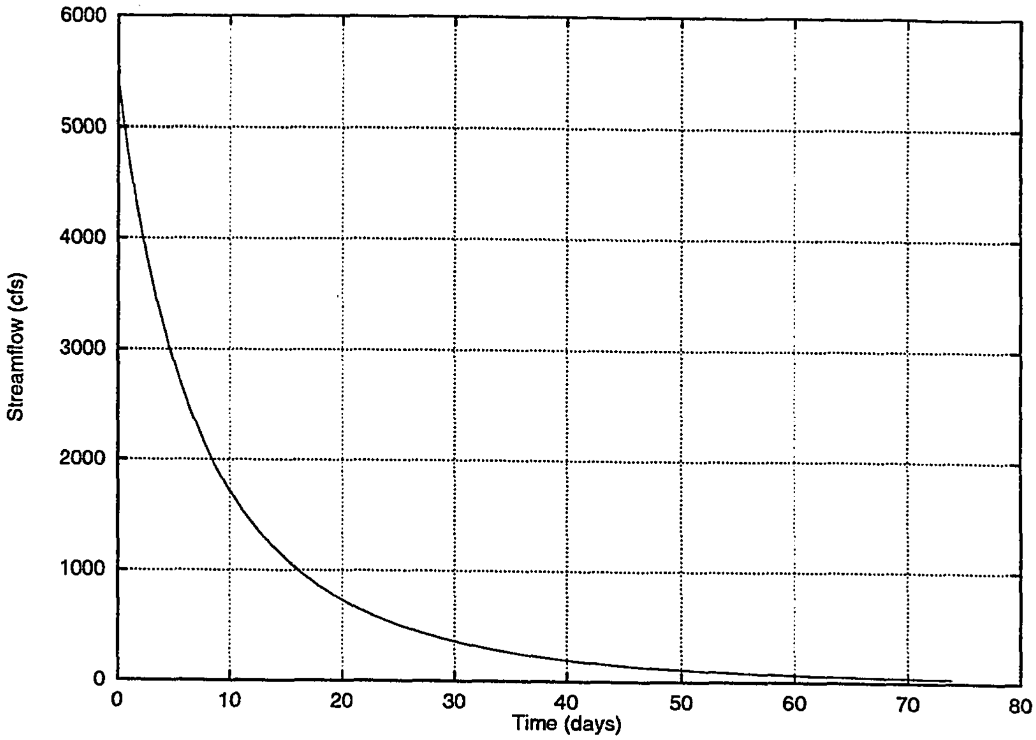

Figure 80.1: MRC of Raccoon River at Van Meter (for winter), ID# 05484500

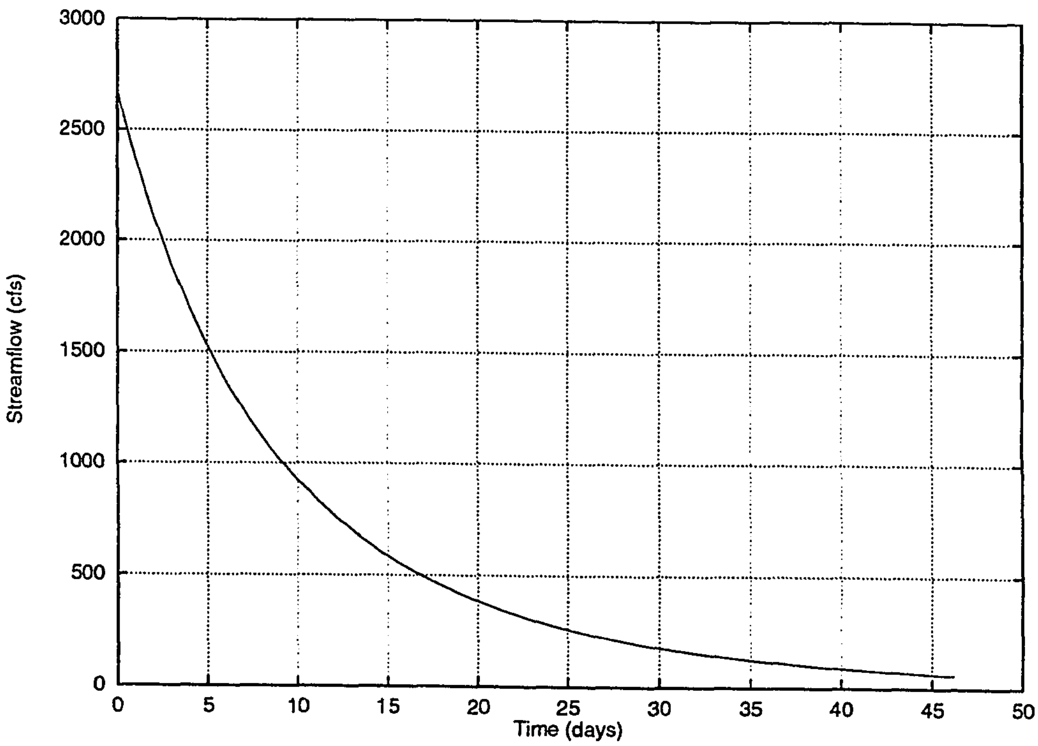

Figure 80.2: MRC of Raccoon River at Van Meter (for summer), ID# 05484500

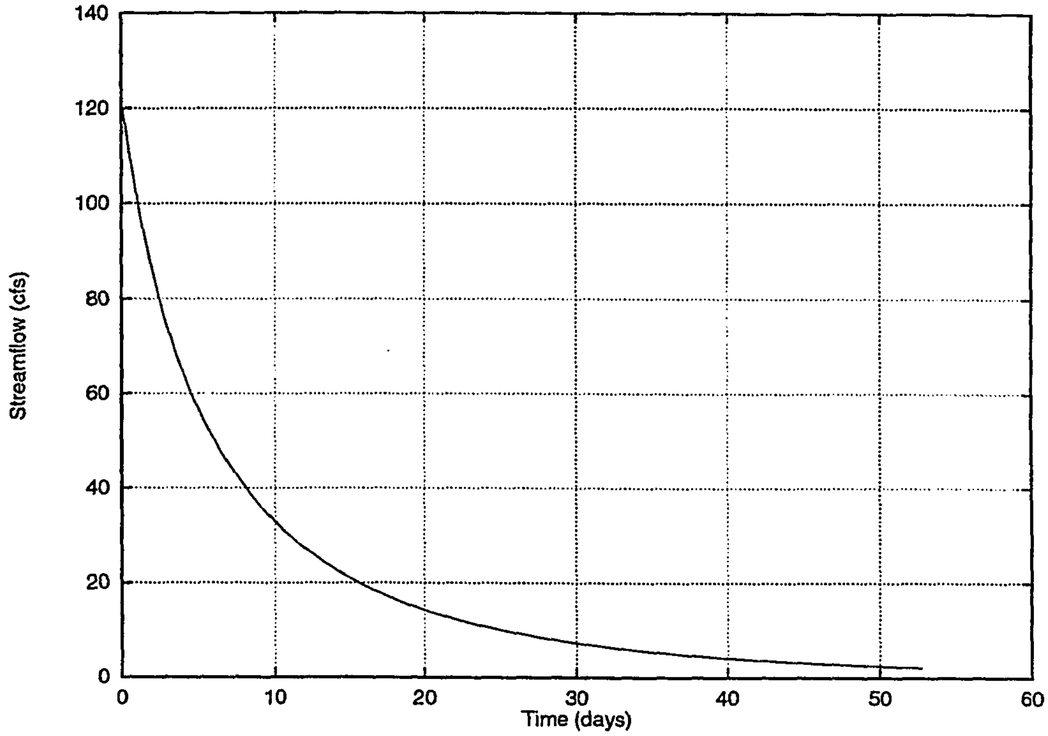

Figure 81.1: MRC of Walnut Creek at Des Moines (for winter), ID# 05484800

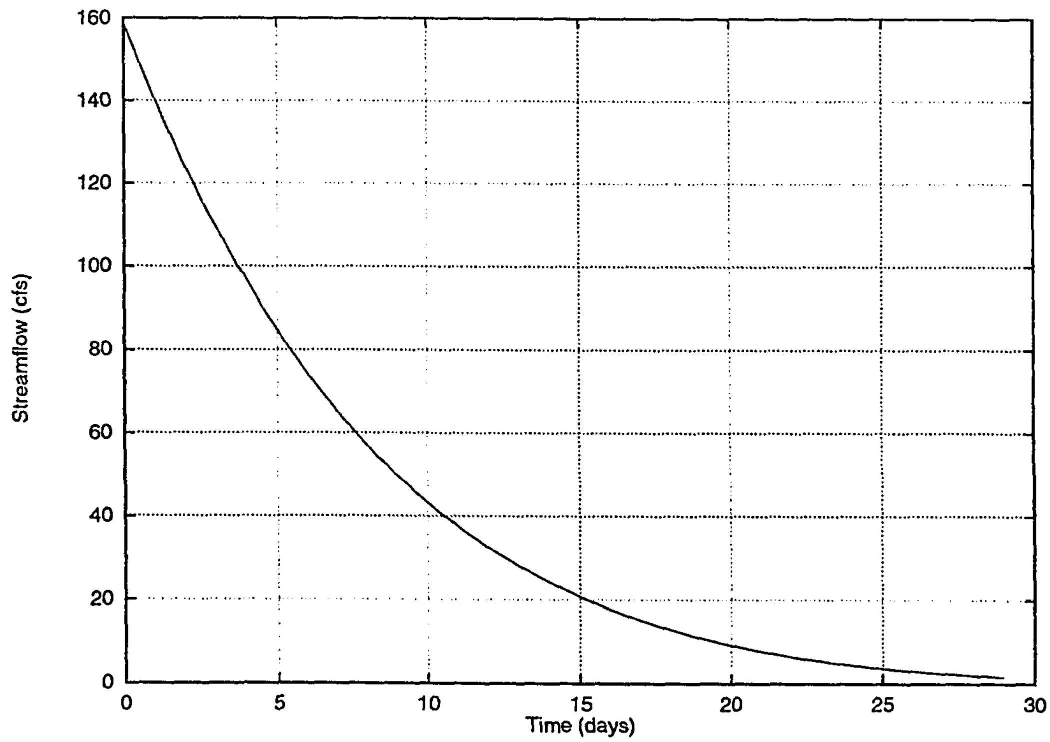

Figure 81.2: MRC of Walnut Creek at Des Moines (for summer), ID# 05484800

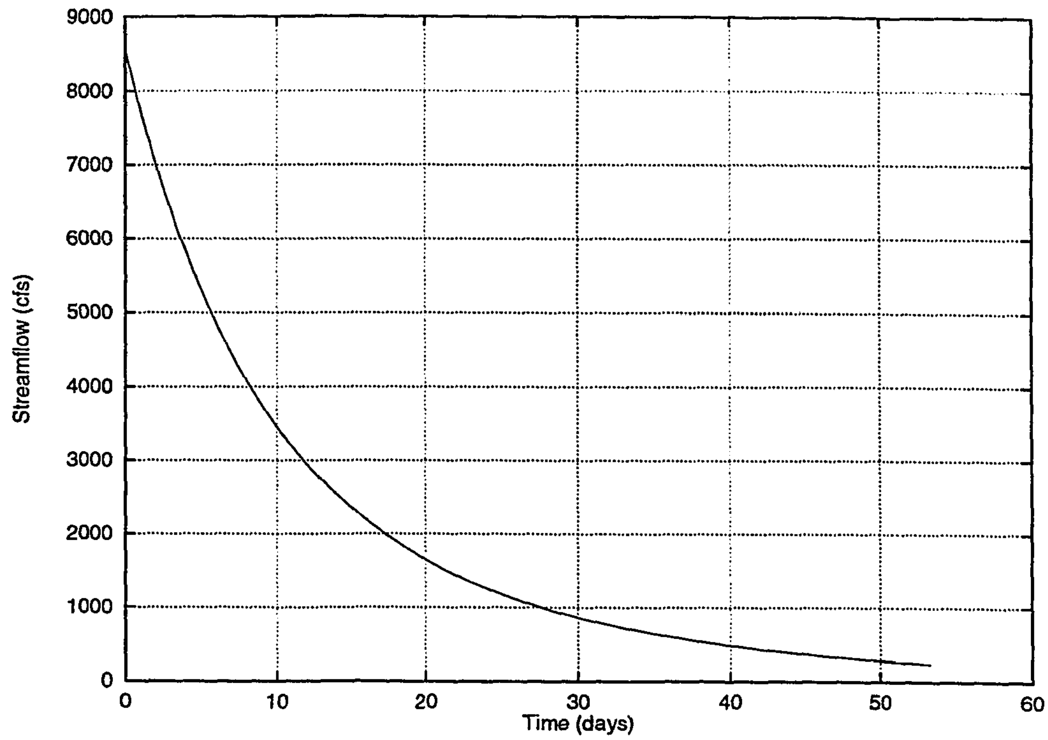

Figure 82.1: MRC of Des Moines R. below Raccoon R. at Des Moines (for winter), ID# 05485500

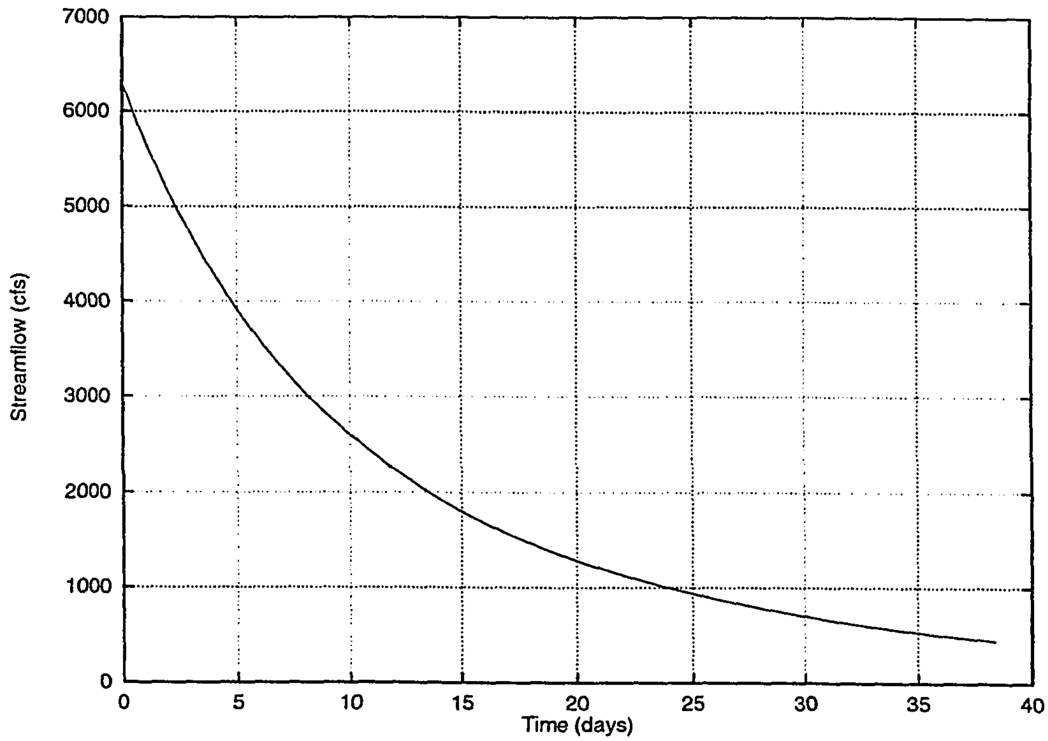

Figure 82.2: MRC of Des Moines R. below Raccoon R. at Des Moines (for summer), ID# 05485500

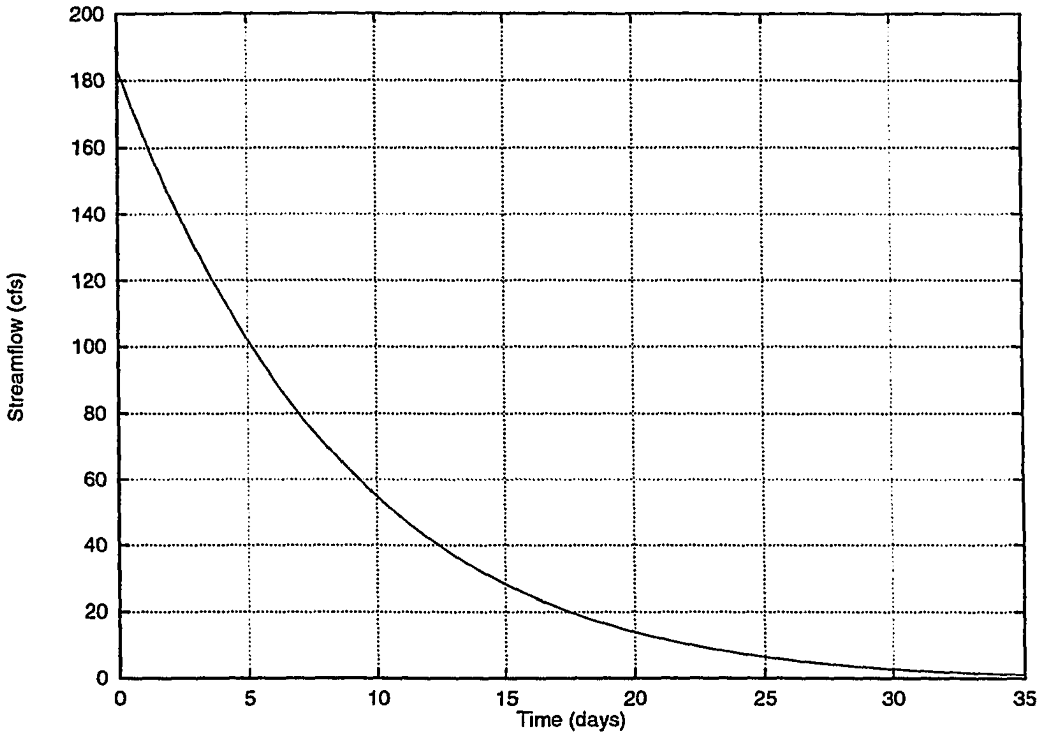

Figure 83.1: MRC of Fourmile Creek at Des Moines (for winter), ID# 05485640

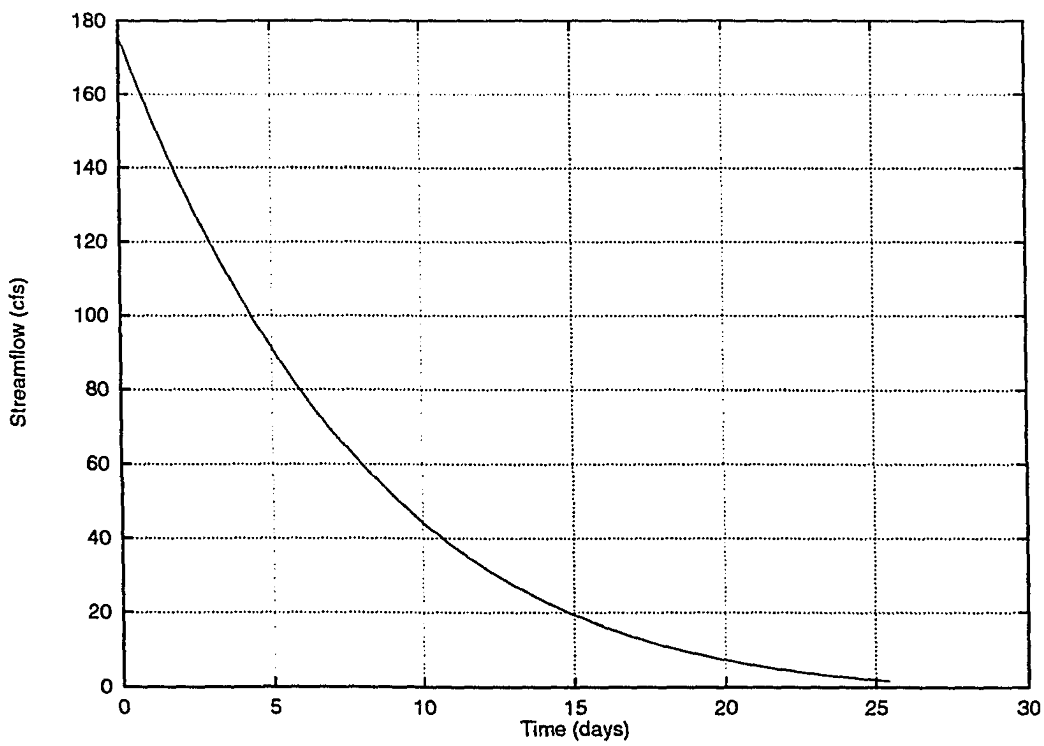

Figure 83.2: MRC of Fourmile Creek at Des Moines (for summer), ID# 05485640

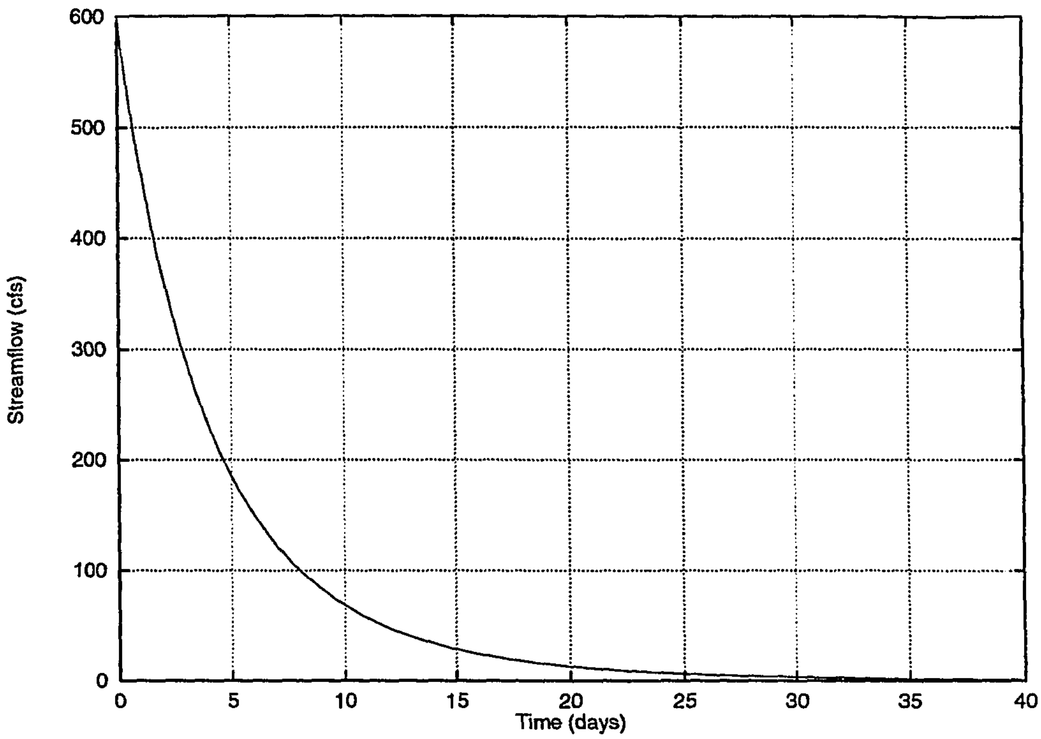

Figure 84.1: MRC of North River near Norwalk (for winter), ID# 05486000

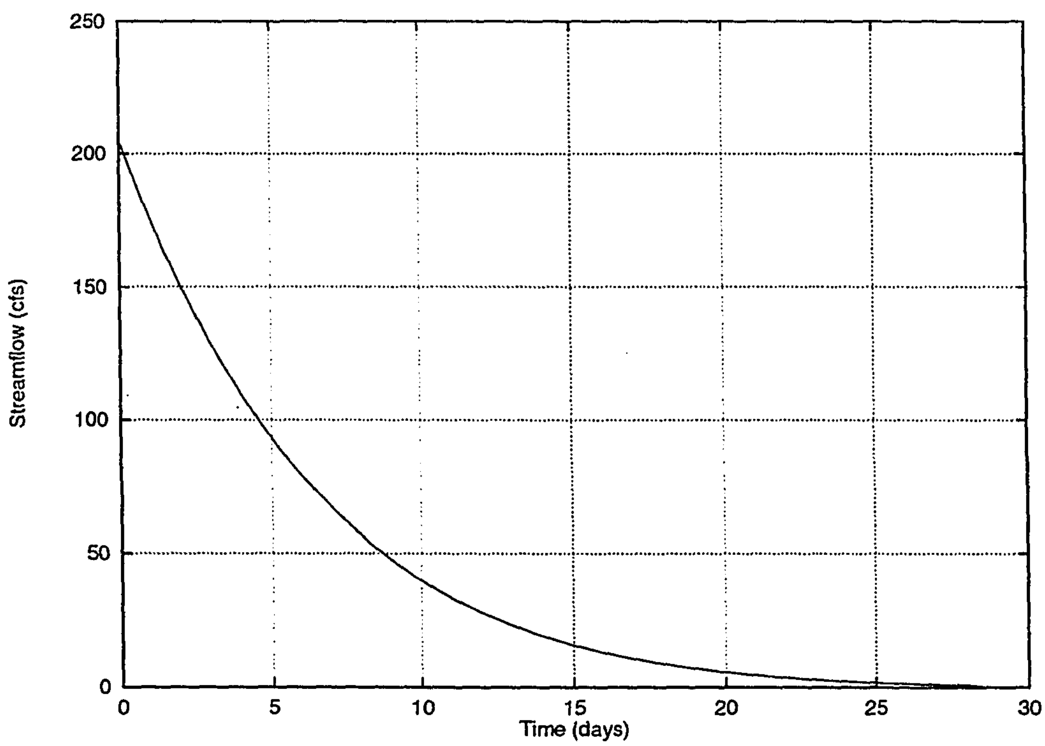

Figure 84.2: MRC of North River near Norwalk (for summer), ID# 05486000

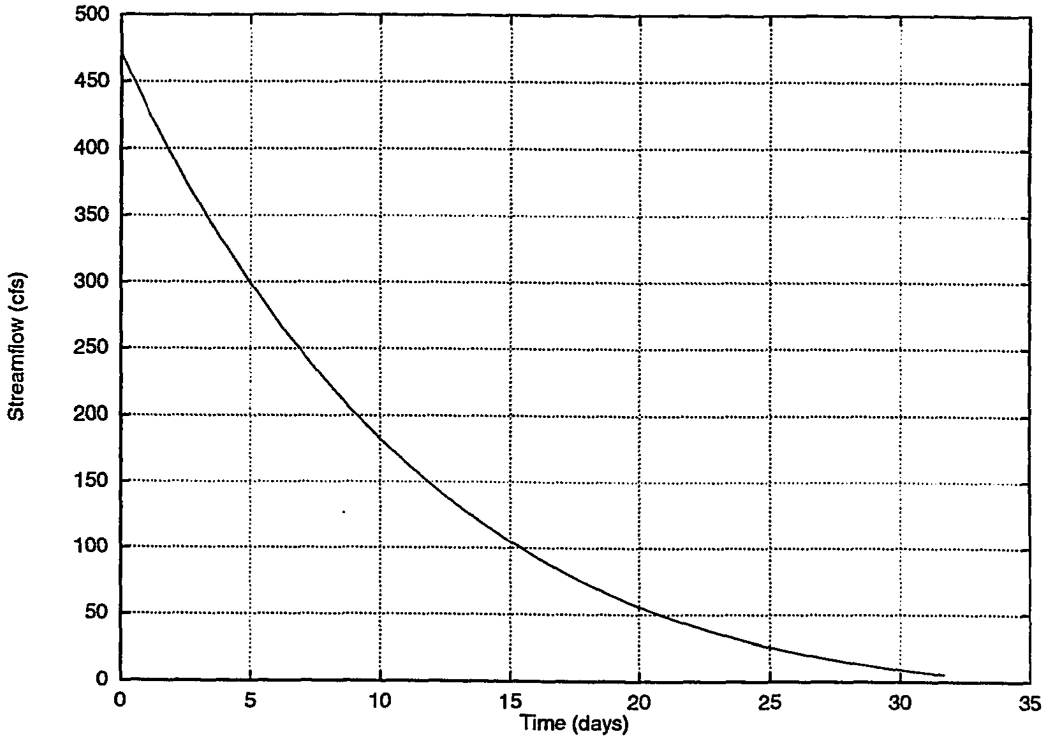

Figure 85.1: MRC of Middle River near Indianola (for winter), ID# 05486490

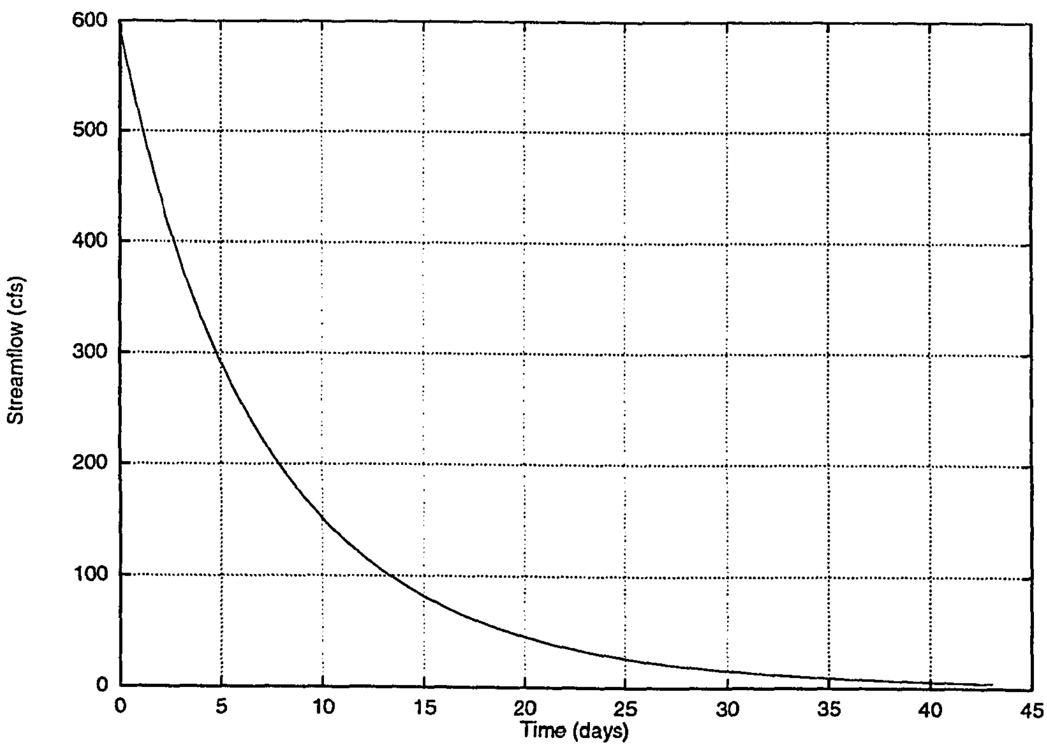

Figure 85.2: MRC of Middle River near Indianola (for summer), ID# 05486490

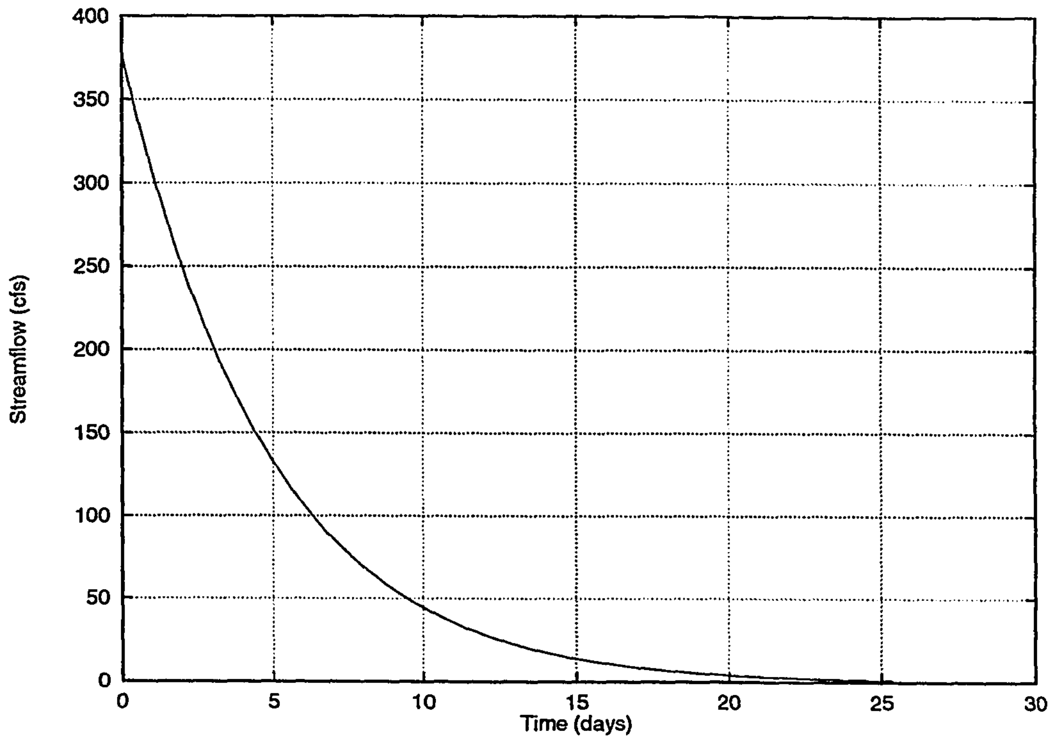

Figure 86.1: MRC of South River near Ackworth (for winter), ID# 05487470

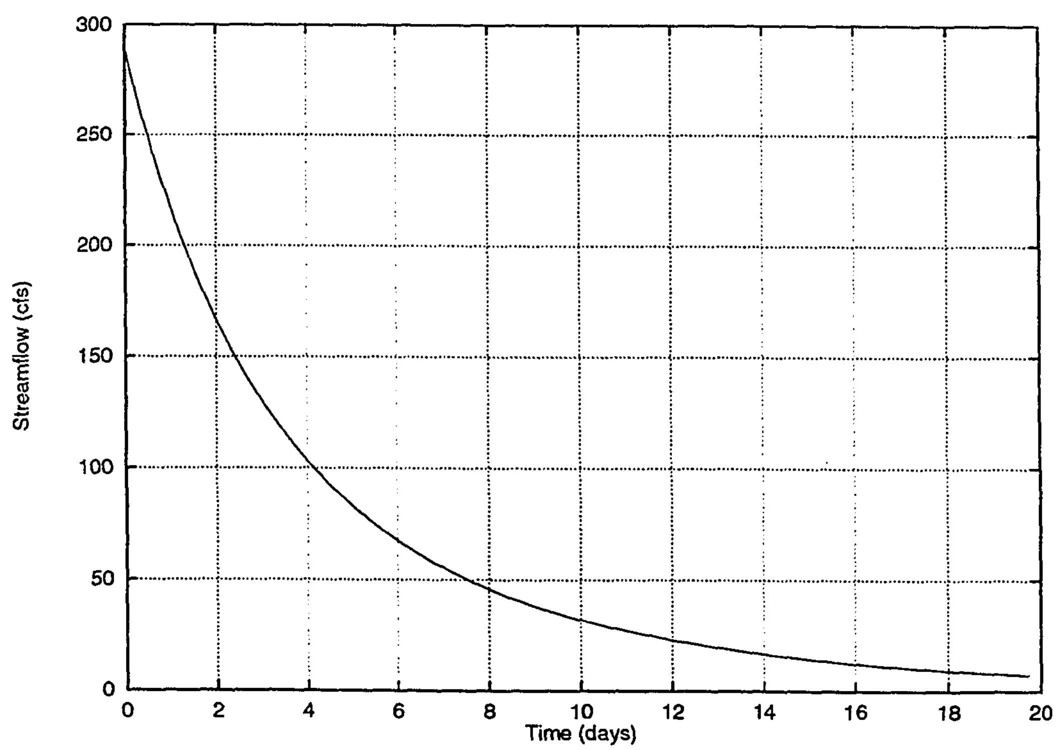

Figure 86.2: MRC of South River near Ackworth (for summer), ID# 05487470

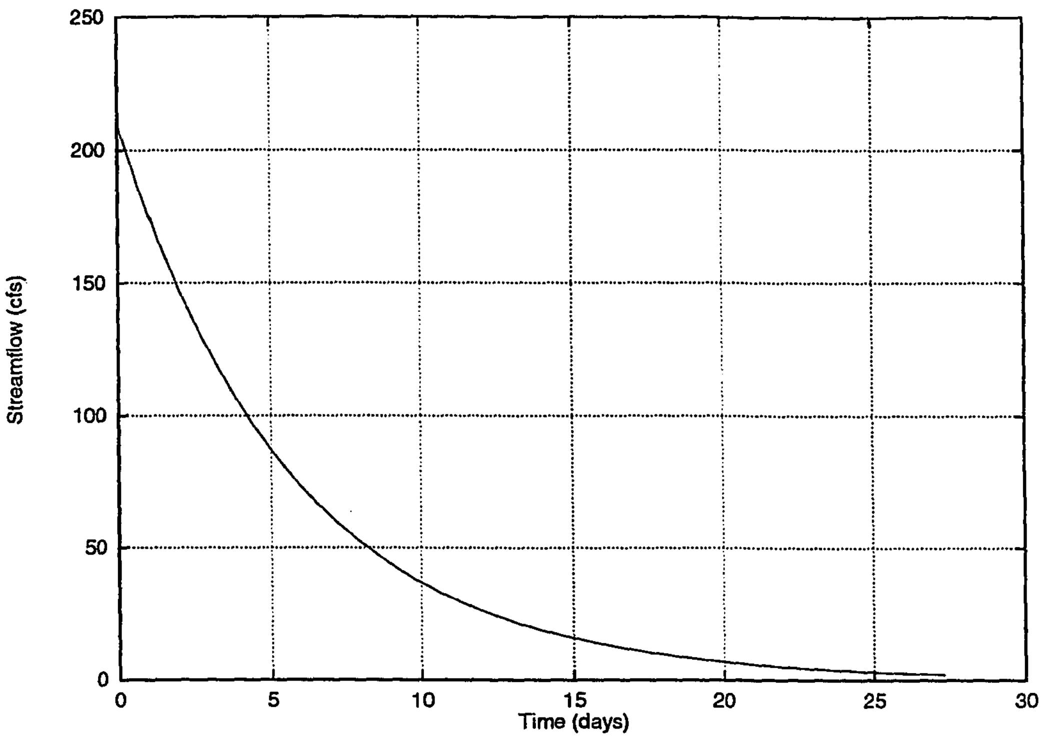

Figure 87.1: MRC of White Breast Creek near Dallas (for winter), ID# 05487980

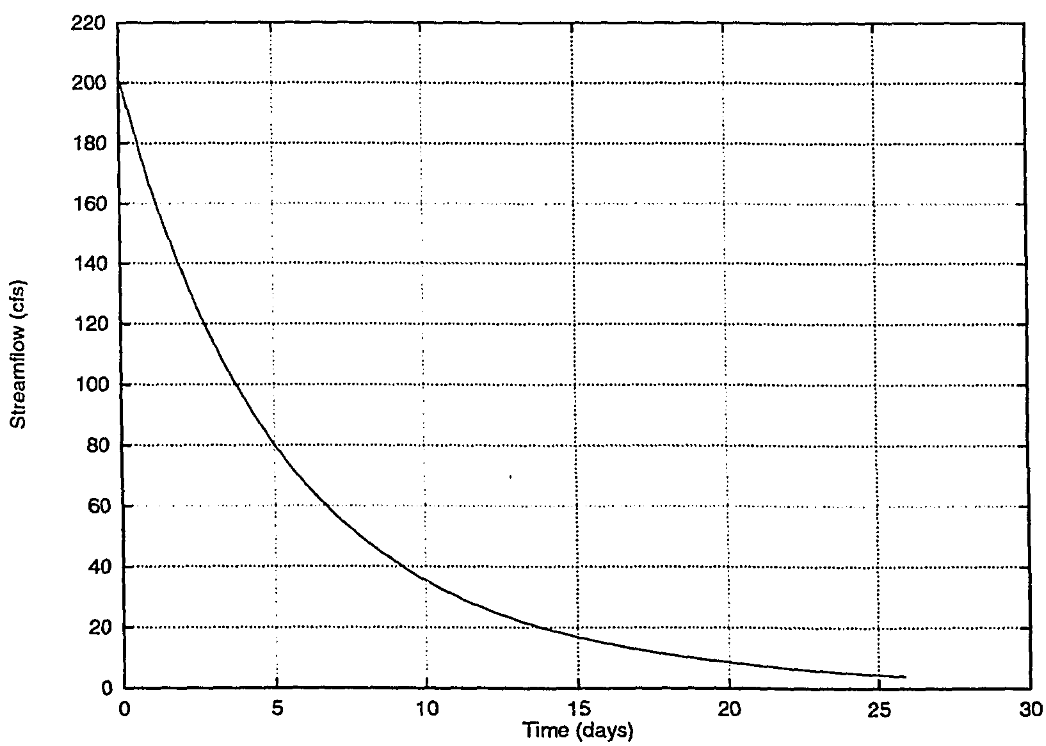

Figure 87.2: MRC of White Breast Creek near Dallas (for summer), ID# 05487980

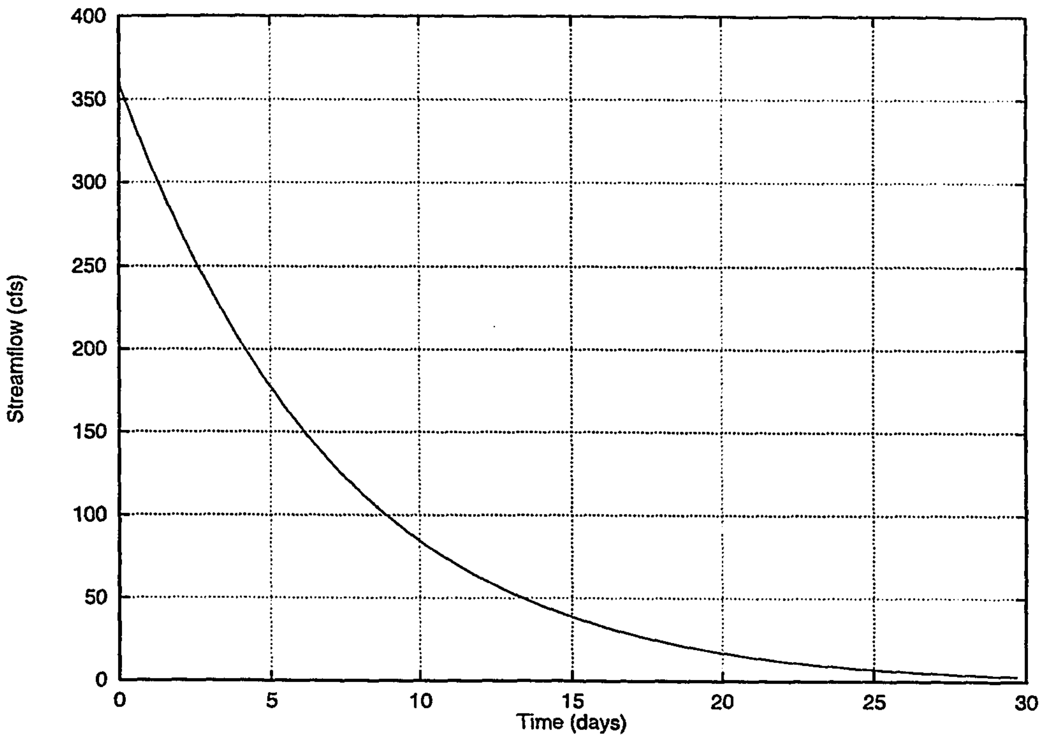

Figure 88.1: MRC of White Breast Creek near Knoxville (for winter), ID# 05488000

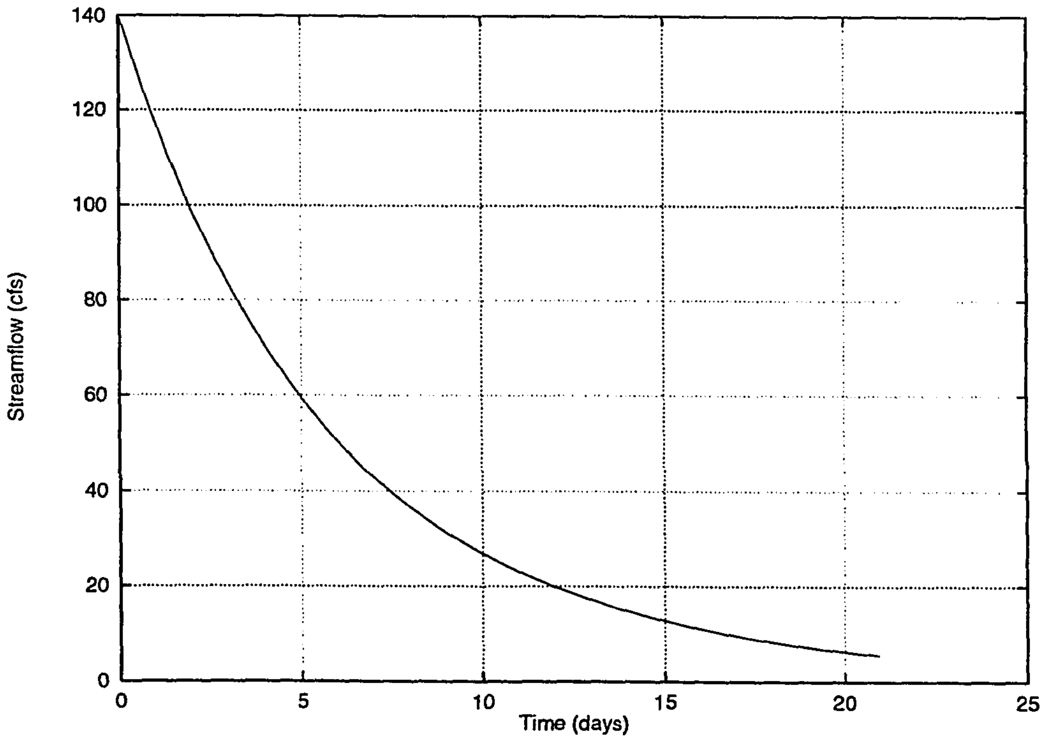

Figure 88.2: MRC of White Breast Creek near Knoxville (for summer), ID# 05488000

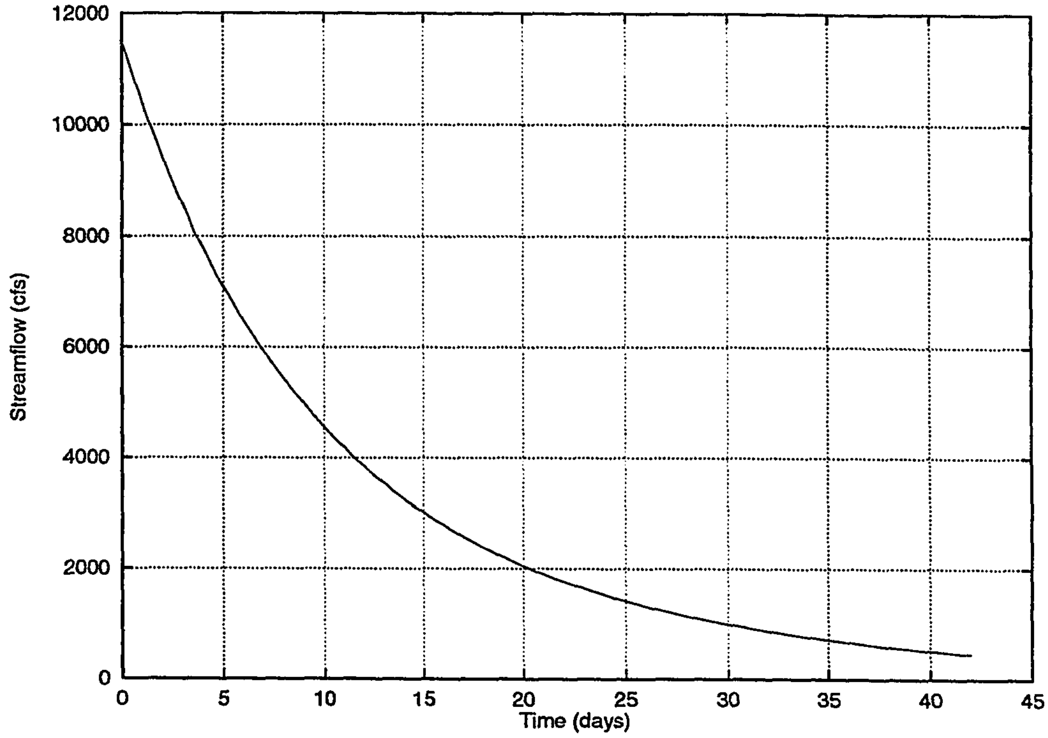

Figure 89.1: MRC of Des Moines River near Tracy (for winter), ID# 05488500

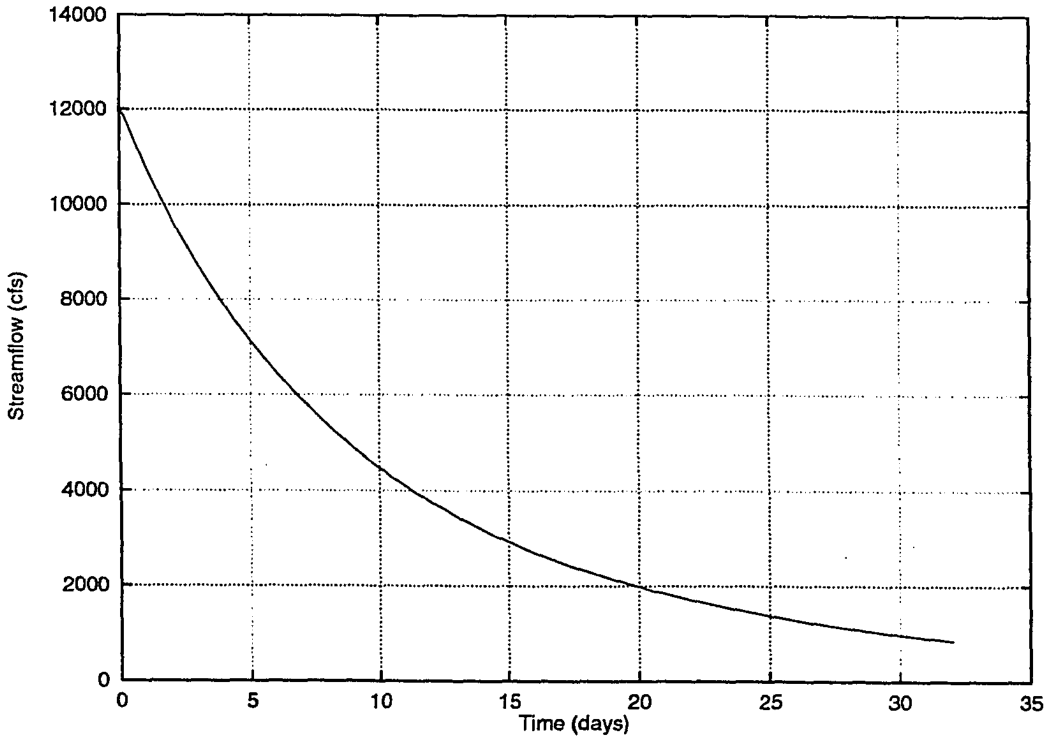

Figure 89.2: MRC of Des Moines River near Tracy (for summer), ID# 05488500

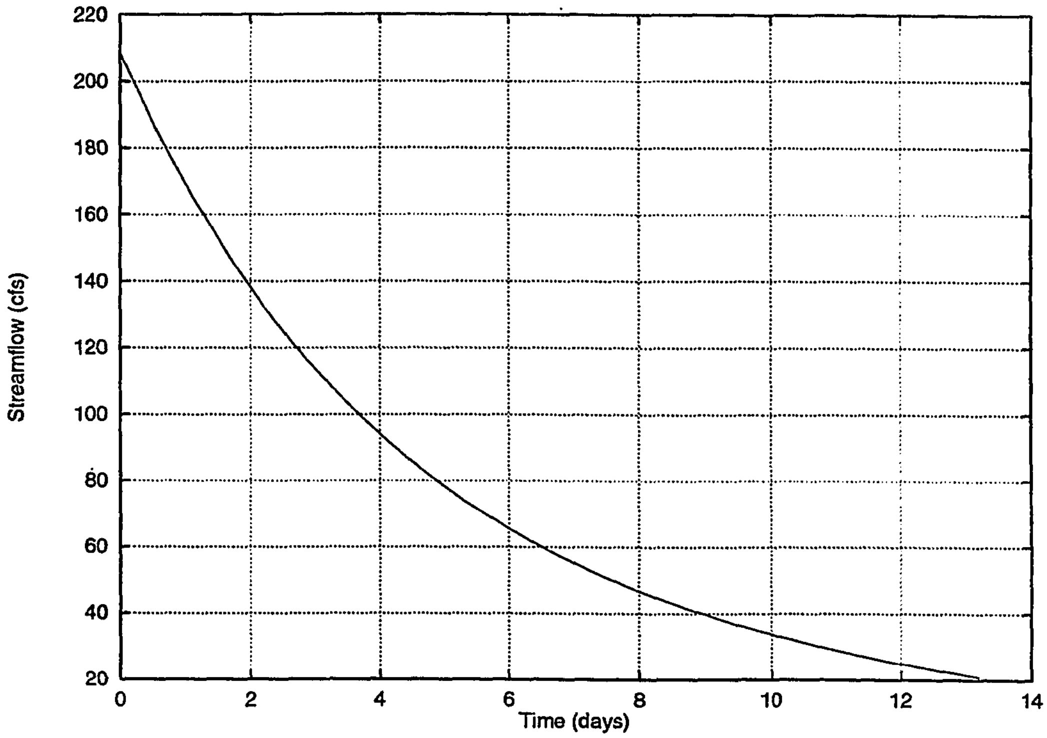

Figure 90.1: MRC of Cedar Creek near Bussey (for winter), ID# 05489000

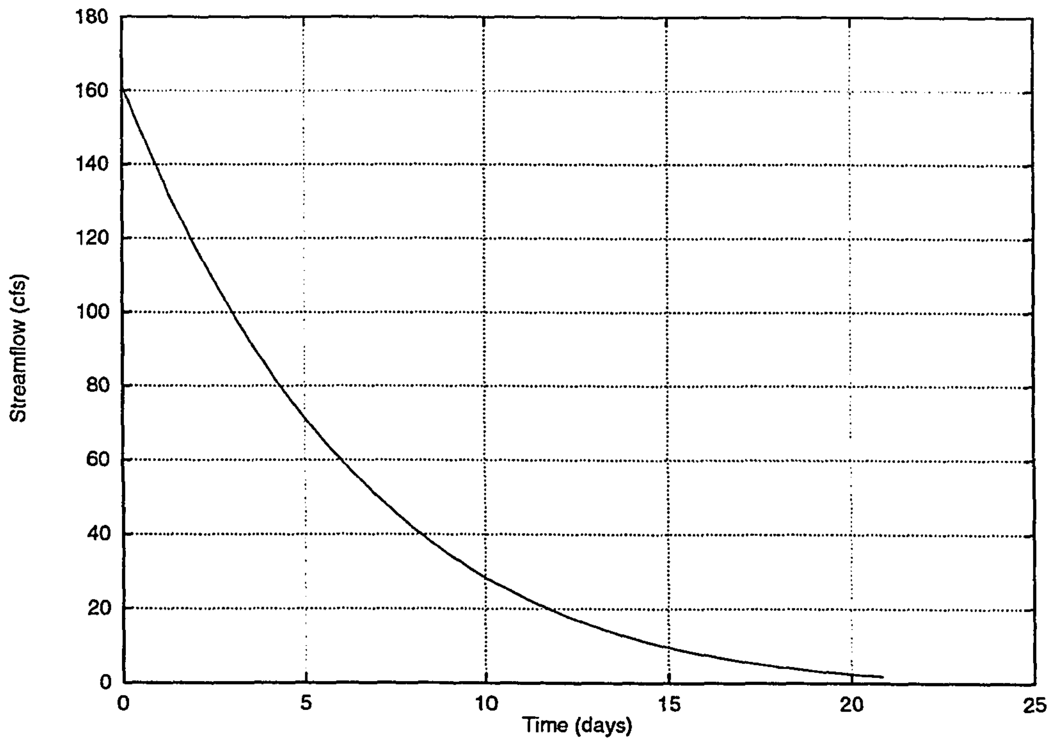

Figure 90.2: MRC of Cedar Creek near Bussey (for summer), ID# 05489000

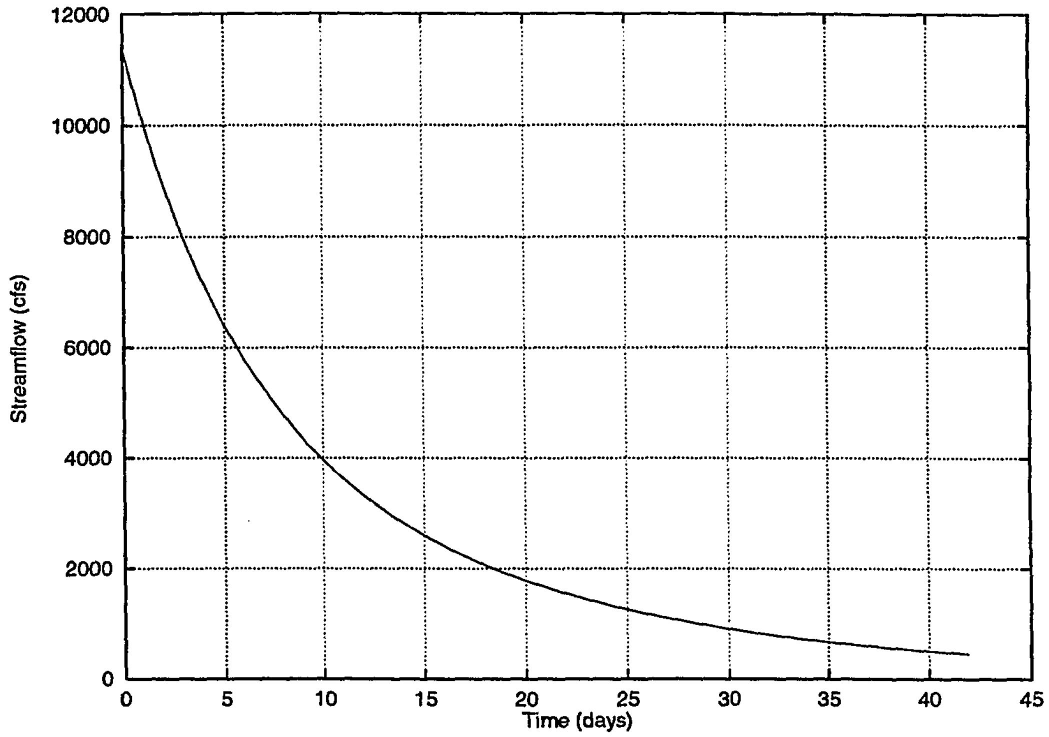

Figure 91.1: MRC of Des Moines River at Ottumwa (for winter), ID# 05489500

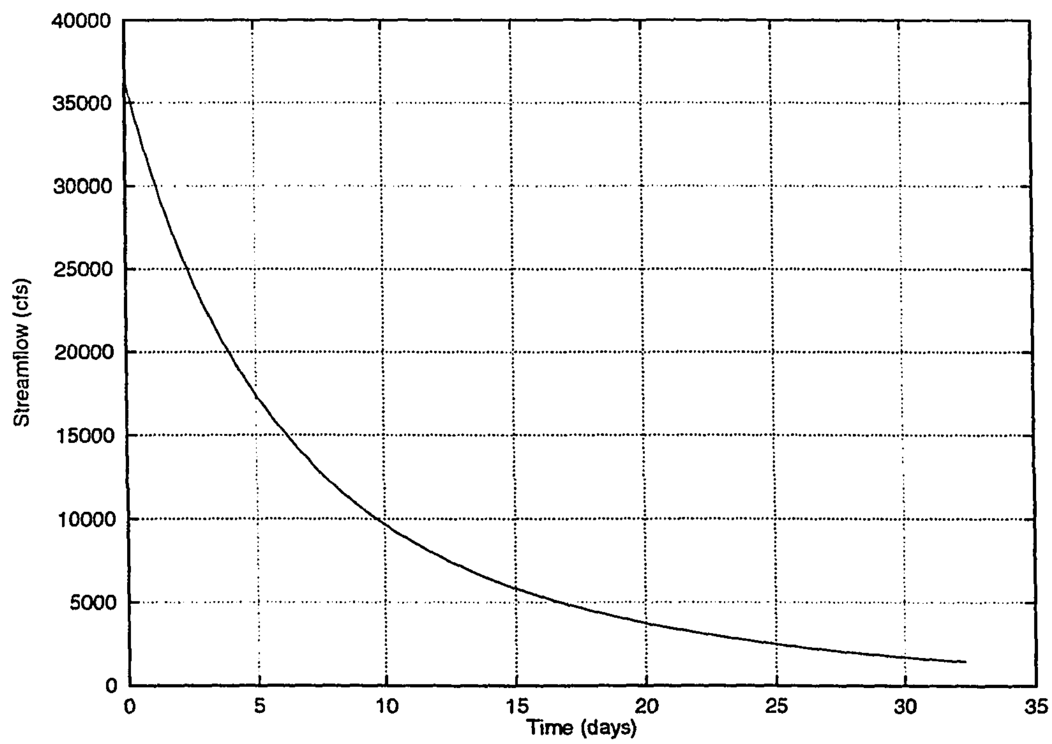

Figure 91.2: MRC of Des Moines River at Ottumwa (for summer), ID# 05489500

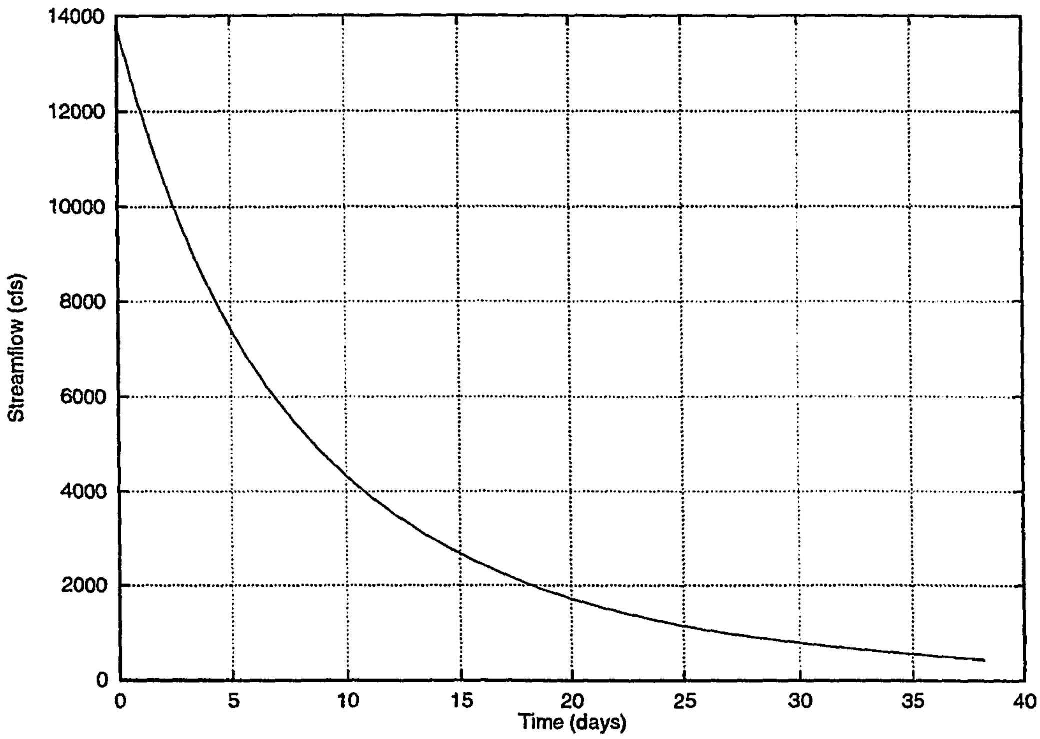

Figure 92.1: MRC of Des Moines River at Keosauqua (for winter), ID# 05490500

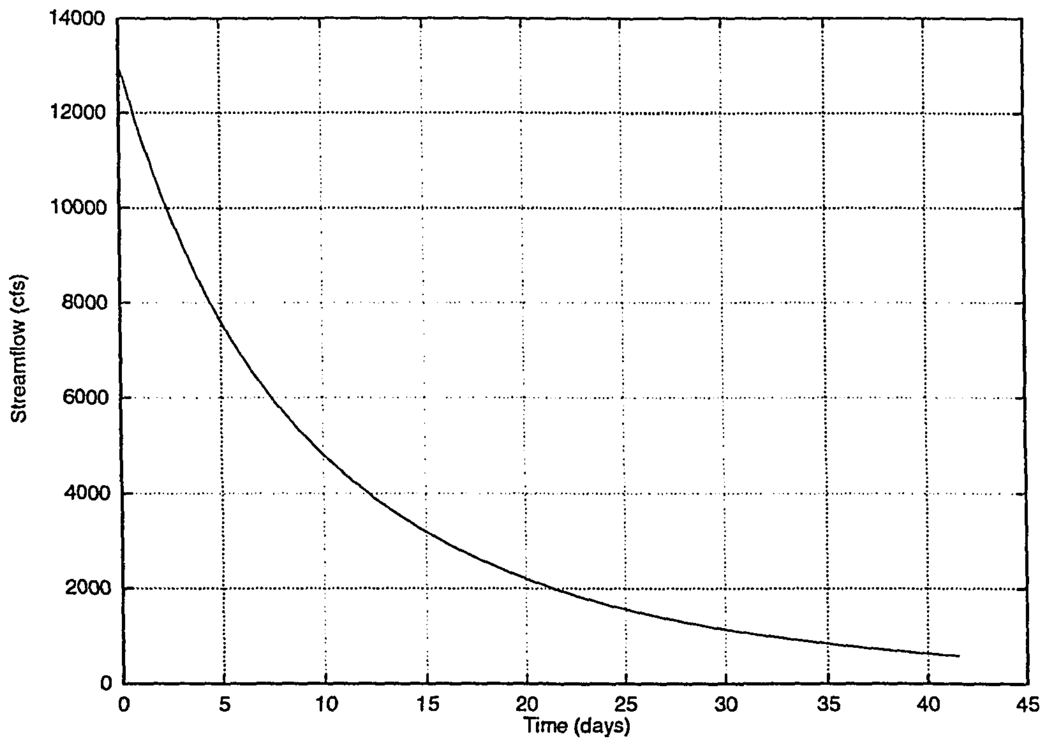

Figure 92.2: MRC of Des Moines River at Keosauqua (for summer), ID# 05490500

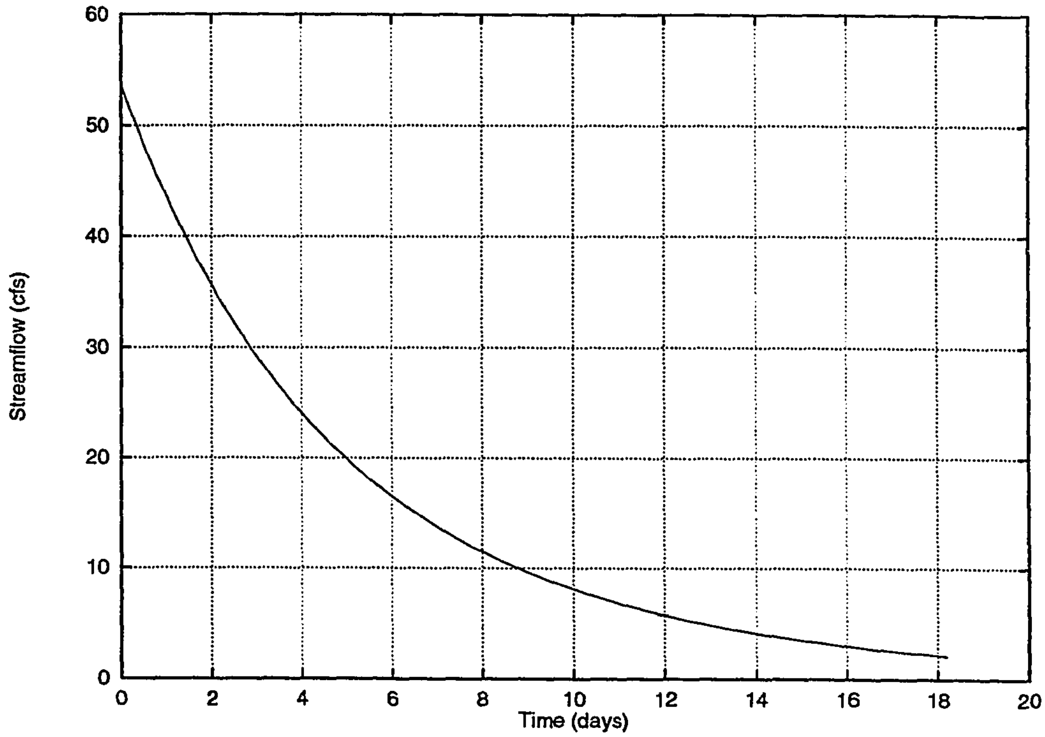

Figure 93.1: MRC of Sugar Creek near Keokuk (for winter), ID# 05491000

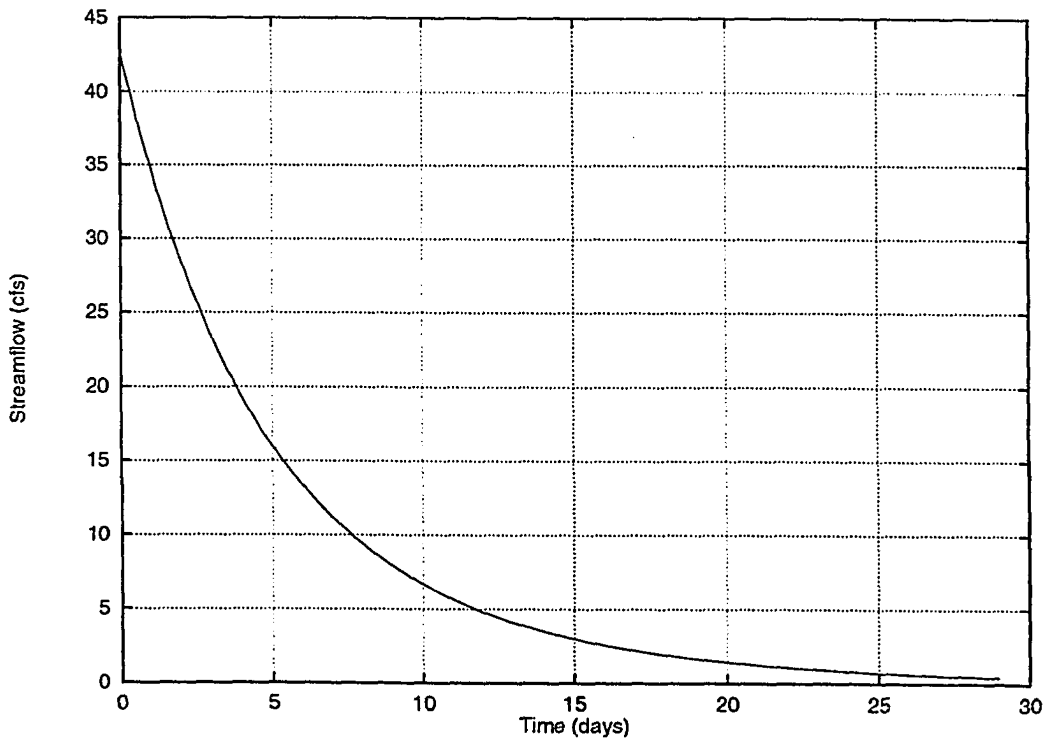

Figure 93.2: MRC of Sugar Creek near Keokuk (for summer), ID# 05491000

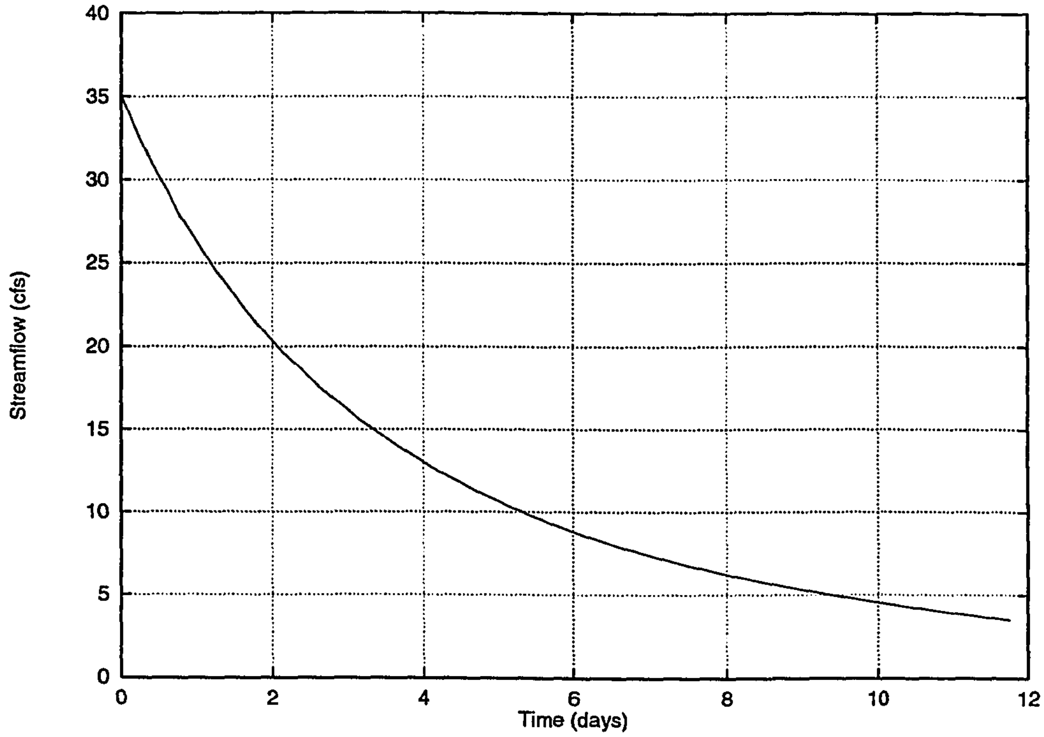

Figure 94.1: MRC of Fox River at Bloomfield (for winter), ID# 05494300

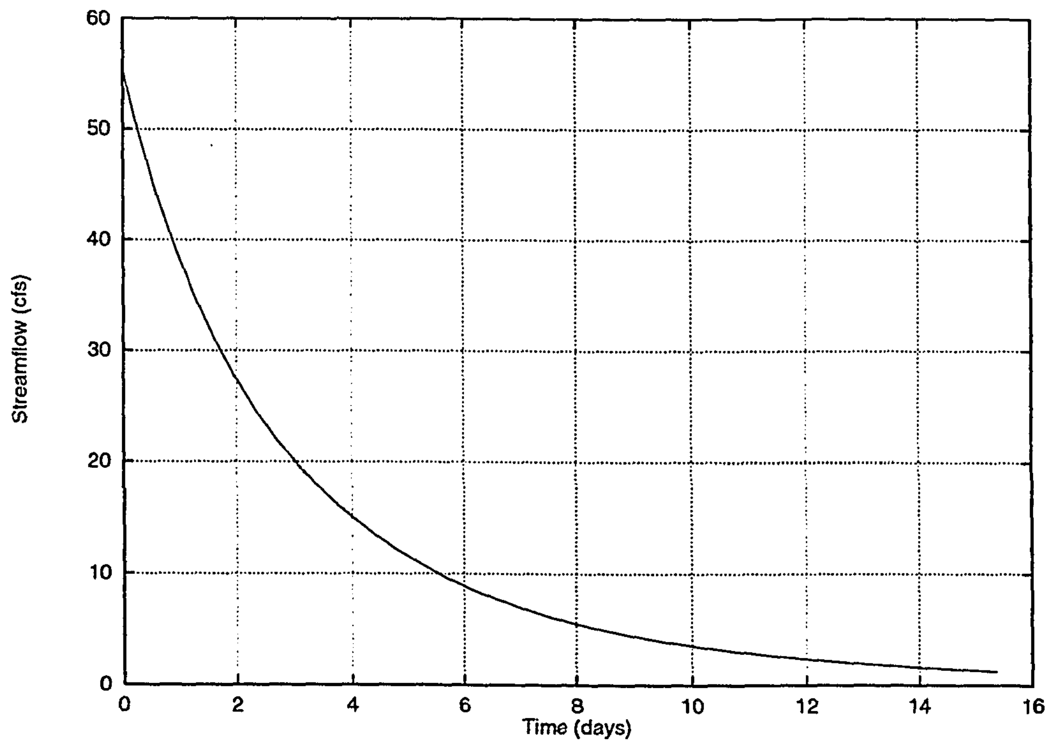

Figure 94.2: MRC of Fox River at Bloomfield (for summer), ID# 05494300

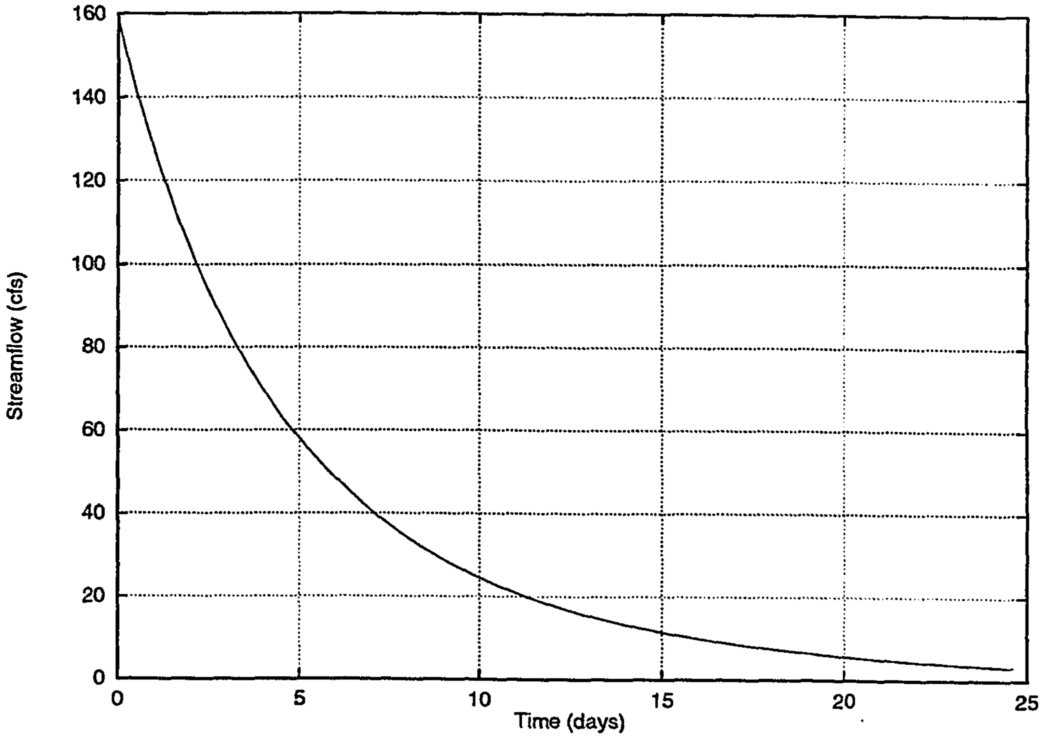

Figure 95.1: MRC of Fox River at Cantril (for winter), ID# 05494500

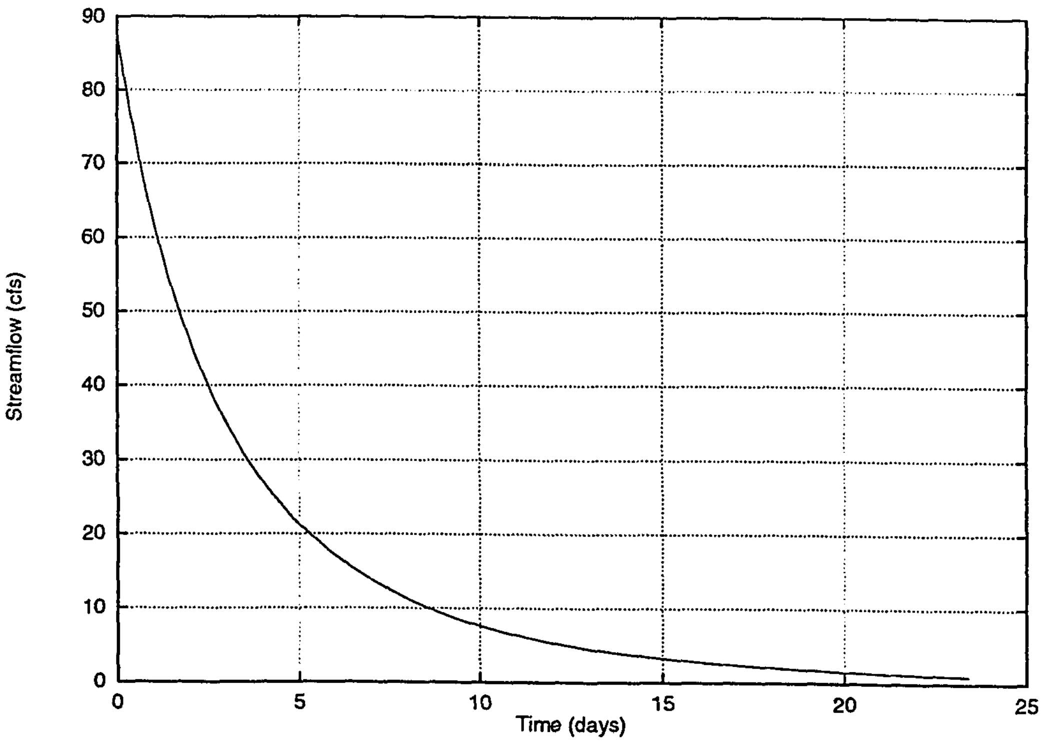

Figure 95.2: MRC of Fox River at Cantril (for summer), ID# 05494500

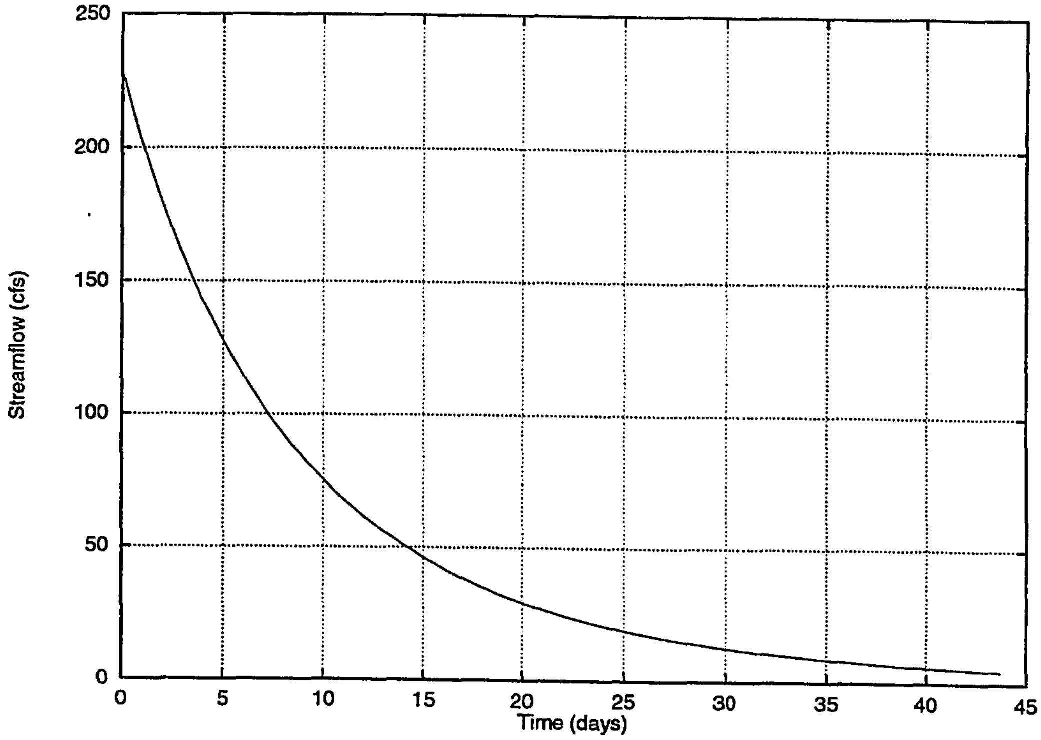

Figure 96.1: MRC of Rock River at Rock Rapids (for winter), ID# 06483270

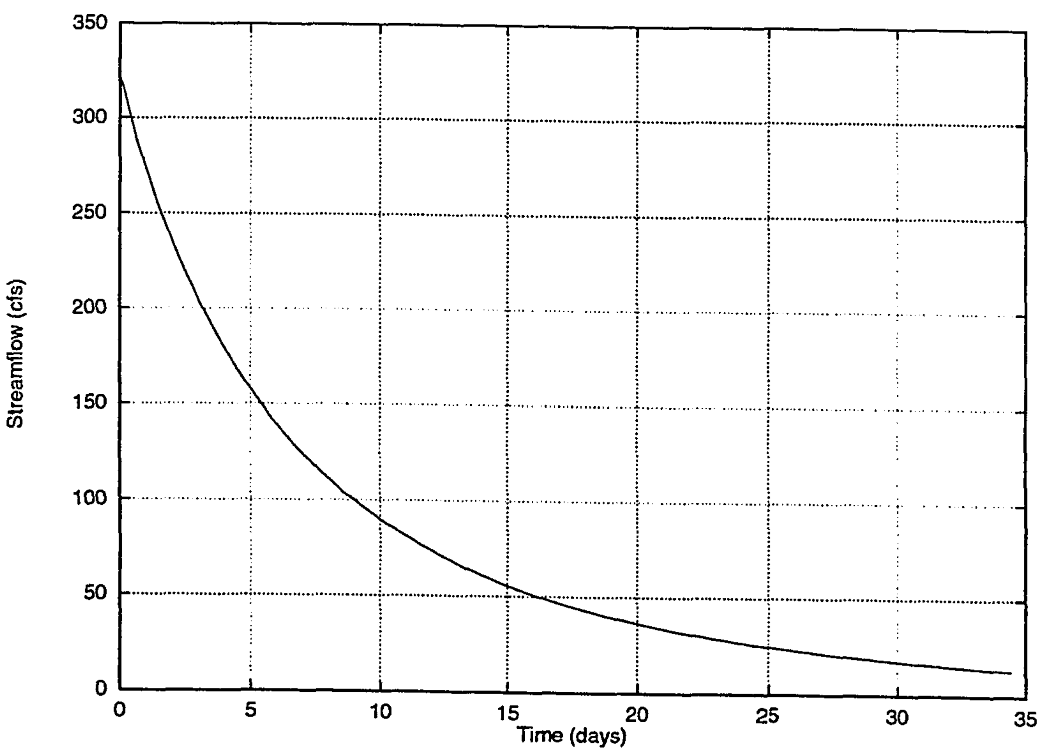

Figure 96.2: MRC of Rock River at Rock Rapids (for summer), ID# 06483270

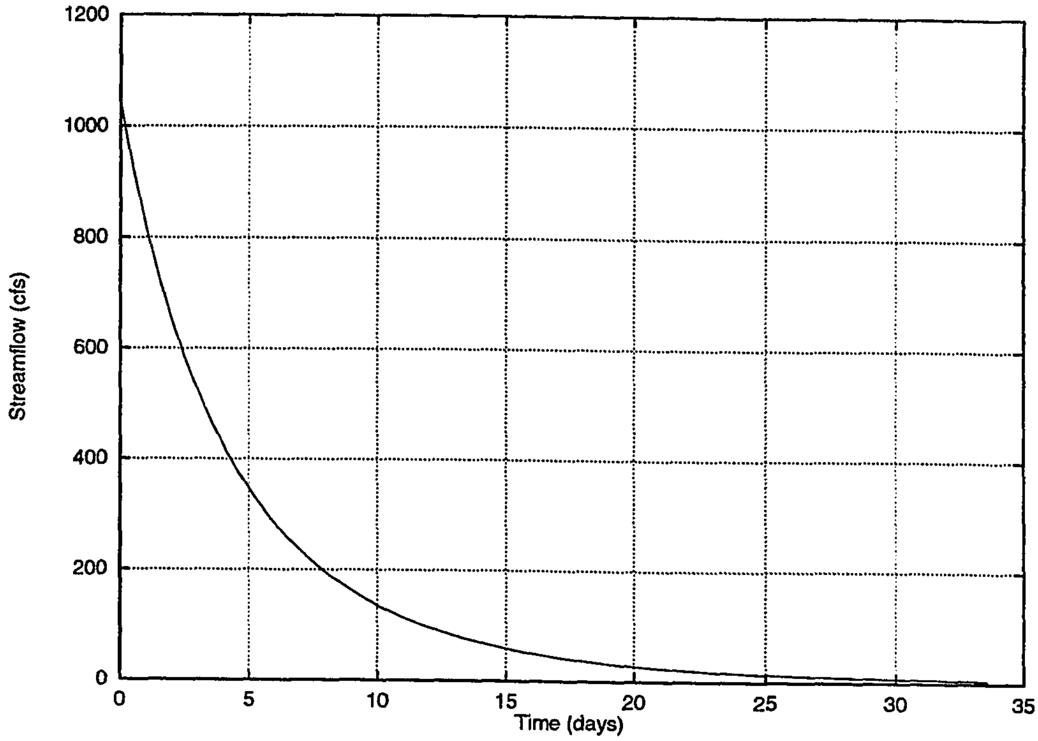

Figure 97.1: MRC of Rock River near Rock Valley (for winter), ID# 06483500

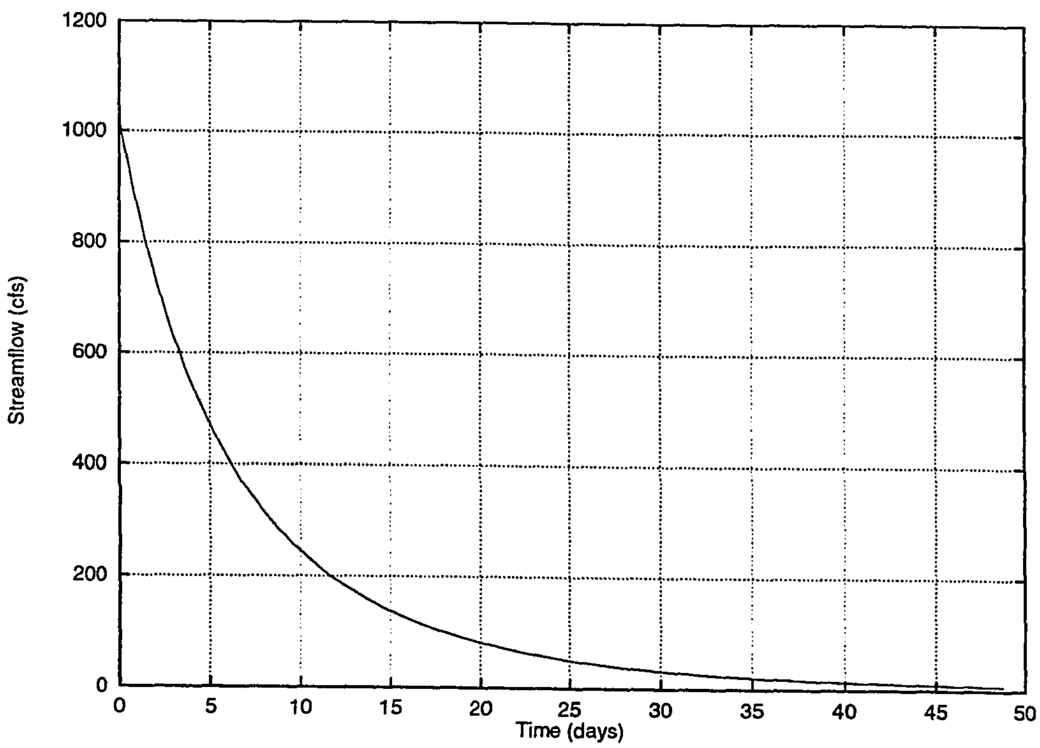

Figure 97.2: MRC of Rock River near Rock Valley (for summer), ID# 06483500

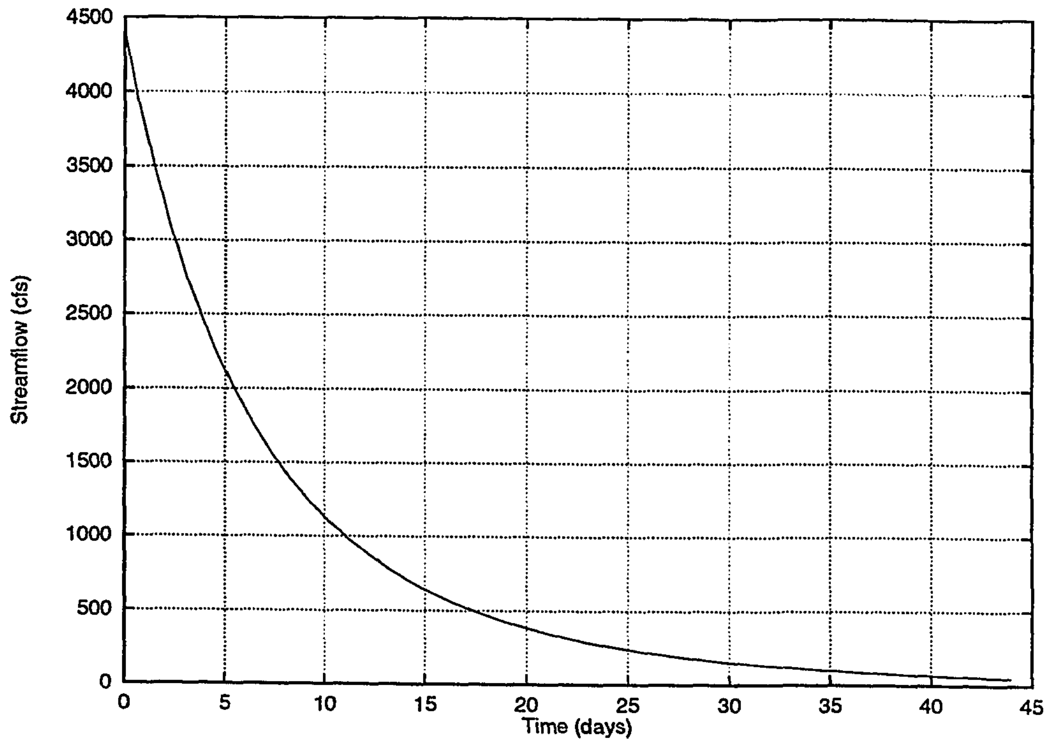

Figure 98.1: MRC of Big Sioux River at Akron (for winter), ID# 06485500

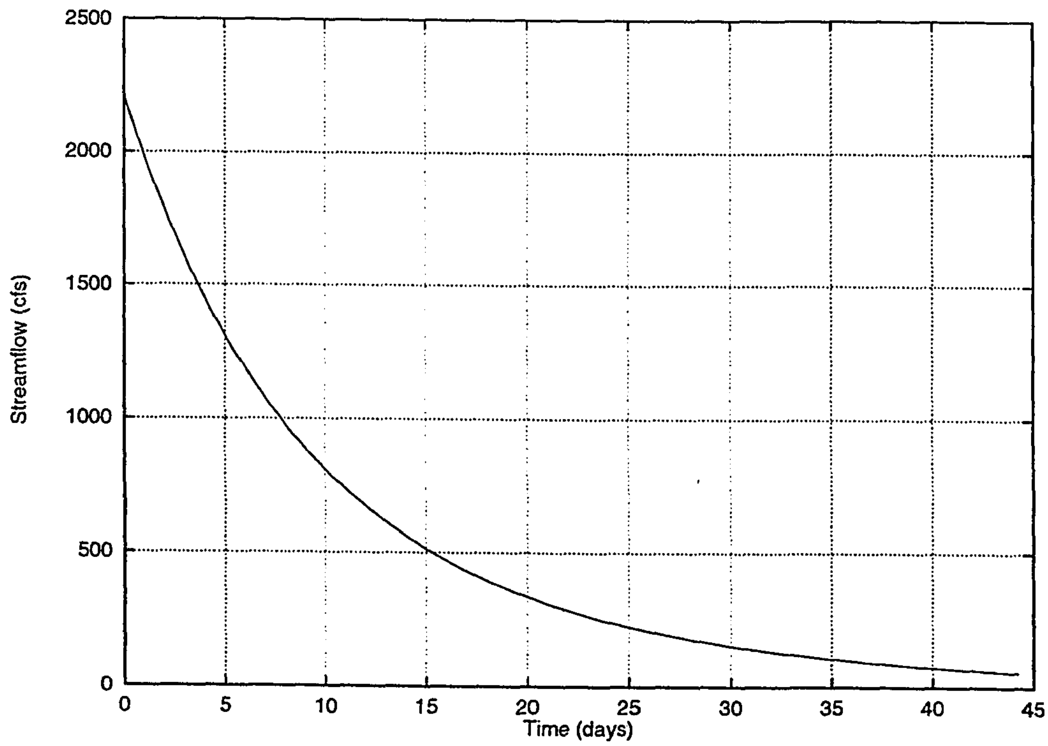

Figure 98.2: MRC of Big Sioux River at Akron (for summer), ID# 06485500

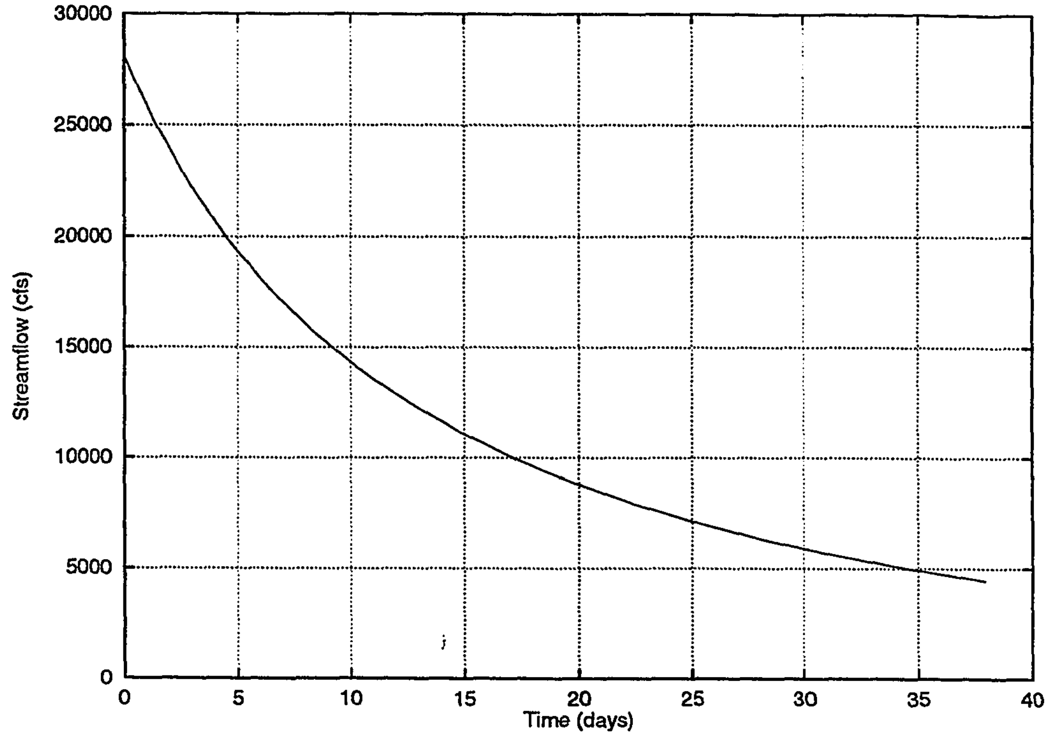

Figure 99.1: MRC of Missouri River at Sioux City (for winter), ID# 06486000

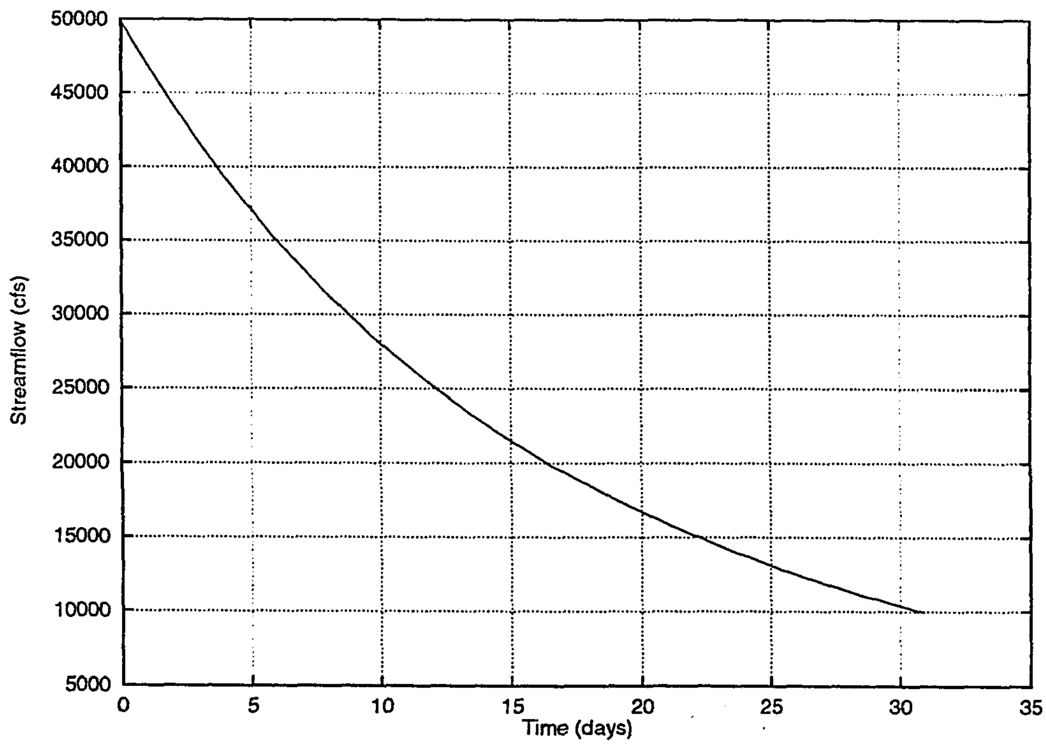

Figure 99.2: MRC of Missouri River at Sioux City (for summer), ID# 06486000

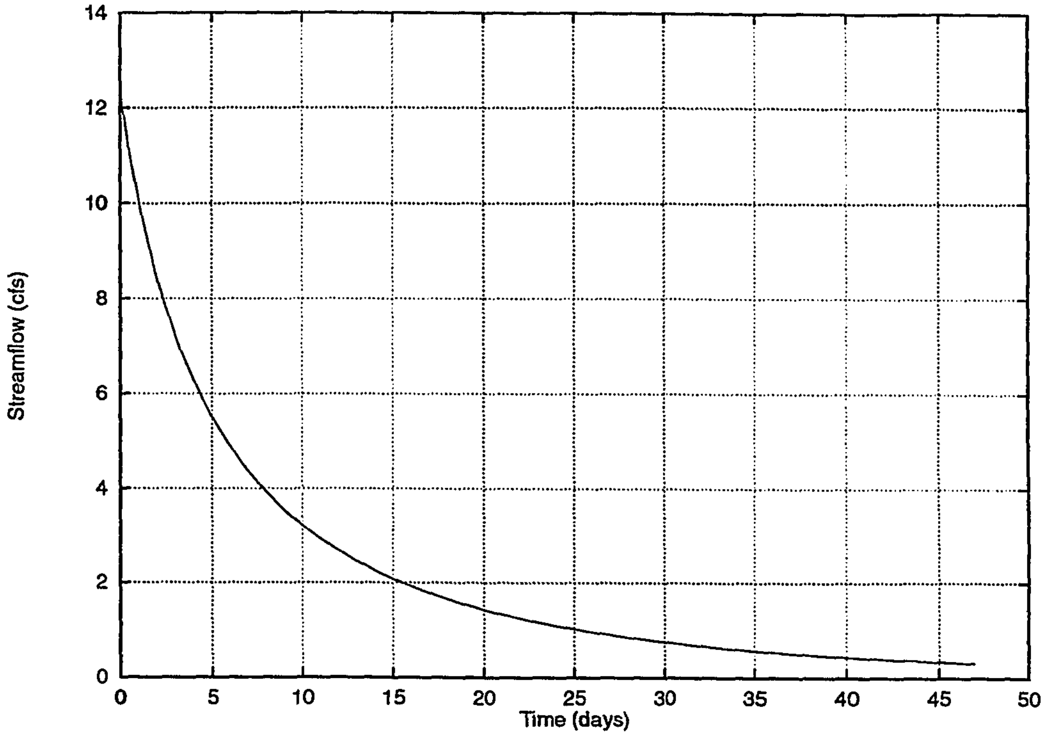

Figure 100.1: MRC of Perry Creek at 38th street, Sioux City (for winter), ID# 06600000

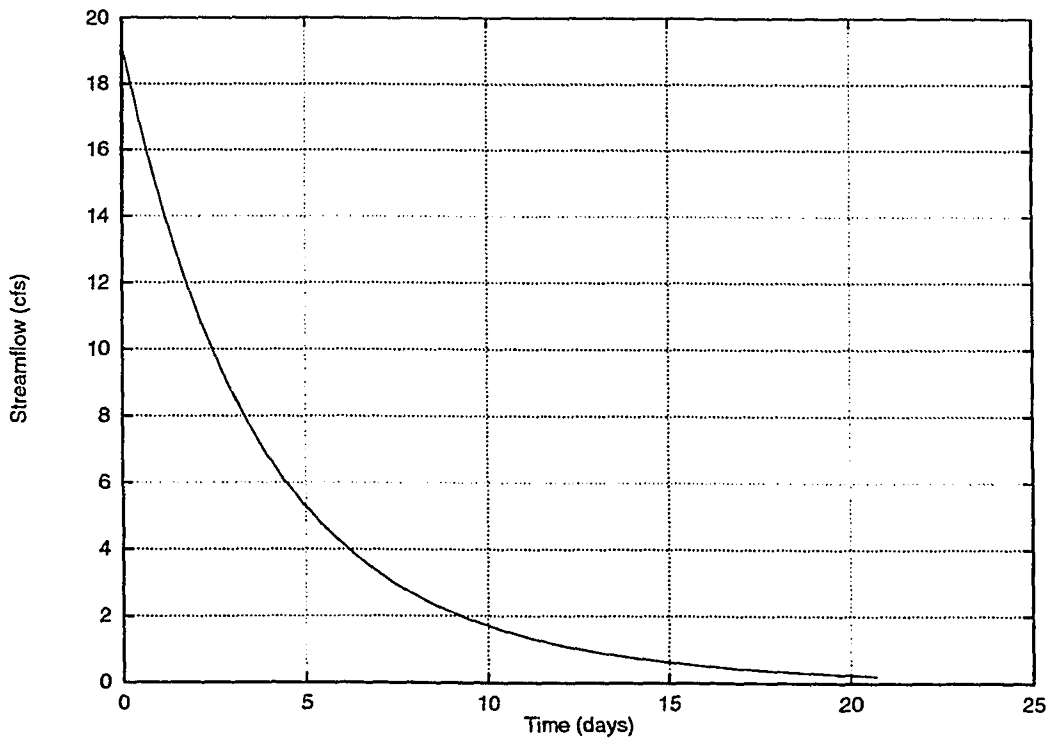

Figure 100.2: MRC of Perry Creek at 38th street, Sioux City (for summer), ID# 06600000

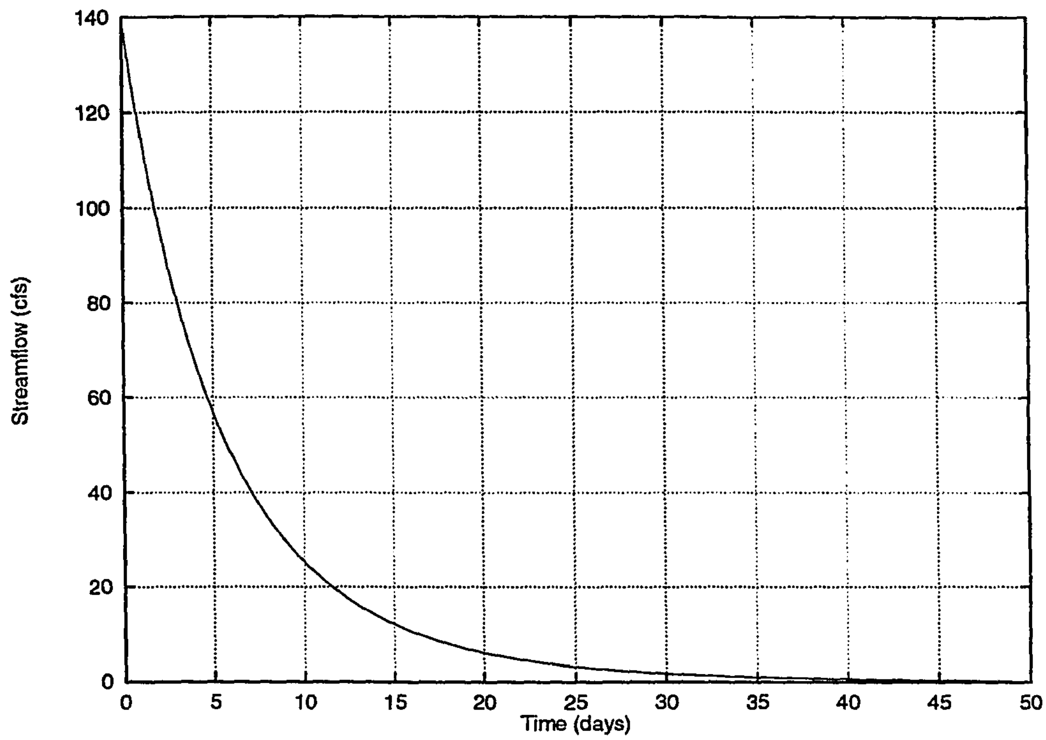

Figure 101.1: MRC of Floyd River at Alton (for winter), ID# 06600100

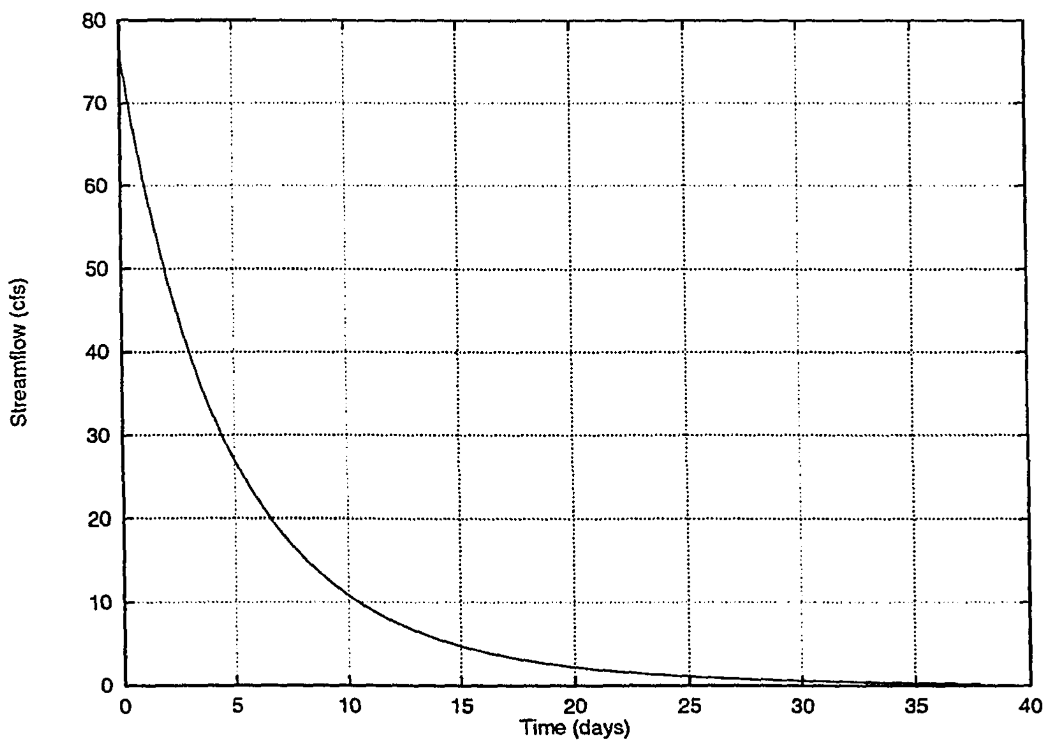

Figure 101.2: MRC of Floyd River at Alton (for summer), ID# 06600100

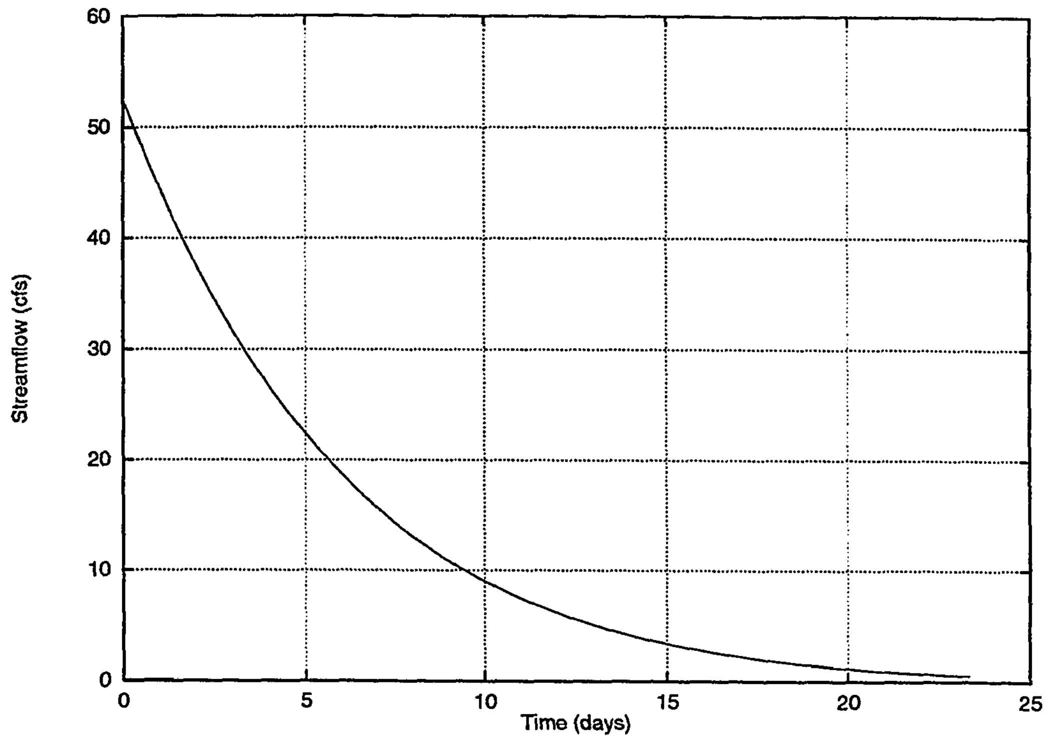

Figure 102.1: MRC of West Branch Floyd River near Struble (for winter), ID# 06600300

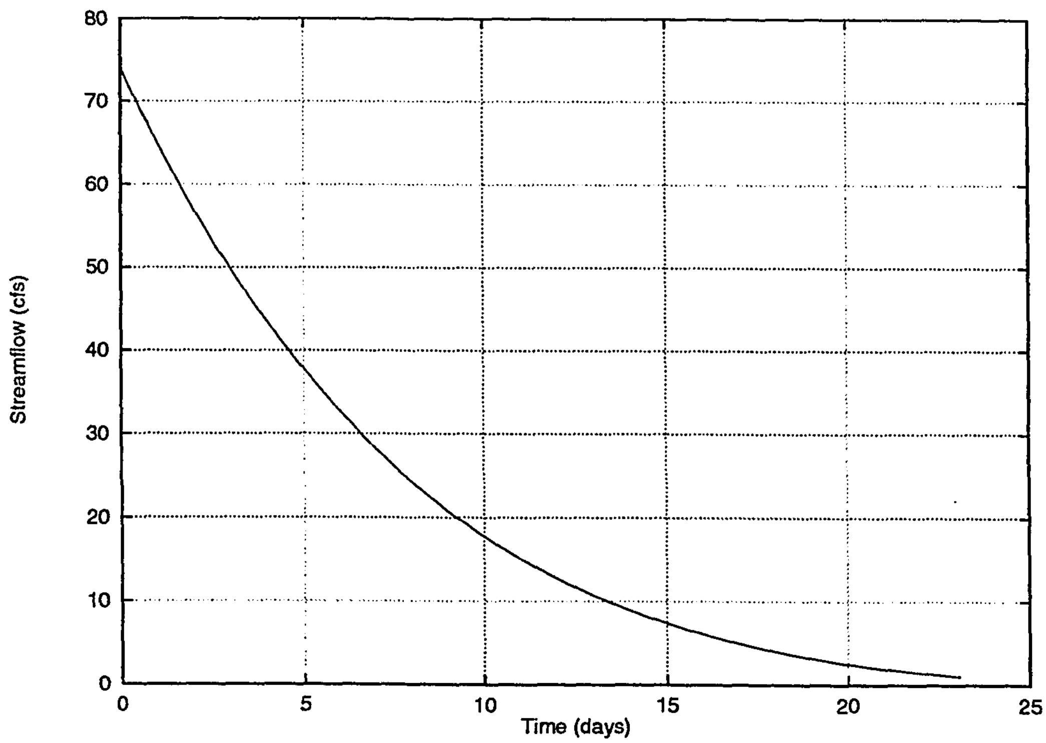

Figure 102.2: MRC of West Branch Floyd River near Struble (for summer), ID# 06600300

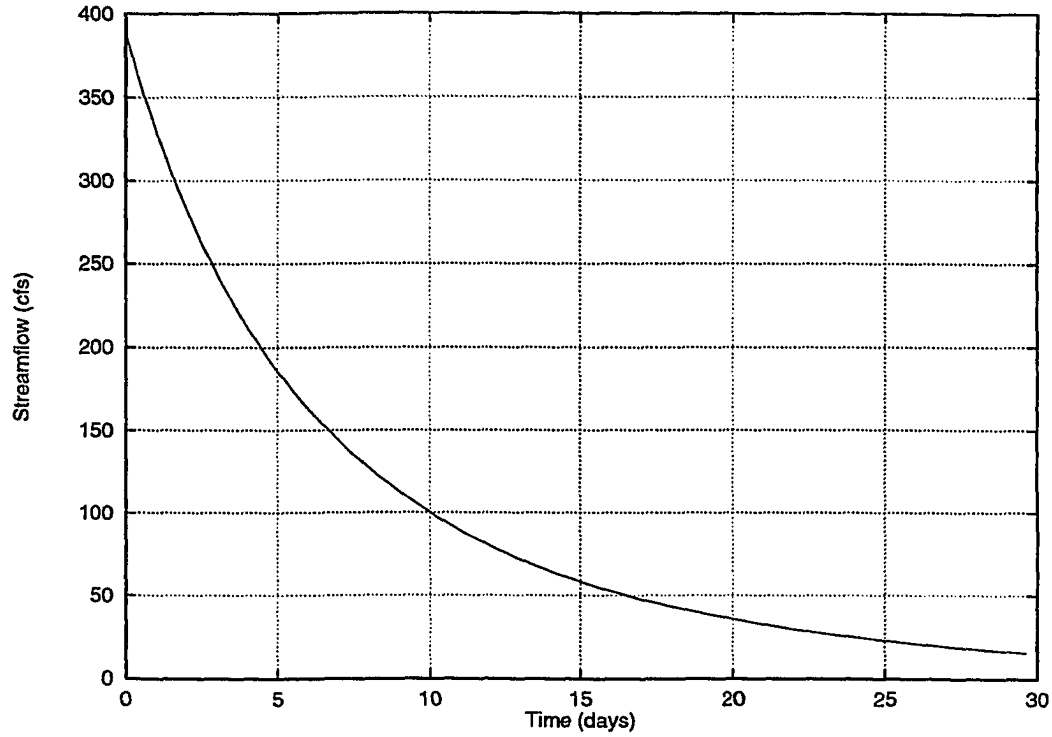

Figure 103.1: MRC of Floyd River at James (for winter), ID# 06600500

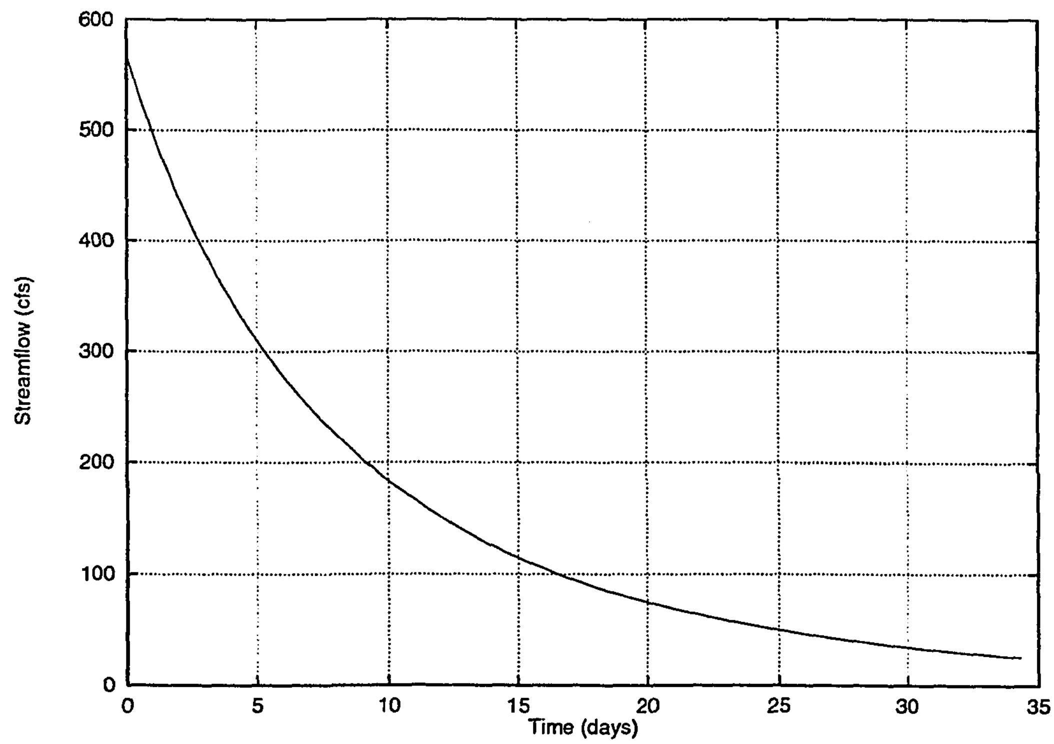

Figure 103.2: MRC of Floyd River at James (for summer), ID# 06600500

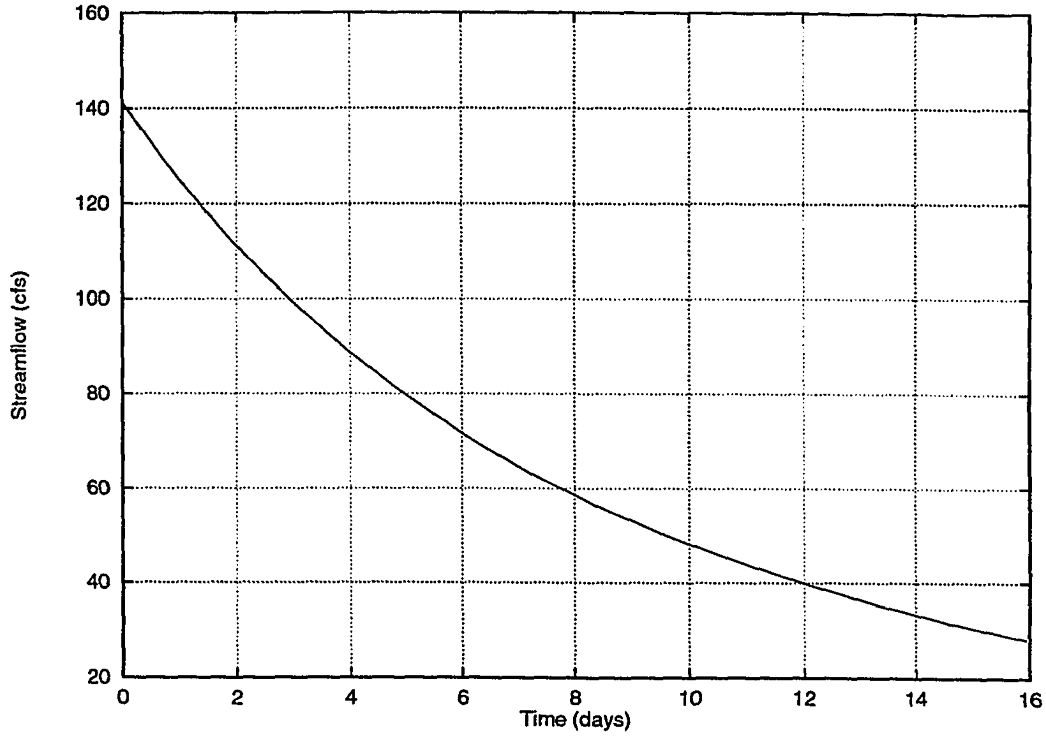

Figure 104.1: MRC of West Fork Ditch at Hornick (for winter), ID# 06602020

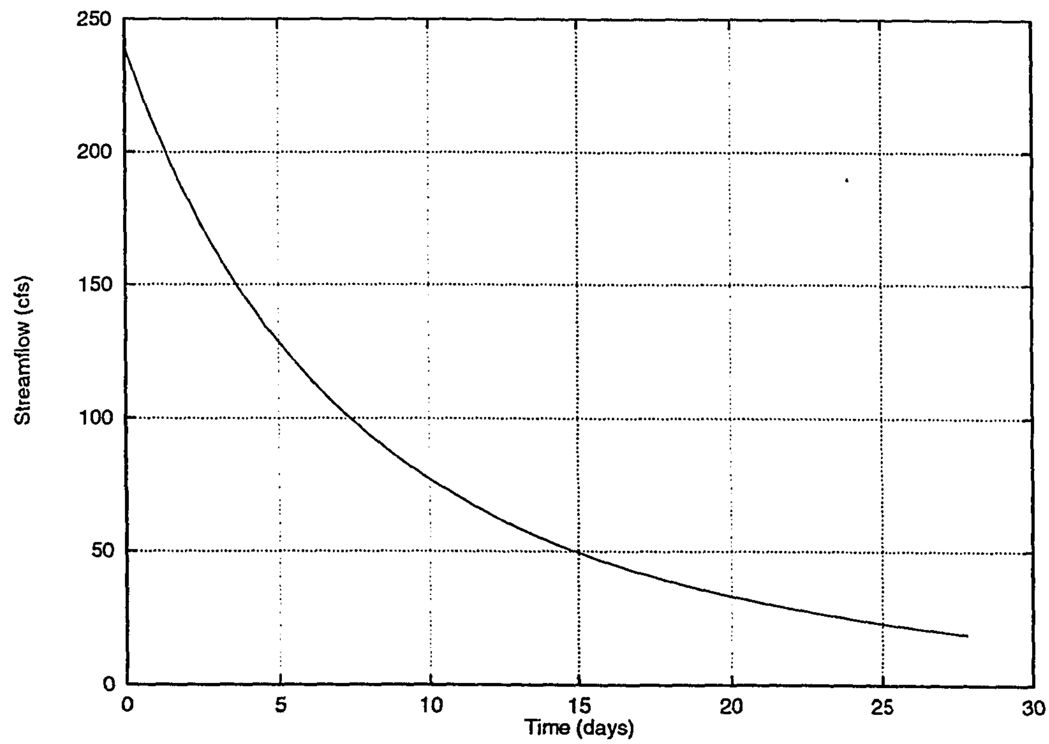

Figure 104.2: MRC of West Fork Ditch at Hornick (for summer), ID# 06602020

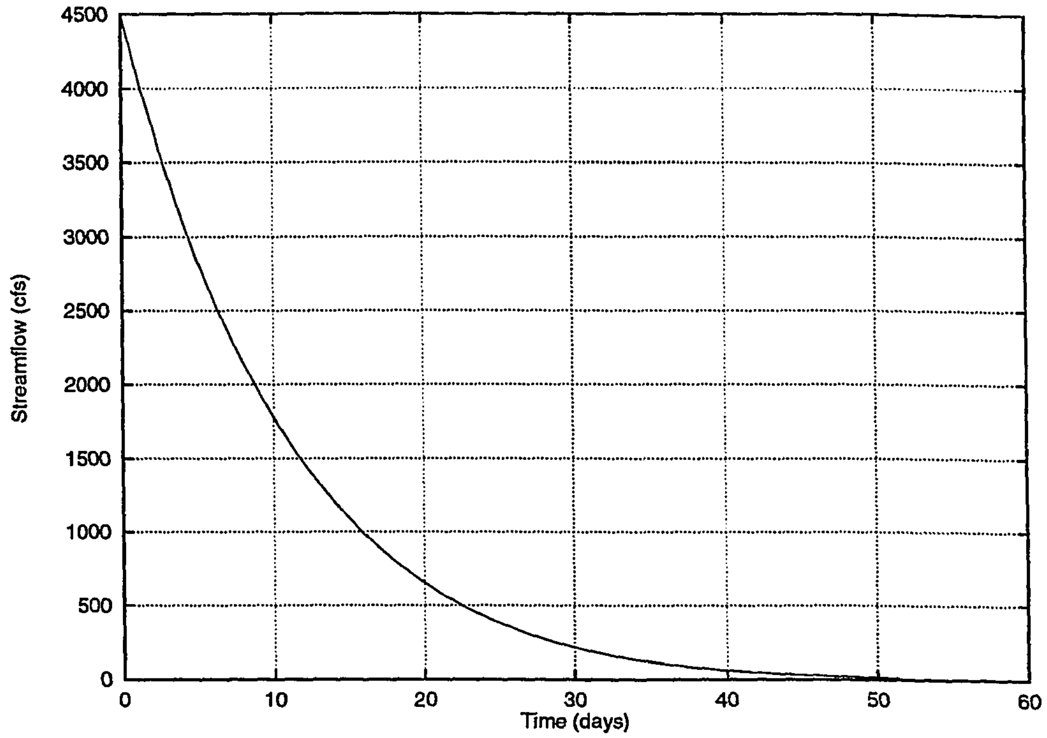

Figure 105.1: MRC of Monona-Harrison Ditch near Turin (for winter), ID# 06602400

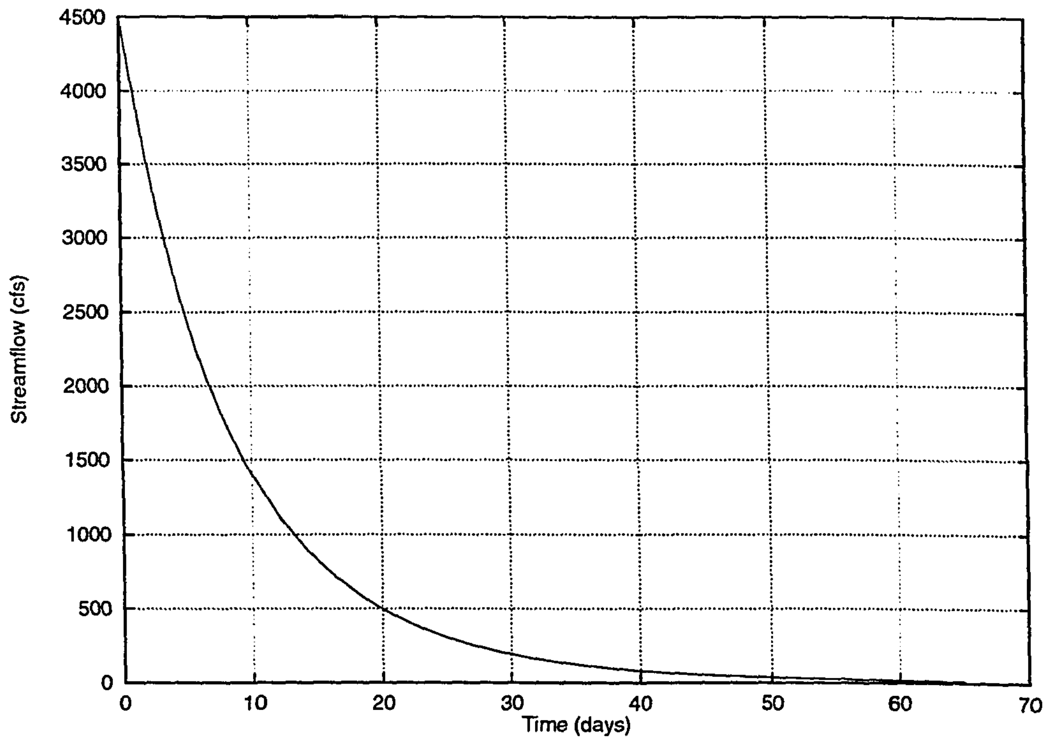

Figure 105.2: MRC of Monona-Harrison Ditch near Turin (for summer), ID# 06602400

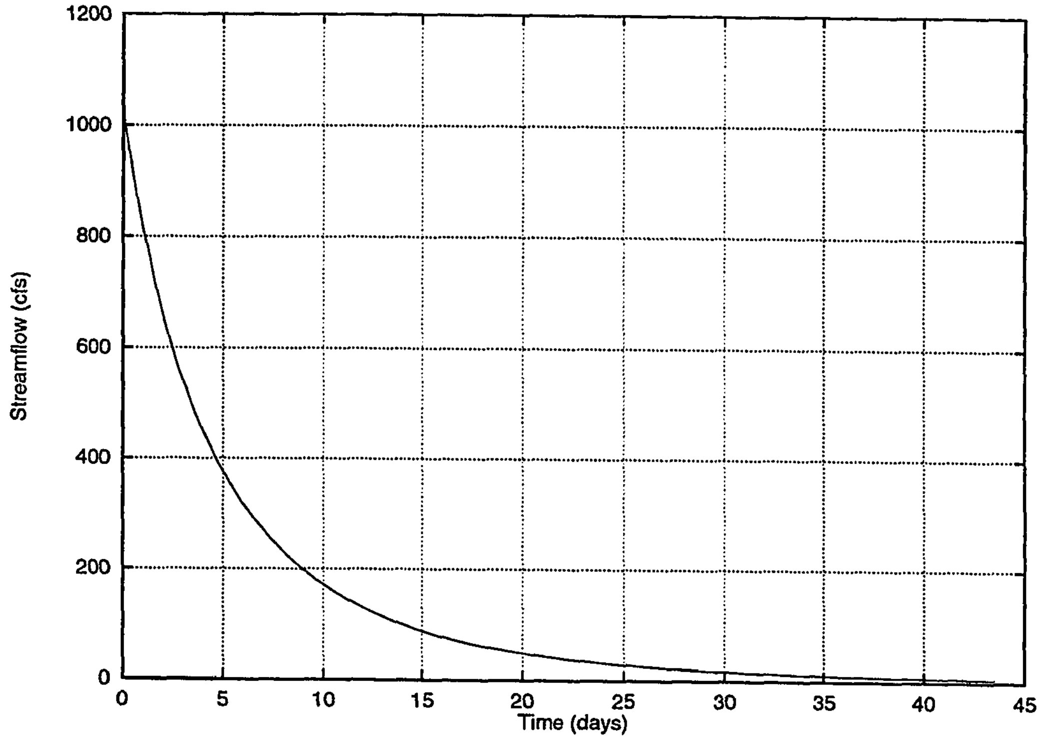

Figure 106.1: MRC of Ocheyedan River near Spencer (for winter), ID# 06605000

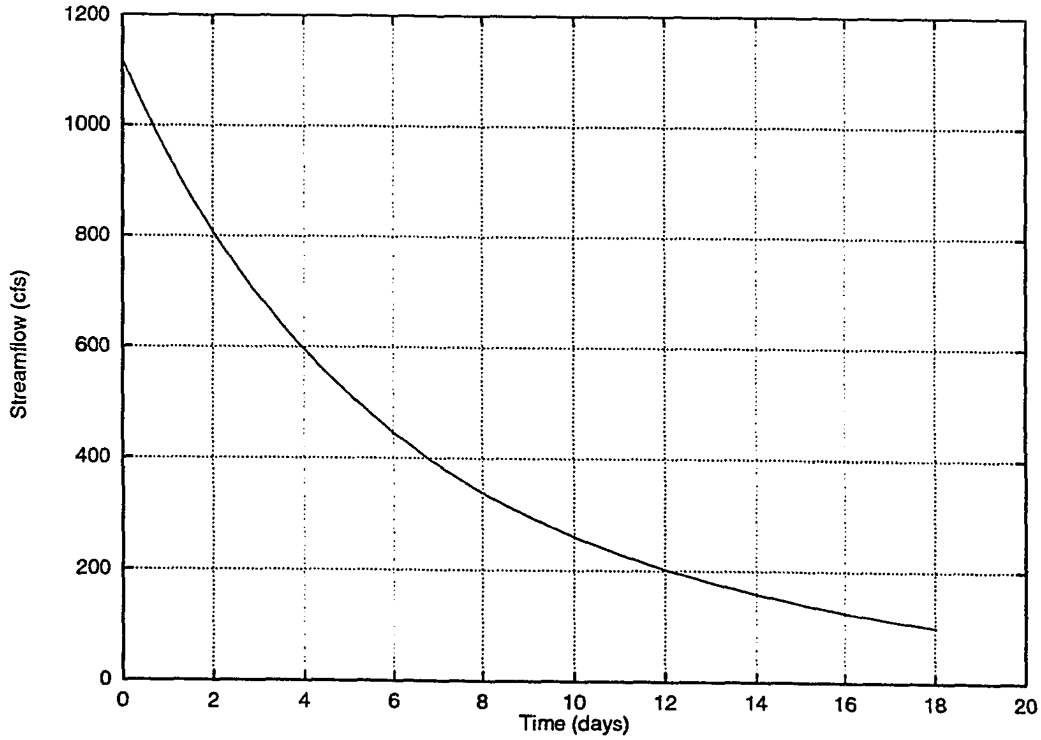

Figure 106.2: MRC of Ocheyedan River near Spencer (for summer), ID# 06605000

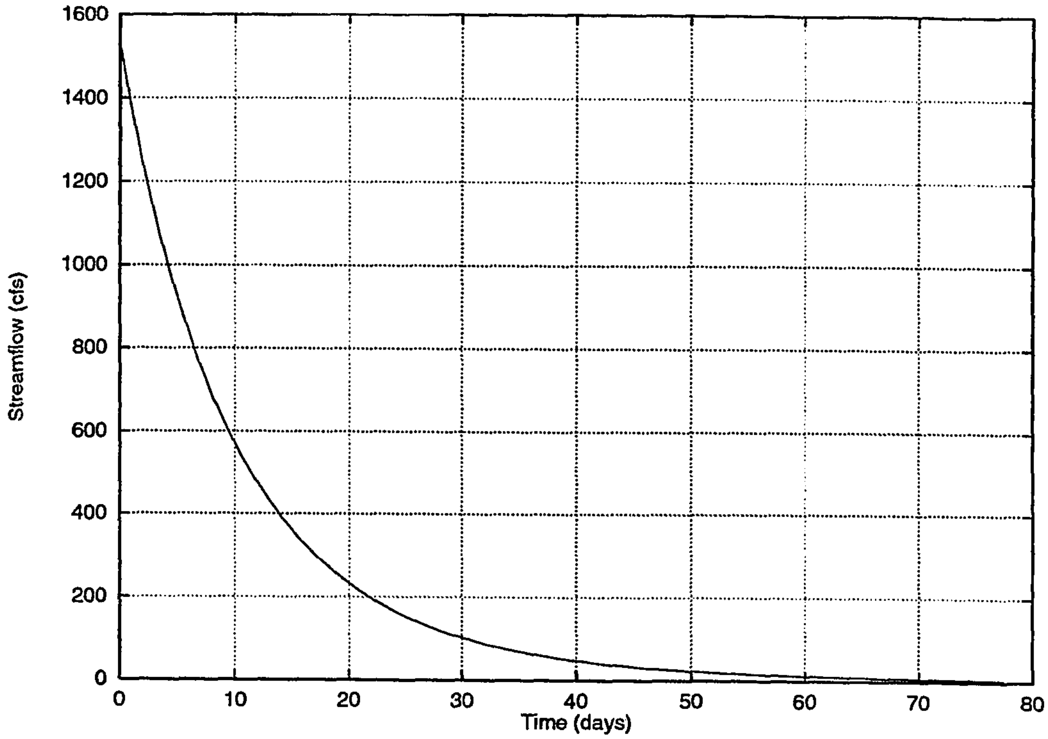

Figure 107.1: MRC of Little Sioux River at Gillett Grove (for winter), ID# 06605600

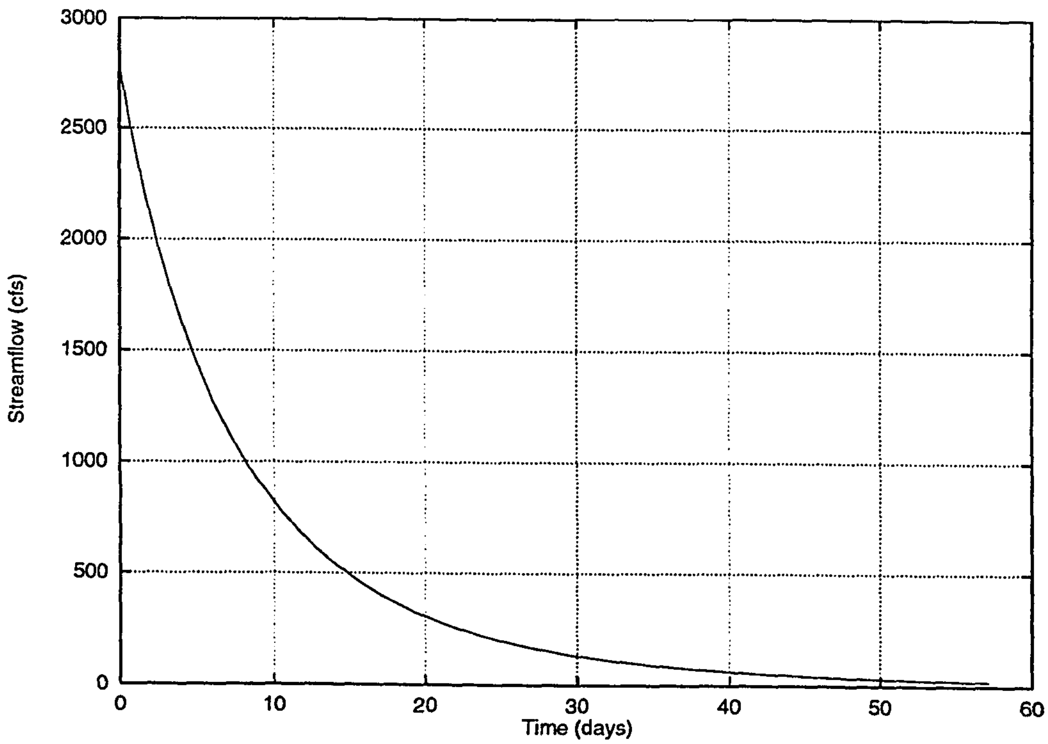

Figure 107.2: MRC of Little Sioux River at Gillett Grove (for summer), ID# 06605600

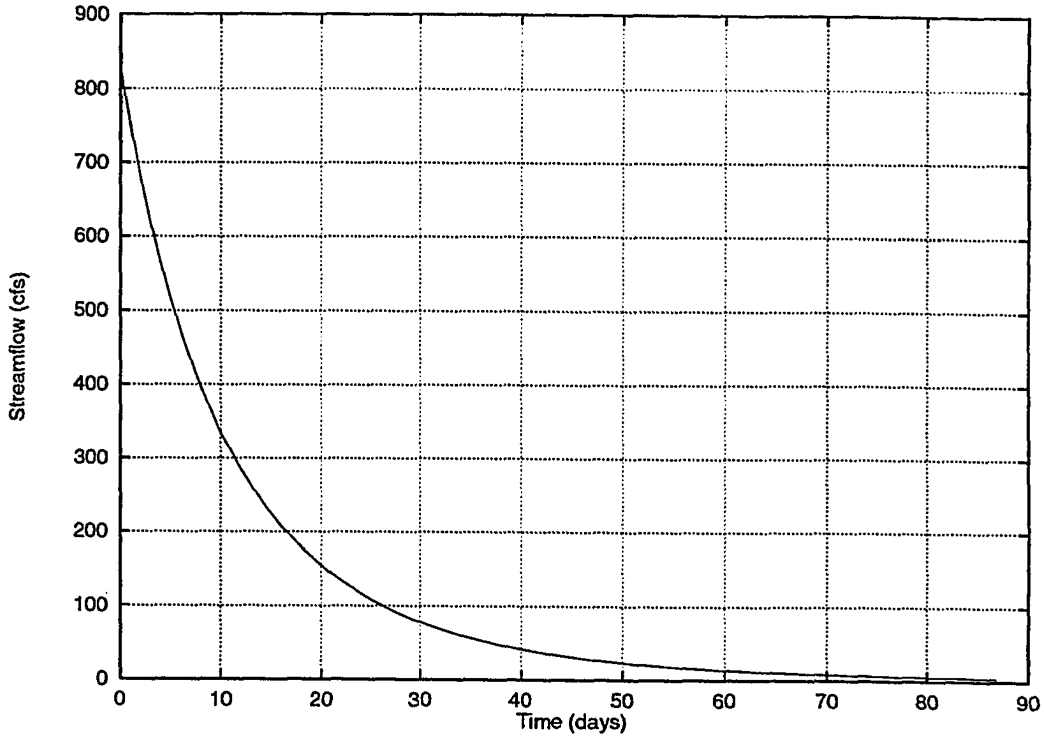

Figure 108.1: MRC of Little Sioux River at Linn Grove (for winter), ID# 06605850

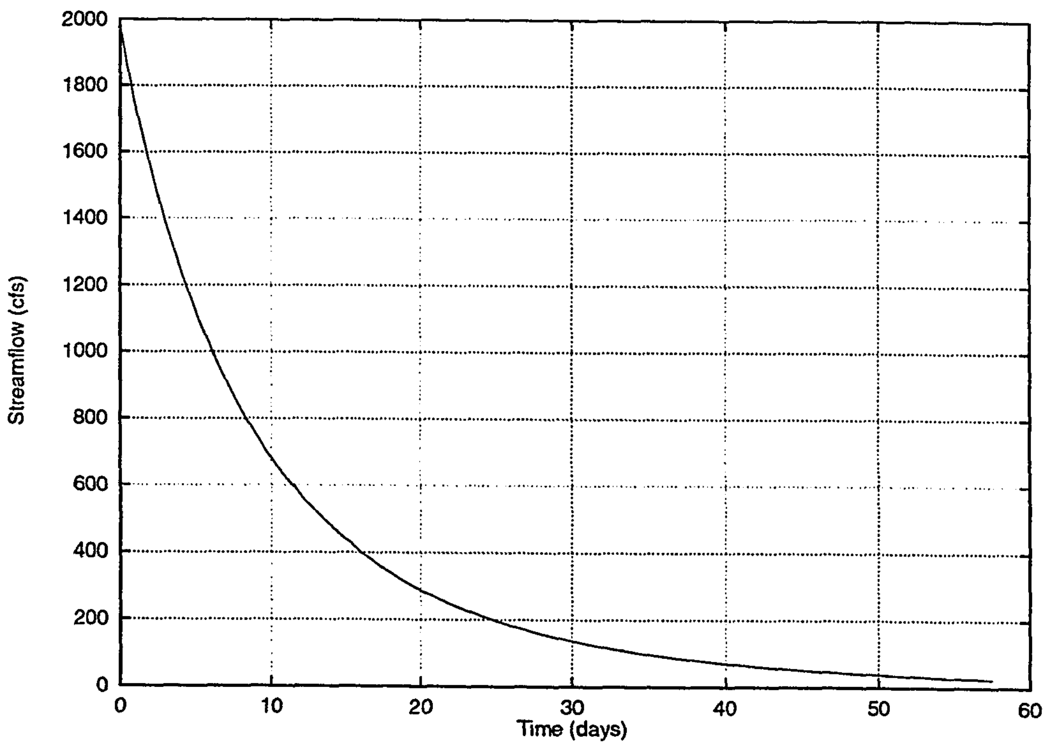

Figure 108.2: MRC of Little Sioux River at Linn Grove (for summer), ID# 06605850

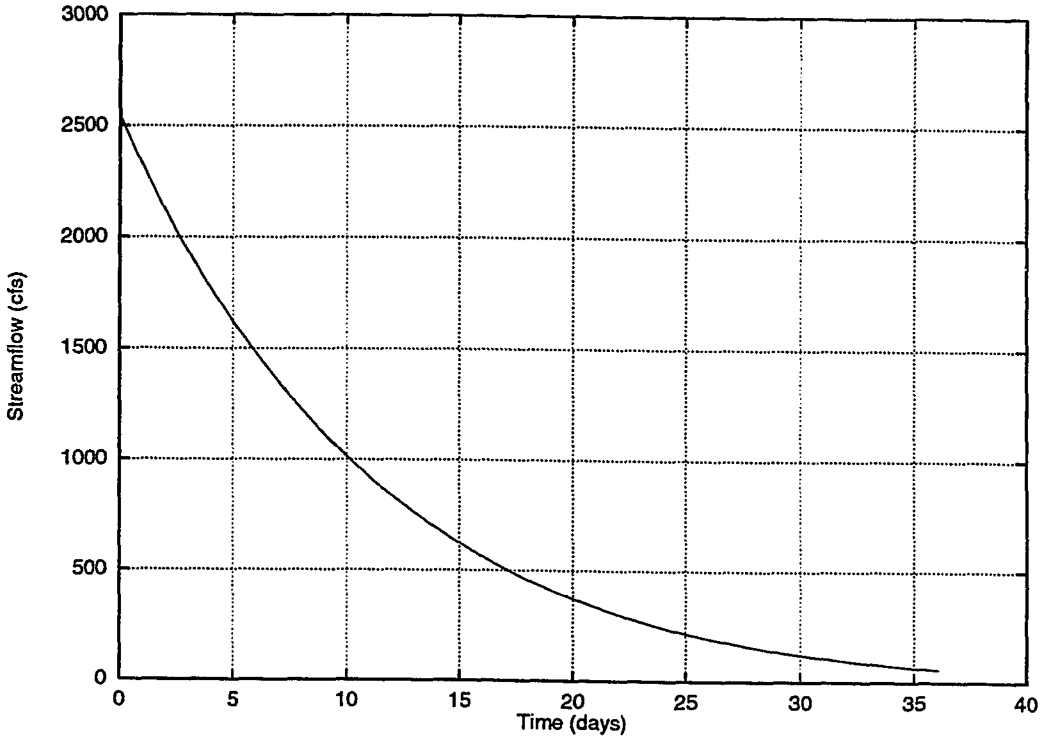

Figure 109.1: MRC of Little Sioux River at Correctionville (for winter), ID# 06606600

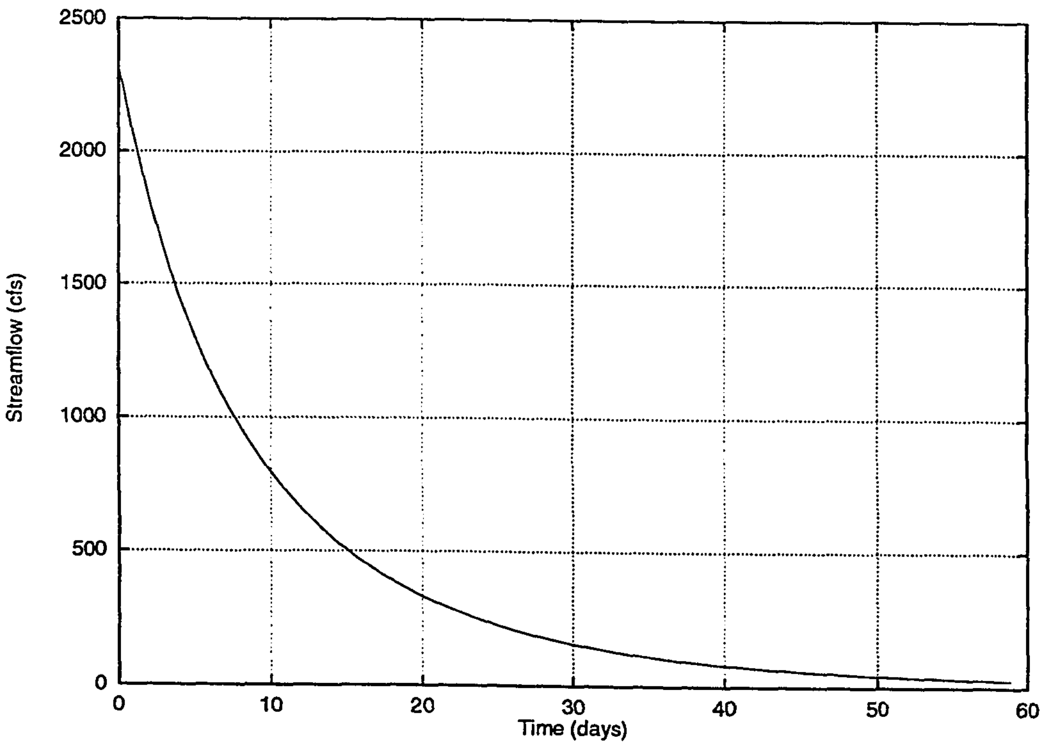

Figure 109.2: MRC of Little Sioux River at Correctionville (for summer), ID# 06606600

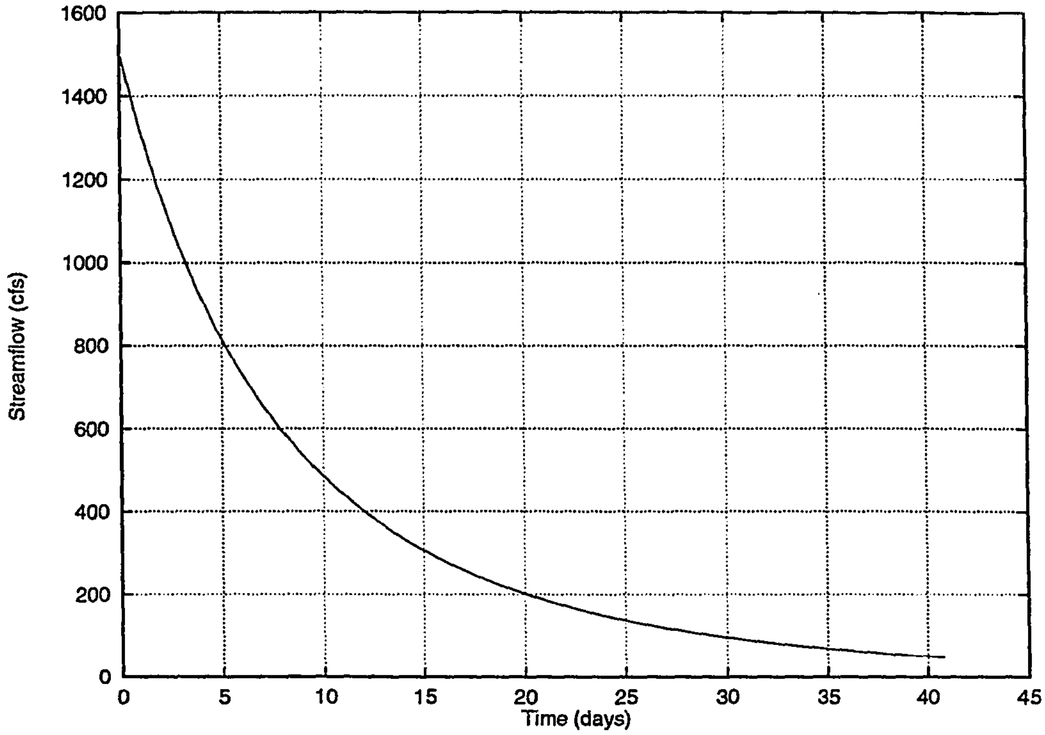

Figure 110.1: MRC of Little Sioux River near Kennebec (for winter), ID# 06606700

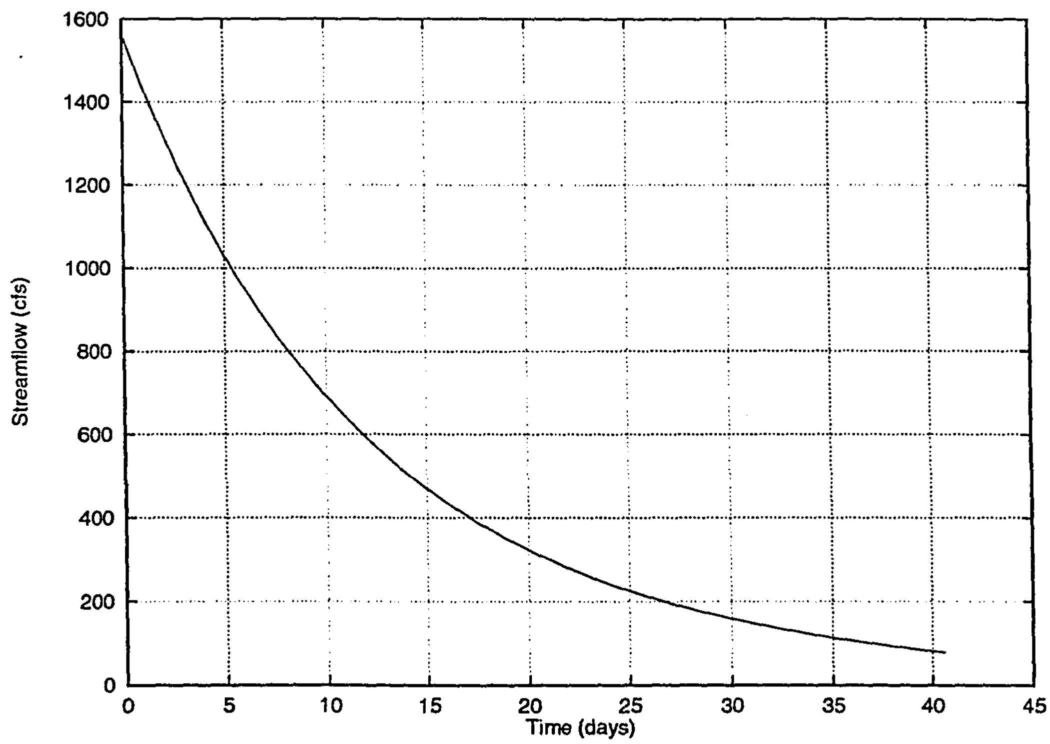

Figure 110.2: MRC of Little Sioux River near Kennebec (for summer), ID# 06606700

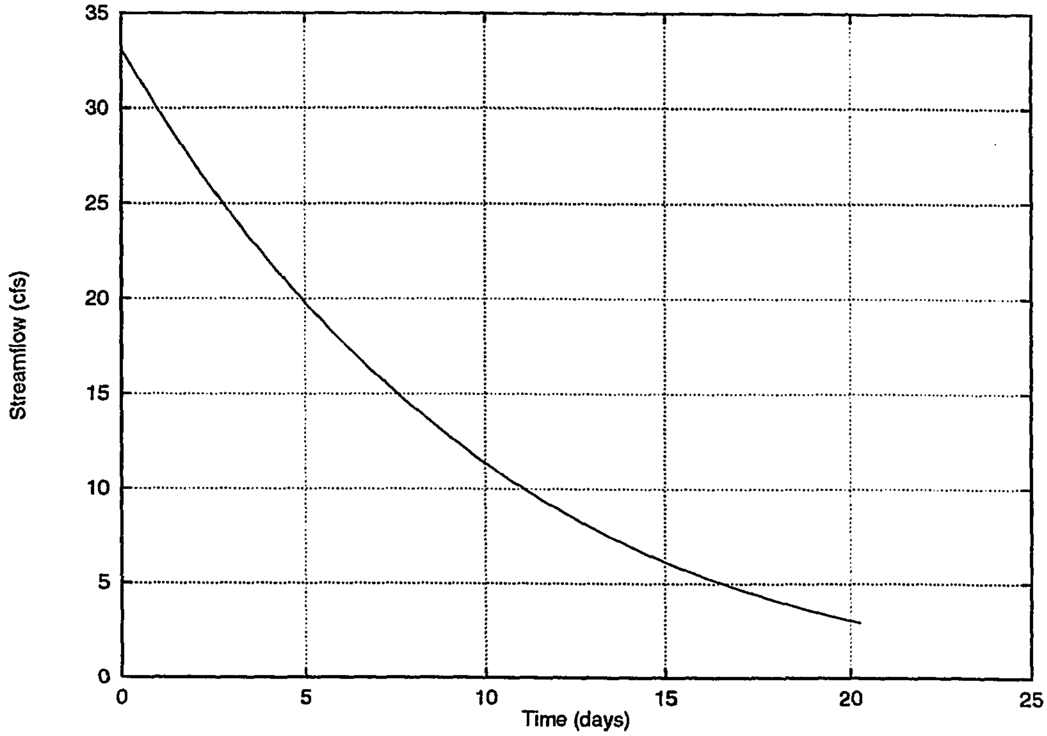

Figure 111.1: MRC of Odebolt Creek near Arthur (for winter), ID# 06607000

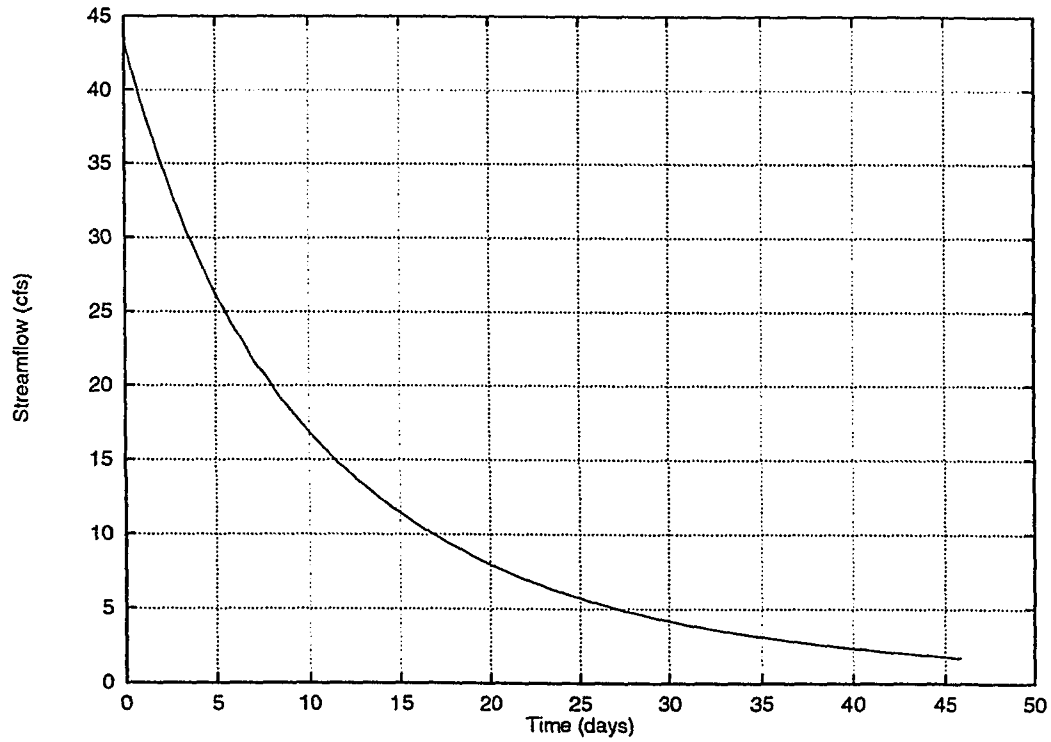

Figure 111.2: MRC of Odebolt Creek near Arthur (for summer), ID# 06607000

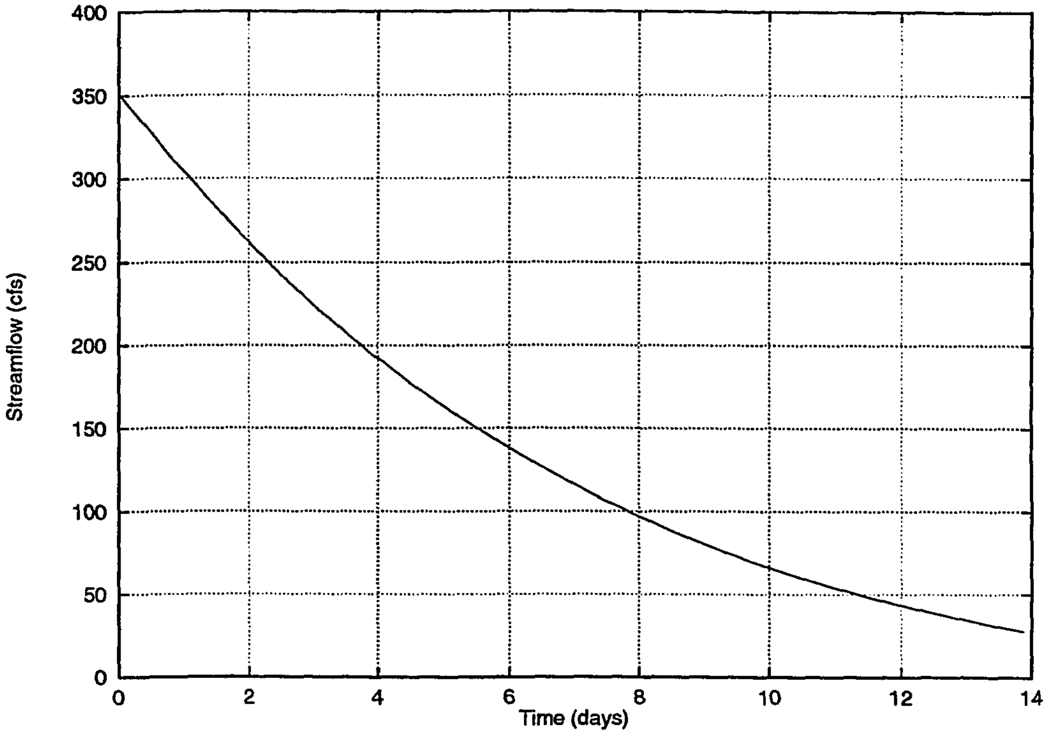

Figure 112.1: MRC of Maple River at Mapleton (for winter), ID# 06607200

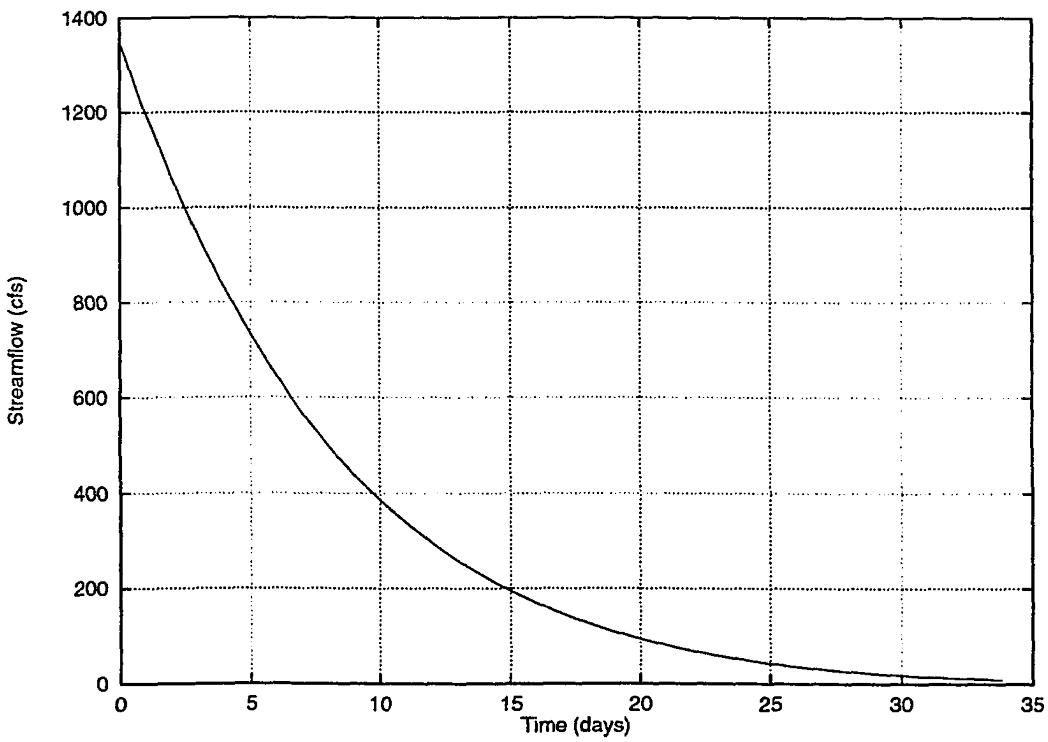

Figure 112.2: MRC of Maple River at Mapleton (for summer), ID# 06607200

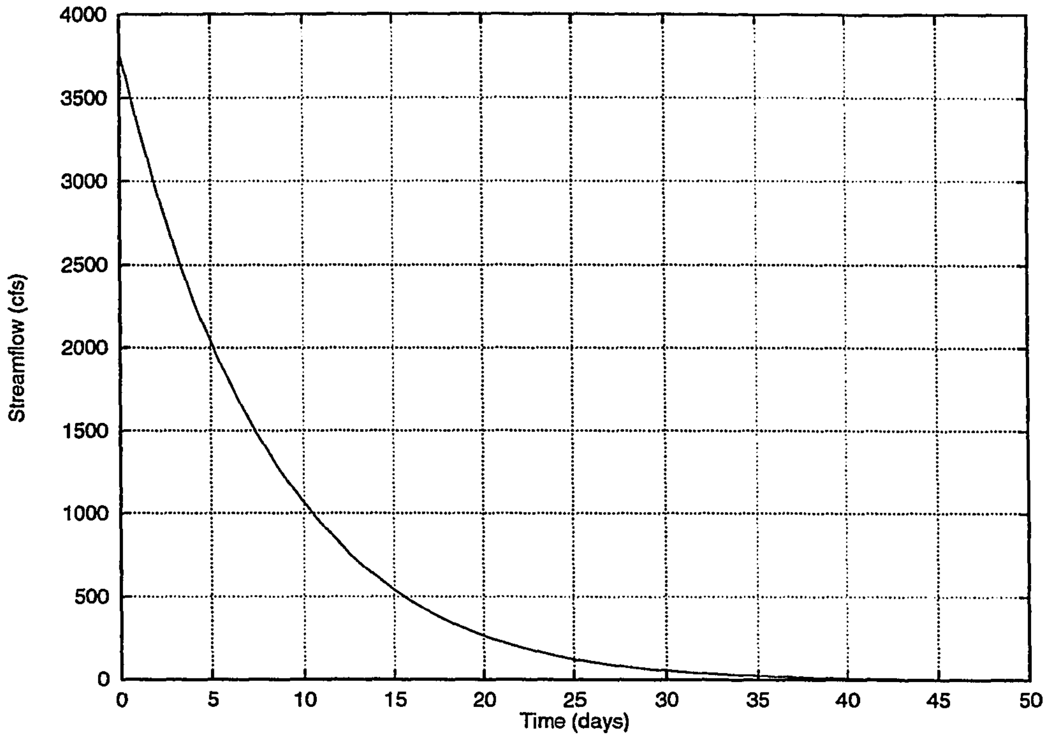

Figure 113.1: MRC of Little Sioux River near Turin (for winter), ID# 06607500

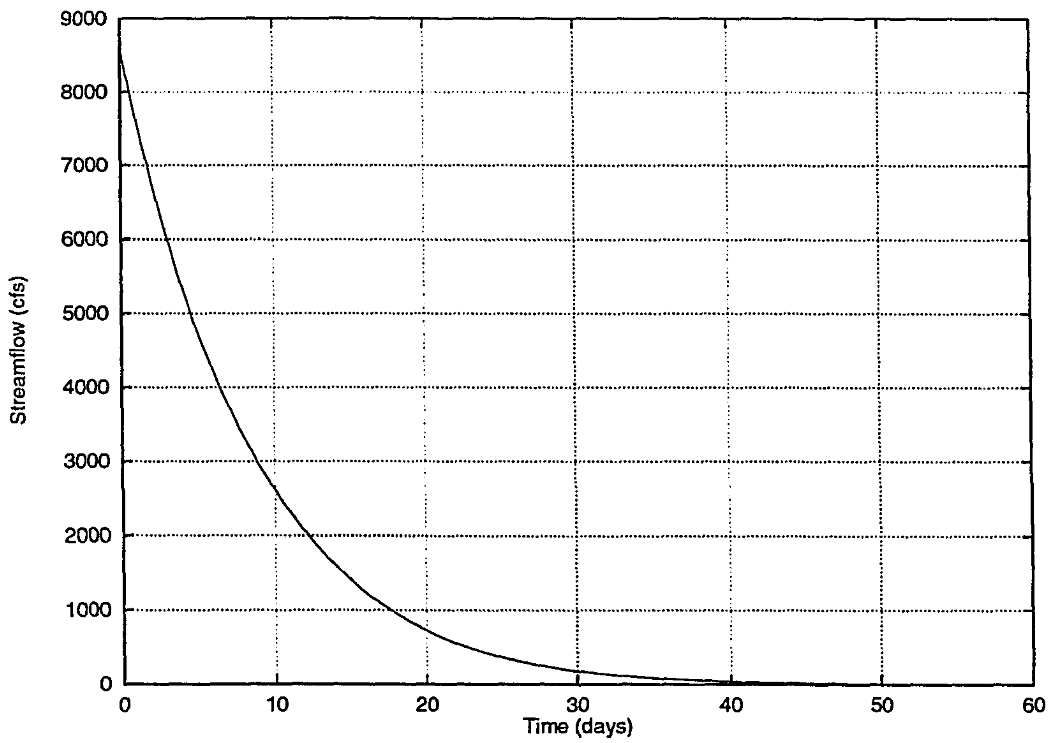

Figure 113.2: MRC of Little Sioux River near Turin (for summer), ID# 06607500

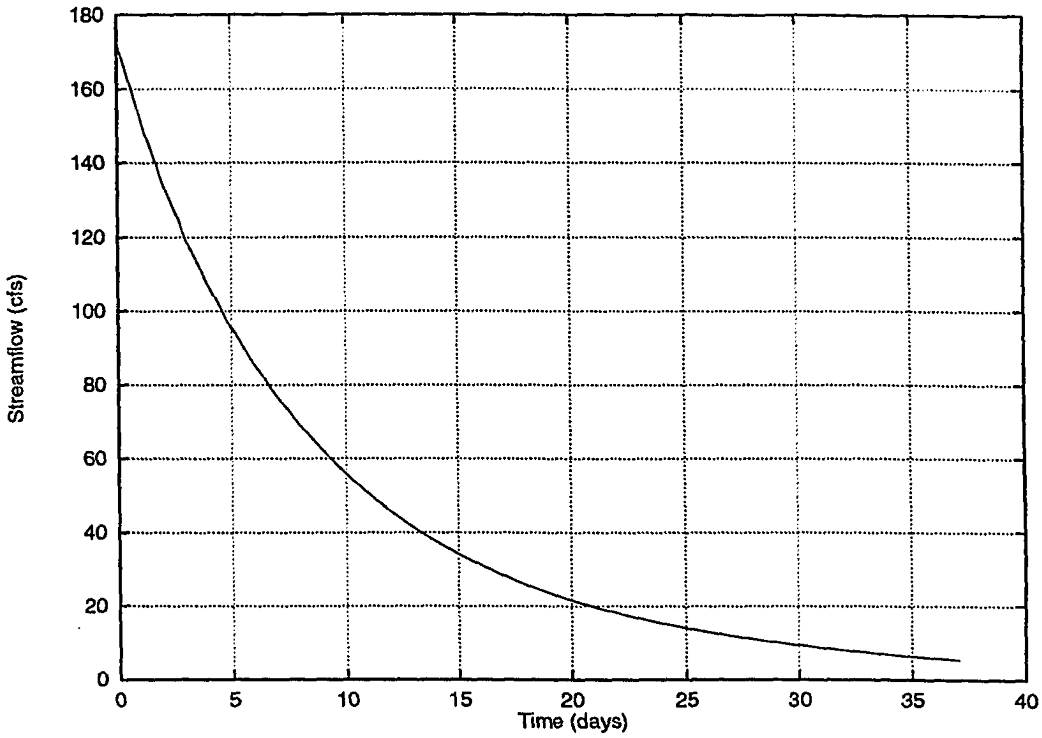

Figure 114.1: MRC of Soldier River at Pisgah (for winter), ID# 06608500

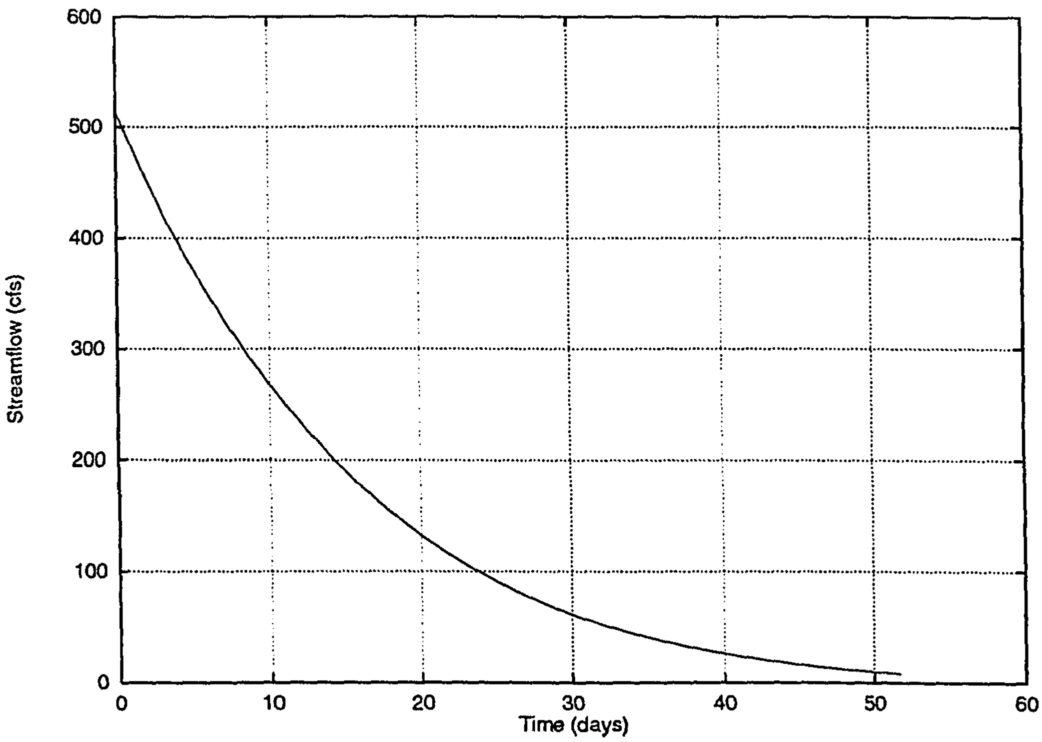

Figure 114.2: MRC of Soldier River at Pisgah (for summer), ID# 06608500

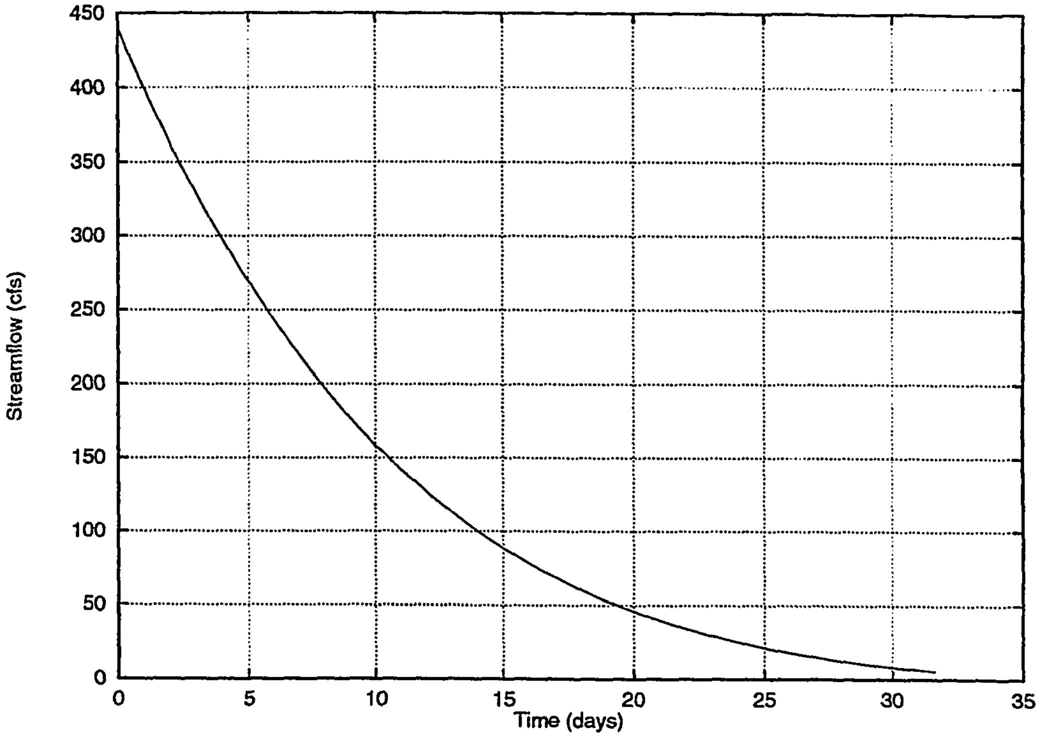

Figure 115.1: MRC of Boyer River at Logan (for winter), ID# 06609500

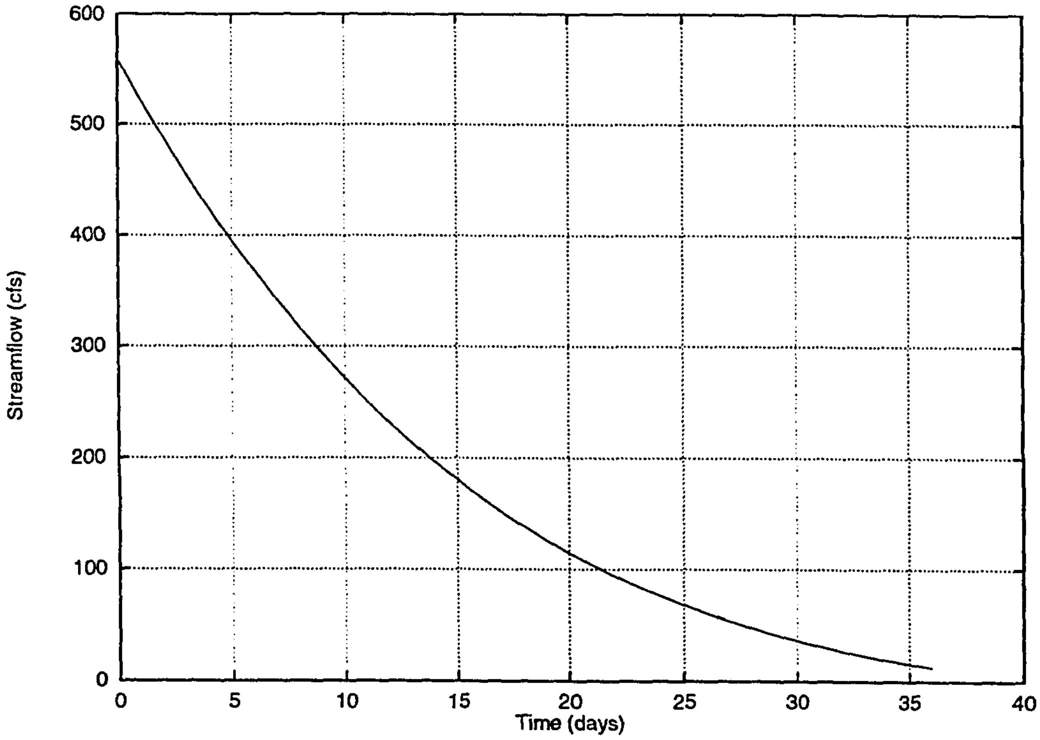

Figure 115.2: MRC of Boyer River at Logan (for summer), ID# 06609500

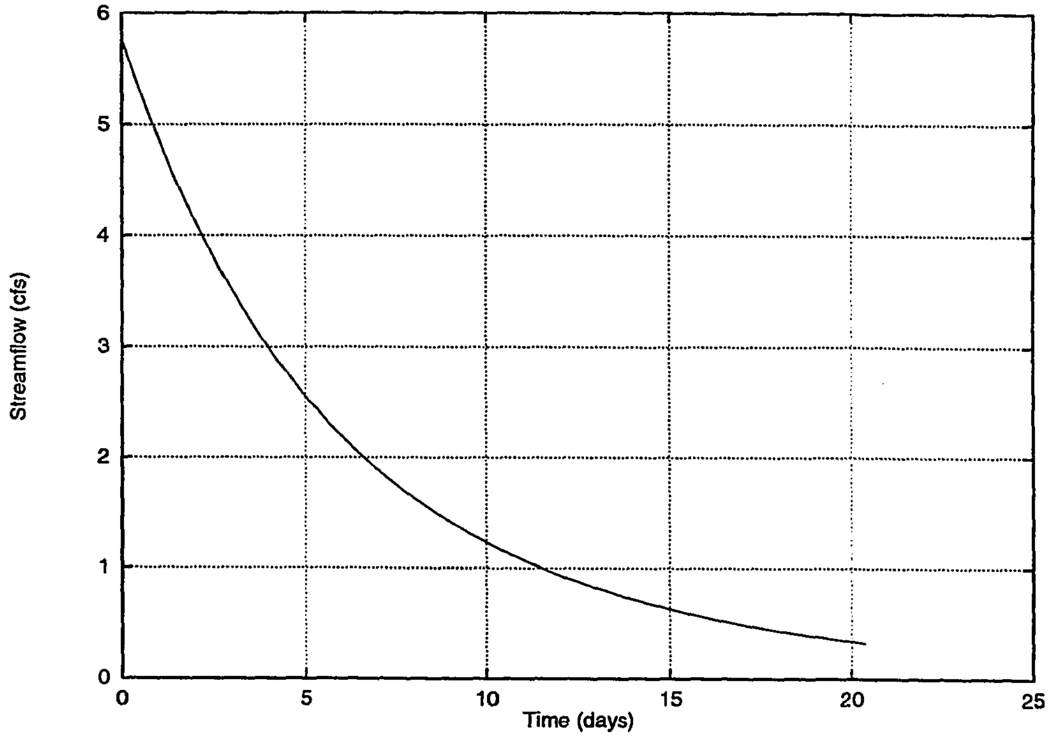

Figure 116.1: MRC of Mosquito Creek near Earling (for winter), ID# 06610520

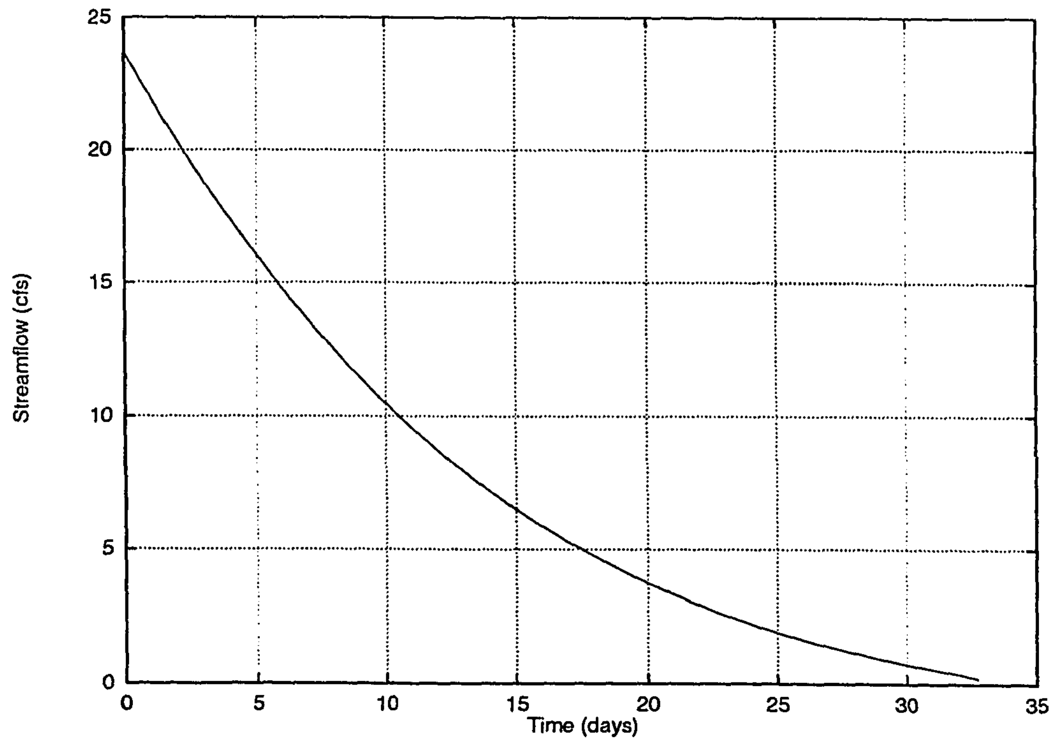

Figure 116.2: MRC of Mosquito Creek near Earling (for summer), ID# 06610520

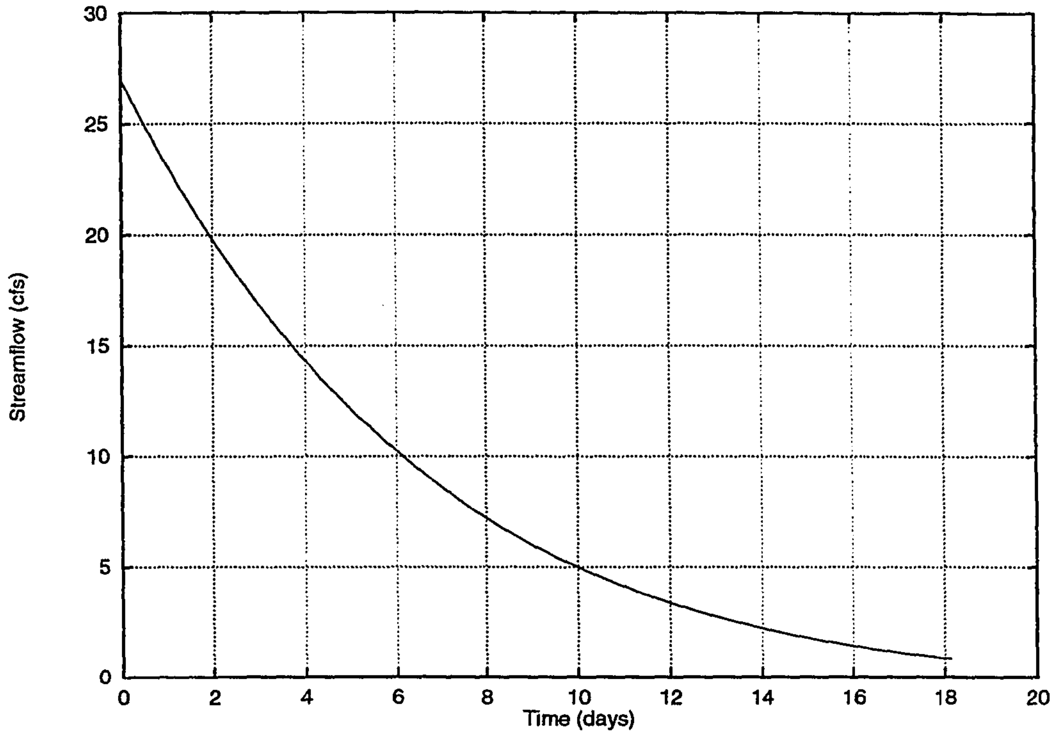

Figure 117.1: MRC of Waubonsie Creek near Bartlett (for winter), ID# 06806000

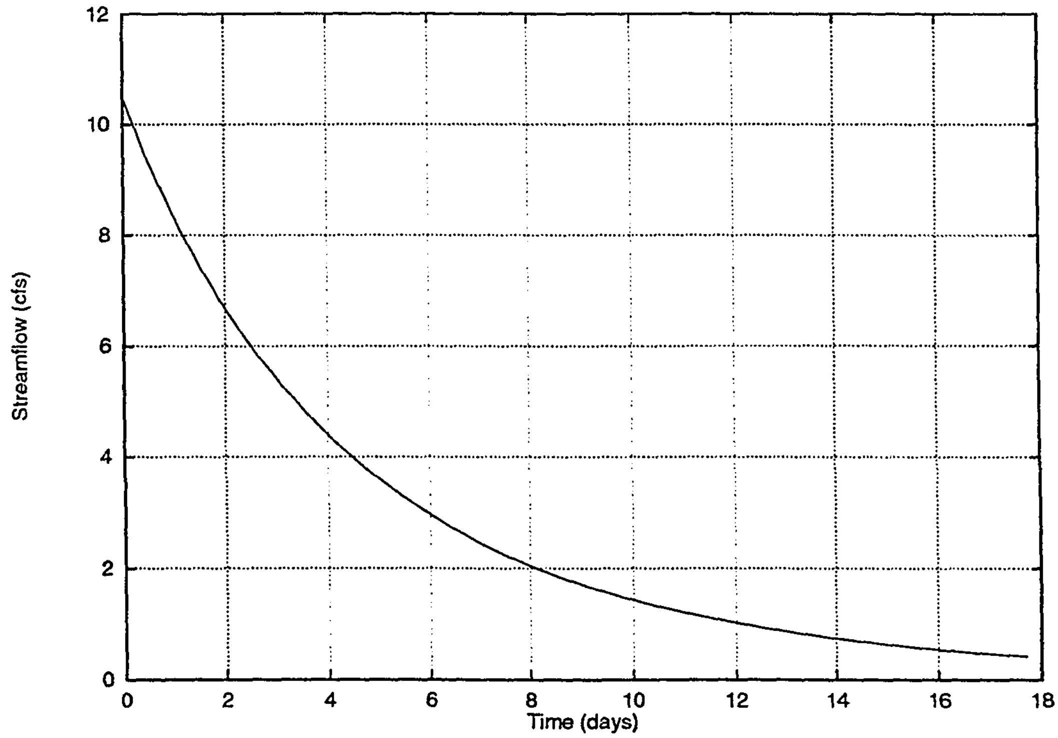

Figure 117.2: MRC of Waubonsie Creek near Bartlett (for summer), ID# 06806000

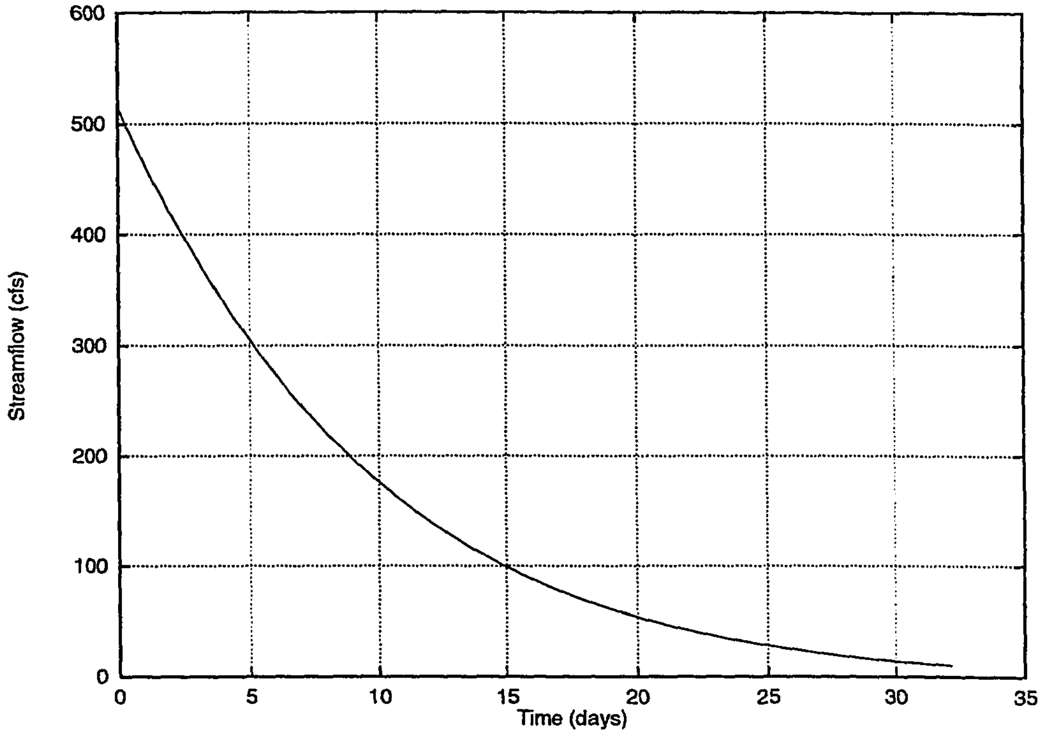

Figure 118.1: MRC of West Nishnabotna River at Hancock (for winter), ID# 06807410

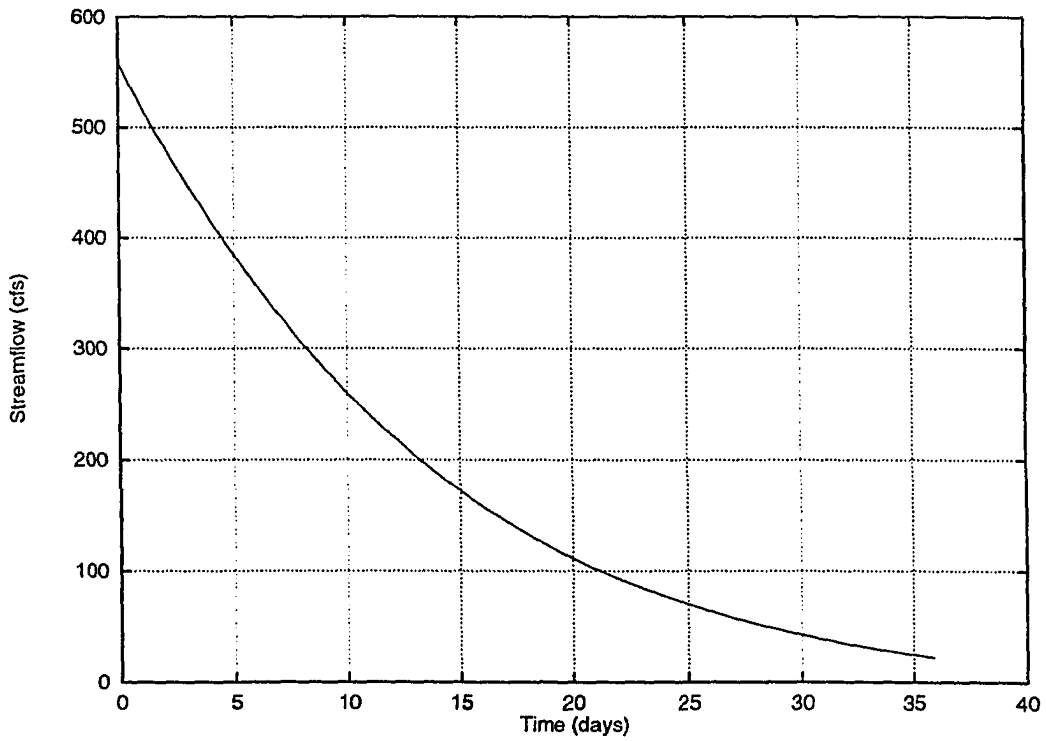

Figure 118.2: MRC of West Nishnabotna River at Hancock (for summer), ID# 06807410

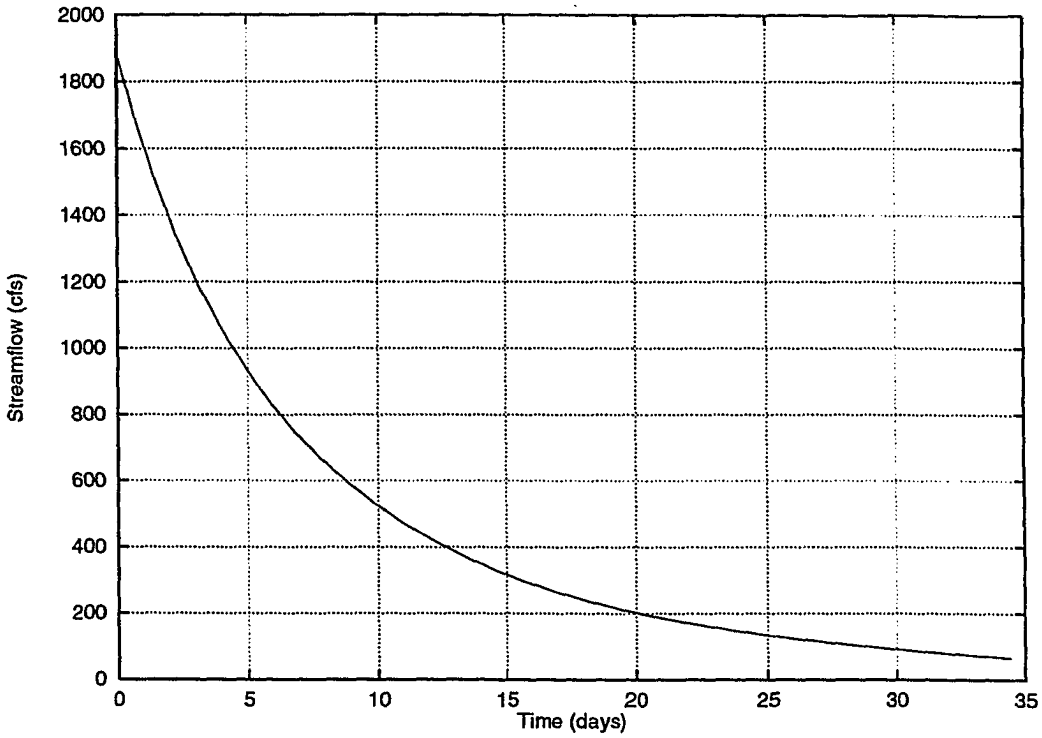

Figure 119.1: MRC of West Nishnabotna River at Randolph (for winter), ID# 06808500

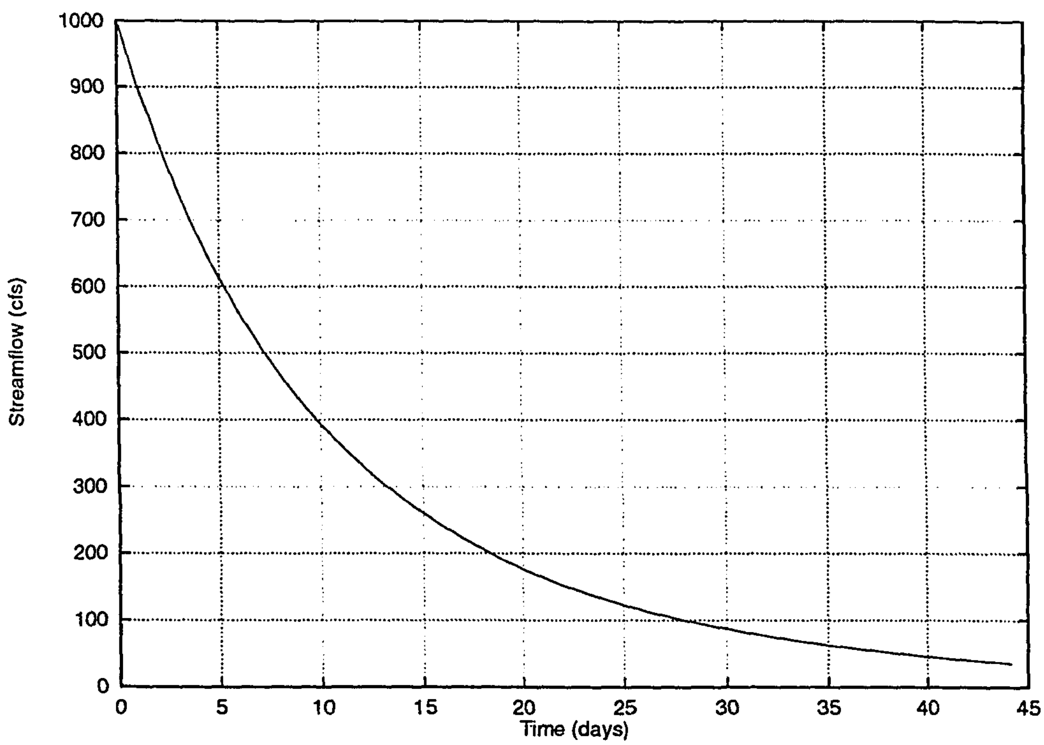

Figure 119.2: MRC of West Nishnabotna River at Randolph (for summer), ID# 06808500

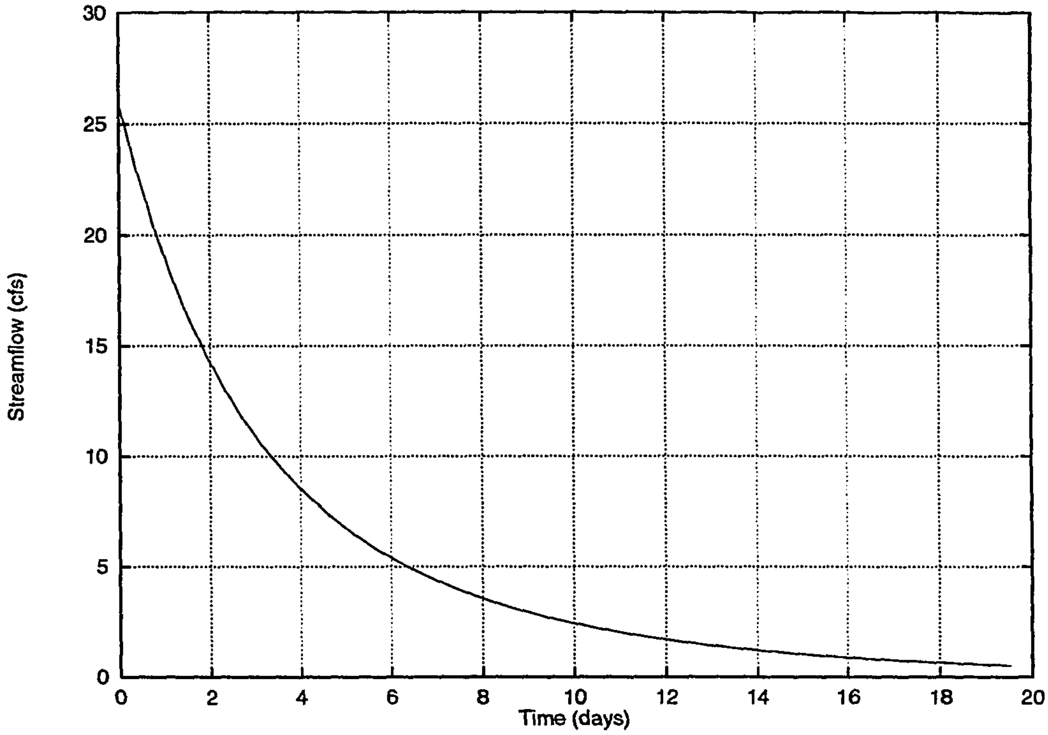

Figure 120.1: MRC of Davids Creek near Hamlin (for winter), ID# 06809000

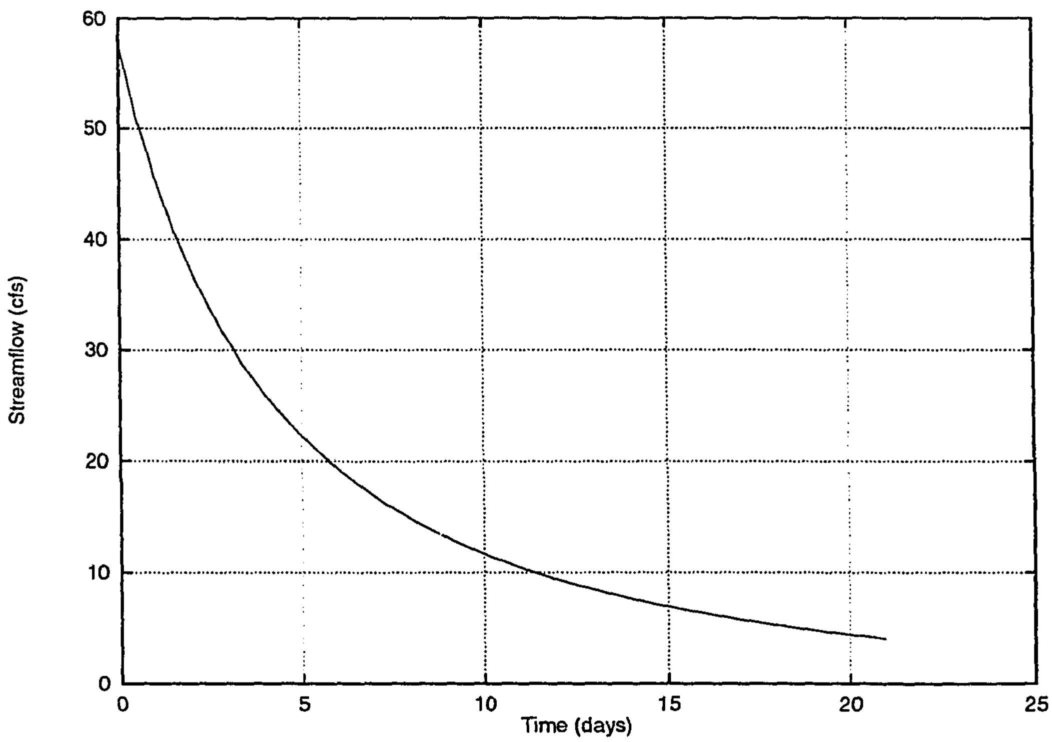

Figure 120.2: MRC of Davids Creek near Hamlin (for summer), ID# 06809000

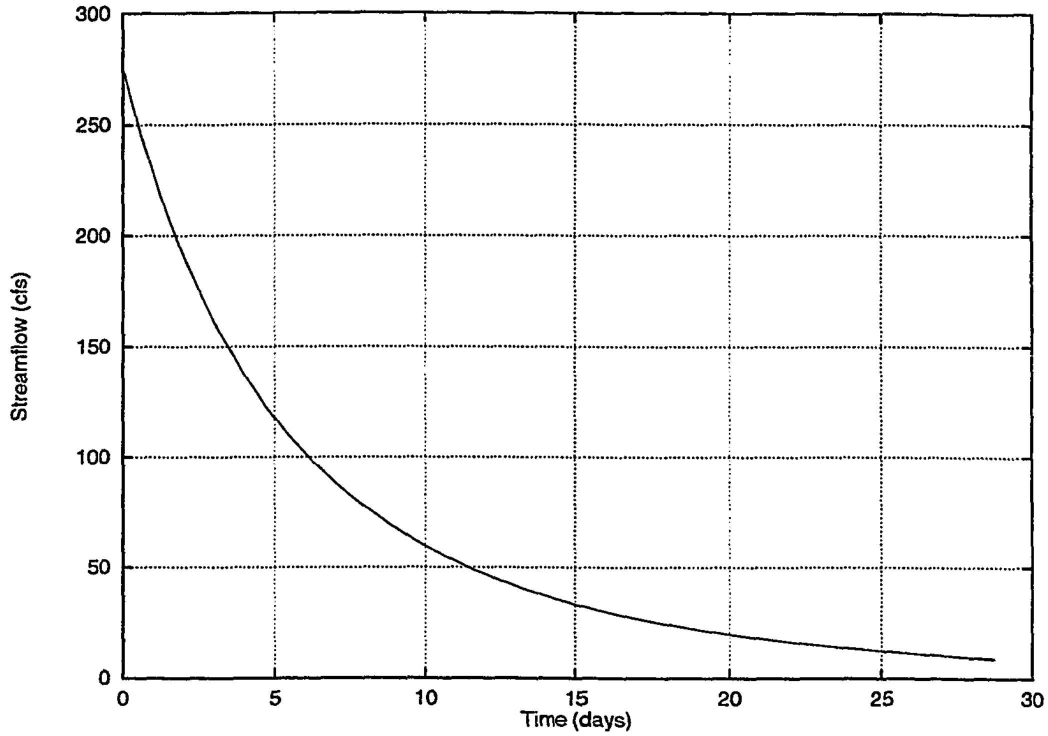

Figure 121.1: MRC of East Nishnabotna River near Atlantic (for winter), ID# 06809210

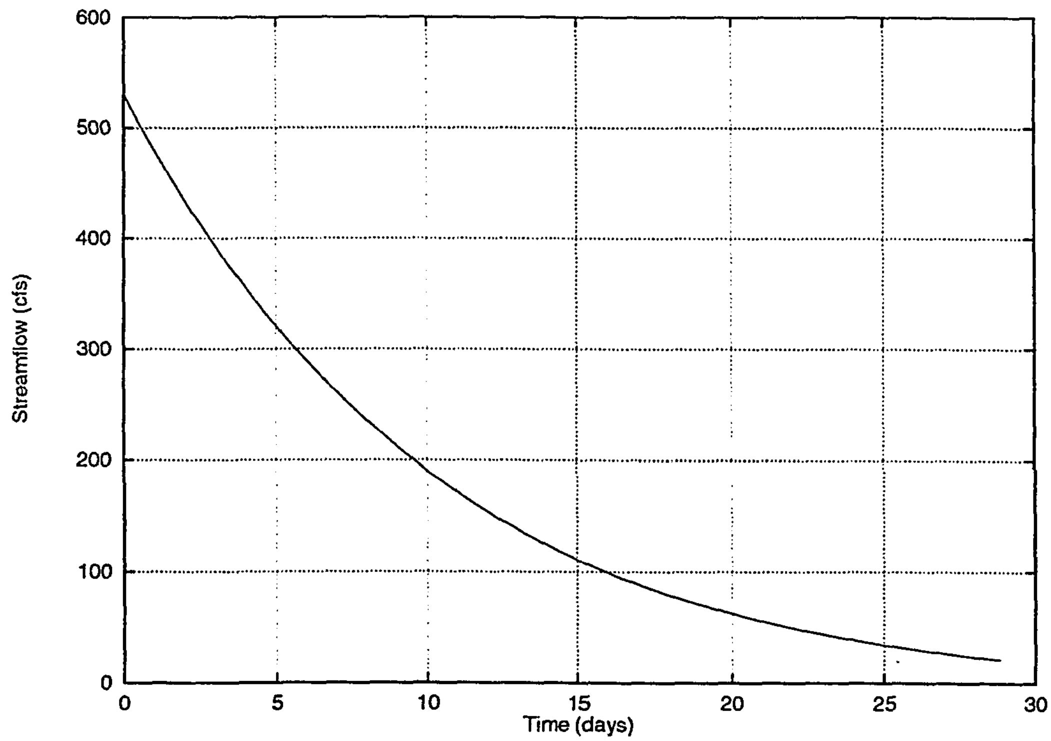

Figure 121.2: MRC of East Nishnabotna River near Atlantic (for summer), ID# 06809210

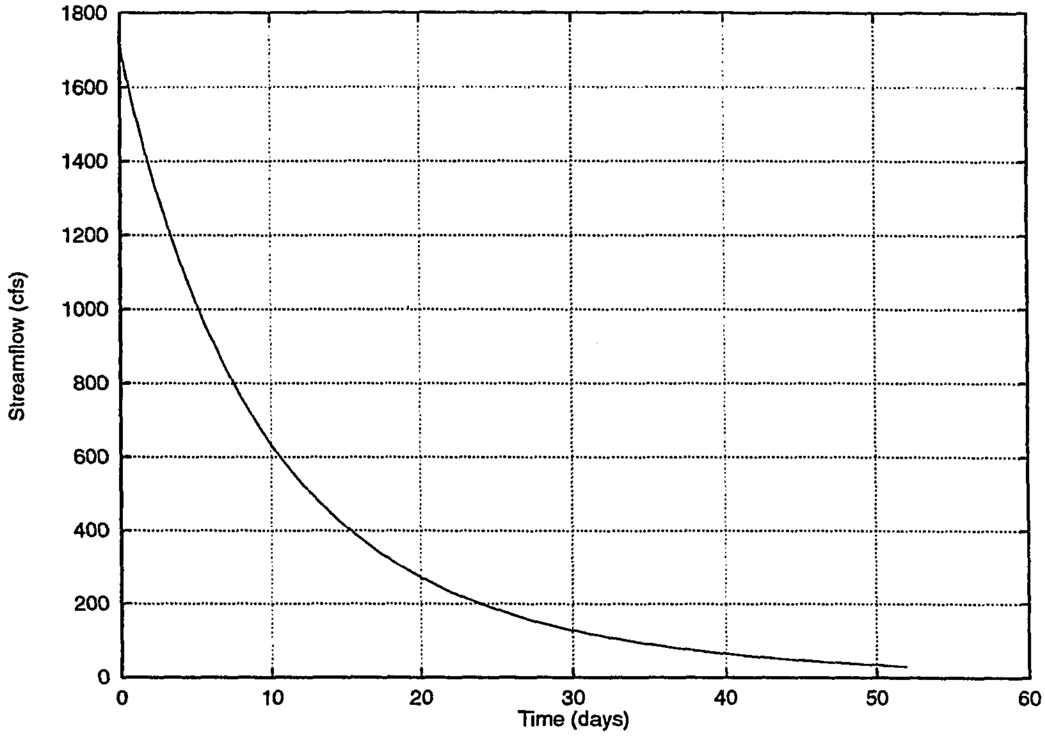

Figure 122.1: MRC of East Nishnabotna River at Red Oak (for winter), ID# 06809500

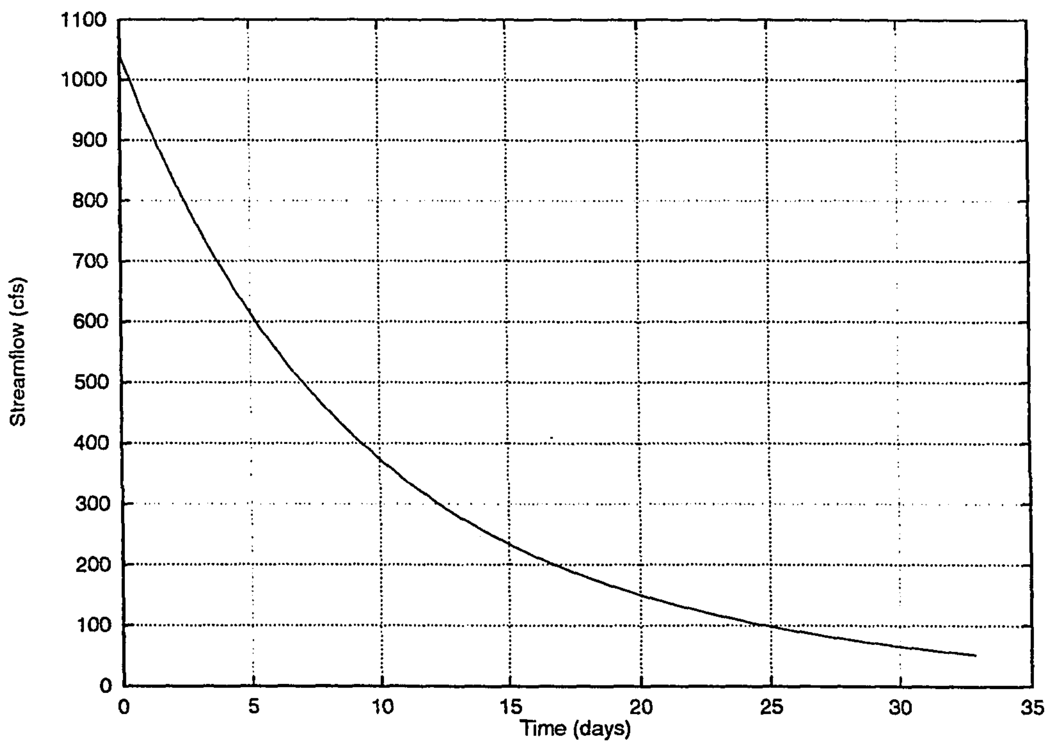

Figure 122.2: MRC of East Nishnabotna River at Red Oak (for summer), ID# 06809500

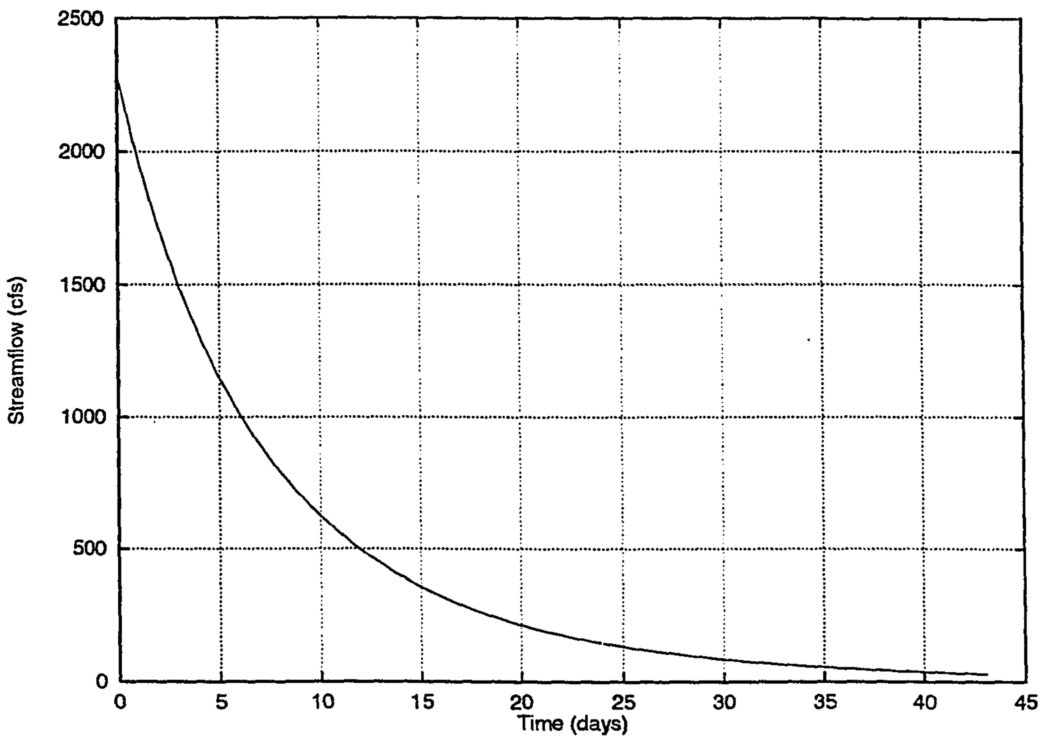

Figure 123.1: MRC of Nishnabotna River above Hamburg (for winter), ID# 06810000

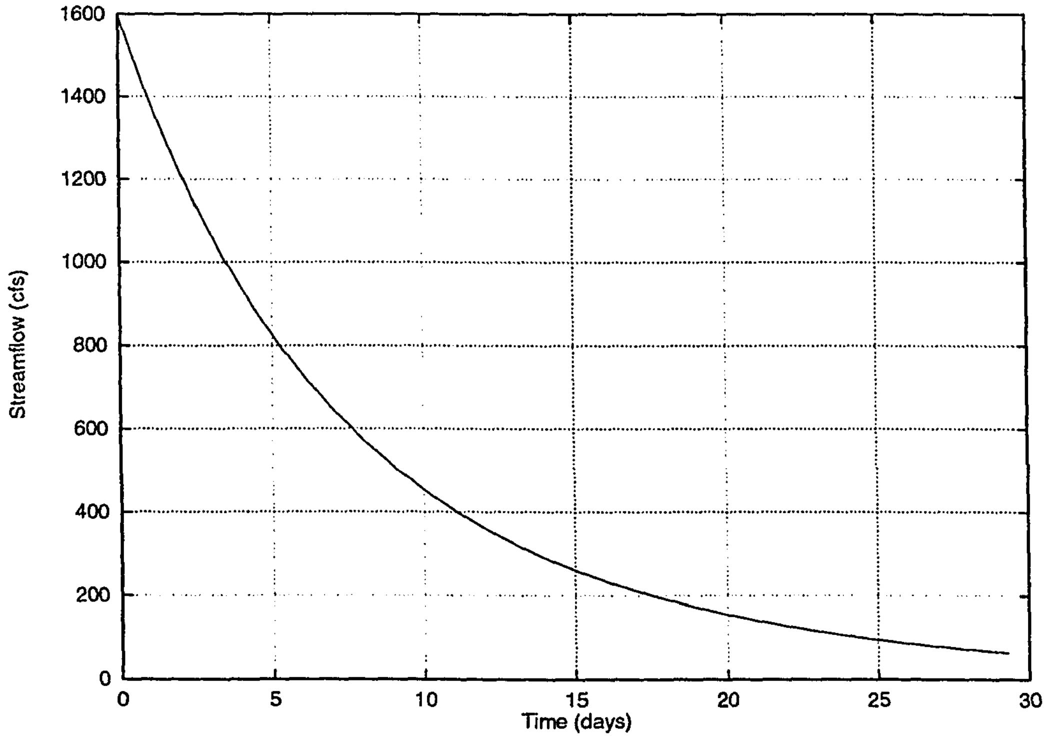

Figure 123.2: MRC of Nishnabotna River above Hamburg (for summer), ID# 06810000

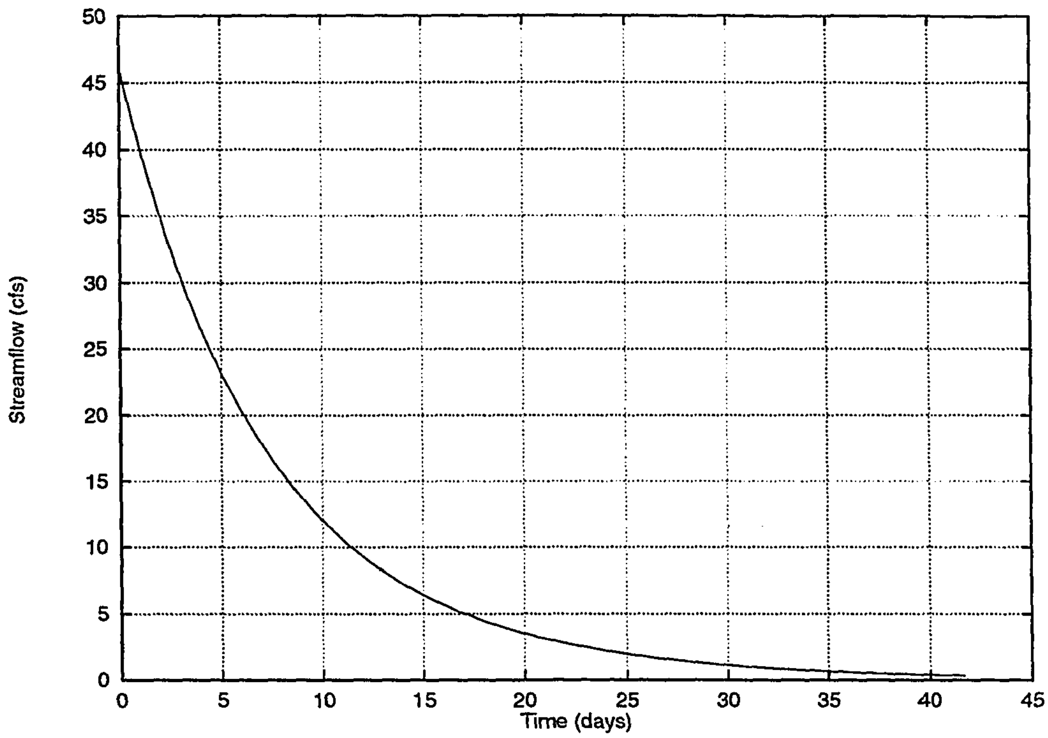

Figure 124.1: MRC of Tarkio River at Stanton (for winter), ID# 06811840

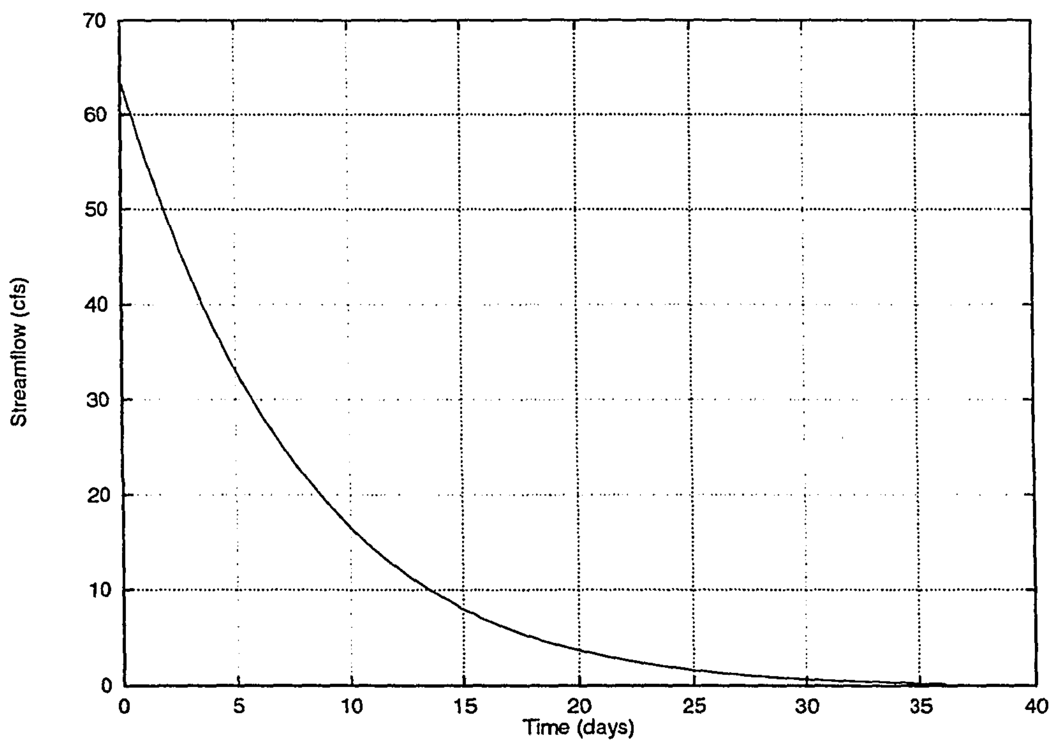

Figure 124.2: MRC of Tarkio River at Stanton (for summer), ID# 06811840

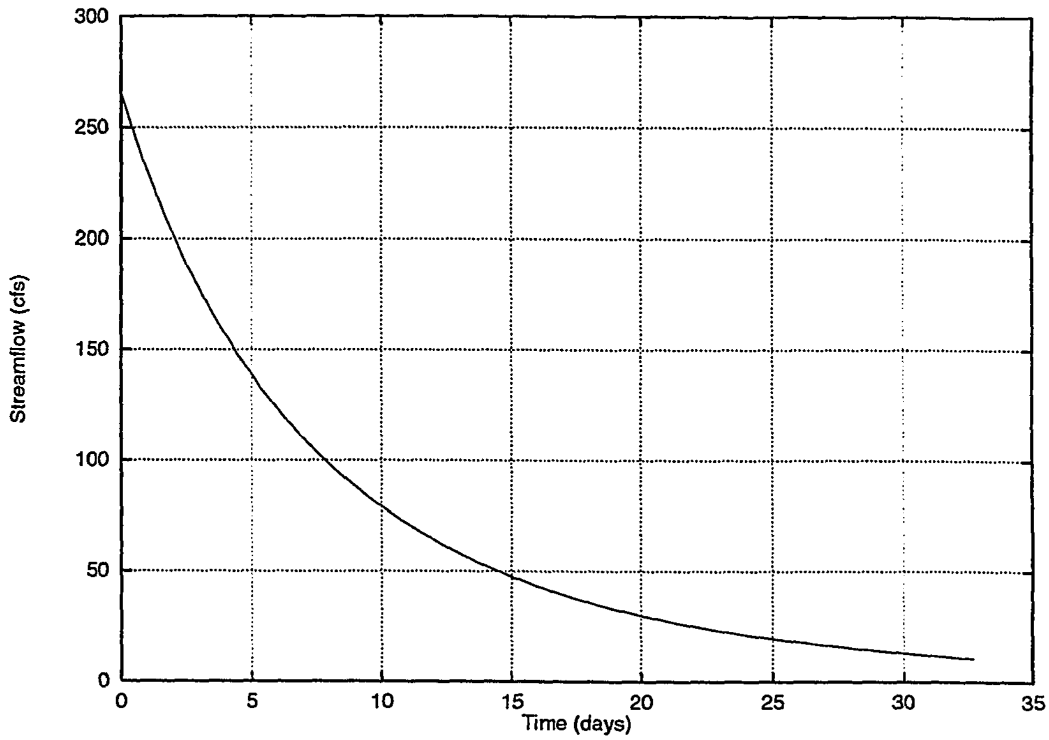

Figure 125.1: MRC of Nodaway River at Clarinda (for winter), ID# 06817000

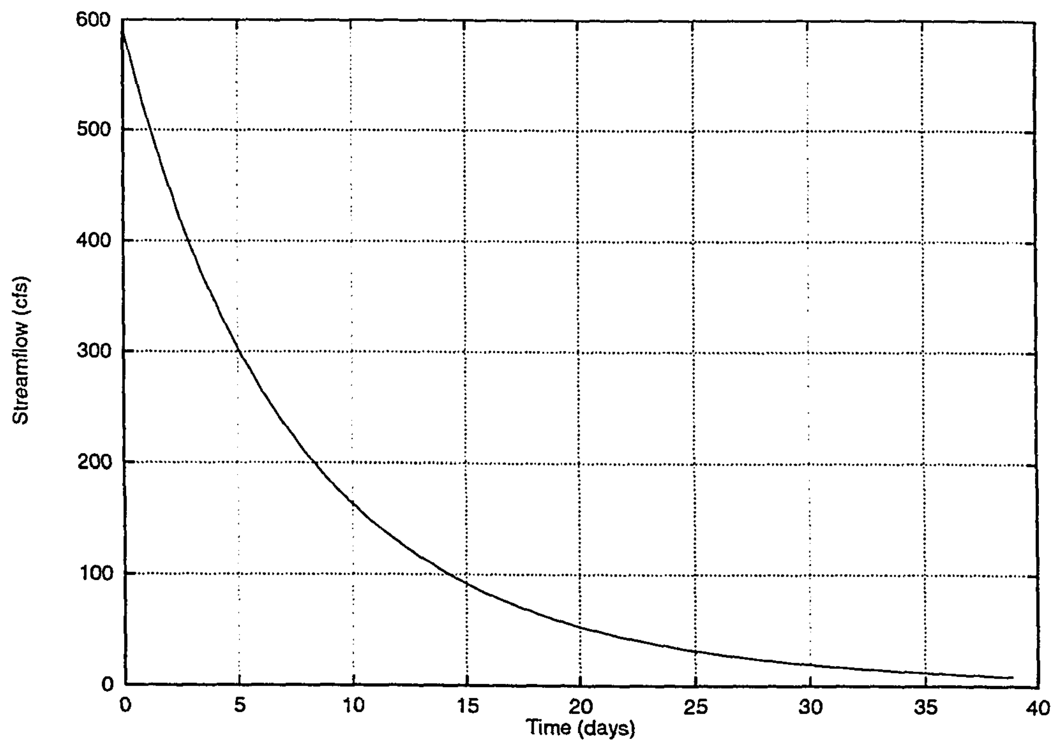

Figure 125.2: MRC of Nodaway River at Clarinda (for summer), ID# 06817000

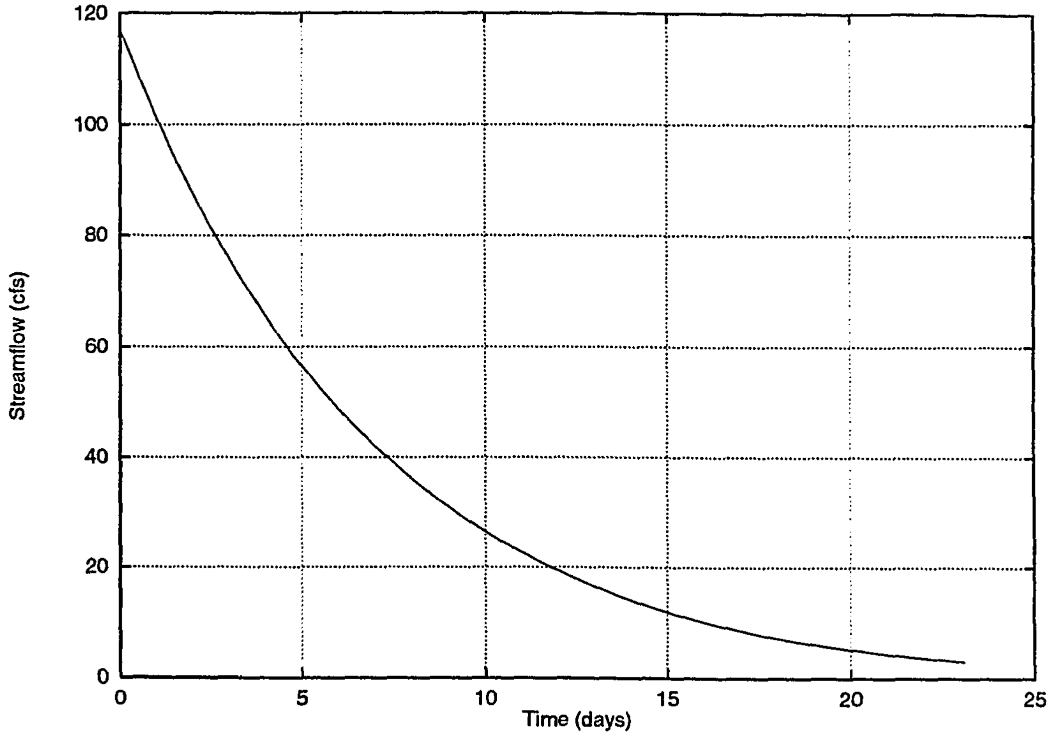

Figure 126.1: MRC of Platte River near Diagonal (for winter), ID# 06818750

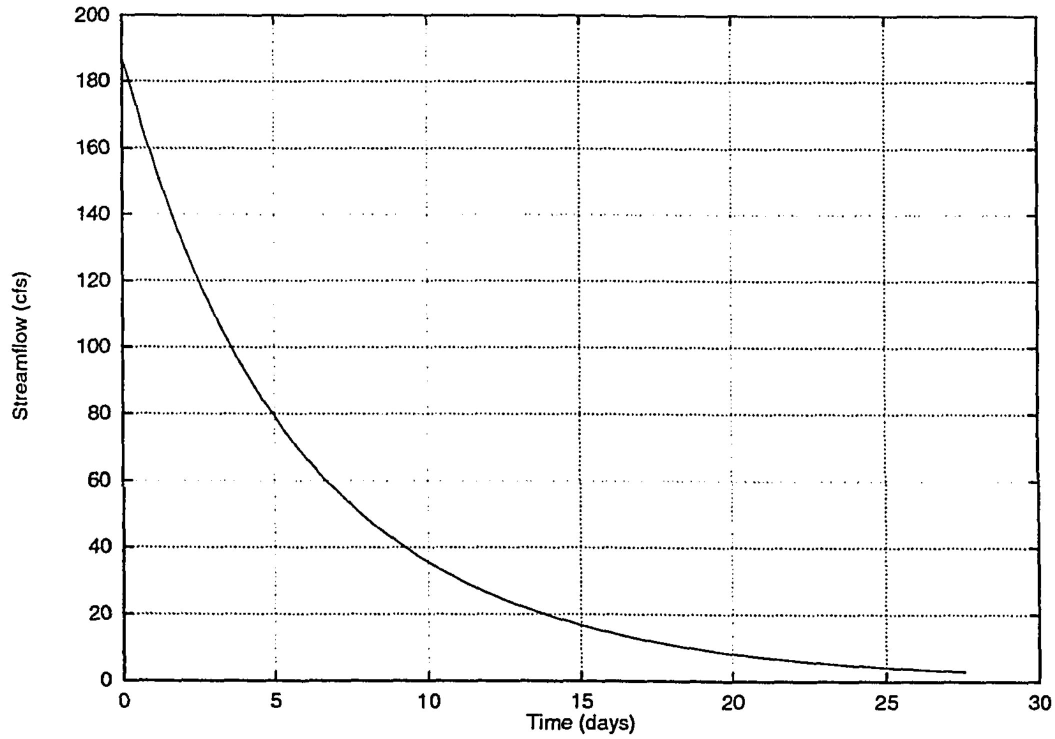

Figure 126.2: MRC of Platte River near Diagonal (for summer), ID# 06818750

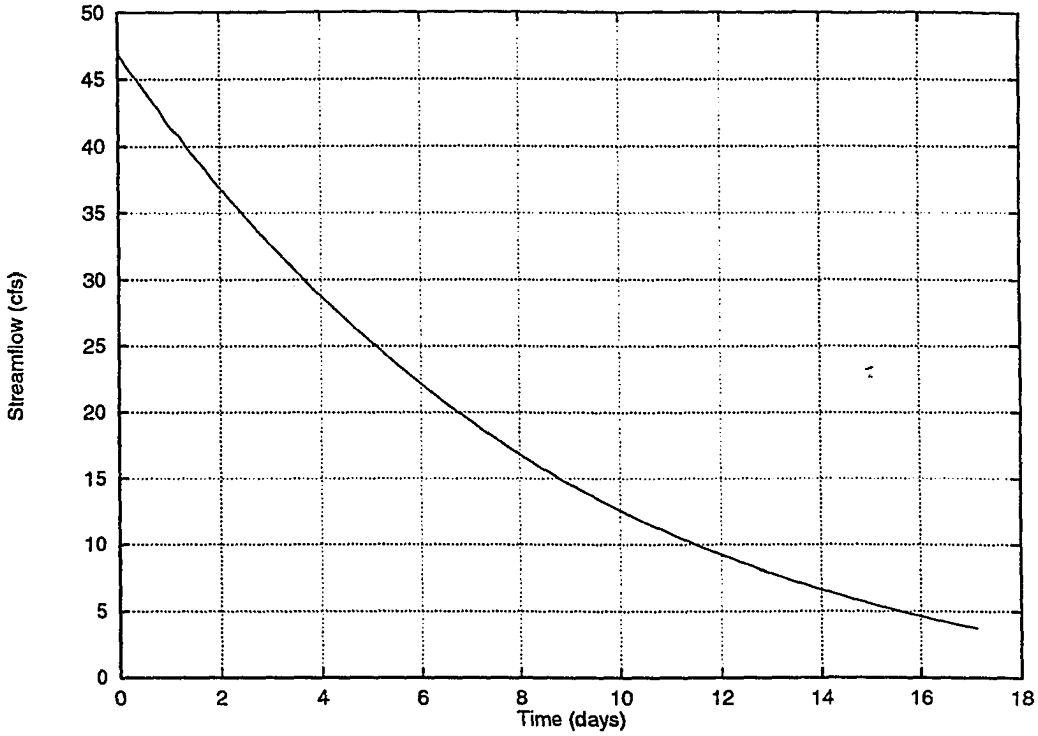

Figure 127.1: MRC of East Fork 102 River at Bedford (for winter), ID# 06819190

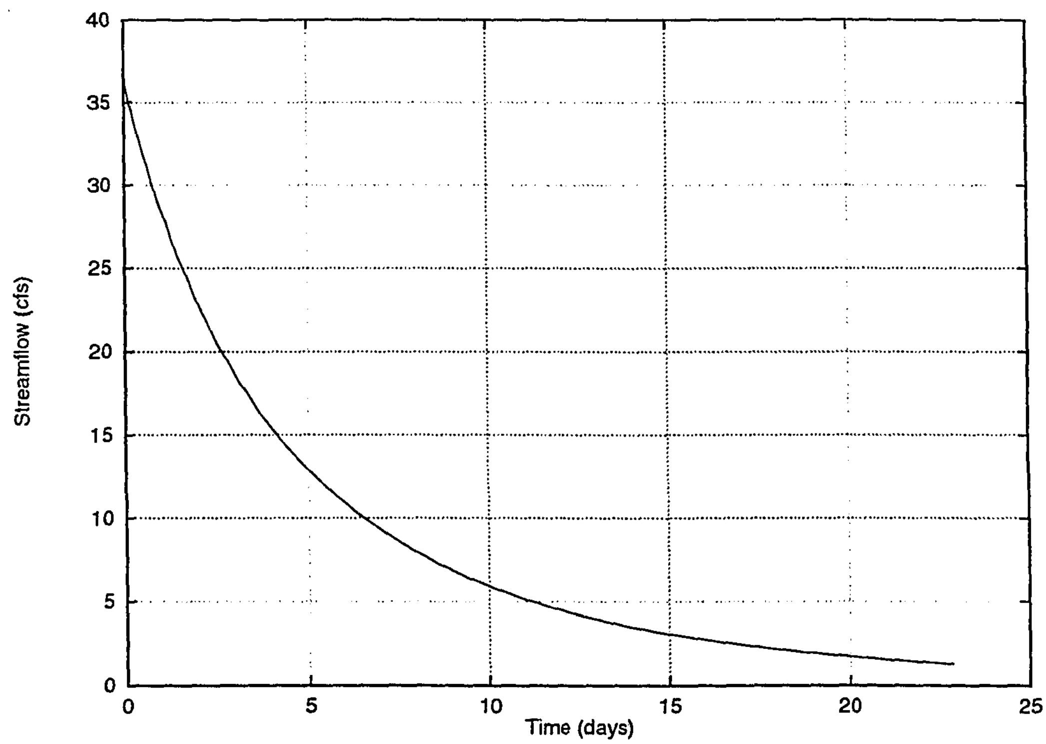

Figure 127.2: MRC of East Fork 102 River at Bedford (for summer), ID# 06819190

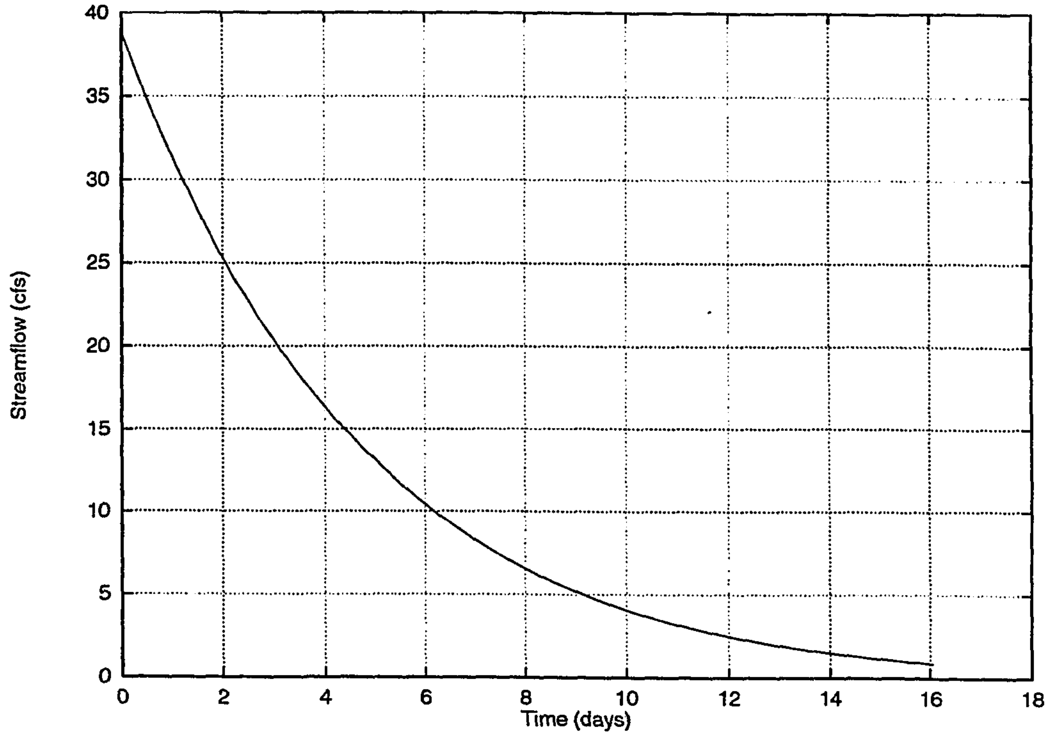

Figure 128.1: MRC of Elk Creek near Decatur City (for winter), ID# 06897950

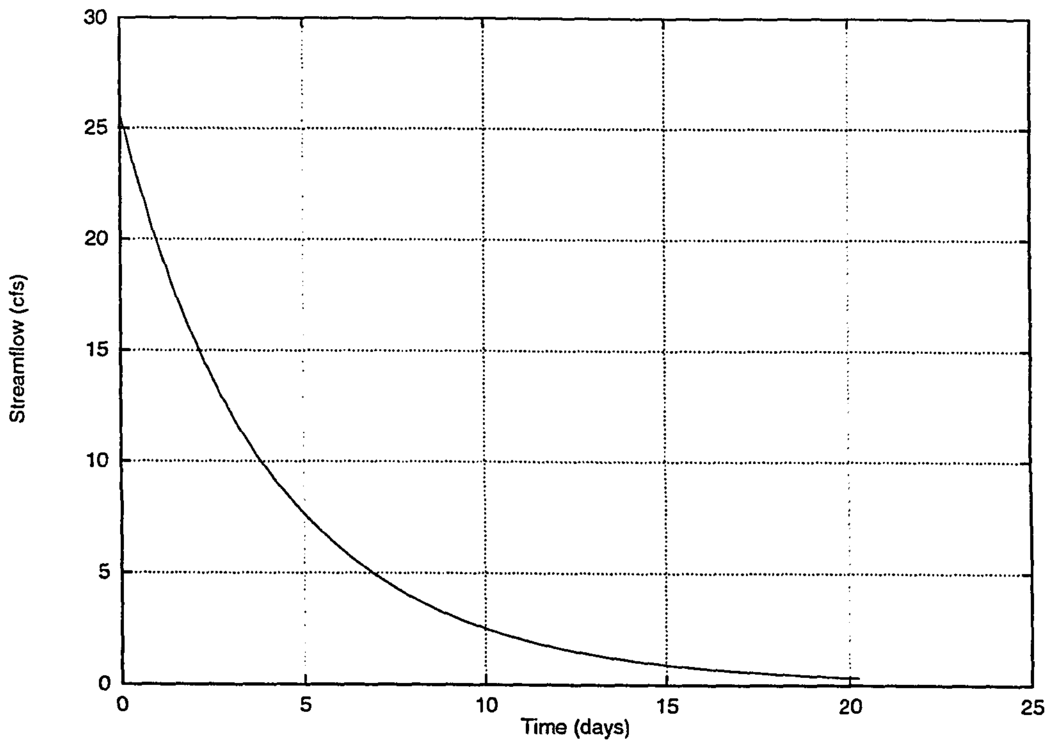

Figure 128.2: MRC of Elk Creek near Decatur City (for summer), ID# 06897950

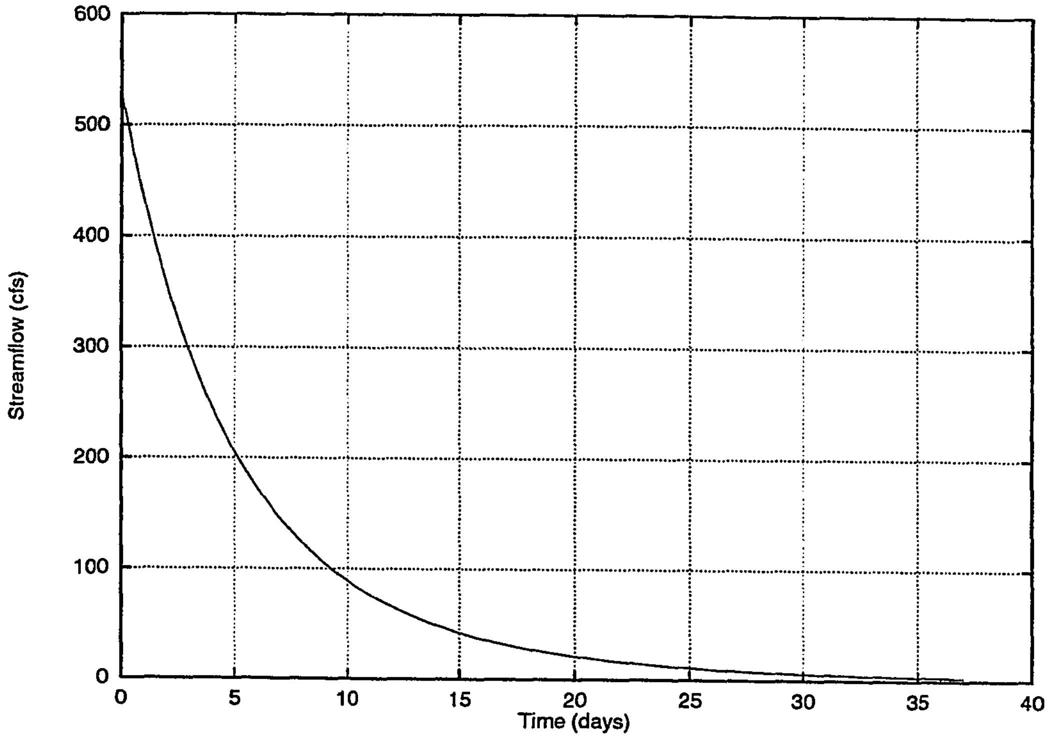

Figure 129.1: MRC of Thompson River at Davis City (for winter), ID# 06898000

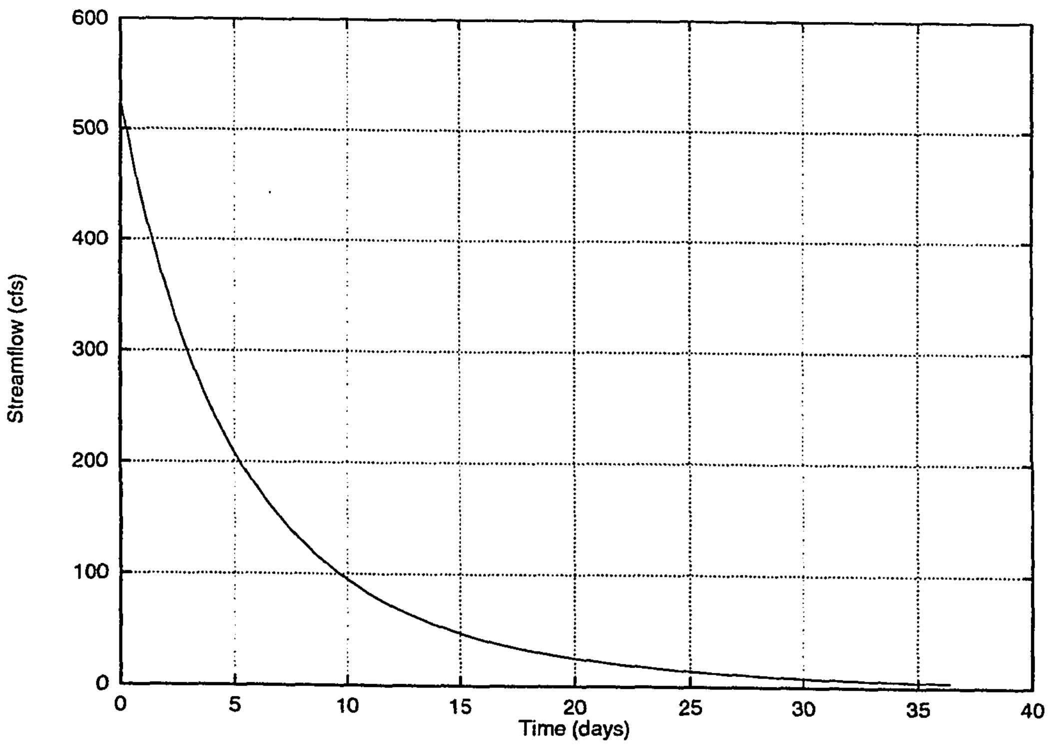

Figure 129.2: MRC of Thompson River at Davis City (for summer), ID# 06898000

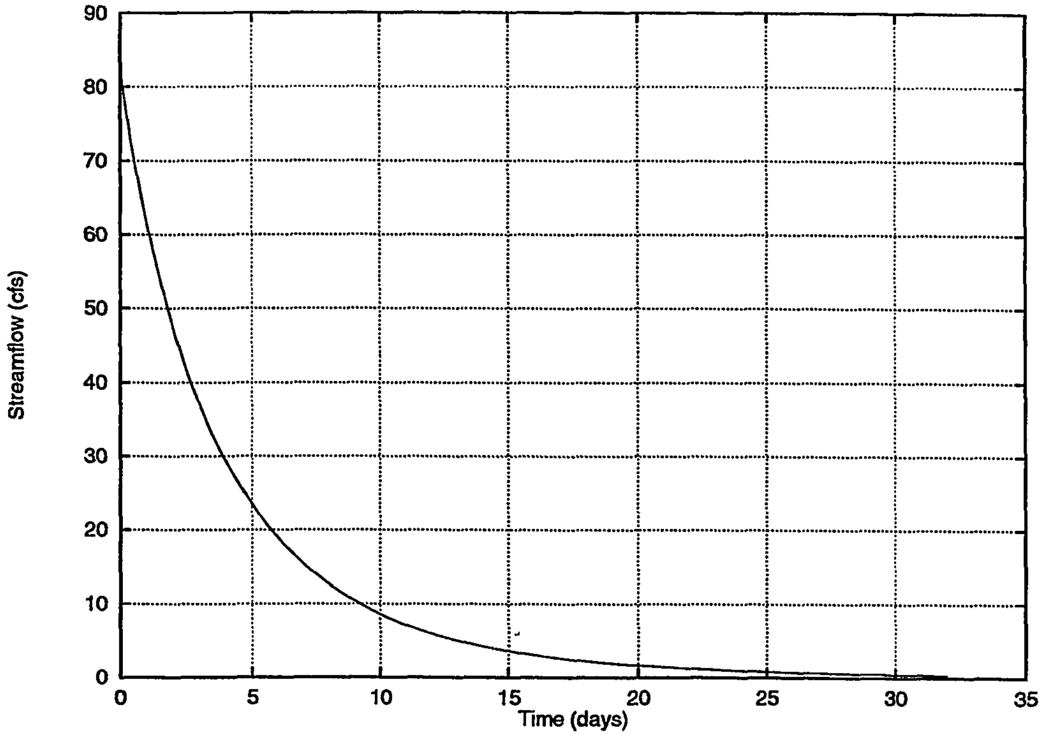

Figure 130.1: MRC of Weldon River near Leon (for winter), ID# 06898400

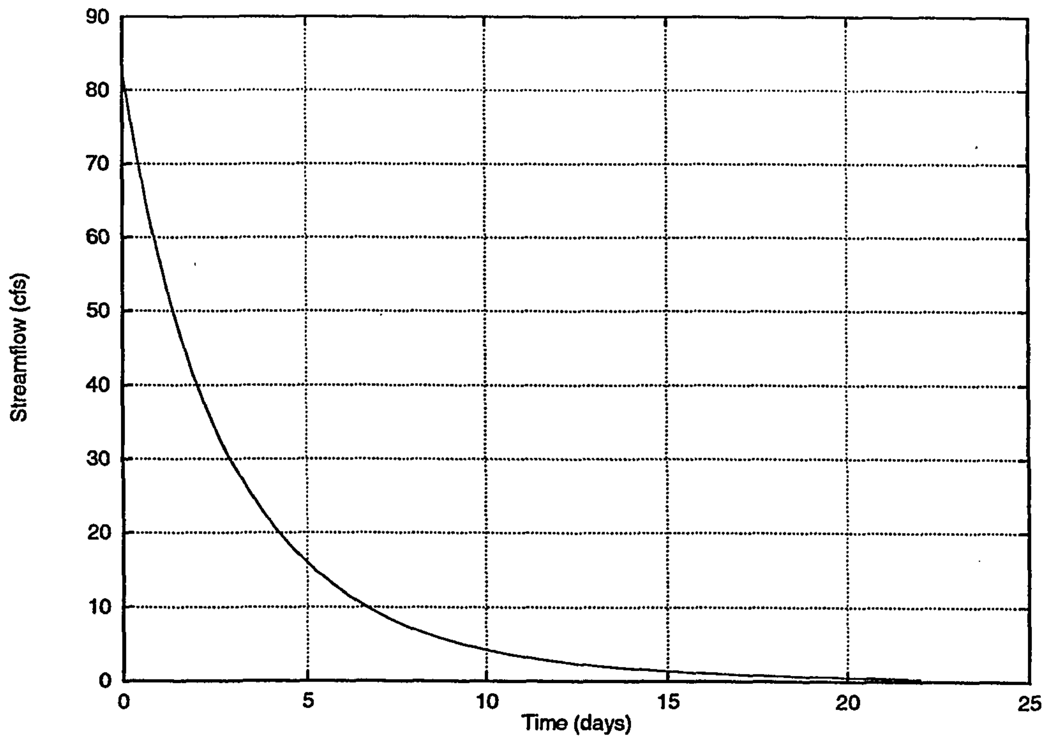

Figure 130.2: MRC of Weldon River near Leon (for summer), ID# 06898400

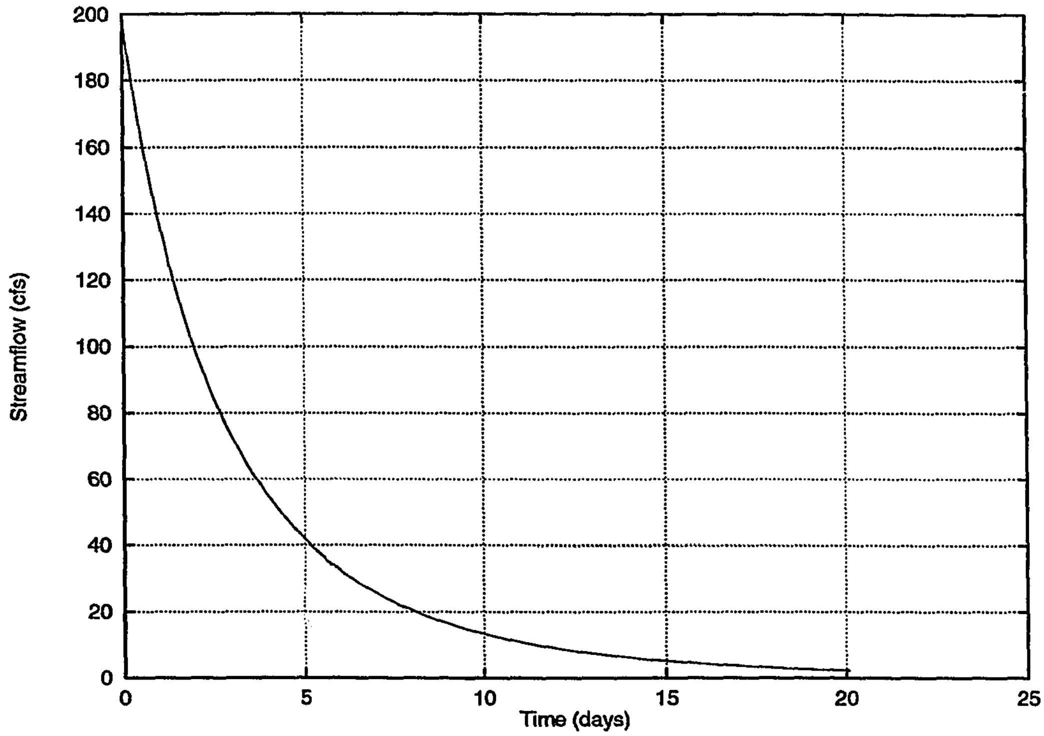

Figure 131.1: MRC of Chariton River near Chariton (for winter), ID# 06903400

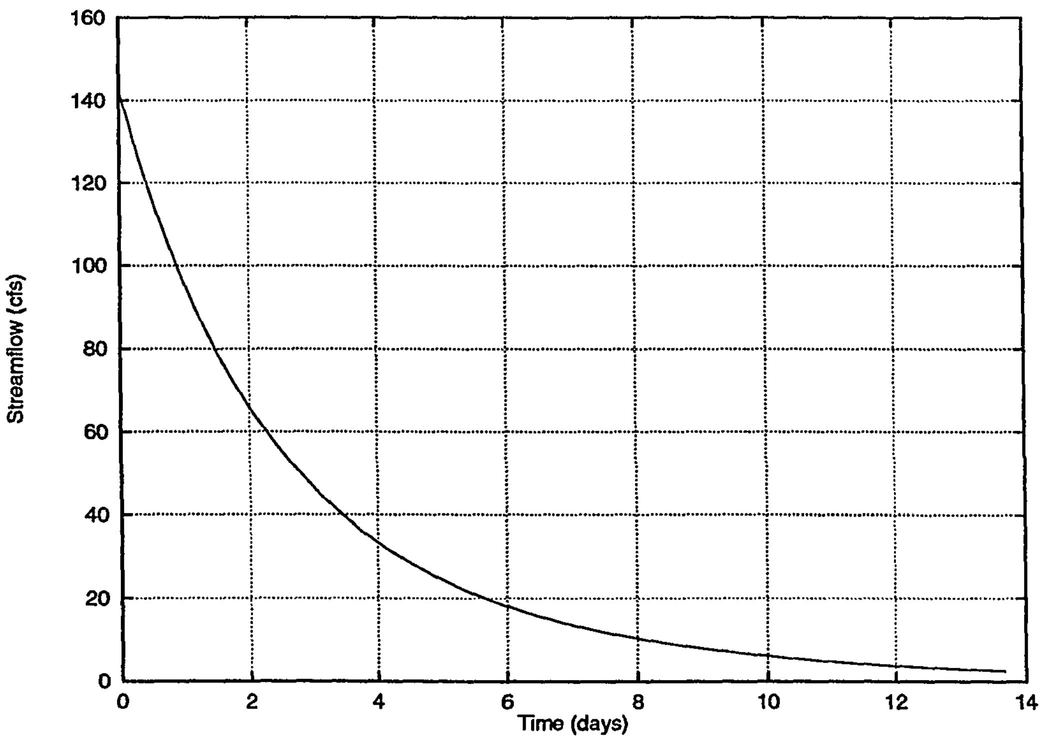

Figure 131.2: MRC of Chariton River near Chariton (for summer), ID# 06903400

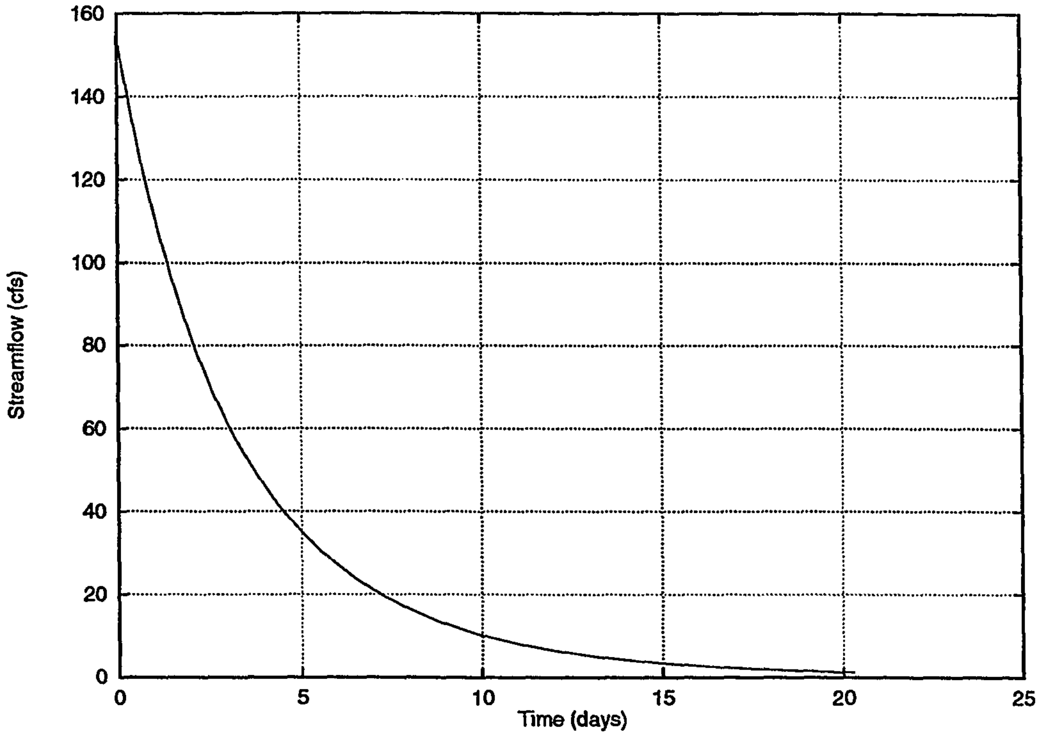

Figure 132.1: MRC of South Fork Chariton River near Promise City (for winter), ID# 06903700

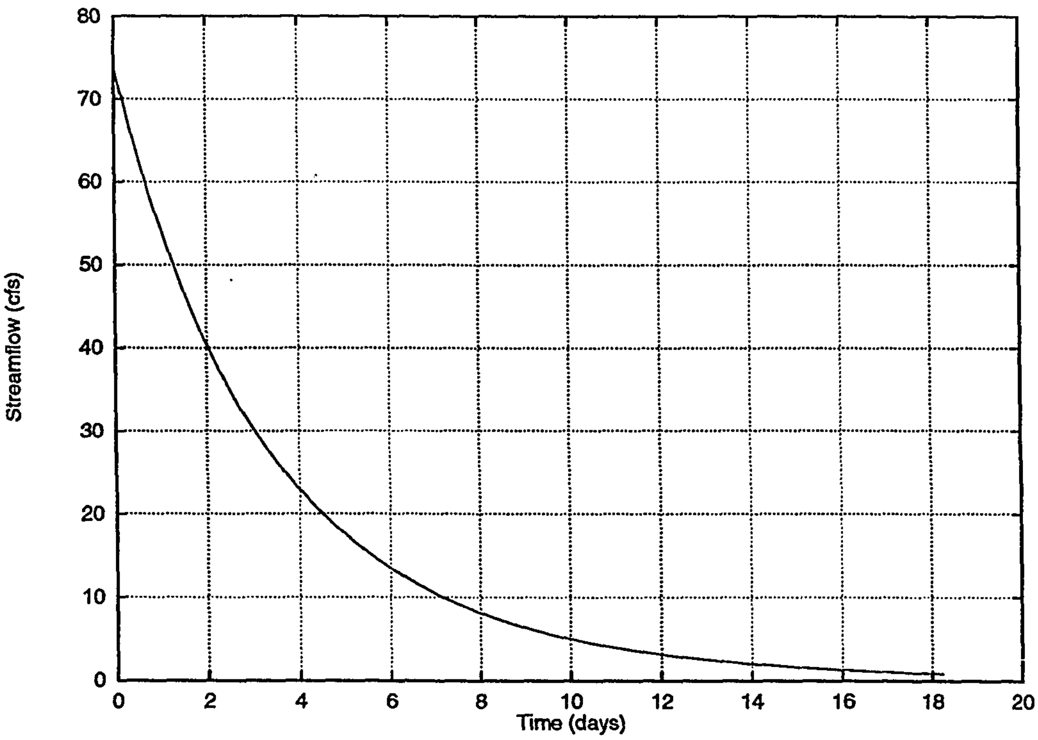

Figure 132.2: MRC of South Fork Chariton River near Promise City (for summer), ID# 06903700

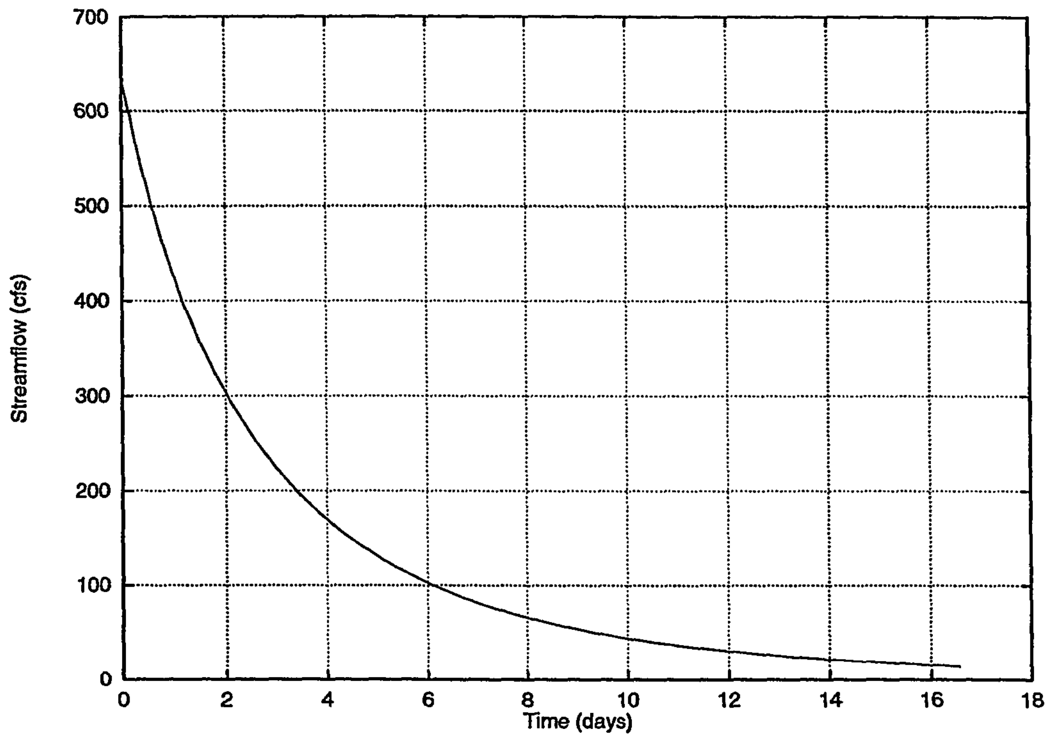

Figure 133.1: MRC of Chariton River near Rathbun (for winter), ID# 06903900

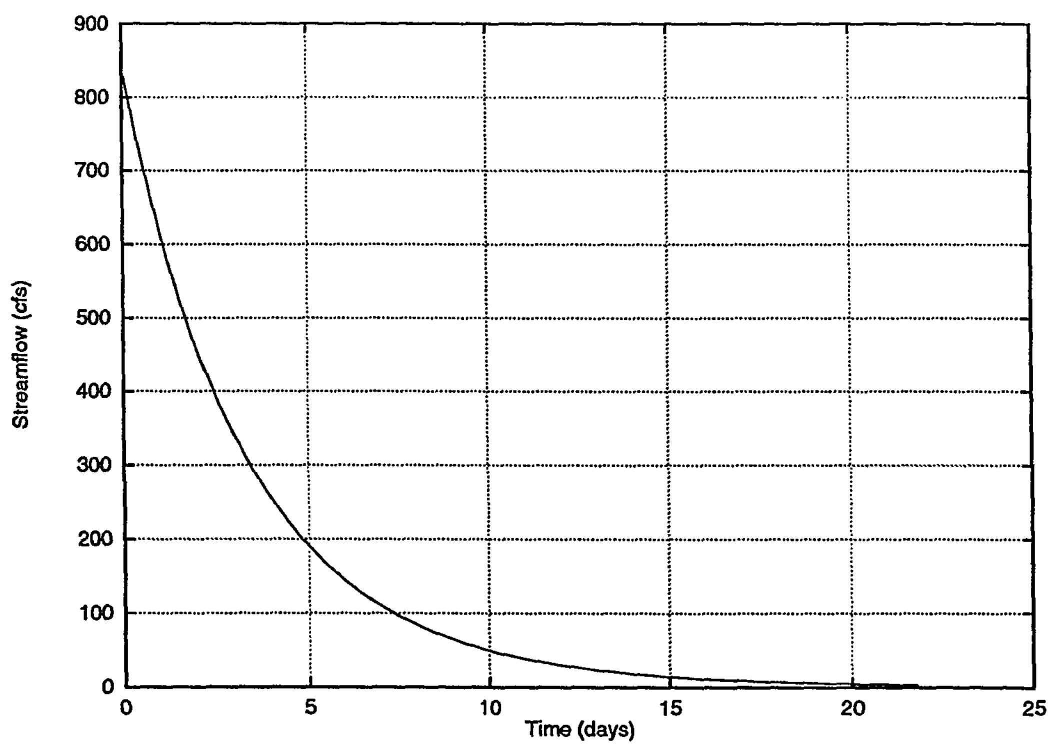

Figure 133.2: MRC of Chariton River near Rathbun (for summer), ID# 06903900

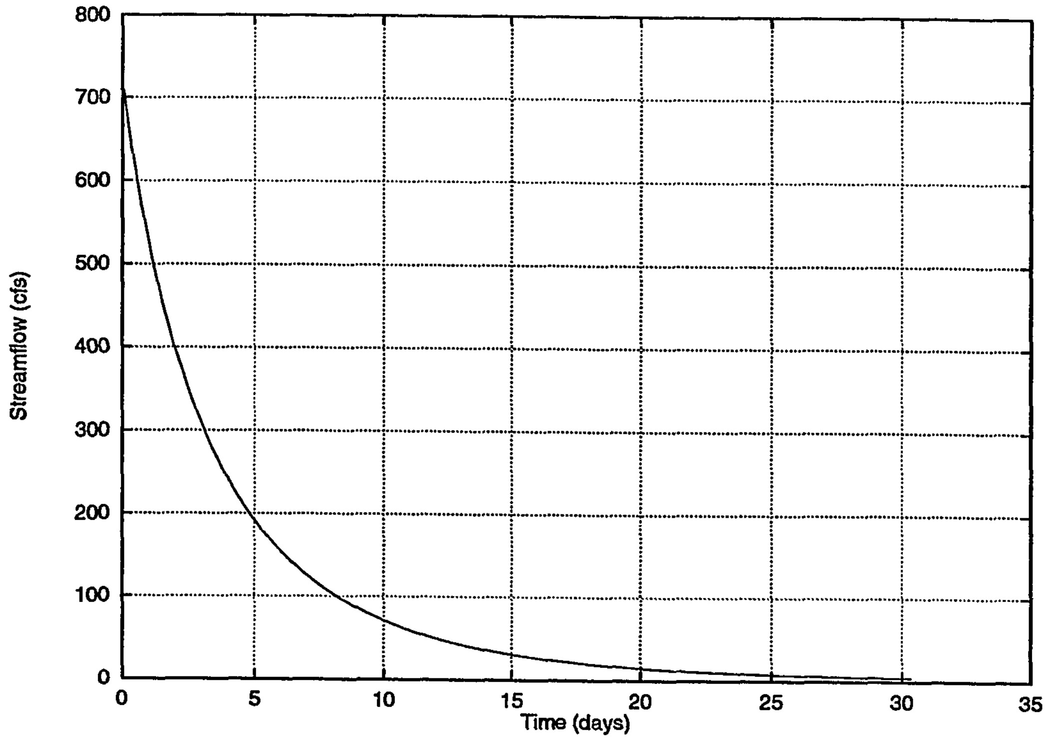

Figure 134.1: MRC of Chariton River near Centerville (for winter), ID# 06904000

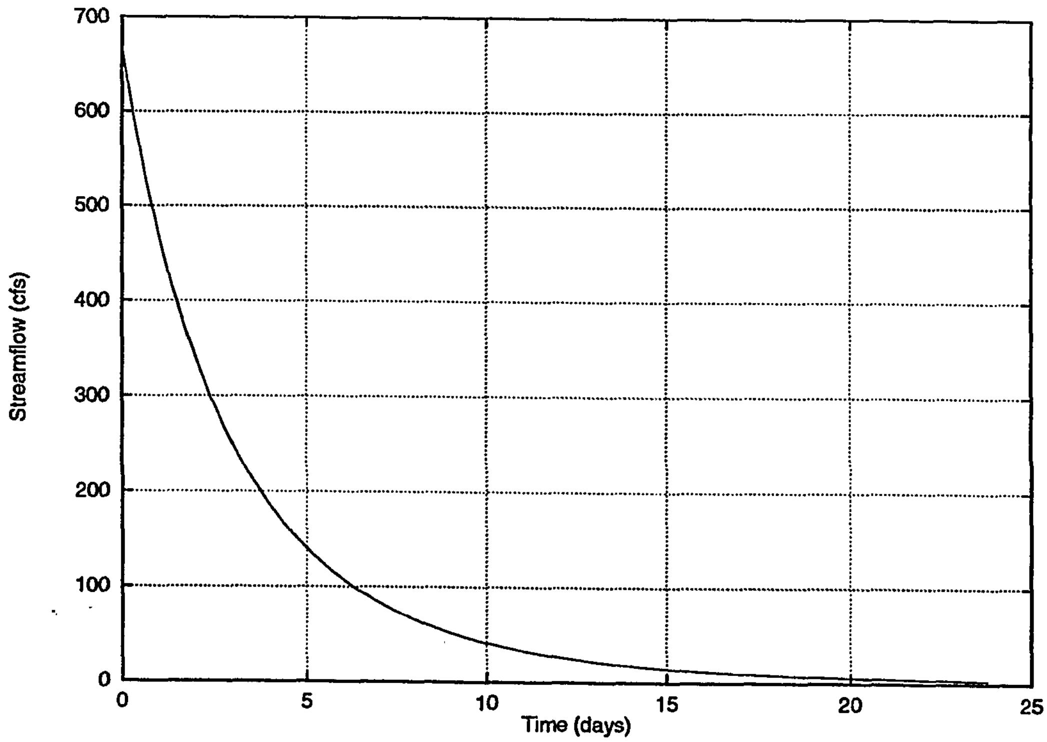

Figure 134.2: MRC of Chariton River near Centerville (for summer), ID# 06904000

APPENDIX C

1. Program RECESS
2. Program FORMAT
3. Program REGRESS

```
      PROGRAM RECESS
C                         BY AL RUTLEDGE, USGS, RICHMOND, VA
C                         MODIFIED BY AHMAD A. RAAII
      COMMON/BIG/Q(90,12,31)
      COMMON/BIG/EST(90,12,31)
      COMMON/BIG/Q1D(33000)
      COMMON/BIG/IYR1D(33000)
      COMMON/BIG/IMO1D(33000)
      COMMON/BIG/IDA1D(33000)
      REAL XX(2000), YY(2000), ZZ(2000)
      REAL FLOW(60), QLOG(60)
      INTEGER INDICAT(2000)
      INTEGER IYR(60), IMO(60), IDA(60)
      REAL Q
      REAL Q1D
      REAL QLOGMAX, QLOGMIN, MXLOGQC
      INTEGER IYR1D
      INTEGER IMO1D
      INTEGER IDA1D
      INTEGER PICKMO(12)
      CHARACTER*1 EST
      CHARACTER*16 INFILE
      CHARACTER*80 PICK
      CHARACTER*80 YESNO
      CHARACTER*1 SEASON
      REAL QMAX, QMIN, KMAX, KMIN, KMED, DA
      CHARACTER*8 STANUM
      CHARACTER*7 LINE
      CHARACTER*16 FNAME
      CHARACTER*29 STANAME
      CHARACTER*1 BLANK(80)
      REAL XMEANAR(50), YMEANAR(50), COEF1AR(50), COEF2AR(50)
      REAL XMNARAY(50), COFARAY(50), X(50), Y(50), K(50), DUMMY(50)
      INTEGER LAT, LONG
      INTEGER IMINAR(50), IMAXAR(50), IYRAR(50),IMOAR(50),IDAAR(50)
      INTEGER IPICK(50), ORIGNO(50)
      OPEN (UNIT=10,FILE='outrec1',STATUS='UNKNOWN')
      OPEN (UNIT=11,FILE='outrec2',STATUS='UNKNOWN')
      OPEN (UNIT=13,FILE='outrec3',STATUS='UNKNOWN')
      OPEN (UNIT=12,FILE='outrec',STATUS='UNKNOWN')
    1 READ (12,21,END=2)
      GO TO 1
    2 CONTINUE
    3 READ (13,21,END=4)
      GO TO 3
    4 CONTINUE
    5 FORMAT (2I6,3F11.2,1F8.2)
      WRITE (*,*) 'THIS PROGRAM READS A DAILY-VALUES FILE OF        '
      WRITE (*,*) 'STREAMFLOW, EXTRACTS PERIODS OF CONTINUOUS       '
      WRITE (*,*) 'STREAMFLOW RECESSION, SELECTS (WITH THE HELP OF  '
      WRITE (*,*) 'THE USER) RECESSION SEGMENTS THAT ARE INDICATIVE '
      WRITE (*,*) 'OF GROUND-WATER DISCHARGE, AND FORMULATES A      '
      WRITE (*,*) 'MASTER RECESSION CURVE (MRC).  THE MRC CAN BE    '
      WRITE (*,*) 'NONLINEAR.                                       '
      WRITE (*,*) 'CODES FOR MISSING DATA ON THE DAILY-VALUES FILE: '
      WRITE (*,*) '-99:DATE IS WITHIN YEARS OF RECORD, BUT DATA MISSING'
      WRITE (*,*) '-999: DATE IS BEFORE FIRST YEAR OF RECORD          '
```

```
      WRITE (*,*) '-9999: NONEXISTENT DATE                                   '
      WRITE (*,*) '   '
C
C------------------------ INITIALIZE VARIABLES : ------------------
      DO 10 IYEAR=1,90
      DO 10 IMONTH=1,12
      DO 10 IDAY=1,31
   10 Q(IYEAR,IMONTH,IDAY)=-999.0
      DO 11 I=1,12
   11 PICKMO(I)=0
      DO 12 I=1,80
   12 BLANK(I)= ' '
      II= 1
      XX(II)= -99.0
      YY(II)= -99.0
      NMRECES=0
      QLOGMAX=0.0
      QLOGMIN=10.0
C
   15 FORMAT (1I3, 2F9.3, 9X, 42A1)
   16 FORMAT (1I6,1I7,2X,A8,1F8.0,2X,A16,3X,A29)
   17 FORMAT (A16,A1,1I4,'-',1I4,1I3,3F6.1,1F6.3,1F9.4,2F10.4)
   18 FORMAT (A26, 1F7.1, 33X, 1F7.1)
   19 FORMAT (1F10.5,1F15.3,3F8.1,10X,1I6,2I3)
   20 FORMAT (1I12, 2F10.4, 1I12, 3I8)
   21 FORMAT (A7)
   22 FORMAT (2X,I4)
   23 FORMAT (1F12.0)
   24 FORMAT (80X)
   25 FORMAT (I4)
   26 FORMAT (5X, 12(1F9.0,1A1))
   27 FORMAT (12F10.2)
   28 FORMAT (1I6, 2I3, 8F10.3)
   29 FORMAT (1I6, 2I3, 8(1F10.3,1A1) )
C
C ------------- READ THE DV FILE OF STREAMFLOW: ---------------------
C
      WRITE (*,*) 'GIVE THE NAME OF ORIGINAL DV FILE OF STREAMFLOW:'
      READ (*,'(A)') INFILE
      INFILE= 'z'//INFILE
      OPEN (UNIT=9, FILE=INFILE,STATUS='OLD')
      IYEAR=1
   30 READ (9,21) LINE
      IF( LINE.NE.'MAXIMUM'.AND.LINE.NE.'MINIMUM') THEN
            GO TO 30
        END IF
      IF(LINE.EQ.'MAXIMUM') THEN
         READ (9,23) QMAX
         GO TO 30
        END IF
      READ (9,23) QMIN
   40 READ (9,25) IYEAR
      IF (IYEAR.NE.9999) THEN
           WRITE (*,*) IYEAR
           IYEAR=IYEAR-1910
          DO 50 IDAY=1,31
   50        READ (9,26) (Q(IYEAR,IMONTH,IDAY),
```

```
     $                      EST(IYEAR,IMONTH,IDAY), IMONTH=1,12)
          GO TO 40
        END IF
      CLOSE (9,STATUS='KEEP')
C
C --------------READ LIST FILE GIVING STATION PROPERTIES: -----------------
C
      WRITE (*,*) 'READING FILE NAMED GAGING'
      OPEN (UNIT=8,FILE='gaging')
   80 READ(8,16) LAT,LONG,STANUM,DA,FNAME,STANAME
      IF(FNAME.NE.INFILE) GO TO 80
      WRITE (*,*) 'STATION NAME:', STANAME
      WRITE (*,*) 'DRAINAGE AREA:', DA
      CLOSE (8,STATUS='KEEP')
      WRITE (*,*) ' '

  100 CONTINUE
C
C ----- OBTAIN USER SPECIFICATIONS ABOUT RECESSION PERIODS DESIRED: ----
C
      WRITE (*,*) 'START IN WHICH YEAR? '
      READ (*,*) IYEARST
      WRITE (*,*) 'END IN WHICH YEAR?'
      READ (*,*) IYEAREN
      IYEARST= IYEARST-1910
      IYEAREN= IYEAREN-1910
      WRITE (*,*) 'ONLY SELECT RECESSIONS BEGINNING IN PARTICULAR '
      WRITE (*,*) 'MONTHS. ENTER NUMBER OF MONTHS SELECTED:'
      READ (*,*) NMONTHS
      IF (NMONTHS.EQ.12) THEN
          DO 120 I=1,12
  120        PICKMO(I)=I
        ELSE
          WRITE (*,*) 'ENTER MONTHS:'
          DO 130 I=1,NMONTHS
  130     READ (*,*) PICKMO(I)
       END IF
  135 CONTINUE
      WRITE (*,*) 'ENTER A SINGLE LETTER TO INDICATE WHAT SEASON, IF  '
      WRITE (*,*) 'ANY, THIS CORRESPONDS TO (s=SUMMER, w=WINTER, OR'
      WRITE (*,*) 'n=NEITHER'
      READ (*,'(A)') SEASON
      IF(SEASON.NE.'s'.AND.SEASON.NE.'w'.AND.SEASON.NE.'n') THEN
          WRITE (*,*) 'OPTION NOT RECOGNIZED.'
          GO TO 135
       END IF
      WRITE (*,*) 'HOW MANY DAYS OF RECESSION ARE REQUIRED?'
      READ (*,*) IFARCRI
C
C -------------- WRITE HEADINGS IN OUTPUT FILES: ------------------
C
      WRITE (11,*) '   OUTPUT FILE "OUTREC2" (UNIT 11) FROM PROGRAM RECE
     $SS:'
      WRITE (11,*) '   INPUT DATA FILE FOR THIS SESSION: ', INFILE
      WRITE (11,*) '---------------------------------------------------
     $------------------'
      WRITE (10,*) ' FILE OUTREC1 (UNIT 10), OUTPUT OF RECESS.F77 '
```

```
      WRITE (10,*) ' INPUT FILE = ', INFILE
      WRITE (13,*) '-------------------------------------------------
     $------------------'
      WRITE (13,*) ' INPUT FILE FOR FOLLOWING SELECTIONS =', INFILE
      WRITE (10,*) ' START = ', IYEARST+1910
      WRITE (10,*) ' END =    ', IYEAREN+1910
      WRITE (10,*) ' DAYS OF RECESSION REQUIRED FOR DETECTION=',
     $  IFARCRI
      WRITE (10,*) ' MONTHS SELECTED:'
      DO 140 I=1, NMONTHS
  140 WRITE (10,*) '   ', PICKMO(I)
      WRITE (10,*) ' '
      WRITE (10,*) '-------------------------------------------------
     $------------------'
      WRITE (10,*) '              RECESSION PERIODS INITIALLY SELECTED:'
      WRITE (10,*) '   LOG Q          SLOPE        TIME SINCE PEAK    .
     $       DATE OF PEAK '
      WRITE (10,*) '   (MEAN)     (-dT/LOG CYC)   (START)(MIDDLE)(END)   .
     $         (yr, mo, d) '
      WRITE (13,*) '              RECESSION PERIODS INITIALLY SELECTED:'
      WRITE (13,*) '   LOG Q          SLOPE        TIME SINCE PEAK    .
     $       DATE OF PEAK '
      WRITE (13,*) '   (MEAN)     (-dT/LOG CYC)   (START)(MIDDLE)(END)   .
     $         (yr, mo, d) '
C
C ------ ASSIGN VALUES TO 1-DIMENSIONAL ARRAYS OF DISCHARGE AND DATE: ----
C
      ICOUNT= 0
      DO 180 IYEAR= IYEARST, IYEAREN
      DO 180 IMONTH= 1,12
      DO 180 IDAY= 1, 31
          SFLOW= Q(IYEAR,IMONTH,IDAY)
          IF(SFLOW.EQ.-99.OR.SFLOW.EQ.-999.OR.SFLOW.EQ.-9999) GO TO 180
          ICOUNT= ICOUNT + 1
          Q1D(ICOUNT)= SFLOW
          IYR1D(ICOUNT)= IYEAR
          IMO1D(ICOUNT)= IMONTH
          IDA1D(ICOUNT)= IDAY
  180 CONTINUE
      IIMAX= 365* (1 + IYEAREN - IYEARST)
      IF(QMIN.LT.0.001) THEN
          WRITE (*,*) 'FOR THIS STATION, THE MINIMUM DISCHARGE IS ZERO.'
          WRITE (*,*) 'TO AVOID PROGRAM TERMINATION DUE TO PROBLEMS  '
          WRITE (*,*) 'WITH THE LOG FUNCTION, ENTER A SMALL POSITIVE'
          WRITE (*,*) 'NUMBER FOR MINIMUM DISCHARGE ON GRAPHICS: '
          READ (*,*)  QMIN
       END IF
      XLGQMAX= LOG(QMAX) / 2.3025851
      XLGQMIN= LOG(QMIN) / 2.3025851
      XLMXOLD= XLGQMAX
      XLMNOLD= XLGQMIN
C
C ---------------------- LOCATE A PEAK: ------------------------------
C
      ICOUNT=1
  200 ICOUNT= ICOUNT + 1
      IF(ICOUNT.GT.IIMAX) GO TO 250
```

```
      IF(IYR1D(ICOUNT).GT.IYEAREN) GO TO 250
      OK=0
      DO 205 I=1,12
  205     IF(IMO1D(ICOUNT).EQ.PICKMO(I)) OK=1
      IF(OK.EQ.0) GO TO 200
      IF(Q1D(ICOUNT).LE.Q1D(ICOUNT-1).OR.Q1D(ICOUNT).LE.Q1D(ICOUNT+1))
     #                                                 GO TO 200
      IPEAK= ICOUNT
      OK=1
C
C ------------- ANALYZE THE RECESSION AFTER THE PEAK: ---------------
C
  210 ICOUNT= ICOUNT+1
         IF (ICOUNT.GT.IIMAX) GO TO 250
         IF (INT(100*Q1D(ICOUNT)).GT.INT(100*Q1D(ICOUNT-1))) OK=0
         IHOWFAR= ICOUNT-IPEAK-1
         IF (OK.EQ.1) GO TO 210
         IF (IHOWFAR.LT.IFARCRI.AND.OK.EQ.0) THEN
             ICOUNT= ICOUNT-1
             GO TO 200
             END IF
         IF (IHOWFAR.GE.IFARCRI.AND.OK.EQ.0) THEN
             DO 215 IT= 1,60
                 FLOW(IT)= 0.0
                 QLOG(IT)= -99.9
                 IYR(IT)=0
                 IMO(IT)=0
                 IDA(IT)=0
  215           CONTINUE
             NUM= ICOUNT-IPEAK-1
             IF(NUM.GT.60) THEN
                 NUM=60
                 ICOUNT= IPEAK+60
              END IF
               IMIN=1
               IMAX=NUM
               DO 220 IT=1,NUM
                  I= IT+IPEAK
                  FLOW(IT)= Q1D(I)
                  IF(Q1D(I).EQ.0.0) THEN
                      QLOG(IT)= -88.8
                    ELSE
                      QLOG(IT)= LOG(Q1D(I)) / 2.3025851
                   END IF
                  IYR(IT)= IYR1D(I) + 1910
                  IMO(IT)= IMO1D(I)
                  IDA(IT)= IDA1D(I)
  220           CONTINUE
              WRITE (*,*) ' '
              WRITE (*,*) ' '
              WRITE (*,*) '--------------------------------------------
     $-------------------'
              WRITE(*,*) 'NUMBER OF RECESSION PERIODS USED SO FAR = ',
     $                     NMRECES
              WRITE(*,*) 'DATE OF NEW PEAK =', IYR1D(IPEAK)+1910,
     $                              IMO1D(IPEAK), IDA1D(IPEAK)
              WRITE(*,*) 'PERIOD OF SUBSEQUENT RECESSION (DAYS) =', NUM
```

```
  230      CONTINUE
C
C ------------------- OBTAIN OPTION FROM USER:----------------------
C
         WRITE (*,*) 'OPTIONS: g or g2:graphical, t or t2:tabular, c:
     $ choose first+last days to use,'
         WRITE (*,*) 'e:choose extremes for log q, o:go back to old e
     $xtremes for log q,'
         WRITE (*,*) 'a:advance to next recession, r:perform regressi
     $on, store results in memory,'
         WRITE (*,*) 'and advance to next recession, b: go back to or
     $iginal time limits, q: quit'
         READ (*,'(A)') PICK
         IF (PICK.EQ.'t'.OR.PICK.EQ.'t2') THEN
             CALL TABLE(QLOG,FLOW,IYR,IMO,IDA,IPEAK,IMIN,IMAX,PICK)
             GO TO 230
           ELSEIF(PICK.EQ.'g'.OR.PICK.EQ.'g2') THEN
             CALL GRAPH(QLOG,FLOW,IYR,IMO,IDA,IPEAK,IMIN,IMAX,
     $                  XLGQMAX,XLGQMIN,PICK)
             GO TO 230
           ELSEIF(PICK.EQ.'c') THEN
             WRITE (*,*) 'ENTER FIRST AND LAST DAY TO USE  **********
     $**  enter NUMBERS only! ***********'
             READ (*,*) IMIN
             READ (*,*) IMAX
             GO TO 230
           ELSEIF(PICK.EQ.'b') THEN
             IMIN= 1
             IMAX= ICOUNT-IPEAK-1
             GO TO 230
           ELSEIF(PICK.EQ.'a') THEN
             ICOUNT= ICOUNT-1
             GO TO 200
           ELSEIF(PICK.EQ.'o') THEN
             XLGQMIN= XLMNOLD
             XLGQMAX= XLMXOLD
             GO TO 230
           ELSEIF(PICK.EQ.'e') THEN
             WRITE (*,*) 'ENTER MIN AND MAX VALUE FOR LOG Q'
             READ (*,*) XLGQMIN
             READ (*,*) XLGQMAX
             GO TO 230
           ELSEIF (PICK.EQ.'r') THEN

             NMRECES= NMRECES+1
              IF(NMRECES.GT.50) THEN
                  WRITE (*,*) 'YOU HAVE ANALIZED THE MAXIMUM NUMBER'
                  WRITE (*,*) 'OF RECESSION PERIODS.'
                  NMRECES= NMRECES-1
                  GO TO 250
                 END IF
             I=0
              IF(IMAX-IMIN.GT.49) THEN
                  WRITE (*,*) 'THE NUMBER OF DAYS SELECTED SHOULD BE'
                  WRITE (*,*) 'LESS THAN 51 BEFORE PICKING OPTION r'
                  GO TO 230
                 END IF
```

```
          DO 240 IT= IMIN, IMAX
          I=I+1
          II=II+1
           IF(II.GT.2000) THEN
               WRITE (*,*) 'THE TOTAL NUMBER OF DAYS IN ALL '
               WRITE (*,*) 'SELECTED RECESSION PERIODS EXCEEDS'
               WRITE (*,*) 'THE LIMIT OF 2000.   '
               GO TO 250
              END IF
          INDICAT(II)= NMRECES
          X(I)= QLOG(IT)
          Y(I)= REAL(IT)
          XX(II)= QLOG(IT)
          YY(II)= REAL(IT)
          IF(QLOG(IT).GT.QLOGMAX) QLOGMAX= QLOG(IT)
          IF(QLOG(IT).LT.QLOGMIN) QLOGMIN= QLOG(IT)
240       CONTINUE
          II=II+1
          XX(II)= 0.0
          YY(II)= 0.0
          NSELECT= I
          WRITE (*,*) '     DAYS          LOG Q                   '
          WRITE (*,*) '   ( Y(I) )       ( X(I) )               I'
          XTOTAL= 0.0
          YTOTAL= 0.0
          DO 245 I=1,NSELECT
          XTOTAL= XTOTAL + X(I)
          YTOTAL= YTOTAL + Y(I)
245       WRITE (*,*)  Y(I), X(I), I
          XMEAN= XTOTAL/NSELECT
          YMEAN= YTOTAL/NSELECT
          COEFF1=0.0
          COEFF2=0.0
          R2=0.0
          CALL REGRES2(X,Y,NSELECT,COEFF1,COEFF2,R2)

          WRITE (*,*) ' BEST-FIT EQUATION:'
          WRITE (*,248) ' T = ( ', COEFF1,'* LOGQ )  +  ', COEFF2
          WRITE (*,*) '  DAYS/LOG CYCLE=', -1*COEFF1
          WRITE (*,*) ' COEFFICIENT OF DETERMINATION = ', R2
248       FORMAT (A,G12.4,A,G12.4)
          WRITE (*,*) '  MEAN LOG Q = ', XMEAN
          WRITE (*,*) ' '
          WRITE (*,*) ' '
          WRITE(10,19) XMEAN, -1*COEFF1, REAL(IMIN), YMEAN,
     $    REAL(IMAX),IYR1D(IPEAK)+1910,IMO1D(IPEAK), IDA1D(IPEAK)
          WRITE(13,19) XMEAN, -1*COEFF1, REAL(IMIN), YMEAN,
     $    REAL(IMAX),IYR1D(IPEAK)+1910,IMO1D(IPEAK), IDA1D(IPEAK)
          XMEANAR(NMRECES)= XMEAN
          YMEANAR(NMRECES)= YMEAN
          COEF1AR(NMRECES)= COEFF1
          COEF2AR(NMRECES)= COEFF2
          IMINAR(NMRECES)=   IMIN
          IMAXAR(NMRECES)=   IMAX
          IYRAR(NMRECES)=    IYR1D(IPEAK) + 1910
          IMOAR(NMRECES)=    IMO1D(IPEAK)
          IDAAR(NMRECES)=    IDA1D(IPEAK)
```

```
                    IF (NMRECES.EQ.50) THEN
                        WRITE (*,*)  ' '
                        WRITE (*,*) 'YOU HAVE ANALIZED 50 RECESSIONS.'
                        WRITE (*,*) 'THIS IS THE MAXIMUM ALLOWABLE.'
                        WRITE (*,*) ' '
                        WRITE (*,*) ' '
                      END IF
                 ICOUNT= ICOUNT-1
                GO TO 200
              ELSEIF (PICK.EQ.'q') THEN
                GO TO 250
              ELSE
                WRITE (*,*) 'OPTION NOT RECOGNIZED. CHOOSE AGAIN.'
                GO TO 230
             END IF
          END IF
  250 CONTINUE
C
C -------------CONTINUE AFTER RECESSION PERIODS HAVE BEEN SELECTED:--------
----
C
      NUMBRII= II
      IIDV=0
      DO 270 III=1,NUMBRII
         IF(XX(III).NE.0.0.AND.YY(III).NE.0.0.AND.XX(III).NE.-99.AND.
     $                              YY(III).NE.-99) THEN
             IIDV=IIDV+1
        END IF
  270 CONTINUE
      WRITE (10,*) 'TOTAL NUMBER OF DAILY VALUES OF STREAMFLOW THAT WERE
     $ USED, FOR ALL RECESSION'
      WRITE (10,*) 'PERIODS INITIALLY SELECTED = ', IIDV
  280 CONTINUE
      WRITE (*,*) 'DO YOU WANT TO ANALIZE THE RECESSIONS SELECTED? (y OR
     $ n) '
      READ(*,'(A)') PICK
      IF(PICK.EQ.'n') THEN
            GO TO 600
         ELSEIF(PICK.EQ.'y') THEN
            GO TO 290
         ELSE
            WRITE (*,*) 'OPTION NOT RECOGNIZED.'
            GO TO 280
         END IF
  290  CONTINUE
C
C ---- DETERMINE MAX AND MIN SLOPES AND TRANSFER LOGQ AND SLOPE TO OTHER --
----
C -------------- VARIABLES FOR LISTING THEM BY DECREASING LOGQ:  ----------
---
        SLOPEMX= 0.0
        SLOPEMN= 2000.0
        DO 300 I=1,NMRECES
        SLOPE= -1*COEF1AR(I)
        IF(SLOPE.GT.SLOPEMX) SLOPEMX=SLOPE
        IF(SLOPE.LT.SLOPEMN) SLOPEMN=SLOPE
        ORIGNO(I)=I
```

```
      XMNARAY(I)= XMEANAR(I)
300   COFARAY(I)= COEF1AR(I)
      CALL ORDER(NMRECES,XMNARAY,COFARAY,ORIGNO)
      WRITE (10,*) 'NUMBER OF RECESSION PERIODS INITIALLY SELECTED=',
   $         NMRECES
      WRITE (10,*) 'MAXIMUM LOG Q FOR ALL RECESSIONS=', QLOGMAX
      WRITE (*,*)  'MAXIMUM LOG Q FOR ALL RECESSIONS=', QLOGMAX
      WRITE (10,*) 'MINIMUM LOG Q FOR ALL RECESSIONS=', QLOGMIN
      WRITE (*,*)  'MINIMUM LOG Q FOR ALL RECESSIONS=', QLOGMIN
      WRITE (10,*) ' '
      WRITE (10,*) '---------------------------------------------------
   $-----------------'
      WRITE (10,*) '      RECESSION PERIODS AFTER SORTING BY LOG Q:'
      WRITE (10,*) 'ORIG.                                   GRAPHIC OF
   $ SLOPE:'
      WRITE (10,18) 'NUMBER LOG Q   SLOPE      ', SLOPEMN, SLOPEMX
     NOWRITE=1
305   CONTINUE
          WRITE (*,*)  'ORIG.  ORDERED                          GRAPHI
   $C OF SLOPE'
          WRITE (*,18)  'NUMBER  LOG Q  SLOPE      ', SLOPEMN, SLOPEMX
          DO 310 I=NMRECES,1,-1
          IPICK(I)= 1
          SLOPE= -1.0*COFARAY(I)
          DIFF= SLOPE - SLOPEMN
          NUMBLNK= INT( DIFF*40/ (SLOPEMX-SLOPEMN) )
          WRITE (*,15)  ORIGNO(I), XMNARAY(I), COFARAY(I),
   $                (BLANK(J),J=1,NUMBLNK), '*'
            IF (NOWRITE.EQ.1) THEN
               WRITE (10,15) ORIGNO(I), XMNARAY(I), COFARAY(I),
   $                   (BLANK(J),J=1,NUMBLNK), '*'
             END IF
310       CONTINUE
          NOWRITE=0
     WRITE (*,*) '------ DO YOU WANT TO SEE IT AGAIN? (y OR n) -----'
     READ (*,'(A)') YESNO
     IF(YESNO.NE.'n') GO TO 305
C
C ---------- SELECT DATA LINES TO BE DELETED BEFORE REGRESSION:  ----------
---

      WRITE (*,*) 'BEFORE OBTAINING THE LEAST-SQUARES BEST FIT'
      WRITE (*,*) 'EQUATION FOR SLOPE (DELTA T/DELTA LOG Q) VERSUS'
      WRITE (*,*) 'LOG Q, HOW MANY RECESSIONS SHOULD BE ELIMINATED?'
      READ (*,*) NUMELIM
      WRITE (10,*) 'BEFORE OBTAINING THE LEAST-SQUARES BEST FIT '
      WRITE (10,*) 'EQUATION FOR SLOPE (DELTA T/DELTA LOG Q) VERSUS'
      WRITE (10,*) 'LOG Q, THIS NUMBER OF RECESSIONS WAS ELIMINATED:',
   $          NUMELIM
      WRITE (13,*) 'THIS NUMBER ELIMINATED : ', NUMELIM
      WRITE (13,*) 'ELIMINATED RECESSIONS INDICATED BELOW:'
      IF(NUMELIM.EQ.0) GO TO 330
         WRITE (11,*) 'NOTE THAT THESE RECESSIONS, IDENTIFIED BY   '
         WRITE (11,*) 'THEIR ORIGINAL SEQUENTIAL NUMBERS, WERE     '
         WRITE (11,*) 'DELETED FROM ANALYSIS BEFORE DETERMINING   '
         WRITE (11,*) 'BEST-FIT EQUATIONS:'
      DO 320 J=1,NUMELIM
```

```
            WRITE (*,*) 'ENTER RECESSION TO ELIMINATE (ENTER ITS "ORIGINA
     $L NUMBER") '
            READ (*,*) ITHIS
            WRITE (13,*) ITHIS
            WRITE (11,*) '                ', ITHIS
            DO 315 I=1,NMRECES
                IF(ORIGNO(I).EQ.ITHIS) THEN
                    ORIGNO(I)=0
                   END IF
  315          CONTINUE
  320      CONTINUE
  330      CONTINUE
C
C -------ASSIGN VALUES TO X AND Y TO BE SENT TO THE REGRESSION SUBROUTINE:-
---
         NUM=0
         DO 340 I=1,NMRECES
            IF(ORIGNO(I).EQ.0) GO TO 340
            NUM= NUM + 1
            X(NUM)= XMNARAY(I)
            Y(NUM)= COFARAY(I)
            ORIGNO(NUM)=ORIGNO(I)
  340    CONTINUE
         NMRECES= NUM
         WRITE (*,*) '    X               Y'
         DO 350 I=NMRECES,1,-1
  350    WRITE (*,*) X(I), Y(I)
C
C  --------------- SHOW ORDERED DATA, AFTER ELIMINATION:  -----------------
----
C
       WRITE (10,*) ' '
       WRITE (10,*) '--------------------------------------------------
      $-------------------'
       WRITE (10,*) '        RECESSION PERIODS LEFT AFTER ELIMINATION: '
       WRITE (10,*) 'ORIG.  ORDERED                           GRAPHIC OF
      $SLOPE'
       WRITE (10,18) 'NUMBER  LOG Q  SLOPE      ', SLOPEMN, SLOPEMX
       DO 352 I=NMRECES,1,-1
          SLOPE=-1.0*Y(I)
          DIFF= SLOPE-SLOPEMN
          NUMBLNK= INT(DIFF*40/(SLOPEMX-SLOPEMN))
  352    WRITE(10,15) ORIGNO(I), X(I), Y(I),
      $              (BLANK(J),J=1,NUMBLNK), '*'
       MXLOGQC= X(NMRECES)
       WRITE (10,*) 'AMONG THE SELECTED RECESSION PERIODS, THIS IS THE'
       WRITE (10,*) 'MAXIMUM VALUE OF LOG Q FOR WHICH A SLOPE(DAYS/LOGQ)'
       WRITE (10,*) 'WAS CALCULATED: ', MXLOGQC
C
C-- PERFORM REGRESSION AND WRITE BEST EQUATION FOR SLOPE AS FUNCT. OF
DISCHARGE
C
         COEFFA= 0.0
         COEFFB= 0.0
         R2= 0.0
         CALL REGRES2(X,Y,NUM,COEFFA,COEFFB,R2)
  353    FORMAT (A,F8.2,A,F8.2)
```

```
354    FORMAT (A,F8.2,A,F8.2,A,F8.2)
       WRITE (10,*) ' '

       WRITE (10,*) '------------------------------------------------
     $------------------'
       WRITE (10,*) 'BEST-FIT LINEAR EQUATION FOR SLOPE VS. LOG Q:'
       WRITE (10,353) 'DELTA T/DELTA LOGQ = (',COEFFA,' * LOGQ ) + ',
     $                          COEFFB
       WRITE (10,*) 'COEFFICIENT OF DETERMINATION = ', R2
       WRITE (10,*) '  RESULTS OF THIS EQUATION:'
       WRITE (10,*) '                    SLOPE (TIME      '
       WRITE (10,*) '                 INCREMENT PER LOG Q       GRAPHIC OF
     $ SLOPE'
       WRITE (10,18) '      LOG Q     INCREMENT)', SLOPEMN, SLOPEMX
       XLOGQ= MXLOGQC
370    CONTINUE
       SLOPE= -1*COEFFA*XLOGQ - 1*COEFFB
       DIFF= SLOPE-SLOPEMN
       NUMBLNK= INT(DIFF*40/(SLOPEMX-SLOPEMN))
        IF(NUMBLNK.LT.0) THEN
            WRITE (10,*) XLOGQ, SLOPE, '     '
           ELSE
            WRITE (10,*) XLOGQ, SLOPE, (BLANK(J), J=1,NUMBLNK), '*'
         END IF
       XLOGQ= XLOGQ - 0.05
       IF(XLOGQ.GT.QLOGMIN) GO TO 370

C ---- AFTER INTEGRATION WRITE EQUATION FOR TIME AS FUNCTION OF DISCHARGE:
---
       COEFFC= -0.5*COEFFA*MXLOGQC**2 - COEFFB*MXLOGQC
       WRITE (10,*) ' '
       WRITE (10,*) '------------------------------------------------
     $-------------------'
       WRITE (10,*) 'AFTER INTEGRATION, THE FOLLOWING EQUATION IS '
       WRITE (10,*) 'OBTAINED. IT GIVES TIME (IN DAYS) AS A FUNCTION'
       WRITE (10,*) 'OF LOG Q. INITIAL CONDITION IS T=0 AT LOG Q= THE'
       WRITE (10,*) 'MAXIMUM LOG Q FOR WHICH A VALUE OF SLOPE WAS '
       WRITE (10,*) 'CALCULATED.'
       WRITE (10,354) ' T =',COEFFA/2,' * LOGQ**2  +', COEFFB,' * LOGQ
     $+',    COEFFC
       WRITE (10,*) '         RESULTS OF THIS EQUATION:'
       WRITE (10,*) '                                                GR
     $APHIC OF TIME:'
       TIMEMAX= 0.5*COEFFA*QLOGMIN**2 + COEFFB*QLOGMIN + COEFFC
       WRITE (10,*) '    TIME(D)         LOG Q            Q       0.0 '
       XLOGQ= MXLOGQC
380    CONTINUE
       T= 0.5*COEFFA*XLOGQ**2 + COEFFB*XLOGQ + COEFFC
       XQ= 10.0**XLOGQ
       NUMBLNK= INT(T*25/TIMEMAX)
       WRITE (10,*) T, XLOGQ, XQ, (BLANK(J),J=1,NUMBLNK), '*'
       XLOGQ= XLOGQ-0.05
       IF(XLOGQ.GT.QLOGMIN) GO TO 380
C
C -----------   DETERMINE MAX, MIN, AND MEDIAN K: -----------------------
---
C
```

```
      DO 390 I=1,NMRECES
         K(I)= Y(I)*(-1)
 390     DUMMY(I)= 1.0
      CALL ORDER(NMRECES,K,DUMMY,ORIGNO)
      KMAX= K(NMRECES)
      KMIN= K(1)
      IDOWN= 0
      IUP= NMRECES + 1
      ICNT=0
 395  CONTINUE
        ICNT=ICNT+1
        IF(ICNT.GT.50) THEN
           WRITE (*,*) 'PROBLEMS WITH DETERMINATION OF MEDIAN'
           GO TO 400
         END IF
        IF(IUP-IDOWN.EQ.2) THEN
           KMED= K((IUP+IDOWN)/2)
           GO TO 400
          ELSEIF(IUP-IDOWN.EQ.1) THEN
           KMED= (K(IUP)+K(IDOWN)) / 2
           GO TO 400
          ELSE
           IDOWN= IDOWN+1
           IUP= IUP-1
           GO TO 395
         END IF
 400  CONTINUE

C ------------------ WRITE RAW RECESSION DATA TO FILE OUTREC2: -----------
-

      WRITE (11,*) '--------------------------------------------------
     $-----------------'
      WRITE (11,*) ' DAYS ON MRC          Q              LOG Q      DAYS SI
     $NCE LAST         ORIG.'
      WRITE (11,*) '   ( Y(I) )       (10**X(I))      ( X(I) )       PEAK
     $( I )            SEQ. #'
      II= NUMBRII + 1
 520  II= II-1
      IF(XX(II).EQ.0.0.AND.YY(II).EQ.0.0) THEN
        WRITE (11,*) '    '
        II= II-1
        T=0.5*COEFFA*XX(II)**2 + COEFFB*XX(II) + COEFFC
        DIFF= T-YY(II)
        ZZ(II)= T
        WRITE (11,*) ZZ(II), 10**(XX(II)), XX(II), YY(II), INDICAT(II)
        GO TO 520
       ELSE IF (XX(II).EQ.-99.AND.YY(II).EQ.-99) THEN
        GO TO 530
       ELSE
        ZZ(II)= DIFF + YY(II)
        WRITE (11,*) ZZ(II), 10**(XX(II)), XX(II), YY(II), INDICAT(II)
        GO TO 520
      END IF
 530  CONTINUE
      WRITE (10,*) '--------------------------------------------------
     $---------------'
```

```
C
  600 CONTINUE
      WRITE (12,17) FNAME,SEASON,IYEARST+1910,IYEAREN+1910,NMRECES,
     $              KMIN,KMED,KMAX,MXLOGQC,0.5*COEFFA,COEFFB,COEFFC
      CLOSE (10,STATUS='KEEP')
      CLOSE (11,STATUS='KEEP')
      CLOSE (12,STATUS='KEEP')
      CLOSE (13,STATUS='KEEP')
      STOP
      END




C --------- THIS SUBROUTINE MAKES TABULAR OUTPUT OF RECESSION DATA: -----

      SUBROUTINE TABLE(QLOG,FLOW,IYR,IMO,IDA,IPEAK,IMIN,IMAX,PICK)
      REAL FLOW(60), QLOG(60), DELQLOG(60)
      INTEGER IYR(60), IMO(60), IDA(60)
      CHARACTER*80 PICK
      IF (PICK.EQ.'t') THEN
         ISTART=1
        ELSE
   10     CONTINUE
          WRITE (*,*) 'ENTER STARTING DAY (1,11,21,OR 31)'
          READ (*,'(A)') PICK
          IF(PICK.EQ.'1') THEN
             ISTART=1
            ELSEIF(PICK.EQ.'11') THEN
             ISTART=11
            ELSEIF(PICK.EQ.'21') THEN
             ISTART=21
            ELSEIF(PICK.EQ.'31') THEN
             ISTART=31
            ELSE
             WRITE (*,*) 'OPTION NOT RECOGNIZED'
             GO TO 10
           END IF
        END IF
      IEND= ISTART+15
      IF(ISTART.GT.60) ISTART=60
      IF(IEND.GT.60) IEND= 60
   20 FORMAT (1I6, 3F10.4, 1I8, 3I8)
      DO 40 IT= ISTART, IEND
          IF(IT.EQ.1) THEN
              DELQLOG(IT)= 999.0
            ELSE
              DELQLOG(IT)= QLOG(IT)-QLOG(IT-1)
           END IF
   40 CONTINUE
      WRITE(*,*) 'TIME AFTER         DELTA                 TIME AFTER'
      WRITE(*,*) '    PEAK    LOG Q     LOG Q       Q          START   YEAR   .
     $  MONTH     DAY'
      DO 230 IT= ISTART,IEND
         IF (IT.GT.IMAX.OR.IT.LT.IMIN) THEN
```

```
          WRITE (*,*) 'DAY IS OUTSIDE OF PERIOD SELECTED'
        ELSEIF (QLOG(IT).EQ.-99.9) THEN
          WRITE (*,*) 'DAY IS OUTSIDE RECESSION PERIOD'
        ELSEIF (QLOG(IT).EQ.-88.8) THEN
          WRITE (*,*) 'STREAMFLOW = ZERO '
        ELSE
         WRITE (*,20) IT, QLOG(IT), DELQLOG(IT), FLOW(IT), IT+IPEAK,
     $                    IYR(IT), IMO(IT), IDA(IT)
       END IF
  230           CONTINUE
      RETURN
      END
C
C
C
C ------ THIS SUBROUTINE MAKES GRAPHICAL OUTPUT OF RECESSION DATA: ----
C
      SUBROUTINE GRAPH (QLOG,FLOW,IYR,IMO,IDA,IPEAK,IMIN,IMAX,
     $              XLGQMAX,XLGQMIN,PICK)
      REAL FLOW(60), QLOG(60)
      INTEGER IYR(60), IMO(60), IDA(60)
      CHARACTER*1 BLANK(80)
      CHARACTER*80 PICK
      DO 2 I=1,80
    2 BLANK(I)= ' '
      IF (PICK.EQ.'g') THEN
           ISTART=1
           INTERVL=1
        ELSE
    3      CONTINUE
           WRITE (*,*) 'ENTER STARTING DAY (1, 11, 21, OR 31)'
           READ(*,'(A)') PICK
            IF(PICK.EQ.'1') THEN
                ISTART= 1
              ELSEIF(PICK.EQ.'11') THEN
                ISTART=11
              ELSEIF(PICK.EQ.'21') THEN
                ISTART=21
              ELSEIF(PICK.EQ.'31') THEN
                ISTART=31
              ELSE
                WRITE (*,*) 'OPTION NOT RECOGNIZED'
                GO TO 3
             END IF
    4      CONTINUE
           WRITE (*,*) 'ENTER TIME INTERVAL (1=EVERY DAY, 2=EVERY OTHER
     $ DAY, OR 3=EVERY THIRD DAY)'
           READ (*,'(A)') PICK
             IF(PICK.EQ.'1') THEN
                 INTERVL=1
               ELSEIF(PICK.EQ.'2') THEN
                 INTERVL=2
               ELSEIF(PICK.EQ.'3') THEN
                 INTERVL=3
               ELSE
                 WRITE (*,*) 'OPTION NOT RECOGNIZED'
                 GO TO 4
```

```
            END IF
         END IF
      IEND= ISTART+16*INTERVL
        IF(ISTART.GT.60) ISTART=60
        IF(IEND.GT.60) IEND=60
        IIEND= ISTART
 8      IIEND= IIEND + INTERVL
        IF(IIEND.LT.60.AND.IIEND.LT.IEND) GO TO 8
        IF(IIEND.GT.IEND) THEN
            IEND= IIEND - INTERVL
          ELSE
            IEND= IIEND
         END IF
        WRITE (*,9) ' LOG Q =', XLGQMIN, XLGQMAX
 9    FORMAT (A8, 6X, 1F6.2, 55X, 1F6.2)
 10   FORMAT (1I3, 1I5, 2I3, 5X, A50)
 12   FORMAT (1I3, 1I5, 2I3, 5X, 60A1)
      DO 80 IT= ISTART, IEND, INTERVL
         IF (IT.GT.IMAX.OR.IT.LT.IMIN) THEN
              WRITE (*,10) IT, IYR(IT), IMO(IT), IDA(IT),
     $             'DAY IS OUTSIDE OF PERIOD SELECTED'
           ELSEIF(QLOG(IT).EQ.-99.9) THEN
              WRITE (*,10) IT, IYR(IT), IMO(IT), IDA(IT),
     $             'DAY IS OUTSIDE OF RECESSION PERIOD'
           ELSEIF (QLOG(IT).EQ.-88.8) THEN
              WRITE (*,10) IT, IYR(IT), IMO(IT), IDA(IT),
     $             'STREAMFLOW = ZERO '
           ELSEIF(QLOG(IT).GT.XLGQMAX.OR.QLOG(IT).LT.XLGQMIN) THEN
              WRITE (*,10) IT, IYR(IT), IMO(IT), IDA(IT),
     $             'FLOW IS OUTSIDE OF RANGE'
           ELSE
              DIFF= QLOG(IT) - XLGQMIN
              NUMBLNK= INT(DIFF*60/(XLGQMAX-XLGQMIN))
              WRITE (*,12) IT, IYR(IT), IMO(IT), IDA(IT),
     $                 (BLANK(J), J=1,NUMBLNK), '*'
          END IF
 80     CONTINUE
      RETURN
      END


C -----THIS SUBROUTINE PERFORMS LEAST-SQUARES REGRESSION TO FIND BEST-FIT
---
C ---------------- EQUATION OF LINEAR BASIS ( Y = A*X + B ) ---------------
--
C
      SUBROUTINE REGRES2(X,Y,NUM,COEFFA,COEFFB,R2)
      REAL A(2,4)
      REAL X(50), Y(50)
      DO 20 I=1,2
      DO 20 J=1,4
 20   A(I,J)= 0.0
      RT1= 0.0
      RT2= 0.0
      RT3= 0.0
```

```
      RT4= 0.0
      RT5= 0.0
      DO 40 I=1,NUM
      A(1,1)= A(1,1) + X(I)**2
      A(1,2)= A(1,2) + X(I)
      A(2,1)= A(2,1) + X(I)
      RT1= RT1 + X(I)*Y(I)
      RT2= RT2 + Y(I)
      RT3= RT3 + X(I)
   40 RT4= RT4 + Y(I)**2
      A(2,2)= REAL(NUM)
      N=2
           write (*,*) 'NUMBER OF DATA PAIRS: ', NUM
           write (*,*) 'SYSTEM OF EQUATIONS:'
           write (*,*) ' Right-hand side: ', RT1, RT2
           write (*,*) ' Left-hand side before inverting: '
           write (*,*) A(1,1), A(1,2), A(1,3), A(1,4)
           write (*,*) A(2,1), A(2,2), A(2,3), A(2,4)
      CALL INVERS(A,N)
           write (*,*) ' Left-hand side after inverting: '
           write (*,*) A(1,1), A(1,2), A(1,3), A(1,4)
           write (*,*) A(2,1), A(2,2), A(2,3), A(2,4)
      COEFFA= A(1,1)*RT1 + A(1,2)*RT2
      COEFFB= A(2,1)*RT1 + A(2,2)*RT2
          R2= COEFFA*(RT1-RT3*RT2/NUM)/(RT4-((RT2)**2)/NUM)
           write (*,*) '  '
      RETURN
      END
C
C ------- THIS SUBROUTINE CHANGES AN N*N MATRIX [A] TO ITS INVERSE -------
C ----------- (Note: The matrix is actually N*(2N) internally) -----------
C
      SUBROUTINE INVERS(A,N)
      REAL A(2,4)
      DO 10 I=1,N
      DO 10 J=N+1,2*N
   10 A(I,J)= 0.0
      DO 20 I= 1,N
   20 A(I,N+I) = 1.0
      DO 90 K=1,N
          DO 40 I=1,N
              TEMP=A(I,K)
                  DO 30 J=1,2*N
                  A(I,J)=A(I,J)/TEMP
   30             CONTINUE
   40     CONTINUE
          DO 80 I=1,N
              IF (I.NE.K) THEN
                  DO 70 J=1,2*N
                     A(I,J)=A(I,J)-A(K,J)
   70             CONTINUE
              END IF
   80 CONTINUE
   90 CONTINUE
      DO 150 I=1,N
           AP=A(I,I)
               DO 130 J=1,2*N
```

```
                    A(I,J)=A(I,J)/AP
  130           CONTINUE
  150 CONTINUE
      DO 180 I=1,N
      DO 180 J=1,N
  180 A(I,J)=A(I,J+N)
      RETURN
      END



      SUBROUTINE ORDER(M,LIST1,LIST2,LIST3)
C   INPUT IS 3 LISTS OF NUMBERS. ALL LISTS (LIST1,LIST2,AND LIST3) HAVE
C   M NUMBERS. OUTPUT IS SAME, IN ASCENDING ORDER, SORTED BY VALUES
C   IN LIST1. NOTE: LIST3 IS MADE UP OF INTEGERS.
      INTEGER I,M,NUM,PASSES
      REAL A
      REAL LIST1(50)
      REAL LIST2(50)
      INTEGER LIST3(50)
      CHARACTER SWAPED*3
      SWAPED= 'YES'
      NUM= M
      PASSES= 0
   10 CONTINUE
         SWAPED= 'NO'
         PASSES= PASSES + 1
         I=1
   20    CONTINUE
            IF(LIST1(I).LE.LIST1(I+1)) THEN
               ELSE
                 A= LIST1(I+1)
                 LIST1(I+1) = LIST1(I)
                 LIST1(I)= A
                 B= LIST2(I+1)
                 LIST2(I+1)= LIST2(I)
                 LIST2(I)= B
                 C= LIST3(I+1)
                 LIST3(I+1)= LIST3(I)
                 LIST3(I)= C
                 SWAPED= 'YES'
            ENDIF
            I=I+1
         IF (I.LE.(NUM-PASSES)) THEN
           GOTO 20
           END IF
      IF (SWAPED.EQ.'YES') THEN
        GOTO 10
        END IF
      RETURN
      END
```

```
PROGRAM FORMAT;

USES
 CRT;

VAR

 BS,AS:STRING[13];
 B1:STRING[1];
 B2:STRING[2];
 B3:STRING[3];
 B4:STRING[4];
 B5:STRING[5];
 CH:CHAR;
 COUNTER,IFINISH,K,J,I,DAY:INTEGER;
 INFILE,OUTFILE:TEXT;
 F:ARRAY[1..31,1..12] OF REAL;
 YEAR:ARRAY[1..300] OF INTEGER;
 MAXF,MINF,MAX,MIN:REAL;
 NAME,OUTF:STRING;

PROCEDURE PAUSE1;
BEGIN
 CH:=READKEY;
END;


{                    program starts here                              }

{         ----------------------------------------------------        }


BEGIN

NAME:=     'A:\INPUT.DAT'      ;             { change name of input file }
OUTF:=     'A:\OUTPUT.DAT'     ;             { change name of output file }


{         ----------------------------------------------------        }


ASSIGN(INFILE,NAME);
RESET(INFILE);
ASSIGN(OUTFILE,OUTF);
REWRITE(OUTFILE);

CLRSCR;


COUNTER:=0;
AS:='          123';
B3:='123';
B5:='12345';
IFINISH:=1;
MAXF:=-10000;
MINF:=+10000;
```

```
REPEAT
 BEGIN

  REPEAT
   BEGIN
    READLN(INFILE);
    READ(INFILE,AS);
    IF(AS='ENDENDENDENDE') THEN
     BEGIN
      IFINISH:=0;
      AS:='         WTR';
     END;
   END;
  UNTIL(AS='         WTR');

  IF(IFINISH>0.5) THEN
   BEGIN
    READ(INFILE,B3);
    COUNTER:=COUNTER+1;
    READ(INFILE,YEAR[COUNTER]);
    WRITELN(' WORKING ON YEAR ',YEAR[COUNTER]:10);
    REPEAT
     READ(INFILE,B1);
    UNTIL(B1='X');
    READ(INFILE,MAX);
    REPEAT
     READ(INFILE,B1);
    UNTIL(B1='N');
    READ(INFILE,MIN);

   END;

   IF(MAXF<MAX)AND(MAX>-9995) THEN
    MAXF:=MAX;
   IF(MINF>MIN)AND(MIN>-9995) THEN
    MINF:=MIN;

  END;
 UNTIL(IFINISH<0.5);

CLOSE(INFILE);


WRITELN(OUTFILE,'MAXIMUM ON RECORD:');
WRITELN(OUTFILE,MAXF:12:2);
WRITELN(OUTFILE,'MINIMUM ON RECORD:');
WRITELN(OUTFILE,MINF:12:2);

RESET(INFILE);

AS:='1234567890123';
IFINISH:=1;
COUNTER:=0;

REPEAT
 BEGIN
```

```
  REPEAT
   BEGIN
    READLN(INFILE,AS);
    IF(AS='ENDENDENDENDE') THEN
     BEGIN
      IFINISH:=0;
      AS:='          DAY';
     END;
   END;
  UNTIL(AS='          DAY');

  IF(IFINISH>0.5) THEN
   BEGIN
    COUNTER:=COUNTER+1;
    WRITELN(OUTFILE,YEAR[COUNTER]:4,'        1         2         3
4         5         6        ',
    ' 7         8         9        10        11        12');
    FOR K:=1 TO 31 DO
     BEGIN
      READ(INFILE,DAY);
      FOR J:=1 TO 12 DO
       READ(INFILE,F[DAY,J]);
      WRITE(OUTFILE,DAY:4);
      FOR J:=1 TO 12 DO
       WRITE(OUTFILE,F[DAY,J]:10:1);
      WRITELN(OUTFILE);
     END;
   END;


  END;
 UNTIL(IFINISH<0.5);

 WRITELN(OUTFILE,9999);

CLOSE(INFILE);
CLOSE(OUTFILE);

END.
```

PROGRAM REGRESS

WRITTEN BY AHMAD A. RAAII

This is a typical SAS program which performs a comprehensive, linear multiple regression analysis.

```
options ls=90;

data old;
infile '~/regression/reg.dat2orig';
input id $ order x1-x6 y1-y8;
ly1=log(y1);
lx1=log(x1);
lx2=log(x2);
lx3=log(x3);
lx6=log(x6);

if order=77 then delete;

proc plot;
plot y1 * (x1 x2 x3 x6);
plot y1 * (lx1 lx2 lx3 lx6);
plot ly1*lx1;
plot ly1*lx2;
plot ly1*lx3;
plot ly1*lx6;

proc corr;
var y1 x1 x2 x3 x6;
run;

proc corr;
var y1 lx1 lx2 lx3 lx6;
run;

proc corr;
var ly1 lx1 lx2 lx3 lx6;
run;

proc RSQUARE CP;
model y1 = x1 x2 x3 x6;

proc RSQUARE CP;
model y1 = lx1 lx2 lx3 lx6;

proc RSQUARE CP;
model ly1 = lx1 lx2 lx3 lx6;

proc reg data=old;
model ly1=lx1 lx2 lx3 lx6/selection=forward
slentry=0.05 p r influence clm cli;
plot r.*p.;
plot r.*lx1;
plot r.*lx2;
plot r.*lx3;
plot r.*lx6;
plot ly1*p.;
```

```
output out=one predicted=yhat residual=resid;

proc reg data=old;
model ly1=lx1 lx2 lx3 lx6/selection=backward
slstay=.1 p r influence clm cli;
plot r.*p.;
plot r.*lx1;
plot r.*lx2;
plot r.*lx3;
plot r.*lx6;
plot ly1*p.;
output out=two predicted=yhat residual=resid;

proc reg data=old;
model ly1=lx1 lx2 lx3 lx6/selection=stepwise
sle=0.05 sls=.1 r p influence clm cli vif;
plot r.*p.;
plot r.*lx1;
plot r.*lx2;
plot r.*lx3;
plot r.*lx6;
plot ly1*p.;
output out=three predicted=yhat residual=resid;

proc rank data=one normal= BLOM out=one1;
var resid;
ranks Q;
proc plot data=one1;
plot resid*Q;
run;

proc rank data=two normal=BLOM out=two1;
var resid;
ranks Q;
proc plot data=two1;
plot resid*Q;
run;

proc rank data=three normal=BLOM out=three1;
var resid;
ranks Q;
proc plot data=three1;
plot resid*Q;
run;
```