TOPOGRAPHIC STATISTICS AND SEDIMENT YIELD ANALYSIS

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CHAPTER I

INTRODUCTION

Statement of the Problem

The natural processes of erosion, detachment, transport, and deposition of sediments, have occurred throughout geologic times and have shaped the landscape of the world in which we live. The word erosion is of Latin origin being derived from the verb erodere - to eat away, to excavate. It is defined as a process where soil particles are detached from the soil mass and transported off site. The main agents of erosion are water, wind and ice, all of which entrain particles and transport them.

Erosion often causes serious damage to agricultural land in many ways, the soil fertility and plant nutrients are removed; the soil texture is changed; the structure is degraded; the soil depth is decreased; the crop productivity is reduced. Soil erosion and deposition also affect stream and river systems by reducing the storage capacity of reservoirs and lakes and clogging navigable waterways. Environmental pollution is caused from excessive silting and damages water resources with sediment-bound chemicals transported by surface runoff from farm land. In terms of total mass eroded soil is the largest pollutant of surface waters in the United States (Meyer, 1972). Erosion related pollutants have been estimated to impose net damages of $3.2 to $13 billion per year in the United States (Clark et al., 1985).

Water erosion causes the most damage. Estimates of soil erosion in the United States range from 1.7 to 3 billion tons lost each year with about 60 percent estimated to be from agricultural land (Lake and Shady, 1993). Sediment affects water quality and its suitability for domestic consumption and industrial use. Soil eroded from upland areas is the source of most sediments transported by rivers to reservoirs. Off-site damages caused by sediment in the United States are estimated at $10 billion annually (Lake and Shady, 1993). Considering these impacts, accelerated soil erosion is a serious global problem and is widely recognized.

The extent of erosion, specific degradation, and sediment yield from watersheds relates to a complex interaction between topography, geology, climate, soil, vegetation, land use, and man-made developments. Erosion has been observed to occur in various forms under the influence of these factors. Erosion is characterized by the detachment and entrainment of solid particles from the land surface or from the bed and banks of streams.

The soil erosion process begins by water falling as raindrops and flowing on the soil surface. There are three steps in this process, (1) detachment, caused by raindrop impact and shearing of flowing water; (2) transport, resulting from energy and steam power of flowing water, and (3) deposition, which occurs when transport capacity is less than sediment load. Soil detachment and transport by surface runoff are dependent on the hydraulic characteristics of surface flow. When rainfall exceeds the soil's infiltration rate, overland flow begins and detached soil particles may be carried away, the detached soil is transported from rill to ephemeral gullies, gullies, and streams. The efficiency of sediment transport from upland areas is dependent on the development and extent of a rill network. Rill network development is related to the surface micro-relief and soil properties. Therefore, the quantity of soil erosion and sediment are clearly dependent on the microtopography of the eroded surface.

For many years, the drainage networks of river basins have been studied. Various attempts have been made to determine the underlying concepts incorporated in the laws of drainage composition (Morisawa, 1985; Wilson and Storm, 1993). A topologically random network of river basins has also been proposed by Shreve (1966, 1967, 1969). Ogunlela et al. (1989) and Wilson and Storm (1992) found that the fractal properties of rill networks are similar to those of river basins. Very few studies have examined the relationships of topographic parameters and sediment yield in small watersheds. Recently erosion and sediment yield modeling has attempted to include these effects (Storm, 1991). Therefore, further analysis of the relationships between topographic features and sediment yield is necessary.

Objectives

The objectives of this research are:

1. Define topographic parameters for random rill networks using detailed digital elevation data.

2. Identify relationships between sediment yield and topographic parameters.

General Procedure

The goal of this research is to correlate sediment yield to quantitative topographic attributes using laboratory and plot scale data. Determination of these attributes will be performed using digital elevation data and Digital Terrain Modeling. In order to get the geomorphologic quantitative information, a Digital Terrain Model (DTM) will be used to derive some information about the morphology of the plot surfaces.

In this study, the first step in the analysis of drainage basins was to define rill networks using a DTM with erosion plot elevation data. The next step was calculating topographic parameters using the DTM results. The topographic parameters used in this study to characterize drainage basins were link lengths including interior and exterior link lengths, link drainage area, random roughness, and rill density. Finally, the relationship between sediment yield and topographic parameters were analyzed, using graphical, statistical, and multivariate techniques.

CHAPTER II

LITERATURE REVIEW

Introduction

The quantitative topographic factors of drainage basins are very important in erosion processes and sediment yield. Since Horton (1945) introduced the idea of ordering channel networks, and Strahler (1952) simplified the Horton ordering scheme in a way that makes it purely topological (Melton, 1959), many geomorphologists and hydrologists have studied the quantitative analysis of drainage networks. Between 1945 and 1966, the study of channel networks developed rapidly. The accomplishments of this period were summarized by Abrahams (1984): (1) the beginnings of a formal theory based on the concept of the drainage basin as an open system (Strahler, 1950); (2) the application of dimensional analysis (Strahler, 1958); and (3) the investigation of process-form relationships (Melton, 1958).

Shreve (1966) introduced the concept of topologically random channel networks by assuming that all distinct networks with a given number of sources are equally likely. Using this concept, Shreve (1967) deduced that a particular channel network could be assumed as a subnetwork of some infinitely large network. Many attempts have been made to improve on the concept of a random topologically representation of channel networks (Dacy and Krumbein, 1976; Abrahams, 1984; Van Pelt et al., 1989). These efforts were aimed at improving Shreve's topological model of equal probability of branching.

The drainage network of basins have been studied for many years. Much of the quantitative work has been in the development of laws of drainage composition (Horton, 1945; Morisawa, 1985), such as the law of stream number, the law of stream length, the law of drainage area, the law of stream gradient and the law of stream falls. These laws indicate that at least some limited dimensionless similarities exist among drainage basins of different size, lithology, climate and other characteristics.

Recently, Ogunlela et al. (1989) analyzed the drainage network of rills using topologically random channel networks. Using an indoor erosion table, they collected approximately one million coordinate points for each erosion run to identify flow paths. Drainage networks were defined by using an algorithm developed by Couger et al. (1989, 1992). The algorithm assumed that water will flow to the surrounding point of lowest elevation and all depressions are assumed to contribute flow. Flow paths were linked and summarized using a rill ordering system similar to Strahler's system. Drainage composition laws and fractal dimensions were used to quantify network characteristics. They found that the average bifurcation ratio, average length ratio and average drainage area ratio were within those values observed from river basins. Their results suggest that concepts from major river systems might prove useful in predicting the drainage network of upland flow and erosion.

Wilson and Storm (1992) examined the fractal characteristics of small-scale drainage networks using the data set of Ogunlela et al. (1989). They found that the drainage networks have fractal characteristics and the small-scale fractal dimensions are similar to those observed in major river networks. Based on Horton's bifurcation and length ratios, using Richardson's method, and a derived relationship, their results support that the small erosion plot data expressed similar characteristics to those of river networks. Other similarities between rills and rivers have also been reported (Lane and Foster, 1980).

More recent advances in hydrology, soil science, erosion mechanics, and computer technology have provided the technology to extend erosion and sediment yield modeling. Examples include the WEPP model (Foster et al., 1987), the DYRT dynamic erosion model (Storm, 1990) and the PROIL model (Lewis et al., 1994a, 1994b).

Topological Properties

1. Link Characteristics

(1) Distribution

Early researchers have studied link length distributions for river systems. Schumm (1956) and Maxwell (1960) have investigated the distribution of first-order stream lengths for a few basins and have concluded that their data could be represented by a log-normal probability density function. Their study did not report interior link lengths. M. A. Melton (Shreve,1969) had obtained the same conclusion concerning both exterior and interior link lengths based on various basins in the western United States. Shreve (1969) also fitted a log-normal probability density function to interior link length from eastern Kentucky data but concluded that the fit was not very good.

Smart (1968) and Abrahams (1972) fitted an exponential probability density function to interior link length data with reasonable success. Another distribution that has been proposed for link lengths is the gamma probability density function. Shreve (1969), and Smart (1978) all fitted the gamma probability density function to various samples of exterior and interior lengths from eastern Kentucky. Abrahams and Miller (1982) suggested that the mixed gamma function fit link length distributions. They used link length data from 12 different areas representing a broad range of environmental and geomorphic conditions to evaluate the log-normal, gamma, and mixed gamma functions. They found that the mixed gamma satisfactorily fitted 84% of the 70 link length distributions examined, compared with 67% fitted by the log-normal and 59% fitted by the gamma.

Wilson (1993) studied the link lengths distribution for small-scale surface drainage networks. He used 426 links obtained from Oklahoma State University erosion plot data. He found the distribution of link lengths was better represented by a log-normal probability density function, but also found that the log-pearson type III and the extreme value type I distributions fit well.

(2) Exterior and Interior link lengths

Shreve (1967) first recognized that exterior and interior links have different length properties in river basins. Schumm (1956) analyzed channel networks in eastern Kentucky and Perth Amboy, Chileno Canyon, and Mill Dam Run basins. He found that L_e/L_i ranged from 1.15 to 1.96, where L_e is the mean of exterior link length and L_i is the mean of interior link length (The definition of exterior link length and interior link length see Chapter IV). Smart (1972) also obtained a mean value of $L_e/L_i > 1$ in the western and southern United States, but found $L_e/L_i < 1$ in the Applachian Plateau. An excellent review of this study is given by Abrahams (1984).

Link lengths and area properties for field-sized areas have not yet been measured. Wilson and Storm (1993) studied surface drainage networks from erosion plot research. They compared length and area characteristics for 151 links to those obtained at two and eight percent slopes. Link lengths at two-percent slope were similar to those at eight percent. The mean link area and the correlation of area and order for the two-percent networks were different than those observed for the eight-percent slope.

(3) Link Drainage Area

Although Horton (1945) did not give a law about drainage basin area, many researchers have studied the relationship of link and link drainage area. Hack (1957) demonstrated the applicability of the power function for length and area for streams in seven areas of Virginia and Maryland. He determined the equation to be:

$$L = 1.4A^{0.6} \qquad (2.1)$$

where L is stream length in miles, and A is area in square miles. The almost same result was obtained by Gray (1961) for basins from the Midwest and the North and Middle Atlantic States, given as:

$$L = 1.4\ A^{0.568} \tag{2.2}$$

Shreve (1967) gives the relationship of link and link drainage area for river systems as:

$$A = wL = kL^2 \tag{2.3}$$

where A is the link drainage area, L is the link length, w is the effective width of link drainage area, and k is a dimensionless constant that approximately equals to one for river systems.

Wilson (1993) analyzed the relationship of link drainage area and link length for rill networks using OSU erosion table data. He found the equations for the interior and exterior link lengths to be:

$$a_{*i} = 6.82L_*^{1.23} \tag{2.4}$$

$$a_{*e} = 9.23L_* + 31.8 \tag{2.5}$$

where a_{*i} is a dimensionless area for interior link lengths, a_{*e} is a dimensionless area for exterior link lengths, L_* is a dimensionless link length and can be defined as:

$$L_* = \frac{L}{L_c} \tag{2.6}$$

where L is the link length, L_c is a characteristic length scale which can be estimated as:

$$L_c = [\Delta x^2 + \Delta y^2]^{0.5} \tag{2.7}$$

where Δx and Δy are length of the grid sides.

2. Rill Density

Rill density is typically defined as the number of rills per unit width or the number of rills that exist at a given cross-section (Haan et al., 1994), but also can be defined as the length of rills per unit area (Storm, 1991). Rill density is a very important parameter for evaluation of sediment source and sediment yield. A detailed review is given by Storm (1991). Ellison and Ellison (1947) observed that for highly erodible soils many small rills were very close together and merged into gullies. These rills and gullies almost had the same size from the top to the bottom of the slope, therefore, indicating transport limiting flow where raindrop detachment and interrill transport were dominant. For relatively low erodibility soils, rill densities are lower and rills vary in width and depth from top to the bottom of the slope, thus indicating that rill incision and sidewall sloughing are significant sources of detached material. In addition, Meyer and Monke (1965) observed that short slope lengths have higher rill densities relative to longer slope lengths.

Meyer et al. (1975) studied the influence of rill density to determine the source of eroded soil in agricultural test plots. They used two different rill densities. The greater rill density was 3 to 5 rills per 12 ft (3.6 m) of width, the lower rill density was one rill per 12 ft (3.6 m) of width. The sediment yield for the greater rill density was 40% higher than that plot with the lower rill density. Meyer et al. (1975) found that the differences in erodibility between two apparently identical test plots could be explained in terms of the differences in rill density. Rill density is governed by factors like slope steepness and length, runoff rate, soil texture, and others. They concluded that rill erosion was the largest contributor to the total sediment yield, and the higher rill density was usually associated with a high sediment yield.

Li et al. (1980) developed a rill density model for laminar and turbulent flows, expressed on a unit width basis. Their model assumed that all rills were the same size for a specified distance downslope. Because of the many empirical constants required by the model, its use is limited. Foster and Lane (1981) criticized this model, and concluded that the Li et al. model choice of a representative particle size in the Shield's diagram caused critical shear stress for rill erosion to be underestimated.

Hirschi and Barfield (1988) performed a sensitivity analysis on the number of rills across a plot using the KYERMO model. They found that sediment yield increased with increasing rill number until a maximum was reached, after which sediment yield decreased. They proposed that the decline in sediment yield at higher numbers of rills was due to lower flow rates in each rill as the surface runoff was distributed over more rills. They also showed that the effects of rill number on sediment yield is governed by the form of the rill detachment and boundary shear stress equations.

The WEPP Erosion model (Nearing et al., 1989) assumes that rill density is analogous to rill spacing, and defines a rill network as a series of parallel rills. Lewis et al. (1990, 1994a, 1994b) developed PRORIL, a model similar to the WEPP model, but with the capability of using a random distribution of rill numbers and flow in rills. Based on the sensitivity analysis results, PRORIL showed that ignoring the stochasticity of rill networks can make a significant difference in predicted erosion, especially when a nonerodible layer is encountered.

3. Random Roughness

Soils roughness is often referred to as soil micro-relief formed as a result of tillage. It can have a significant impact on the rate and amount of erosion. Surface roughness induced by tillage has two distinct configurations, random and nonrandom (Sadeghian and Mitchell, 1988). Random roughness is that part of the surface irregularity that is made up of clods or a mixture of clods and particles. Non-random roughness is that part of the surface configuration caused by tillage tools. Zobeck et al. (1986) and Moore et al. (1979) reviewed the development process, and Kuipers was the first to quantify soil roughness in 1957. Luttrell (1963) defined a roughness coefficient, R, as the sum of absolute differences between slopes of lines which connect the end points of successive probe tips. In the same time, Burwell et al. (1969) used the term "random roughness" to describe the variations in elevations that occur at random on the soil surface. Allmaras et al. (1966) and Burwell et al. (1969) have used surface roughness as a means of describing depression storage on the soil surface.

Random roughness of the soil surface has been studied by many other investigators using a variety of methods and materials. Allmaras et al. (1966) described the method a calculating random roughness, RR, wherein each height measurement was expressed as a natural logarithm. Several researchers have suggested alternative measures of soil RR (Currence and Lovely, 1971; Moore and Larson, 1979). Podmore and Huggins (1980) characterized seven surfaces using spectral analysis, amplitude-separation techniques and area-wetted perimeter methods. These methods provided additional means of describing the soil surface. Mossaad and Wu (1984) developed an erosion model that computes the rill and inter-rill flow over a surface with random roughness, which used a method of zero-crossing analysis to generate a random surface model. Zobeck and Onstad (1986) used a simple model to predict the changes in random roughness with changes in tillage and rainfall amount. They found RR varied from 5.0 cm for a large offset disk operation to 0.7 cm for no-till systems, and decreased exponentially with increasing rainfall. Storm (1991) developed a random surface generation model using the turning bands method (TBM).

4. Stream Orders

Horton (1945) was the first to use the methods of classifying stream channels by order. Later, Strahler (1952) slightly modified the Horton ordering scheme. Melton

(1959) explains the mathematical concepts involved. Generally, Strahler's method is preferred because of its simplicity and freedom from subjective decisions (Smart, 1972). The Strahler ordering procedure has three steps: (1) channels that originate at a source are defined to be first-order steams; (2) when two streams of order u join, a stream of order (u+1) is created; (3) when two streams of different order join, the channel segment immediately downstream has the higher of the orders.

The order of a channel network or drainage basin is its highest order stream. Two different drainage networks can be compared with respect to corresponding points in their geometry through use of order number, because order number is dimensionless.

5. Bifurcation

The individual ratios of successive stream numbers are called bifurcation ratios (Smart, 1972), given as:

$$R_b = \frac{N_u}{N_{u+1}} \tag{2.8}$$

where N_u is the number of segments of a given order u, and N_{u+1} is the number of segments of higher order (u+1). Because of variations in watershed geometry, the bifurcation ratio will not be precisely the same from one order to the next. Several other bifurcation ratios have been employed by various researchers (Maxwell, 1960). However, the bifurcation ratios characteristically range between 3.0 and 5.0 for watersheds in which the geologic structures do not distort the drainage pattern (Strahler, 1964). A theoretical minimum value of 2.0 is rarely approached under natural conditions. Bifurcation is relatively constant throughout the series with small variations from region to region. Also, Abrahams (1984) found that the bifurcation ratio and length ratio range from 3 to 5 and 1.5 to 3.5 at a basin scale, respectively. Ogunlela et al. (1989) studied rill networks based on a large scale indoor laboratory from two surface roughness conditions and two rainfall intensities. They concluded that for the conditions studied, the rill networks may be characterized using the bifurcation ratio, length ratio, and an area ratio deemed similarly to the length ratio.

6. Fractal Parameter

Recently, fractal geometry has been shown to be a useful method to describe processes that exhibit similar features over a range of scales. Self-similarity is an important concept in fractal geometry. It specifies that patterns repeat themselves at all scales of observation, and as such there is no unique or dominating scale. Mandelbrot (1983) defines similarity dimension that is equally to the fractal dimension. For example, consider a unit square where the length of each side is divided into b equal line segments. The square is then divided into a grid of $N = b^2$ rectangular parts, and each of these rectangular parts can be determined from the whole for a given $b = N^{1/2}$. A general definition of similarity of ratio is:

$$r = \frac{1}{N^{1/D}} \tag{2.9}$$

where r is the similarity of ratio, N is the number of parts and D is the similarity dimension, usually synonymous with the fractal dimension.

Tarboton et al. (1988) suggested a fractal dimension for networks of approximately two based on the fractal characteristics of the total drainage network. Hjelmfelt (1988) and Rosso et al. (1991) found the fractal dimension range between 1.0 and 1.3, after examining the fractal characteristics of the mainstream length. A fractal analysis is presented for the erosion plot networks gathered by Ogunlela et al. (1989). Wilson and Storm (1992) studied the fractal analysis of these rill networks, and found that the small-scale fractal dimensions obtained from erosion plot data are generally in good agreement with reported values for large-scale river system. The fractal dimensions were approximately two.

7. Stream Frequency

The stream frequency or channel frequency, F, is the number of stream segments per unit area (Horton, 1945), given by:

$$F = \frac{\sum_{i=1}^{k} N_u}{A_k} \tag{2.10}$$

where N_u is the number of segments of different orders within the given basin of order k, and A_k is the area of that basin in square miles. Drainage density (D) is defined as the cumulative length of all streams in the basin divided by the total drainage area:

$$D = \frac{\sum_{i=1}^{n} L_i}{A_d} \tag{2.11}$$

where L_i is the length of stream i, n is the total number of streams in the basin, and A_d is the total drainage area.

Melton (1958) studied the relationships between drainage density and frequency, and derived the dimensionally correct equation:

$$F = 0.694D^2 \tag{2.12}$$

where F / D^2 is the dimensionless number that tends to approach the constant value 0.694. It shows that the relationship of density and frequency tends to be a constant in nature. Kenney (1982) found that although this relationship is useful, it cannot be employed for prediction with anything like the accuracy suggested by its associated correlation coefficient.

8. Relief Ratio

Relief is the elevation difference between reference points defined in a watershed, i.e. maximum basin relief is the elevation difference between basin mouth and the highest point on the basin perimeter. Relief ratio, R_h, is defined as the basin relief H divided by the horizontal distance. Schumm (1956) measured relief ratio R_h as the ratio of maximum basin relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line. The relief ratio measures the overall steepness of a drainage basin and is an indicator of the intensity of erosion processes operating on slopes of the basin. He also found that sediment loss per unit area is closely correlated with relief ratio based on the possibility of a close correlation between relief ratio and hydrologic characteristics. Melton (1958) used relative relief, R_{hp}, expressed in percent, given by:

$$R_{hp} = \frac{100H}{5,280P} \tag{2.13}$$

where H is maximum basin relief in ft, and P is basin perimeter in miles.

Maner (1958) used a relief-length ratio with sediment-delivery ratio of watersheds in the Red Hill area of southern Kansas, Oklahoma, and Texas. He found that the ratio had a higher correlation with sediment delivery ratio. Maxwell (1960) used basin diameter as the horizontal distance for calculating of a relief ratio.

Digital Terrain Model

A Digital Terrain Model (DTM) is typically complex but useful model that uses digital data to represent the spatial distribution of terrain attributes. Generally, there are three major ways of structuring networks using elevation data. These are: 1) square-grid network, 2) triangular irregular network (TIN), and 3) contour-based network (Moore et al., 1991). Grid-based methods use a regularly spaced triangular, square, or rectangular mesh to represent the land surface. TINs usually form an irregular network of points representing peaks, ridges, and breaks in slope. Contour-based methods consist of digitized contour lines stored as vector data (Onstad and Brakensiek, 1968). Topographic attributes such as slope, specific catchment area, aspect, plan, and curvature can be derived from all three types of DTMs.

The techniques developed to extract topographic information from gridded digital elevation data are based on neighborhood operations (Jenson and Domingue, 1988; Van Deursen and Kwadijk, 1990; Quinn et al., 1991; and Smith and Brilly, 1992). Douglas (1986) gives an excellent description of techniques that have been developed to define ridges, channels, watershed, and other hydrologic features from DTMs. These techniques are generally based on neighborhood operations where calculations and decisions are made for a cell based on the values in the eight adjacent cells.

DTMs have created a profusion of topographic analysis procedures (Tarboton et al., 1991). These topographic procedures include determination of watershed boundaries, slope angle and aspect, elevation interpolation, cut and fill estimates, extraction of channel networks and flow accumulation estimates. To date, most digital terrain analysis methods are based on gridded data structures. The most common method of estimating topographic attributes from DTMs involves fitting a surface to the point elevation data using either linear or nonlinear interpolation (Moore et al., 1991). The use of gridded DTMs for topological analysis is well documented by Jenson (1988), Tarboton et al. (1991) and Smith and Brilly (1992).

Digital elevation data are available for many areas of the United States from the U.S. Geological Survey (USGS) in several formats (Dept. of Int. -USGS, 1987). The digital elevation data available for this study will be from laboratory and plot scale data.

Geographical Information Systems

Geographical Information Systems (GIS) are computerized resource data base systems that can collect, manage, analyze and display various spatial data including land use, topography, vegetation, cover, climate, soil and geology (Burrough, 1986). In addition, GIS combine hardware and software to perform numerous functions and operations on the various spatial data layers residing in the data base. There are two data types based on their methods for storing spatial data, i.e. vector and raster. GIS data are stored as a series of layers which are called coverages. In the area of environmental management, these data layers could include soils, land use, water bodies, topography, climate, crop yields, chemical use patterns, and others. Each type of data has its own layer and is stored separately. These layers can be overlaid for display or combined mathematically to create new coverages. Also, the advent of GISs allows for efficient use and analysis of large data sets. In this study, the GIS used is the Geographic Resources Analysis Support System (GRASS), developed by the U. S. Army Corps of Engineers (U. S. Army Corps of Engineers, 1991). GRASS allows for the import of DEM data and has routines providing for digital terrain analysis, and display of rill networks.

CHAPTER III

METHODOLOGY

Introduction

In order to obtain the necessary quantitative topographic information, a DTM was used to derive information about the morphology of the erosion plots surfaces. The DTMs extract topographic information from gridded digital elevation data. In this study, the University of Kentucky erosion plots and Oklahoma State University erosion table elevation data were used to generate random rill networks using a DTM model. Information obtained by the DTM was used to define flow paths, define the rill network, subdivide the network into a series of connecting branches, and define subwatersheds for each branch.

Statistical methods were used to analyze relationships and a Storm Water Management Program (SWAMP II) (Haan, 1994) was employed to estimate link length including interior and exterior length distributions.

Data Description

1. University of Kentucky Data

The erosion plots from the University of Kentucky were selected for this study. The elevation data were obtained by Storm (1991). These erosion plots are located at the University of Kentucky Coldstream Farm in Lexington, Kentucky. Six topsoil and six subsoil plots were used. Each plot measures 22.1 m (72.6 feet) in length and 4.57 m (15 feet) in width with an uniform slope of 8.7%.

i. Soil Type

As the erosion plot field was planted in alfalfa prior to construction, heavy equipment was used to scrape the upper 5 cm of a McAfee silt loam soil to remove the vegetation and the majority of roots. For the topsoil plots, when the upper 5 cm of soil was removed and the remaining upper 15 cm of soil was mixed, a silt clay loam surface layer was formed. For the subsoil plots, after scraping and leveling, a Maury silty clay loam was trucked to the site and compacted to a 30 cm depth.

ii. Soil Surface

Either a smooth or rough random micro-relief surface was created for this experiment. Therefore, before any tillage operation could be conducted, the soil was left to dry thoroughly. The subsoil plots were carefully roto-tilled up and down slope with a 6 foot roto-tiller. For the creation of a subsoil rough surface, after roto-tilling, garden rakes were used to reduce preferences. For the creation of a subsoil smooth surface, the plots were roto-tilled and then an 80 kg steel tube was dragged up slope with a winch attached to a small garden tractor.

For the topsoil plots, the smooth surface were created by roto-tilling up and down slope, and then hand raking cross slope with a garden rake to reduce preference. The rough topsoil surface was created by performing a one pass disking operation up and down slope.

iii. Experimental Procedures

The erosion plot experiment was conducted using a rainfall simulator with constant rainfall intensity (Moore et al., 1983). Rainfall simulators were position over each plot, and rainfall applied at an intensity of 78 mm/hr until surface runoff was initiated somewhere on the plot.

A second rainfall was applied for 1.5 or 2.0 hours for the topsoil and subsoil plots, respectively. During the rainfall event, rill networks were developed and the surface runoff was measured at the plot bottom using a tipping bucket apparatus (Storm, 1991). At the same time, rill development was photographed at 2 minute intervals, and hand drawings of the networks were made. The surface profile was measured every 0.61 m (2.0 ft) down slope and 1.27 cm (0.5 in) crosslope using a surface profile meter. Topographic data were obtained both before and after the rainfall event. Sediment data were also obtained from this experiment. Pseudo steady state erosion and sediment yield for each plot are given in Table 3.1.

A run ID was used to reference all field experiments. Each ID code includes the soil type, plot number, surface treatment and run number. A run ID consists

Table 3.1: Pseudo Steady State Erosion Rates and Sediment Yield for University of Kentucky Erosion Study (Storm, 1991)

ID Code	Pseudo Steady State Sediment Load (kg/min)	Sediment Yield (kg)
S1R2	4.4	351
S2R2	6.5	438
S3R2	5.0	331
S1S2	4.4	242
S2S2	7.4	409
S3S2	5.3	296
T1R2	5.2	429
T2R2	1.7	168
T3R2	2.1	227
T1V2	4.6	482
T2V2	3.7	395
T3V2	3.6	392

of 4 digits with the first digit indicating the soil type as either subsoil (S) or topsoil (T), the second digit showing the plot number, and the third digit indicating the surface treatment as either roto-tilled (R), or roto-tilled and dragged (S), or disked (V). The last digit defines the run number. Run 1 was the initial rainfall event initiating surface runoff, and run 2 was the 1.5 or 2.0 hour rainfall event.

2. Oklahoma State University Data

The Oklahoma State University erosion table is located at the western edge of the Oklahoma University campus in the Biosystems and Agricultural Engineering Department West Laboratories. The large scale experimental apparatus was designed by Wilson and Rice (1987), erosion table surface is 2.4 m (8 ft) wide and 9.8 m (32 ft) long with two slope segments. One is fixed and the other is adjustable. The fixed slope segment is at the outlet and the adjustable slope segment is at the inlet or upslope end of the table. The table can be adjusted from 0 to 8 percent slope. A schematic of this system is shown in Figure 3.1 (Rice, 1988). A Rainfall simulator is suspended above the erosion table to simulate the rainfall process.

Soil surface elevation measurements were obtained using an image processing system with structured lighting concepts developed by Rice et al. (1988). Using an imaging system, a line laser is projected onto the soil surface. Elevations are computed from the location of the reflected light received by a video camera. The imaging system is moved over the plot using computer driven stepper motors.

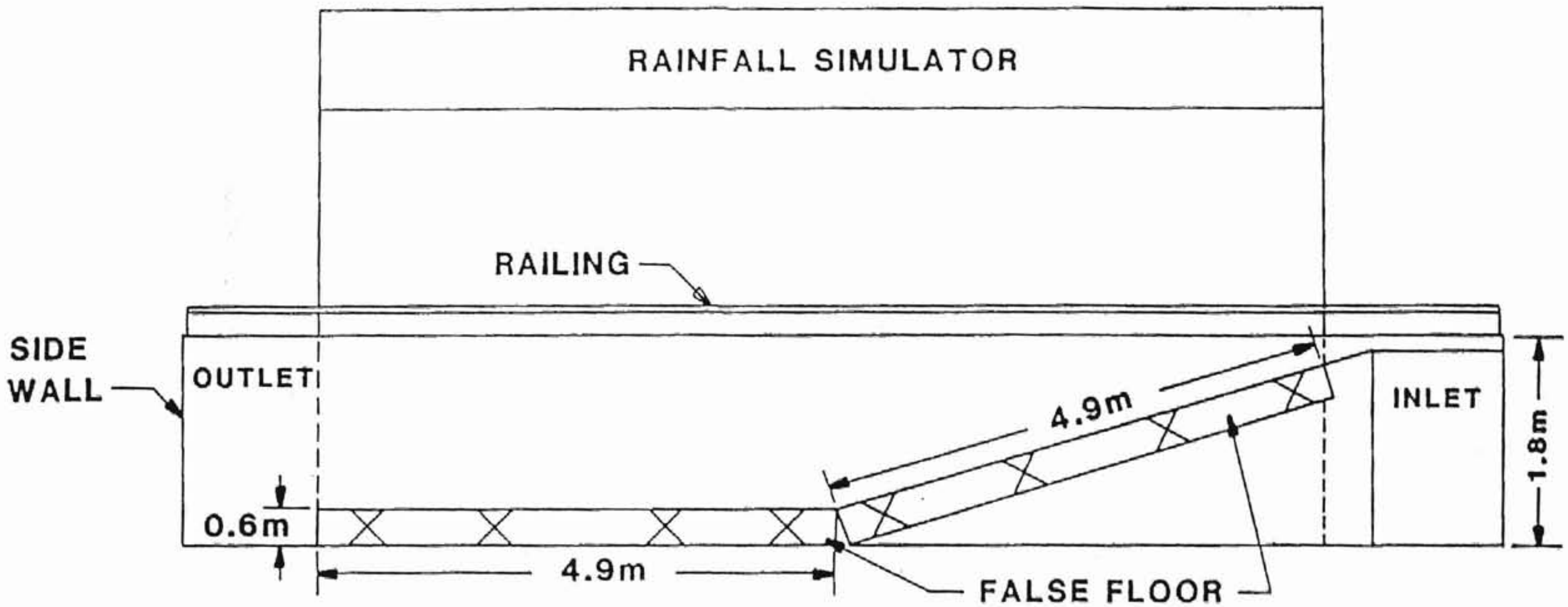


Figure 3.1: Side View of OSU Erosion Table (Rice, 1985).

A bare soil experiment was conducted using OSU erosion table by Storm and Wilson from 1992 to 1994. The loam soil has a dispersed soil matrix of 38% sand, 40% silt, and 22% clay. The experiment were conducted at two uniform slopes: two and four percent. The soil profile information was interpolated to a square grid, the dimensions of the grid was 10 cm in the downslope and upslope directions. Photographs were also taken, and rill networks were documented by hand drawings as rill networks developed during the rainfall event. The rainfall intensity and sediment yield data are given in Table 3.2.

Table 3.2: Rainfall and Sediment Yield for the Oklahoma State University Erosion Study

Run Code	Rainfall Duration (min)	Rainfall Intensity (in/hr)	Sediment Yield (kg)
AAA	150	3.1	0.15
ABA	150	2.7	0.12
ACA	125	2.4	0.11

All experiments were described using a run ID . A run ID contains 3 digits, the first digit indicates the slope of either 1% slope (A) or 2% slope (B), the second digit indicates run number, and the third digit identifies either after the rainfall event (A) or before the rainfall event (B) surface profile data.

Digital Terrain Model

The Digital Terrain Model (DTM) determines the information that represents the spatial distribution of terrain attributes by extracting topographic information from gridded digital elevation data (Jenson and Domingue, 1988). Storm (1991) developed a dynamic erosion model using a DTM to define flow networks and delineate rill networks with subwatersheds and branches. In addition, the DTM was developed as a component of SIMPLE (Sabbabh et al., 1995), which is a distributed parameter phosphorus transport model.

Using gridded digital elevation data, the DTM delineates and enumerates rill networks, outlines subwatershed boundaries, and estimates the surface area, average slope, and maximum flow travel length and slope. Also the DTM can estimate, for each grid, the slope, path length to the stream and path slope. The DTM identifies flow paths for a given data. Procedures for making these estimates were described in the following steps.

1. Model Procedure

Step one in the DTM modeling is to transform the original gridded elevation data into a depressionless Digital Elevation Model (DEM). With the original DTM an initial conditioning phase is performed, from which three data sets are generated and utilized for all subsequent steps. The three data sets are a DEM with depressions filled, a data set indicating the flow direction for each cell, and a flow accumulation data set in which each cell receives a value equal to the total number of cells that drain to the cell. Based upon this set of information, rill networks are defined and subdivided into branches by a special numbering scheme. With the application of another subroutine developed by Storm (1991), subwatershed cells are found for each branch and thus subwatershed boundaries are identified.

(1) Filling Topographic Depressions

A random surface micro-relief will typically include depressions which will impede flow routing. These depression may be real or an artifact of the sampling scheme. The depressions may be a single cell or made up of multiple cells (Figure 3.2a), and occur when all surrounding cells have higher elevation values. To eliminate the depressions, the first step is to fill all single-cell depressions. For each single-cell depression, the cell elevation is artificially increased to the level of its lowest neighboring cell. The purpose of doing this is to reduce the complexity of filling multi-cell depressions.

The following steps are performed to generate the depressionless DEM:

a. Fill single-cell depressions by artificially making each cell's elevation equal to its lowest elevation neighbor if that neighbor has a higher elevation than the cell.

b. When single-cell depressions have been filled, flow directions for each cell are defined. (Figure 3.2b and 3.2c).

c. Identify the cells that contain multi-cell depressions.

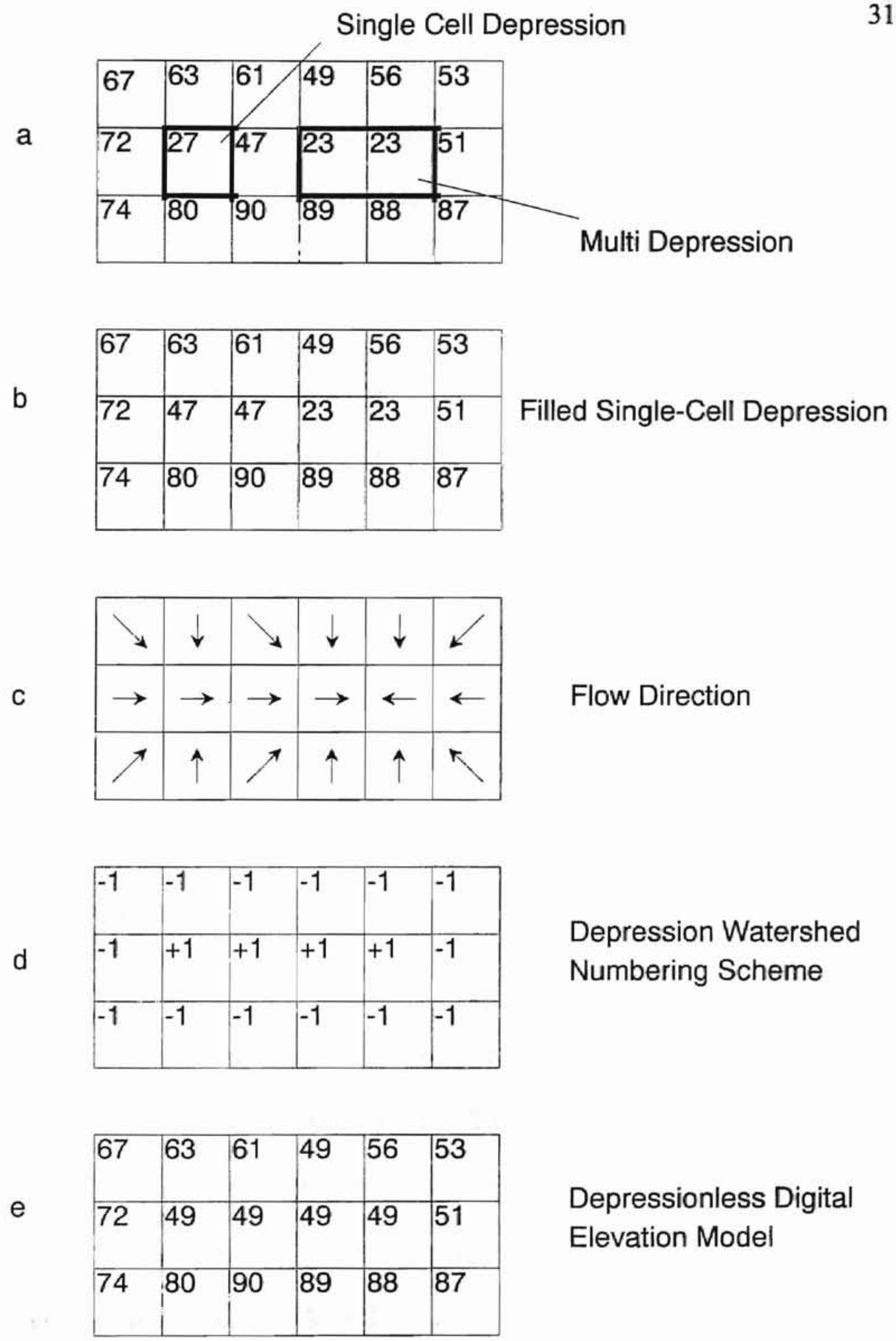


Figure 3.2: Generating Depressionless Digital Elevation (Storm, 1991)

d. Build a pour point elevation table between all neighboring multi-cell depression watersheds. A pour point is the lowest elevation cell linking two watersheds.

e. Mark pour points. Each multi-cell depression watershed is marked with a pour point, which must be the lowest elevation. If there are duplicate lowest pour points for a given watershed, select one arbitrarily.

f. Update elevation values for each multi-cell depression watershed cell. For each boundary cell, elevation of neighboring cells outside of the watershed are compared to select the lowest elevation pour point in the multi-cell depression watershed. Then elevation values for all the depression cells in the watershed are raised to that pour point elevation (Figure 3.2e).

(2) Flow Directions

A cell's flow direction is defined as the direction where water will flow out of the cell. The flow direction for a cell x is assigned on the basis of the steepest elevation slope away from the cell. As shown in Figure 3.3, there are eight possible flow directions. In the determination of flow directions, there are usually four possible conditions which are briefly described. Condition 1 occurs when all eight neighboring cells have elevations higher than the center cell, resulting in an undefined flow direction. Condition 2 occurs when the center cell's distance-weighted drop is higher for one neighboring cell. In this case, the flow direction is assigned towards that cell. The distance-weighted drop is calculated as the difference in elevation between the center cell and a neighboring cell, divided by the distance to the cell. The distance is 1 for a

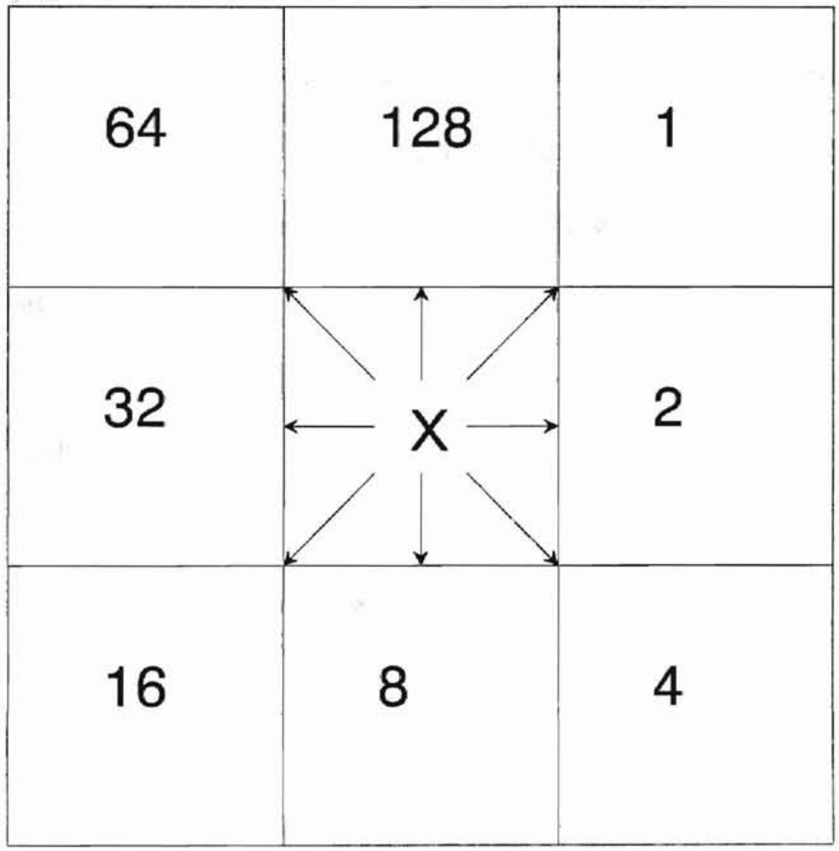


Figure 3.3: Example Showing Potential Flow Directions For Cell X

noncorner cell and $2^{0.5}$ for a corner cell. Most cells fall into the category of condition 2. Condition 3 occurs when two to seven cells have equal distance-weighted drops. Flow direction is assigned based on predefined rules of logic, i.e. a look up table. Condition 4 occurs when all the neighboring cells have the same distance-weighted drop. After cells with the first, second and third conditions are assigned, the fourth condition cells are resolved in an iterative process. In each iteration, a flow direction is assigned with one cell being tested at a time. If the flow direction does not result in flow returning back to the original cell, the flow direction is accepted. The iterative process continues in this way until all cells have defined flow directions.

(3) Flow Accumulation and Rill Network Delineation

This procedure creates the flow accumulation relying on the flow direction assigned to each cell. The flow accumulation for cell x represents the total number of cells that have upstream flow paths passing through it. It is illustrated in Figure 3.4 with a simple example. Cells located in lower elevations will have higher accumulation values.

Rill networks are identified and enumerated based on the flow accumulation values and on a defined threshold value. The threshold value is simply a flow accumulation threshold value. If the cells have the flow accumulation value equal to or greater than the threshold value, these cells are identified as network cells. As the threshold value increases, the density of the rill network decreases. For example, at a threshold value of 2, five cells are identified as network cells as illustrated in Figure 3.4d.

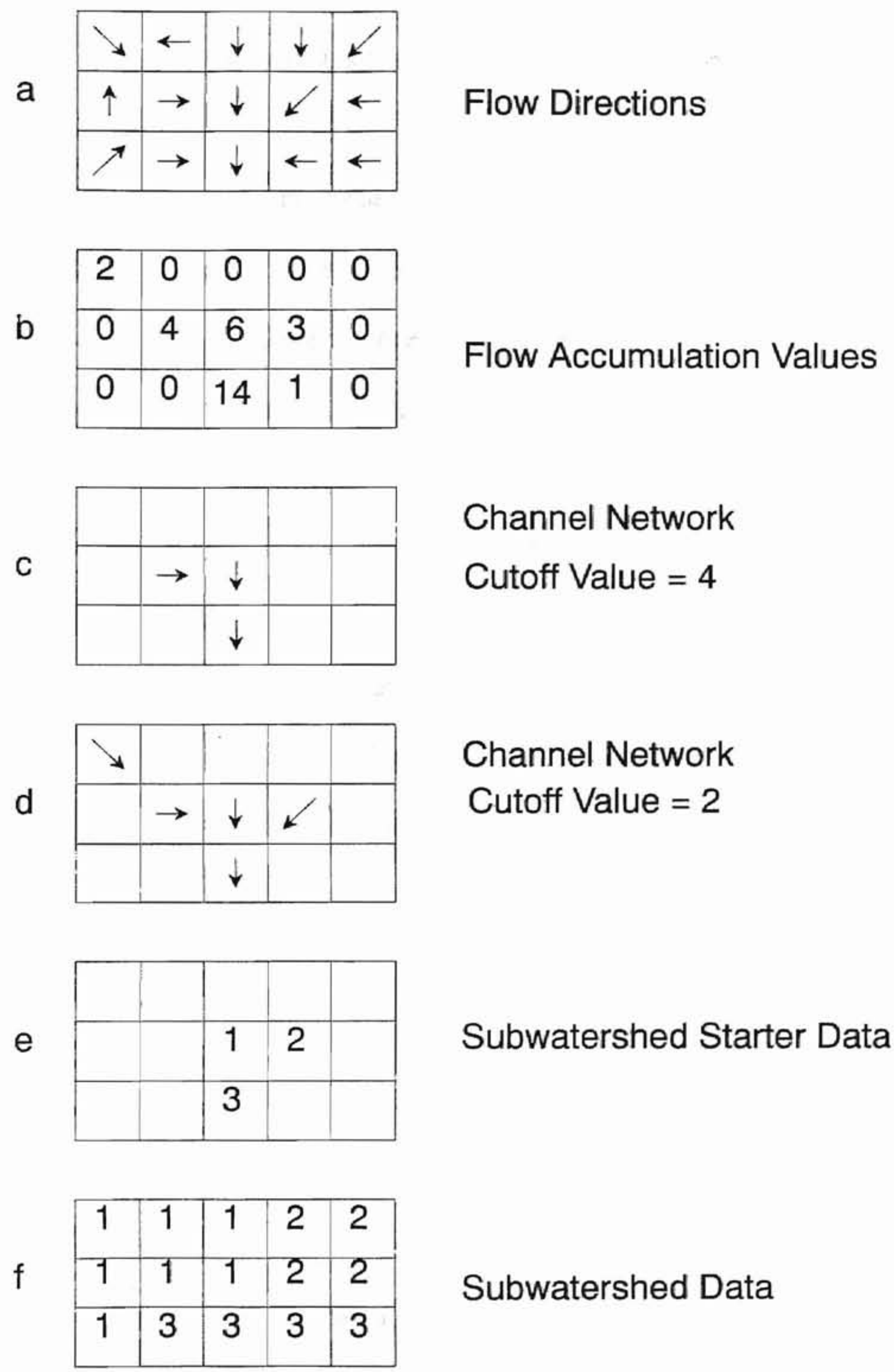


Figure 3.4: Delineating Rill Network Example (Storm, 1991)

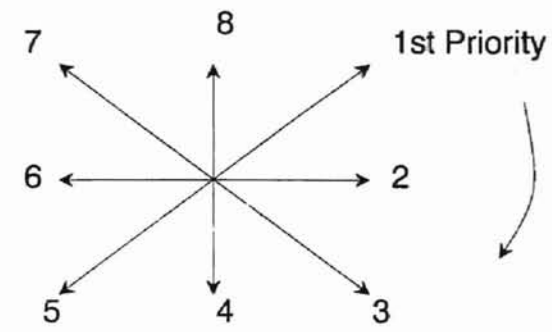
If the threshold value changes to 4 in this same example, three cells will be identified as network cells (see Figure 3.4c).

When the network has been defined, the rills are numbered left to right looking uphill. Further, these rills are divided at junction nodes into a series of branches (Storm, 1991). At each junction, there are eight possible flow direction. The branch numbering is performed clockwise beginning with the flow direction at the "1:30" clock position (see Figure 3.5a). The initial junction for each rill is found depending on the maximum flow accumulation. Subsequent to the enumeration of the upper most junction, the previous junction is evaluated. At this junction, a new unenumerated path with a maximum flow accumulation gradient is established. This process continues until all branches are numbered for each rill. Then a stream ordering routine is utilized to renumber the branches for each rill, as illustrated in Figure 3.5. All first-order streams are enumerated in sequence, followed by the remaining stream orders. This ordering system is implemented to facilitate the processing of all upstream branches before any downstream branch.

(4) Watershed and Subwatershed Delineation

This procedure identifies the watersheds and subwatersheds and delineates their boundaries. The number of watersheds is dependent on the number of independent rills. Each watershed has only one outlet or start cell, which is the rill outlet. The watershed is composed of one or more subwatersheds, each of which is associated with a branch of the rill.

a . Branch Numbering Direction Direction Priority



b . Example Branch Numbering Scheme

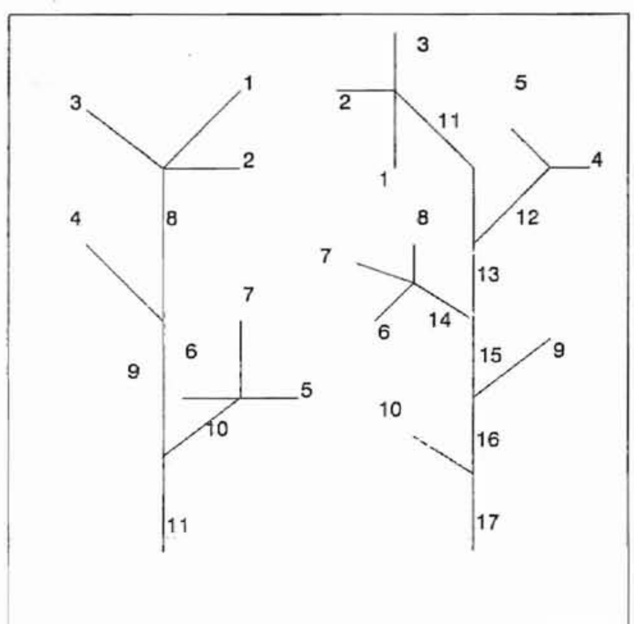


Figure 3.5: Rill network delineation Numbering Scheme
(Storm, 1991)

Subwatersheds are delineated using the following steps. First, cell flow directions and a subwatershed starter data set are used to locate the subwatershed start cells. These are given a subwatershed number (Figure 3.4f) according to the same numbering order as the one used to enumerate branches. Then the subwatershed number for each cell is compared with its neighboring cells to identify the boundary cells. Finally, the cells are enumerated to reflect the associated watershed and boundary cells.

Statistic Analysis

A Storm Water Management Program (SWAMP II) (Haan, 1994) was employed to analyze link length distributions. Exceedance probabilities were estimated using the standard plotting position method and the theoretical values for four probability density functions: Normal, Log-Normal, Extreme Value Type I, and Log-Pearson Type III. After this process a Chi-square goodness of fit test (Haan, 1977) was performed to judge whether or not a particular distribution fit the link length data. The Chi-square goodness of fit test is a comparison between the actual number of observations and the expected number of observations that fall in class intervals. The test statistic is given as:

$$\chi_c^2 = \sum_{i=1}^{k} (O_i - E_i)^2 / E_i \qquad (3.1)$$

where k is the number of class interval, O_i is the observed number of observation in the class interval, and E_i is the expected number of observations in the class interval. If the χ_c^2 is less than $\chi^2_{1-\alpha,\, k-p-1}$, the particular distribution hypothesis is accepted.

A linear regression method was used to analyze the relationship between sediment yield and topographic parameters, or between two topographic parameters. The linear regression model is given as:

$$Y = a + bX + \varepsilon \tag{3.2}$$

where Y is the dependent variable, X is the independent variable, a is the Y intercept, b is the slope and ε is an error term.

To test whether or not a relationship can be appropriately described by a linear function with parameters a and b, a Student-T test is used at the 95% confidence level. Estimated parameters a and b are tested assuming a = 0 and b = 0.

CHAPTER IV

RILL NETWORKS AND TOPOGRAPHIC PARAMETERS

In order to generate the rill networks for the University of Kentucky (UK) and Oklahoma State University (OSU) erosion plots, the DTM model was used with their elevation data. Based on these results, topographic parameters were calculated.

Generating UK Rill Networks

The DTM required a uniform grid of elevations. However, the UK surface profile data was taken at 0.61 m (2.0 feet) and 0.013 m (0.5 in) upslope and cross-slope intervals, respectively. In order to balance accuracy and computer requirements, an interpolated grid 0.025 m (1.0 in) square was used to represent the micro-relief. The original surface profile data were a 353 by 37 elevation matrix. In order to provide a 0.025 m square grid, every other cross-slope elevation was eliminated, and missing upslope elevation were interpolated. Interpolated elevations were calculated using a linear interpolation scheme with a random component given as:

$$\hat{z} = z_0 + (\hat{y} - y_0)\frac{z_1 - z_0}{y_1 - y_0} + \varepsilon RR \tag{4.1}$$

where $\hat{z}$ is an interpolated elevation (mm), z_1 is a upslope elevation (mm), $\hat{y}$ is an interpolated upslope distance (mm), y_1 is an upslope distance where surface profile measurements were taken, the z_0 and y_0 are down-slope elevation or distance, respectively, RR is a surface roughness parameter (mm) and ε is a normally distributed random deviate with a mean of zero and variance of one.

After the interpolated elevations were calculated, boundary elevations of 9999 mm were defined along the upslope boundary and along each of the side boundaries to define the watershed boundary. The final elevation grid file consisted of 159,759 elevations in a 183 by 873 matrix covering 101 m^2. The DTM's threshold values for UK erosion plots ranged from 750 to 2500 cells. This threshold value was chosen for its closeness to approximating the observed flow network (Lewis, 1990). Table 4.1 gives the UK threshold values for each run code. The information generated by the DTM were imported in the GIS GRASS for graphical display. The Figures 4.1 to 4.10 show the predicted rill networks for the UK erosion plots. A summary of the all network data is given in Appendix A.

Generating OSU Rill Networks

The soil surface elevation values for the OSU erosion table were

Table 4.1: DTM Threshold Values for the University of Kentucky Erosion Study (Lewis, 1990)

Run Code	Cutoff	Number of Rills
S1R2	2500	7
S2R2	2000	8
S3R2	2500	8
S1S2	1500	9
S2S2	1500	7
S3S2	2000	8
T1R2	1500	7
T2R2	1000	9
T3R2	1000	12
T1V2	750	12
T2V2	750	10
T3V2	1000	12

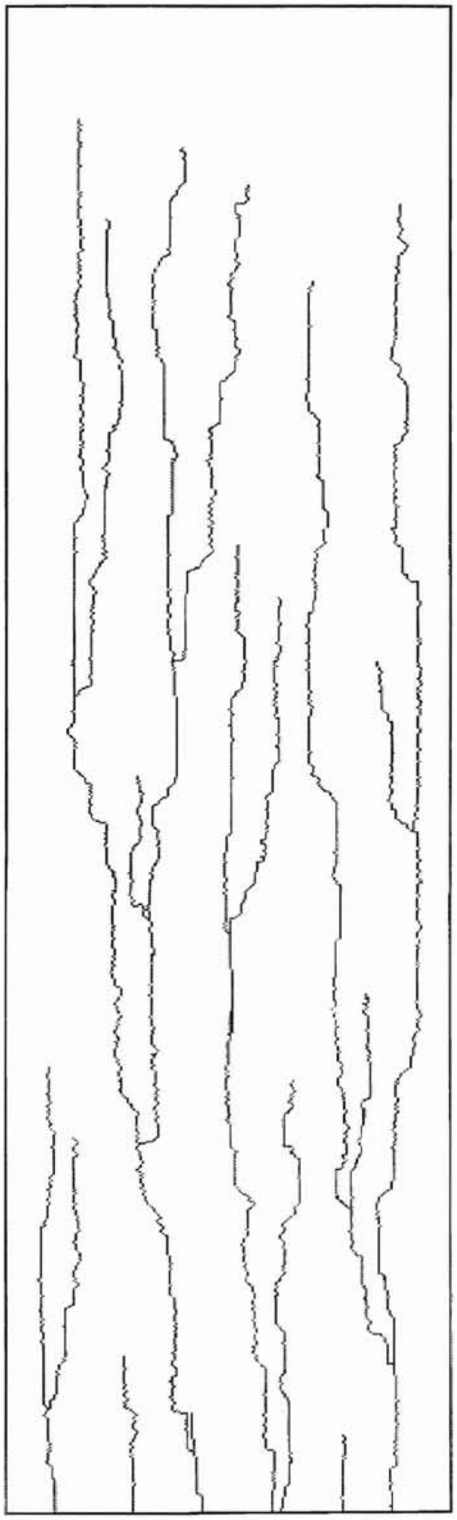


Figure 4.1: S1R2 Network

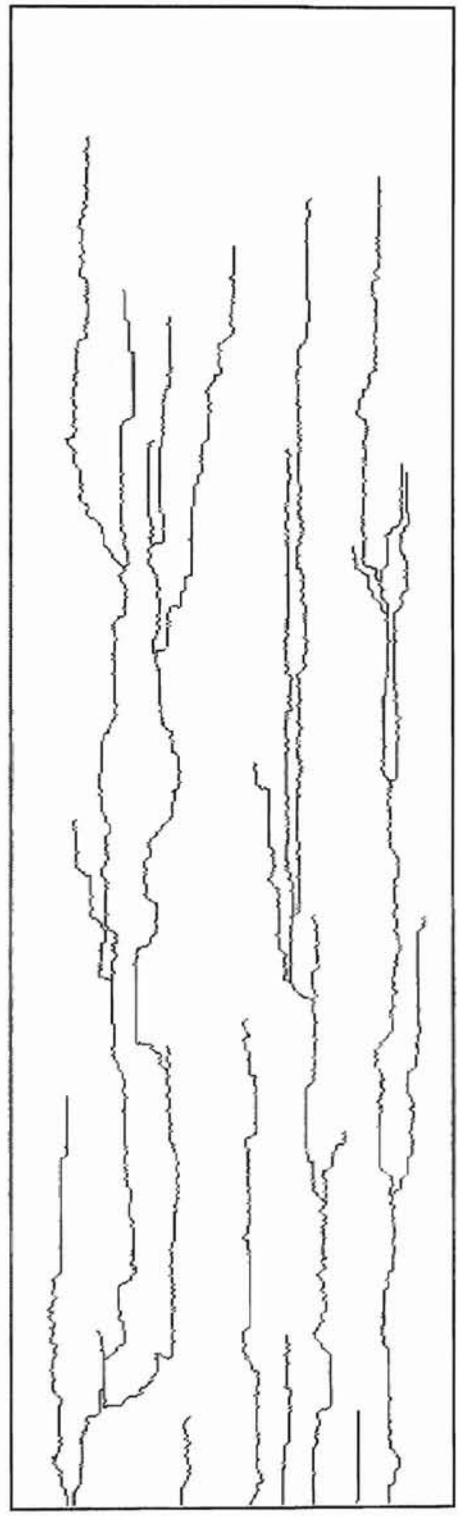


Figure 4.2: S3R2 Network

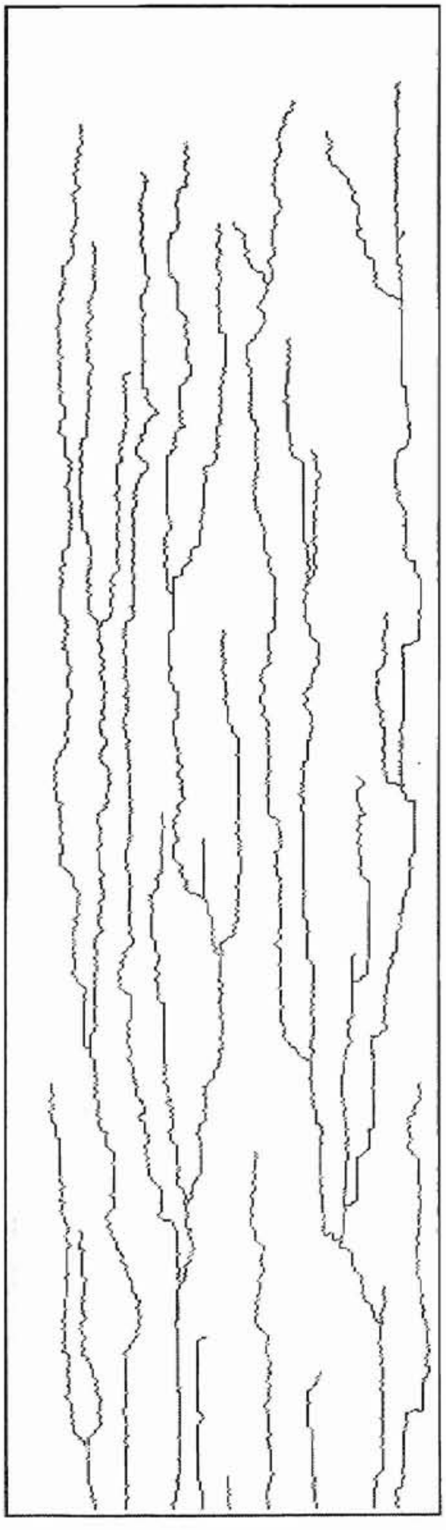


Figure 4.3: S1S2 Network

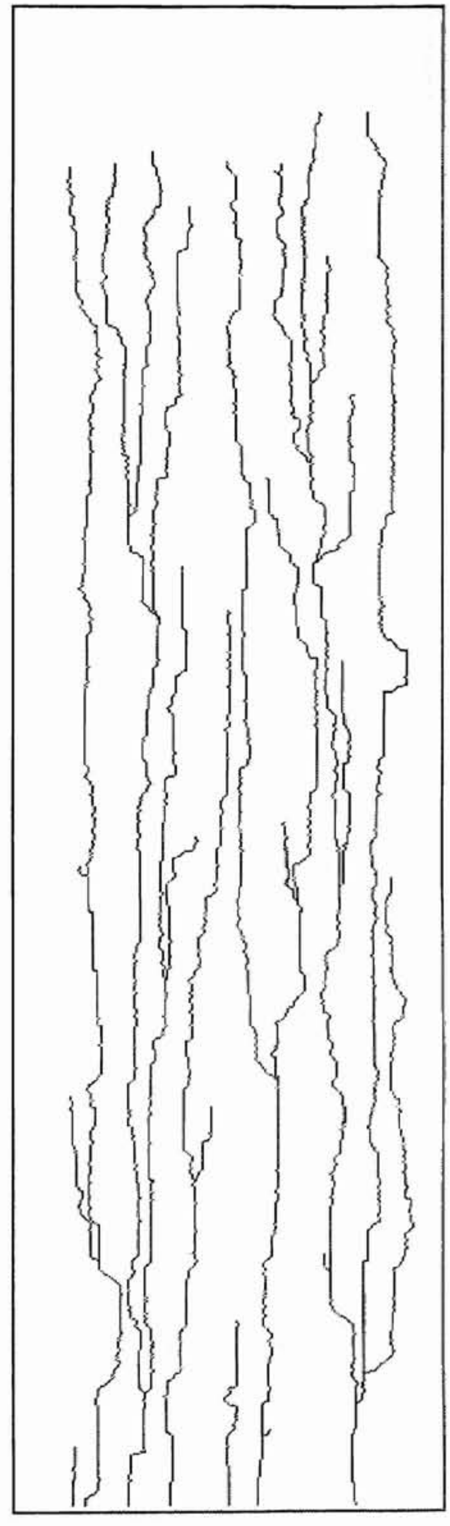


Figure 4.4: S2S2 Network

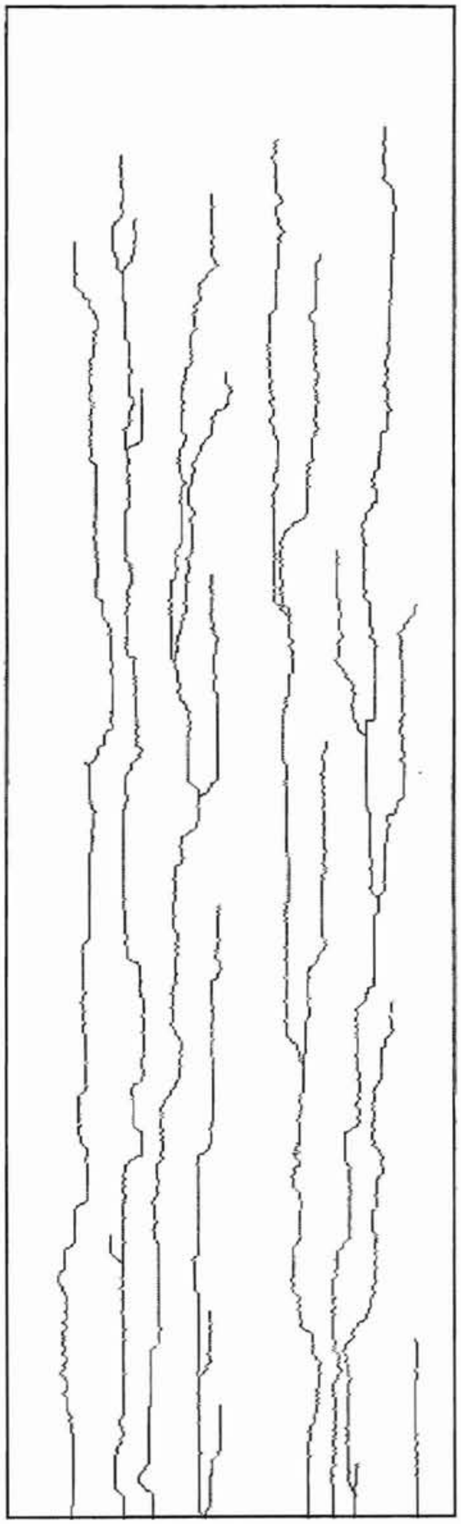


Figure 4.5: S3S2 Network

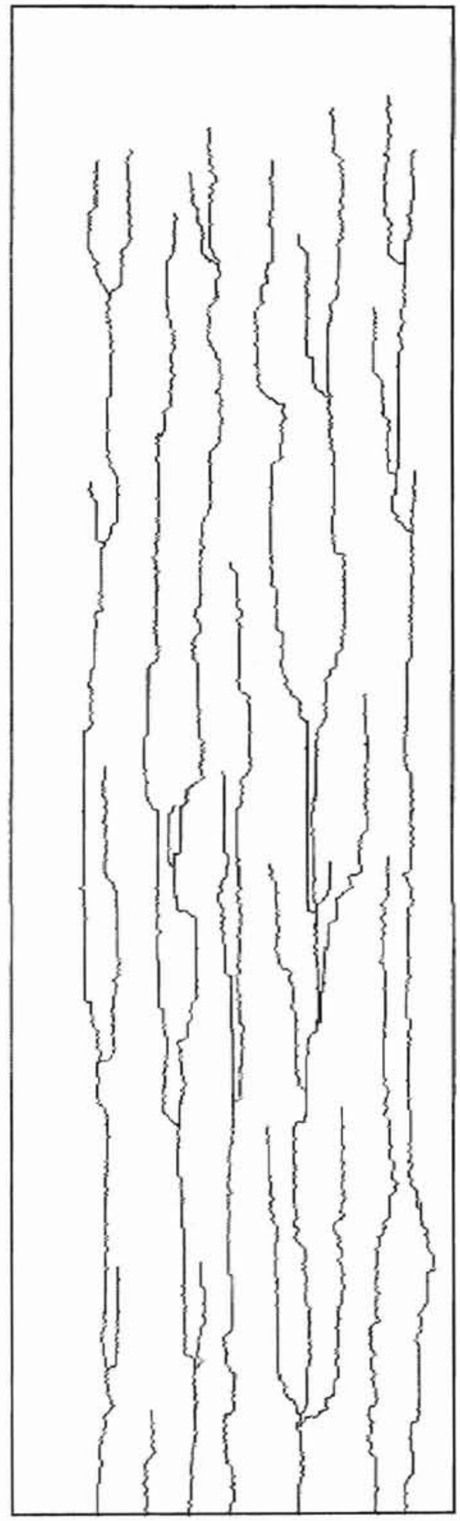


Figure 4.6: T1R2 Network

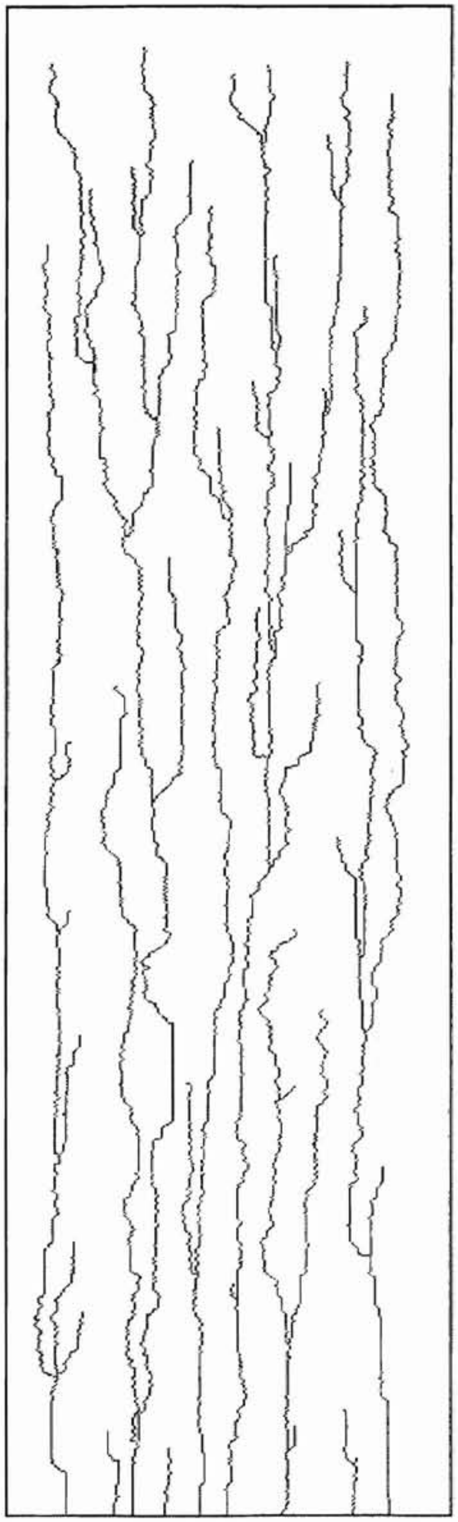


Figure 4.7: T2R2 Network.

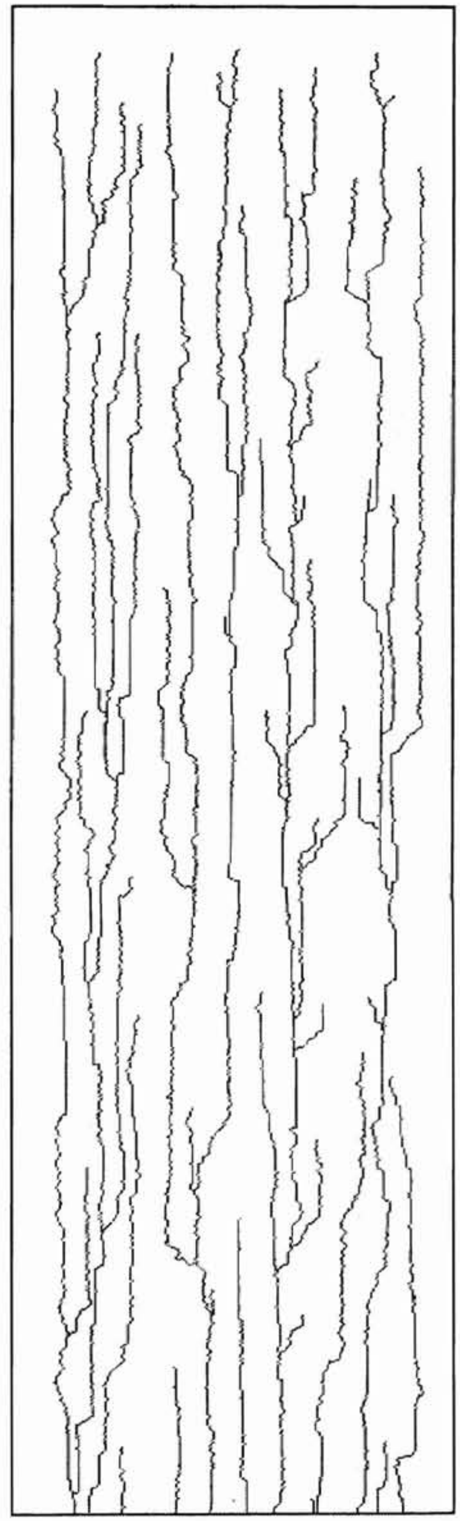


Figure 4.8: T1V2 Network

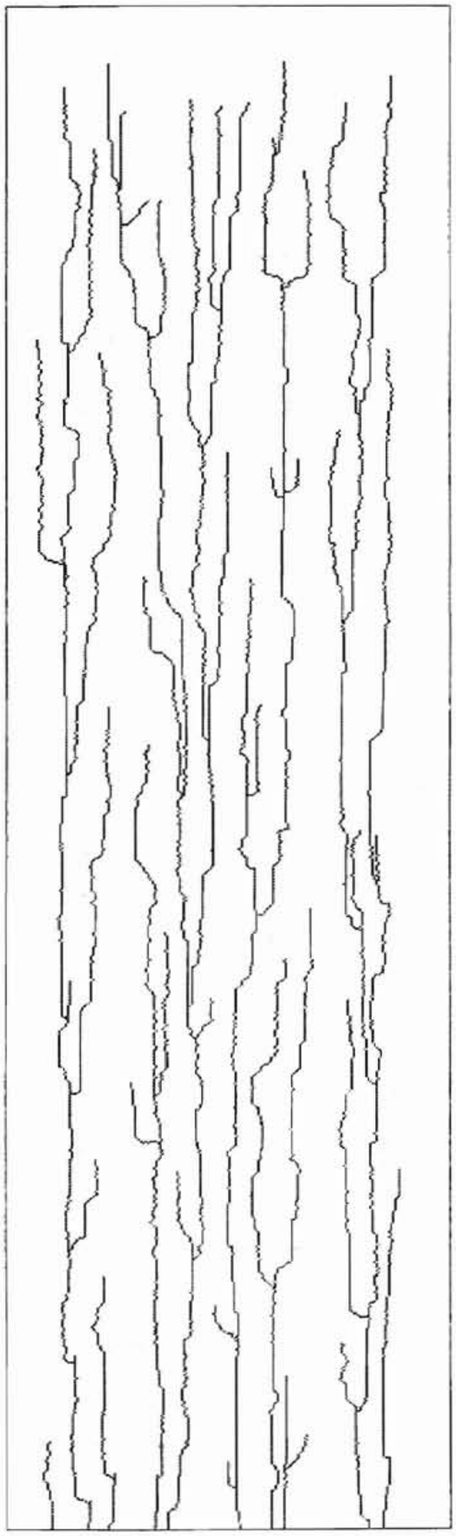


Figure 4.9: T2V2 Network

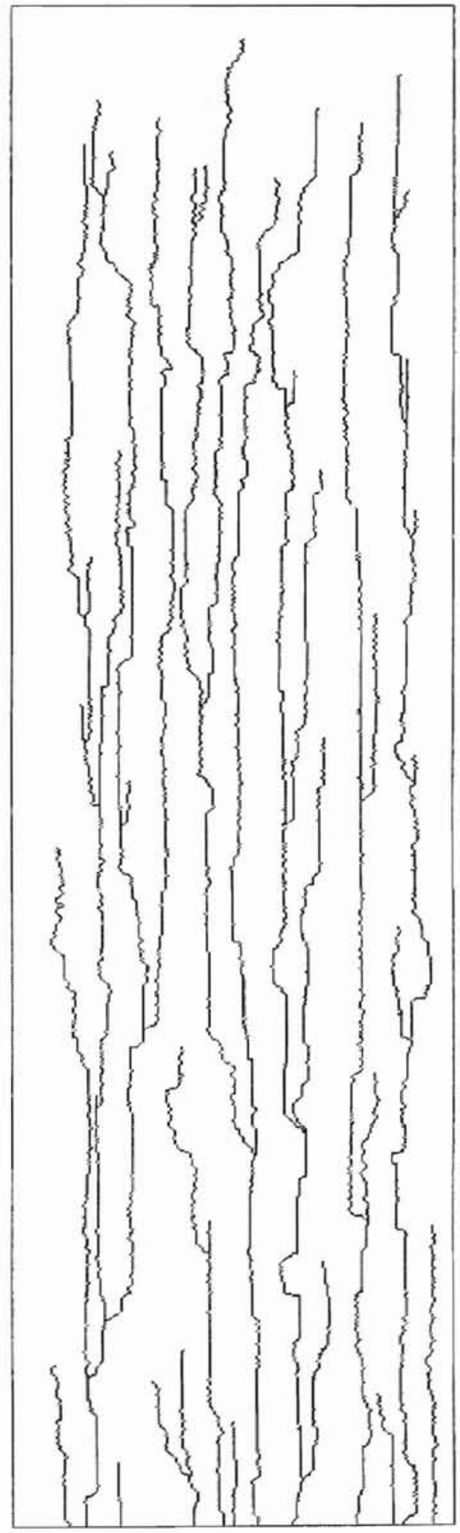


Figure 4.10: T3V2 Network

measured using an image processing system. This system was used to gather X-Y-Z data points after the rainfall event. A square grid of 10 mm in the across-slope direction and 10 mm in the down-slope direction was used.

For successes delineation of the drainage networks and watershed boundary, the elevation Z value was extracted from a X,Y,Z file, boundary elevations of 9999 mm were defined along the upslope boundary and along each of side boundaries, and an elevation of zero was defined along the bottom boundary. Finally, the elevation file consisted of 215,600 elevations in a 980 by 220 matrix and covered 23.52 m^2. Data reduction programs are given in Appendix B.

Defining the rill networks were conducted for several threshold network densities. The DTM generated rill networks were compared with observed rill networks which were hand drawn. The selected threshold values ranged from 7000 to 8500 cells, and are given in Table 4.2.

Table 4.2: DTM Threshold Values for the OSU Erosion Study

ID Code	Cutoff	Number of Rills
AAA	7500	2
ABA	8500	3
ACA	7000	2

Due to missing elevation data for ADA and BAA, predicted rill networks

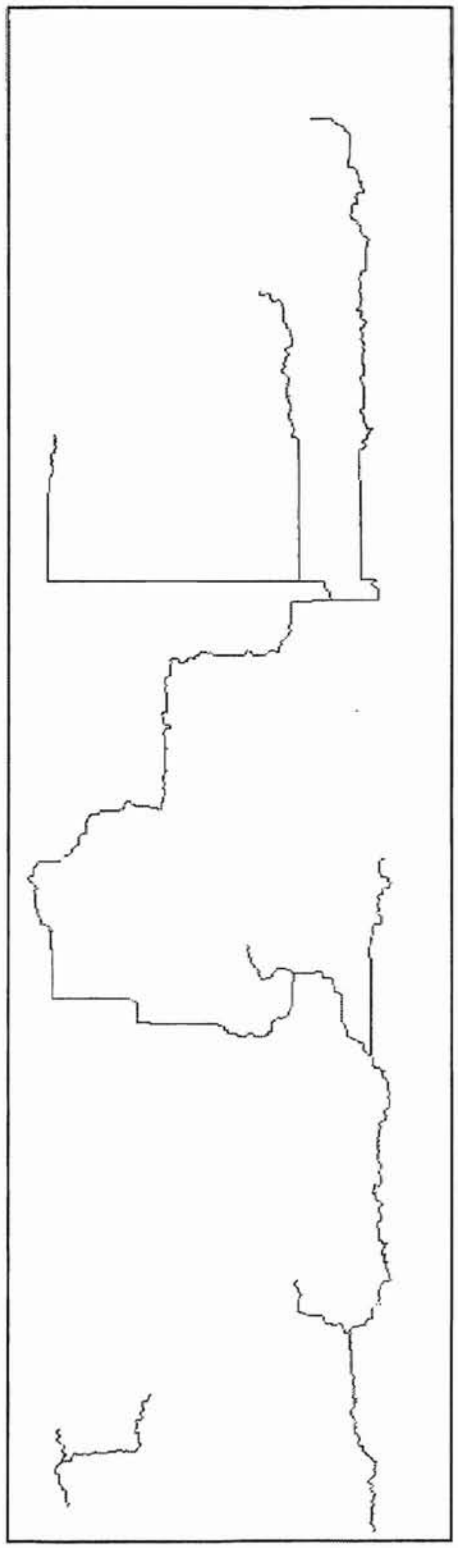


Figure 4.11: AAA Rill Network

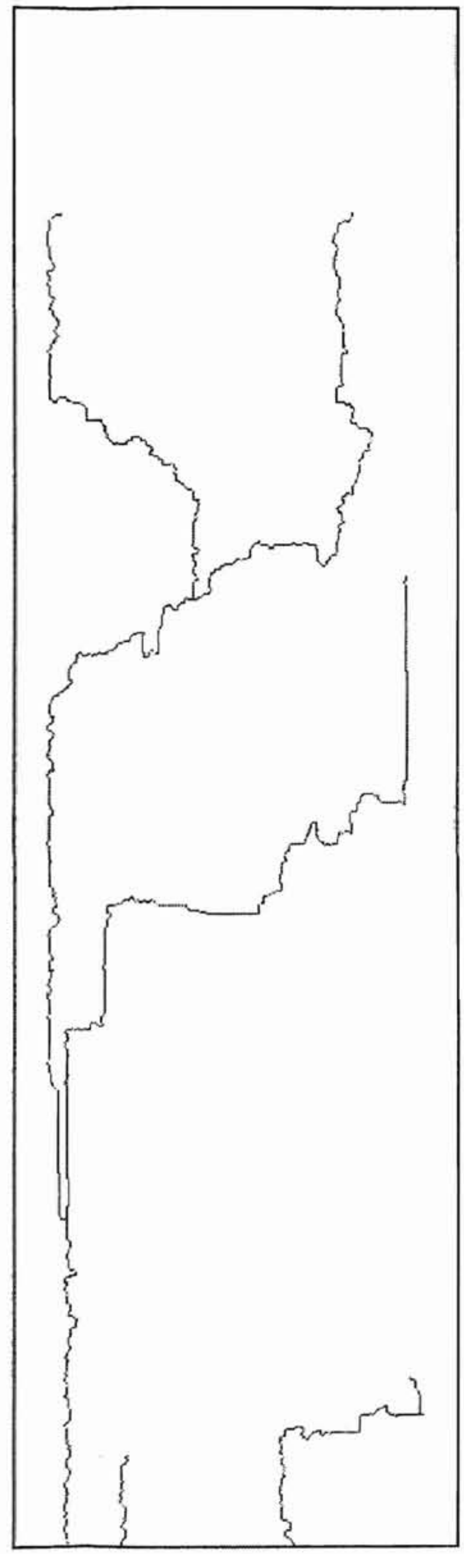


Figure 4.12: ABA Rill Network

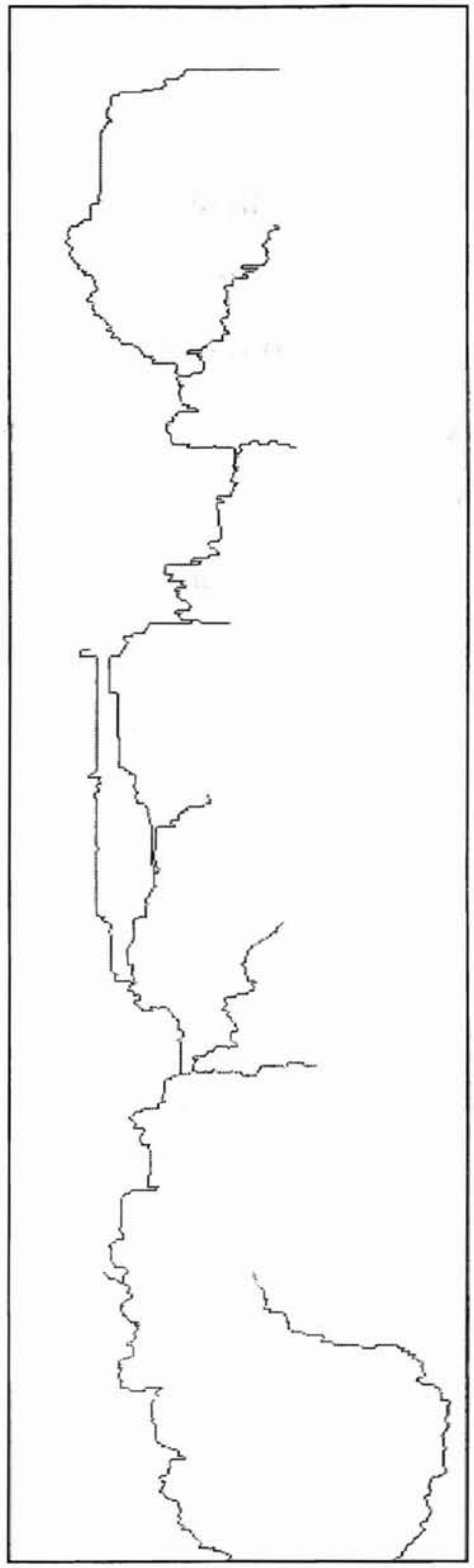


Figure 4.13: ACA Rill Network

were not obtained. The predicted rill networks for the OSU data are displayed in Figures 4.11 to 4.13. The DTM generated rill networks compare favorably with the observation rill networks. A summary of the DTM rill network data is given in Appendix A.

A comparison between the UK and OSU rill networks show considerable differences in rill density. In addition, the UK rill networks were relatively straight with minimal meandering. In comparison, the OSU networks had very low rill density and showed a highly meandering pattern. The reasons for the differences may be a) the surface profiles of the UK data contained interpolated elevation data, b) the slope of the UK erosion plots was much higher then the OSU erosion table, and c) the soil type, rainfall duration and rainfall intensities were different.

Topological Parameters

Four topologic parameters were chosen for this study: 1) link length including exterior link and interior link length, 2) link drainage area, 3) rill density, 4) random roughness. The parameters were chosen because of their potential influence on the rill erosion process.

1. Link Length

The specialized topological terms used in this paper have been defined by Shreve (1966, 1967). The points farthest upslope are termed sources. The point farthest downslope is called the outlet. The point of confluence of two channel is a junction (or

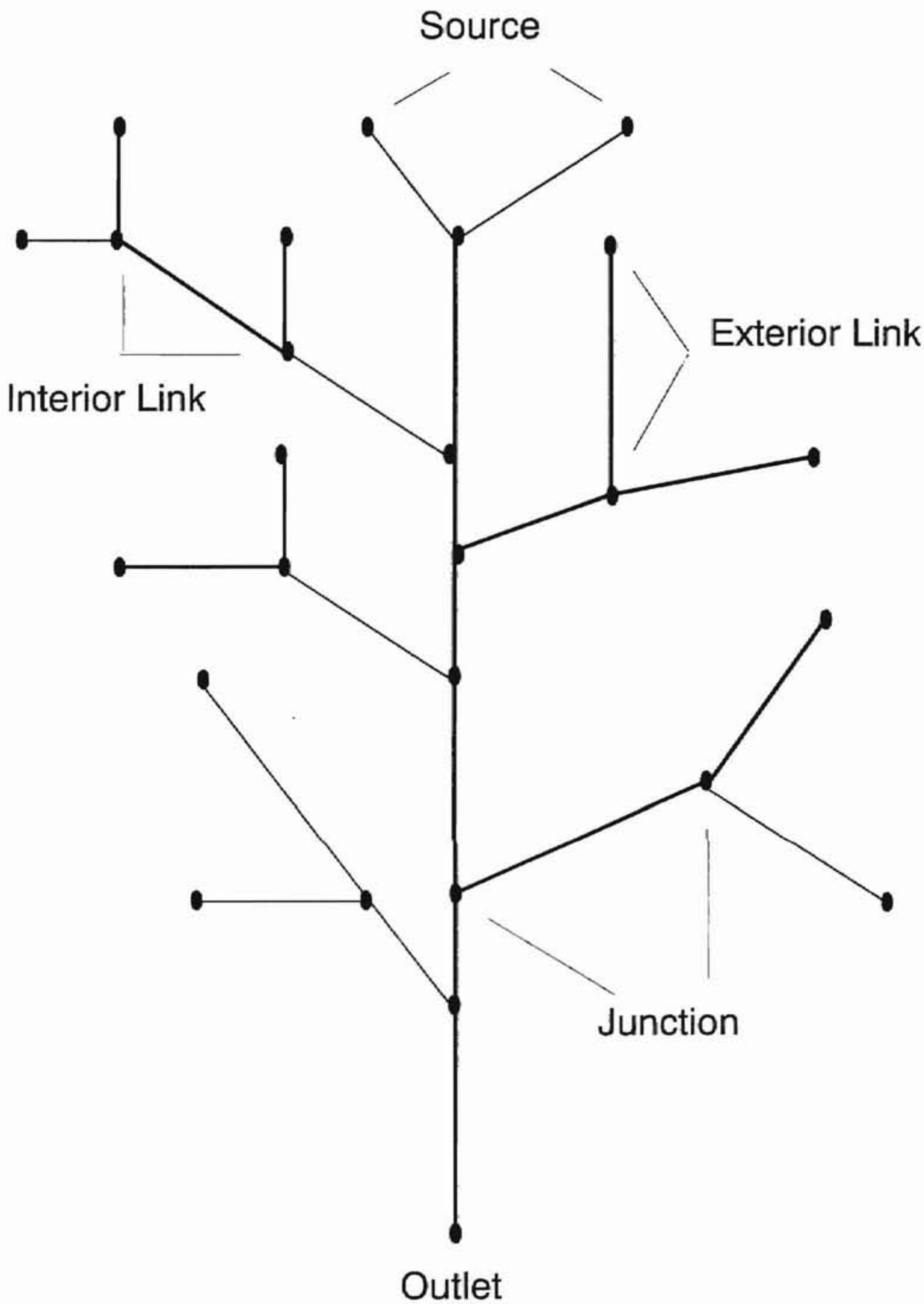


Figure 4.14: Definition of Topologic Terms

fork), and the term link represents a channel segment. An interior link length is a channel segment between two junctions or between the outlet and the first upslope junction. An exterior link length is a channel segment between a source and the first downslope junction. These concepts are illustrated in Figure 4.14. The magnitude of a link is equal to the number of sources upslope from it. Therefore, all exterior links have a number of sources and interior links have a number of sources equal to sum of their upslope adjoining links. Assuming a junction can only be combined by two links, the following definitions can be given as (Wilson, 1993):

$$f = n - 1 \tag{4.2}$$

$$v_e = n \tag{4.3}$$

$$v_i = n - 1 \tag{4.4}$$

$$v = v_e + v_i = 2n - 1 \tag{4.5}$$

where n is the number of sources, f is the number of junction, v_e is the number of exterior links, v_i is the number of interior links, v is the total number of interior and exterior links.

Given a micro-relief, a DTM identifies preferential flow paths and defines the rill networks. The rill networks of UK and OSU data were obtained using the DTM as described in Chapter IV (see Figure 4.1 to 4.13). Also the rill number, total branch number, each branch cells number and interrill cells number were determined (see

Table 4.3: Link Length Statistics for the UK Data

ID Code	Exterior Link Length (m)		Interior Link Length (m)		Total Link Length (m)	
	Number	Mean	Number	Mean	Number	Mean
S1R2	18	5.05	11	3.80	29	4.57
S2R2	25	4.55	17	3.17	42	4.00
S3R2	23	3.63	15	3.31	38	3.51
S1S2	27	4.00	18	3.92	45	3.96
S2S2	25	4.36	18	3.56	43	4.03
S3S2	21	3.71	13	5.30	34	4.32
T1R2	28	3.10	21	4.14	49	3.55
T2R2	41	2.30	32	3.05	73	2.63
T3R2	48	2.77	36	2.21	84	2.53
T1V2	47	2.90	35	2.81	82	2.85
T2V2	49	2.40	39	2.52	88	2.45
T3V2	37	3.26	25	3.98	62	3.55

Table 4.4: Link Length Statistics for the OSU Data

ID Code	Exterior Link Length (m)		Interior Link Length (m)		Total Link Length (m)	
	Number	Mean	Number	Mean	Number	Mean
AAA	8	1.50	6	1.86	14	1.65
ABA	5	2.90	2	3.33	7	3.02
ACA	6	1.33	4	2.71	10	1.88

Appendix A).

Flow path link length is considered to be the fundamental measure of length in this study. The total links for each rill network were separated into exterior and interior links. If there was a single link in one rill, the single link was defined as an exterior link. The total, exterior, and interior link lengths were obtained using the DTM's output (see Appendix A). Tables 4.3 and 4.4 summarize the mean lengths obtained using the UK and OSU erosion plot data.

A dimensionless link length can be given as:

$$L_{*} = \frac{L}{L_c} \tag{4.6}$$

where L_* is a dimensionless link length, L is the link length, L_c is a characteristic length scale. L_c can be estimated as (Wilson, 1993):

$$L_c = [(\Delta x)^2 + (\Delta y)^2]^{0.5} \tag{4.7}$$

where Δx and Δy are length of the grid sides. For the UK erosion plots Δx is 25.4 mm, Δy is 25.4 mm, and thus L_c is 35.9 mm.

2. Link Drainage Area

The link drainage area parameter is an important characteristic of the rill network. It impacts the potential erosion and sediment yield. The mean link drainage area is calculated based on the number of interrill cells predicted the DTM (see Appendix A). The mean link drainage area for the UK and OSU data are shown in Tables 4.5 and

Table 4.5: Link Drainage Area Statistics for the UK Data

ID Code	Exterior Link Area (m^2)		Interior Link Area (m^2)		Total Link Area (m^2)	
	Number	Mean	Number	Mean	Number	Mean
S1R2	18	4.21	11	1.76	29	3.28
S2R2	25	3.01	17	1.26	42	2.30
S3R2	23	3.19	15	1.40	38	2.48
S1S2	27	2.55	18	1.59	45	2.17
S2S2	25	2.78	18	1.52	43	2.25
S3S2	21	3.03	13	2.50	34	2.83
T1R2	28	2.21	21	1.64	49	1.97
T2R2	41	1.49	32	1.17	73	1.35
T3R2	48	1.52	36	0.70	84	1.17
T1V2	47	1.38	35	0.97	82	1.21
T2V2	49	1.28	39	0.92	88	1.12
T3V2	37	1.76	25	1.37	62	1.61

Table 4.6: Link Drainage Area Statistics for the OSU Data

ID Code	Exterior Link Area (m^2)		Interior Link Area (m^2)		Total Link Area (m^2)	
	Number	Mean	Number	Mean	Number	Mean
AAA	8	1.51	6	0.93	14	1.26
ABA	5	1.97	2	1.18	7	1.74
ACA	6	2.05	4	1.82	10	1.96

4.6.

The link drainage area can be written in dimensionless form as:

$$a_* = \frac{a}{a_c} = \alpha L_*^{\beta} \tag{4.8}$$

where a_* is a dimensionless link area, a is the link area (m^2) and a_c is a characteristic area scale (m^2). α and β are dimensionless coefficients, and L_* is the dimensionless length given by Equation 4.6. a_c is defined as (Wilson, 1993):

$$a_c = \Delta x * \Delta y \tag{4.9}$$

For the UK data $\Delta x = \Delta y = 0.025$ m, and thus a_c is 0.000625 m^2.

3. Rill Density

In this study rill density is defined by length of rills per unit area. The equation is given as:

$$D = \frac{L}{A} \tag{4.10}$$

where D is rill density (m/m^2), L is total rill length (m), and A is the rill network area (m^2) . Rill density for the UK data is shown in Table 4.7. Each UK plot area is 101 m^2 (4.57 m by 22.1 m). The OSU erosion table area is 23.5 m^2 (9.8 m by 2.4 m). Table 4.8 shows the rill density for the OSU data.

Table 4.7: Rill Density for the UK Data

ID Code	Total Length (m)	Rill Density (m/m^2)
S1R2	133	1.31
S2R2	168	1.66
S3R2	133	1.32
S1S2	178	1.77
S2S2	173	1.71
S3S2	147	1.45
T1R2	174	1.72
T2R2	192	1.90
T3R2	212	2.10
T1V2	234	2.31
T2V2	216	2.14
T3V2	220	2.18

Table 4.8: Rill Density for the OSU Data

ID Code	Total Length (m)	Rill Density (m/m^2)
AAA	23.1	0.98
ABA	21.2	0.90
ACA	18.8	0.80

4. Random Roughness

The physical condition of the surface soil is altered in many ways by human induced and natural forces. Tillage changes the surface roughness. In addition, climatic can rapidly alter surface characteristics.

There are two types of roughness. The first type, oriented roughness, is produced by tillage equipment and is characterized by furrows and ridges that run parallel to the direction of tillage. The second type of surface roughness is random roughness, which is unrelated to the direction of tillage and is characterized by the irregular occurrence of peaks and depressions.

In this study only random roughness is considered and is defined as the standard deviation of soil surface heights. All random roughness values were estimated using the initial surface elevation data. Random roughness was estimated using elevation deviations from a series of lines regressed through each cross-slope transect (Storm, 1991). The equation is given as:

$$\hat{z} = mx + b \tag{4.11}$$

where $\hat{z}$ is the average cross-slope elevation (mm), x is the cross-slope distance (mm), and b and m are regression coefficients. The elevation deviates about the line, Δz in mm, are defined by:

$$\Delta z = z_i - \hat{z} = z_i - \hat{m}x_i + \hat{b} \tag{4.12}$$

where z_i is an observed elevation, and $\hat{m}$ and $\hat{b}$ are parameter estimates for a particular cross-section. Random roughness, RR in mm, was calculated from:

$$RR^2 = \frac{1}{\alpha\beta} \sum_{j=1}^{\alpha} \sum_{i=1}^{\beta} (z_i - \hat{z})^2 \qquad (4.13)$$

or,

$$RR = \left[\frac{1}{\alpha\beta} \sum_{j=1}^{\alpha} \sum_{i=1}^{\beta} \left(z_i - \hat{m}_j x_i - \hat{b}_j\right)^2\right]^{0.5} \qquad (4.14)$$

where α is the number downslope cross-sections, and β is the number of cross-slope position.

A portion of the original elevation data for the AAB and ABB experiments had some obvious errors. For example, there were sudden changes in the elevations from 33.5 mm to 334.2 mm. The errors in the AAB data were removed by deleting rows 192 to 221. However, for the ABB data a program was used to adjust the errors by multiplying the high value by 0.1. This method for the ABB data had to be adopted because the errors were dispersed in a different part of the data. It was assumed that these alterations did not significantly alter the analysis.

Based on above method and elevation data, a C language program (Appendix B) was made to calculate the random roughness. The results of UK data are given in Table 4.9. Average random roughness for the smooth and rough treatments were 13 and 18 mm for the subsoil plots, and 13 and 17 mm for the topsoil plots, respectively. The random roughness for the OSU erosion plots are given at Table 4.10, with an average random roughness of 10 mm.

Table 4.9: Random Roughness for the UK Data

ID Code	Random Roughness (mm)
S1R2	17
S2R2	19
S3R2	17
S1S2	13
S2S2	16
S3S2	12
T1R2	10
T2R2	10
T3R2	17
T1V2	17
T2V2	15
T3V2	17

Table 4.10: Random Roughness for the OSU Data

ID Code	Random Roughness (mm)
AAA	9.5
ABA	8.2
ACA	12.4

CHAPTER V

RESULTS AND DISCUSSION

This chapter describes the results of the topographic parameter estimates, and the analysis of topographic parameters and sediment yield relationships. First, probability density functions were evaluated for exterior link length, interior link length and total link length for the UK rill networks. Second, the relationship between link length and link drainage area was discussed for the UK rill networks. Finally a statistic analysis was performed to relate sediment yield and topographic parameters for link length, random roughness, and rill density using the UK and OSU rill networks.

Link Length Distribution Analysis

Twelve of the DTM predicted rill networks from the UK data were used to estimate the probability density functions for link lengths. Link lengths were analyzed by separating interior, exterior, and total links for each rill network. Exceedance probabilities were computed using standard plotting position methods and parameters for the Normal, Log-Normal, Extreme Value Type I, and Log-Pearson Type III probability density functions were approximated (Haan, 1977). The SWAMP program was used in this analysis. A summary of the link length distributions is given in Table 5.1 and distribution plots are given in Appendix C. The distribution selected was based on a visual comparison.

(1) Total Link Length. Total link length distributions for the twelve rill networks from the UK data, nine of the rill networks fit a Log-Normal distribution, two of them fit a Log-Pearson Type III distribution, and one rill network fits an Extreme Value Type I. The Log-Normal distribution fit 75% of the 12 rill networks for total link length.

(2) Exterior Link Length. Exterior link length distributions for the UK data, ten of the rill networks fit a Log-Normal, one of the rill networks fits Log-Pearson Type III, and one of the rill networks fit a Normal distribution. The Log-Normal distribution fit 83% of the 12 rill networks for exterior link length.

(3) Interior Link Length. The probability density function of interior link lengths is similar to total and exterior link length distributions. ten of the rill networks fit a Log-Normal distribution, one of them is fit a Log-Pearson Type III distribution, and only one fit a Normal distribution. The Log-Normal distribution fit 83% of the 12 rill networks for interior link length.

From the link length distribution plots, most of link lengths visually fit a Log-Normal distribution and a few fit the Log-Pearson Type III distribution. In order to statistically judge the fit of the distributions, a Chi-Square goodness of fit test is used. As described in the previous Chapter, the test statistic is calculated based on the relationship:

Table 5.1: Link Length Probability Density Function Summary for the UK Data

ID Name	Exterior	Interior	Total
S1R2	LN**	LN**	LN***
S2R2	LN***	LN**	LN**
S3R2	LN**	NR**	EV***
S1S2	LN**	LN**	LN*
S2S2	LN**	LN**	LN**
S3S2	LN*	LN**	LN***
T1R2	LN**	LN**	LN*
T2R2	LN**	LN**	LN**
T3R2	LN***	LN**	LN**
T1V2	LN**	LN**	LN**
T2V2	NR*	LP**	LP**
T3V2	LP*	LN**	LP**

Note:

a. NR is Normal distribution;
b. LN is Log-Normal distribution;
c. LP is Log Pearson Type III distribution;
d. EV is Extreme Value Type I distribution;
e. Using Chi-square test
  - *** Significant at $\alpha = 0.05$.
  - ** Significant at $\alpha = 0.1$.
  - * Not significant at $\alpha = 0.1$.

$$\chi_c^2 = \sum_{i=1}^{k} (O_i - E_i)^2 / E_i \tag{5.1}$$

If

$$\chi_c^2 < \chi^2_{1-\alpha,\, k-p-1} \tag{5.2}$$

the hypothesis is accepted. The Log-normal hypothesis was accepted by 72% of link lengths at the $\alpha = 0.1$ level including total, exterior, and interior link lengths. However, all the distributions were accepted based on a visual comparison. The results are shown in Table 5.1. An example of test process for S2S2 data is shown in Table 5.2. For this test link lengths are divided into 10 class intervals having equal expected numbers of observations in each interval. In this case when α level is 0.1, $\chi^2_{0.90,\,7}$ is 12.00, and χ^2 is 9.79 which is less than $\chi^2_{0.90,\,7}$. Therefore, the hypothesis is accepted.

Schumm (1956), Maxwell (1960), Smart (1968), Shreve (1969) and Abrahams (1982) found that the stream link lengths followed a Log-Normal distribution in river basins. Also Wilson (1993) found that link lengths were represented by the Log-Normal distribution in the OSU erosion table. The present study compares well with past research, and it is especially close to the OSU link lengths distribution characteristics studied by Wilson (1993).

Link Length and Link Drainage Area

The UK rill networks were used to evaluate the relationship between

Table 5.2: Chi-Square Test Based on Equal Expected Number Per Class Interval for the UK S2S2 data

Class Number	Boundaries		Observed Number	Expected Number	$(O-E)^2/E$
	Lower	Upper			
1	Minus Infinite	1.04	8	4.3	3.18
2	1.04	1.49	5	4.3	0.11
3	1.49	1.92	3	4.3	0.39
4	1.92	2.38	2	4.3	1.23
5	2.38	2.92	4	4.3	0.02
6	2.92	3.58	1	4.3	2.53
7	3.58	4.44	3	4.3	0.39
8	4.44	5.73	7	4.3	1.69
9	5.73	8.16	5	4.3	0.11
10	8.16	Plus Infinite	5	4.3	0.11
Total			43	43	9.79

Note:

a. O is observed number;

b. E is expected number.

link length and link drainage area. Summarizing all link lengths and link drainage areas for the twelve rill networks result in 389 exterior link lengths and correlative exterior link drainage areas, 280 interior link lengths and link drainage areas, and 669 total link lengths and link drainage areas.

From past research, it was found that the relationship of link drainage area and link length for river basins is a power function (Hack, 1957; Gray, 1961; Shreve, 1967). Wilson (1993), using earlier OSU erosion table data, found that the relationship of link drainage area and link length are represented by the power and linear functions for interior and exterior link length, respectively. Therefore, the first analysis was performed using a power function between link drainage area and link length. A general formulation is given in dimensionless form as:

$$a_* = \alpha L_*^{\beta} \tag{5.3}$$

A regression analysis of natural logarithm transformed data was used to determine the values of dimensionless coefficients α and β. Table 5.3 gives the results of regression analysis and the dimensionless coefficients for exterior, interior, and total link length. Figure 5.1, 5.2 and 5.3 show link drainage area and link length plots. The results in Table 5.3 show that the power coefficients, β, are 0.63, 0.43 and 1.18 for total, exterior, and interior links, respectively. β's are less than two, which is similar for river basins (Hack, 1957; Gray, 1961; Shreve, 1967). For the interior link, β is very close to 1.23, which was obtained using earlier OSU erosion table data by Wilson (1993).

The above three equations were tested using a Student-T test. The

Table 5.3: Regression Results of Link Length and Link Drainage Area for Natural Logarithm Transformed UK Data

Link Type	α	β	R^2	Standard Error	Significant at 95% Confidence Level
Total Link	147	0.63	0.48	0.73	Yes
Exterior Link	469	0.43	0.64	0.40	Yes
Interior Link	8.7	1.18	0.88	0.42	Yes

Table 5.4: Regression Results for Link Length and Link Drainage Area for the UK Data

Link Type	Number	Intercept, b	Slope, m	R^2	Standard Error	Significant at 95% Confidence Level
Total Link	669	526	24	0.73	1188	Yes
Exterior Link	389	1067	24	0.78	1127	Yes
Interior Link	280	-221	24	0.82	798	Yes

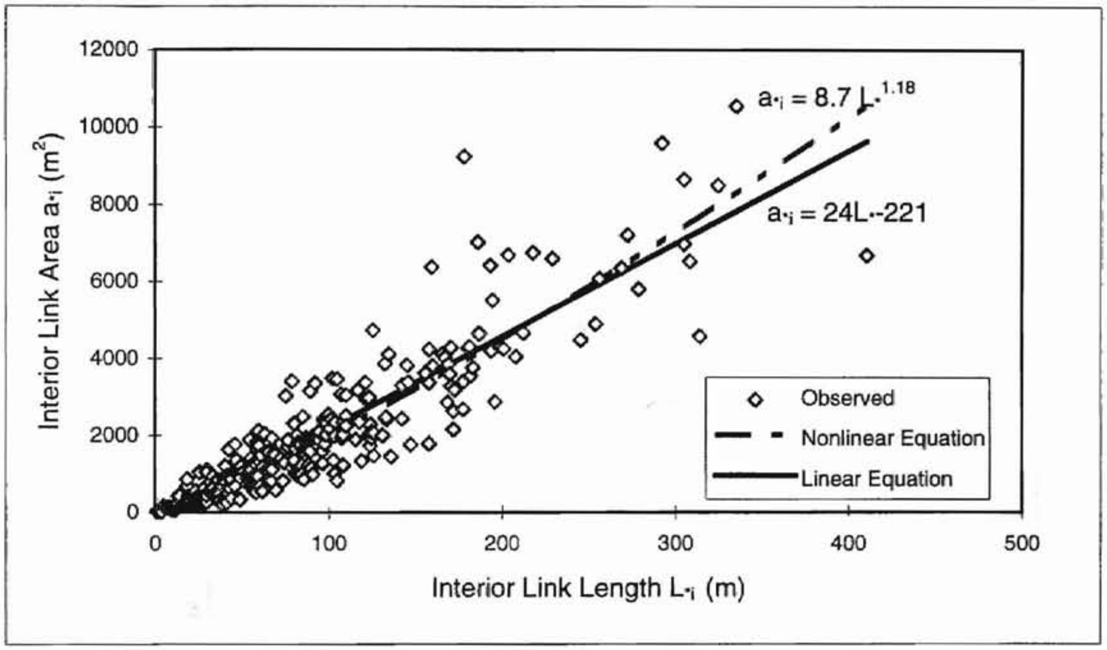


Figure 5.1: Interior Link Area and Link Length for the UK Data

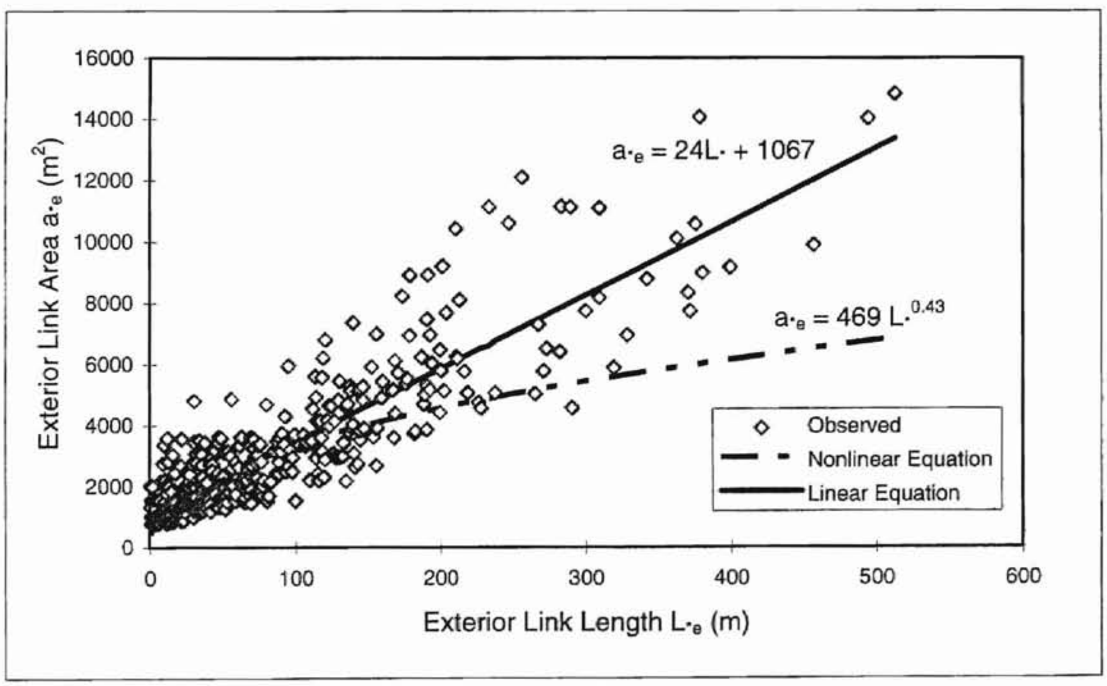


Figure 5.2: Exterior Link Area and Link Length for the UK Data

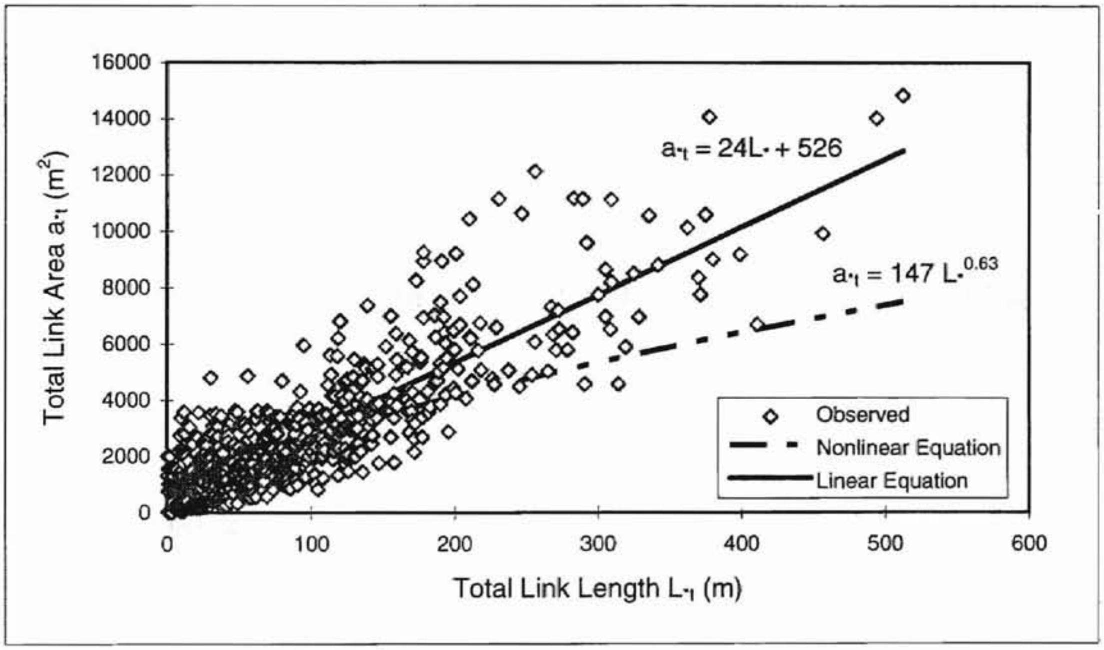


Figure 5.3: Total Link Area and Link Length for the UK Data

results show that above three equations can explain a significant amount of the variation in the observed data at the 95% confidence level. The residual plots are given in Appendix D. From these plots, it can be seen that the interior link length residual plot show a random distribution indicating the normality assumption of the residuals is correct. However, exterior link length residuals are not random distributed and have a trend indicating an incorrect model. The total link length residuals show a random distribution. The variance of the residuals is not constant.

Because the β coefficient is relatively close to 1.0, a second analysis was performed using a linear regression. A general linear equation is given as following:

$$a_* = mL_* + b \tag{5.4}$$

The results of linear regression analysis are given in Table 5.4. Link drainage area and link length plots are showed in Figures 5.1, 5.2, and 5.3. The three linear equations were tested using the Student-T Test. The results show that there are significant linear relationships at a 95% confidence level. The residual plots are given in Appendix D. These residual plots are randomly distributed for total, exterior, and interior link length. It should be noted, however, that the exterior and interior link length do not have a constant residual variance indicating an incorrect model.

Figures 5.1, 5.2 and 5.3 show that the relationship is represented well by power and linear function for interior link, and better represented by linear function for the exterior and total link. These results were similar to past research for river basins and are especially close to the small-scale drainage network characteristics studied by Wilson (1993). Wilson (1993) studied link length characteristics using earlier OSU erosion table data analyzed by Ogunlela et al. (1989). Approximately one million x-y-z data points were gathered using the image-processing instrumentation system. The soil profile information was interpolated to a rectangular grid of 102 x 13 mm. Flow paths was determined using an algorithm developed by Couger et al. (1992).

Although the present study used a DTM and different elevation data from that of Wilson (1993), link length characteristics were found to be similar. A comparison of the relationship between the present study and Wilson (1993) for link length and link drainage area show significant similarity for the exterior link lengths using linear regression. For the interior link length the relationship obtained by Wilson was:

$$a_{*i} = 6.82\ L_*^{1.23} \tag{5.5}$$

In the present study, however, the relationship is found to be

$$a_{*i} = 8.7\ L_*^{1.18} \tag{5.6}$$

using a power function for the interior link length. Comparing these equations for interior link, it is evident that the relationship and power coefficient β are similar.

Topographic Parameters and Sediment Yield

In this section, relationships between link length, random roughness and rill density with sediment yield and pseudo steady-state sediment load were analyzed using linear regression methods for the UK and OSU data. The regression analysis results were tested using a Student-T test with a 95% confidence level.

(1) Topographic Parameters and Sediment Yield Relationships for the UK Data

(a) Topographic Parameters and Pseudo Steady-State Sediment Load

Table 5.5 shows the results of the linear regression analysis between link length, rill density, random roughness including subsoil and topsoil random roughness and pseudo steady state sediment load. The plots are displayed in Figures 5.5, 5.7, 5.9, 5.11, and 5.13. Using the Student-T test above relationships, the test results show that only the link length regression is significant to explain the variation in pseudo steady-state sediment load at the 95% confidence level.

(b) Topographic Parameters and Sediment Yield

A linear regression method also was used to analyze the relationship between link length, rill density, random roughness including subsoil and topsoil roughness and sediment yield. Table 5.6 shows the results of the linear regression analysis. Figures 5.4, 5.6, 5.8, 5.10, and 5.12 give the regression plots. Using the Student-T test, the results show that there is a significant relationship between subsoil surface random roughness and sediment yield at the 95% confidence level.

Table 5.5: Regression Results For Topographic Parameters and Pseudo Steady State Sediment Load for UK Data

Parameter	Intercept, b (kg/min)	Slope, m	R^2	Standard Error (kg/min)	Significant at 95% Confidence Level
Link Length	-0.88	1.53	0.50	1.27	Yes
Rill Density	8.28	-2.10	0.11	1.53	No
Random Roughness	2.59	0.13	0.05	1.65	No
Subsoil Random Roughness	3.34	0.14	0.11	1.28	No
Topsoil Random Roughness	3.40	0.01	0.00	1.53	No

Table 5.6: Regression Results for Topographic Parameters and Sediment Yield for the UK Data

Parameter	Intercept, b (kg)	Slope, m	R^2	Standard Error (kg)	Significant at 95% Confidence Level
Link Length	261	24	0.03	99.2	No
Rill Density	274	40	0.02	99.9	No
Random Roughness	131	14	0.20	90.3	No
Subsoil Random Roughness	34	20	0.62	49.0	Yes
Topsoil Random Roughness	185	11	0.09	131.2	No

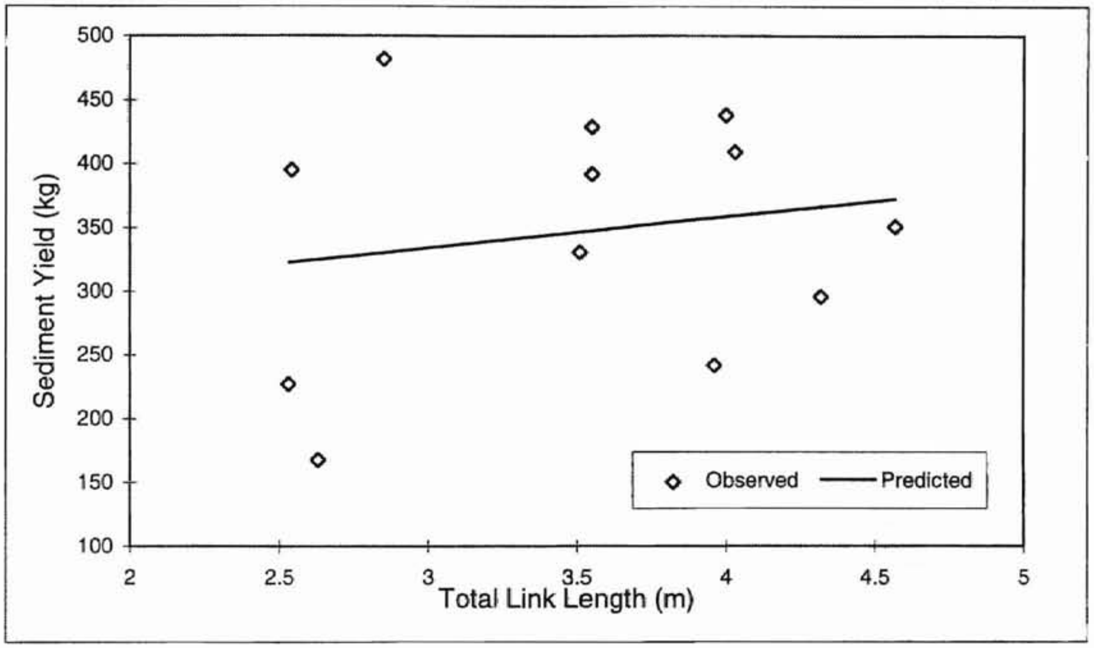


Figure 5.4: Total Link Length and Sediment Yield for the UK Data

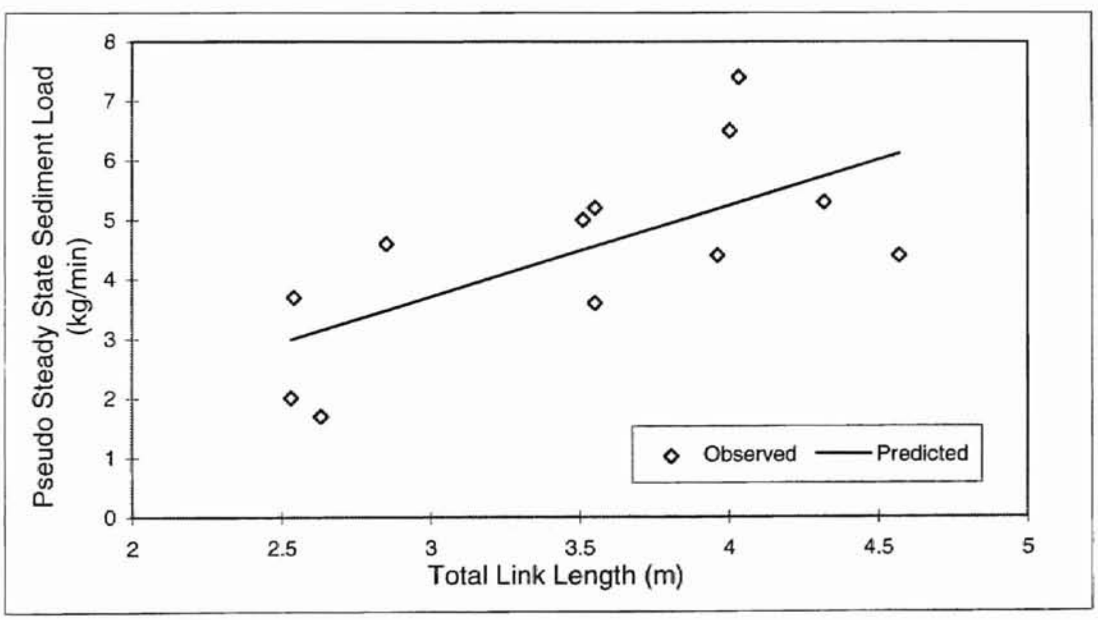


Figure 5.5: Total Link Length and Pseudo Steady State Sediment Load for the UK Data

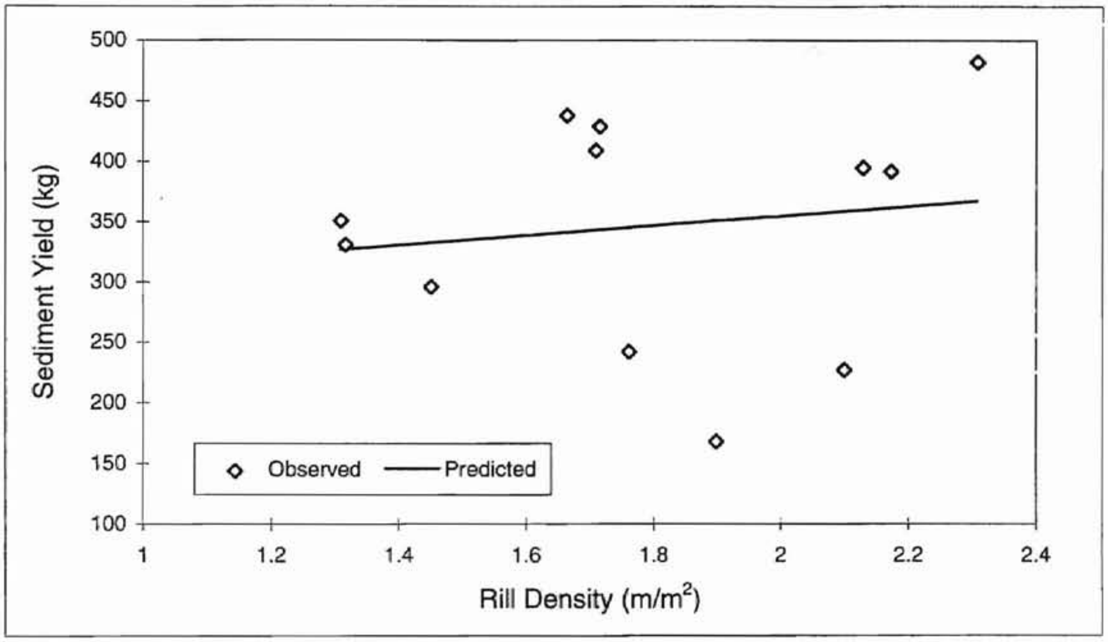


Figure 5.6: Rill Density and Sediment Yield for the UK Data

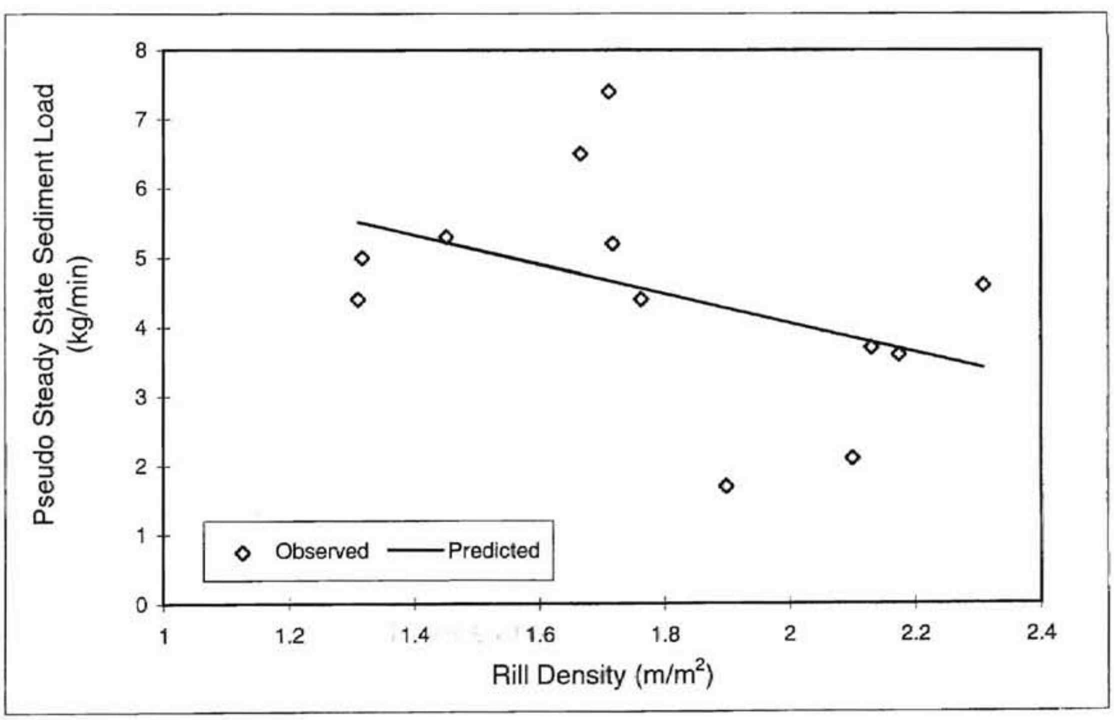


Figure 5.7: Rill Density and Pseudo Steady State Sediment Load for the UK Data

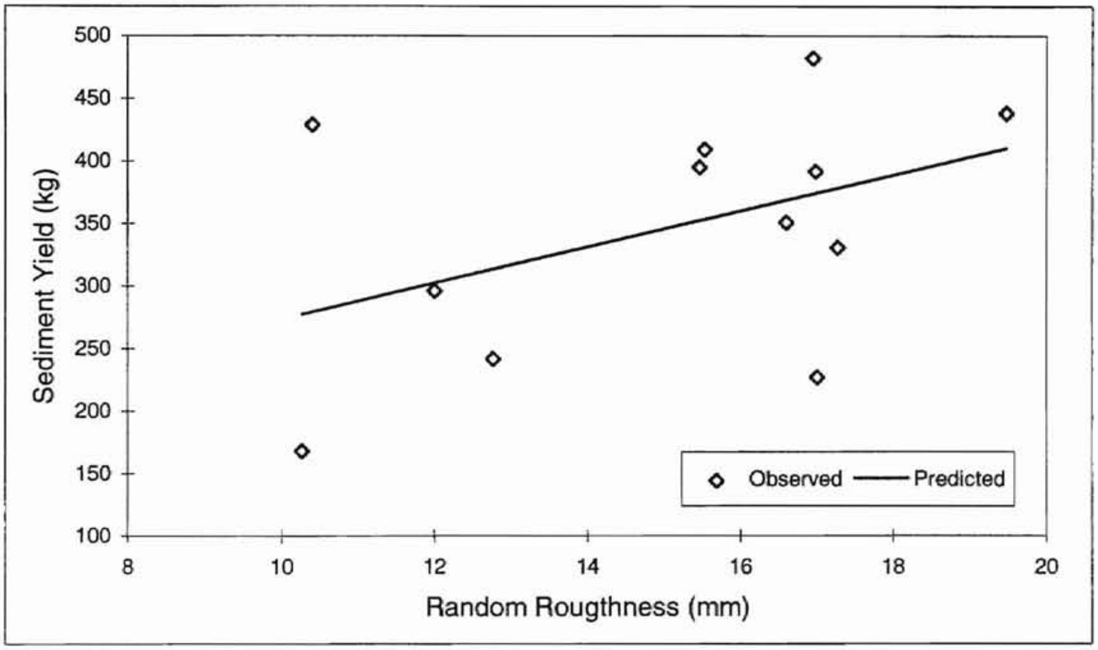


Figure 5.8: Random Roughness and Sediment Yield for the UK Data

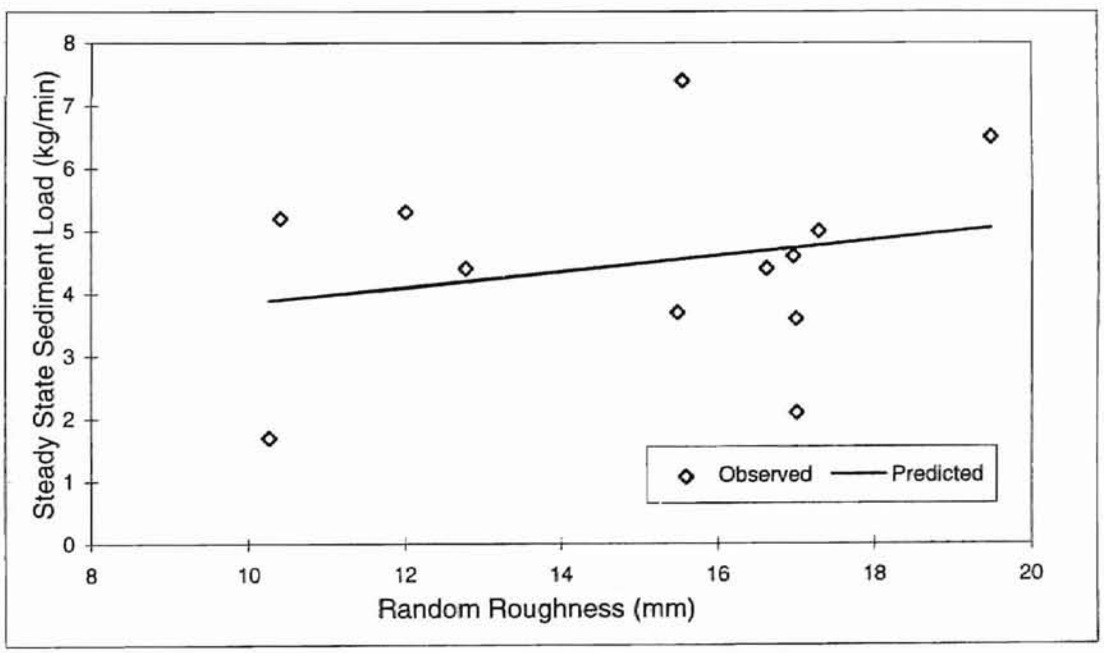


Figure 5.9: Random Rougthness and Pseudo Statedy State Sediment Load for the UK Data

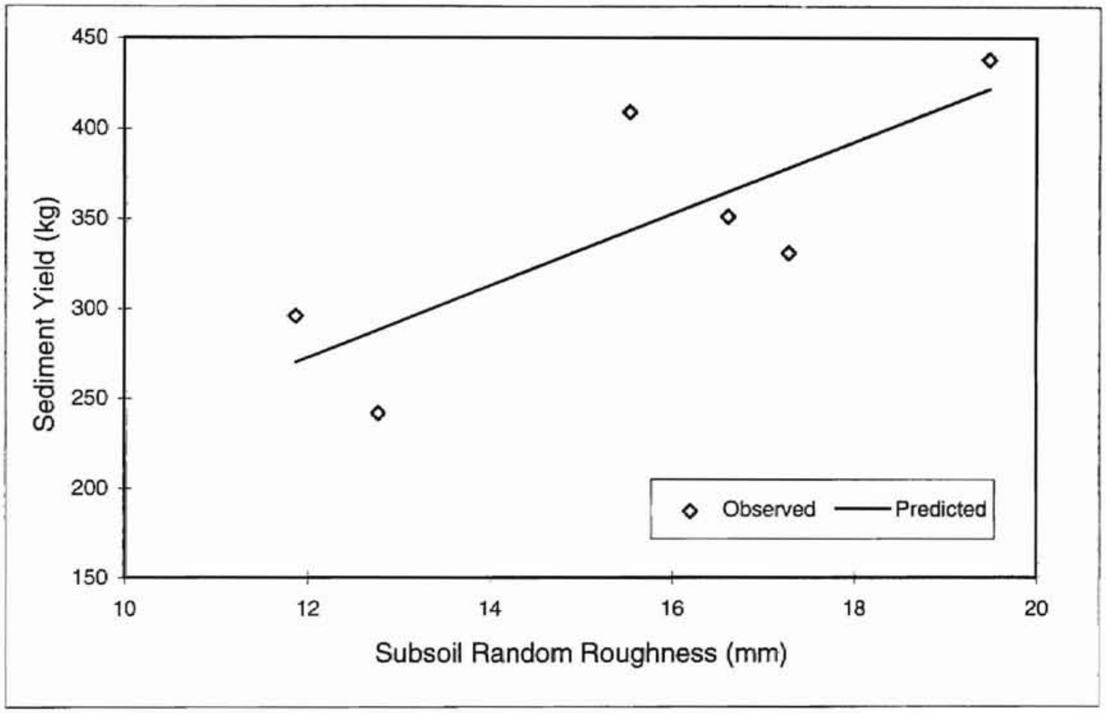


Figure 5.10: Subsoil Random Rougthness and Sediment Yield for the UK Data

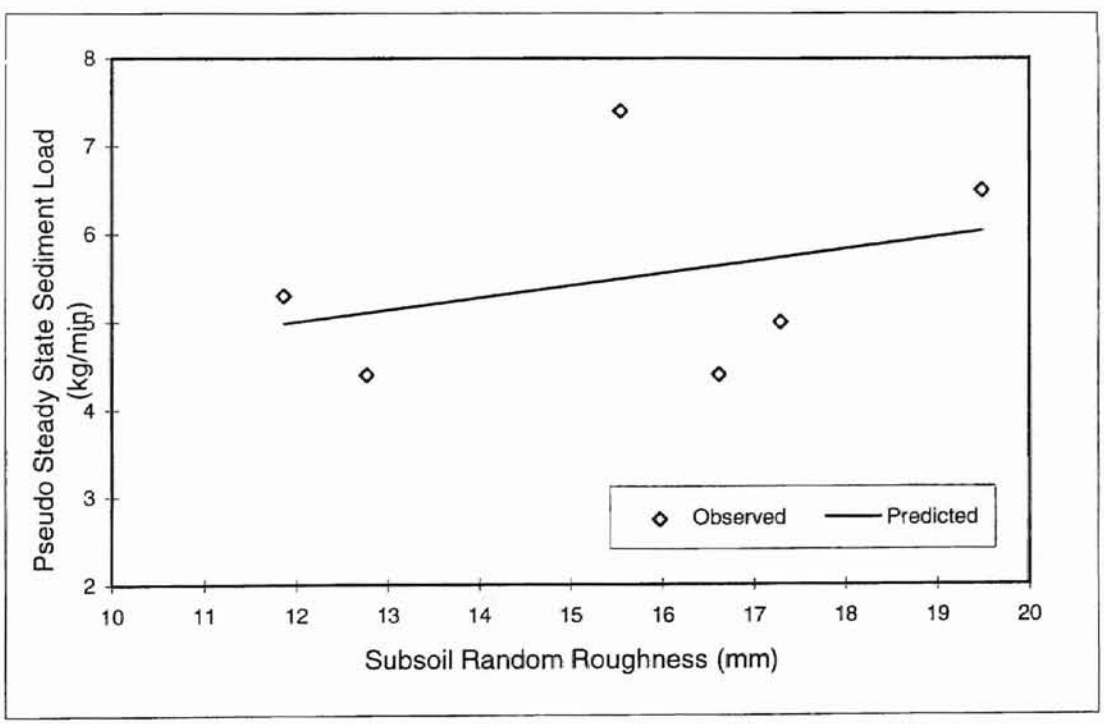


Figure 5.11: Subsoil Random Rougthness and Pseudo Seady State Sediment Load for the UK Data

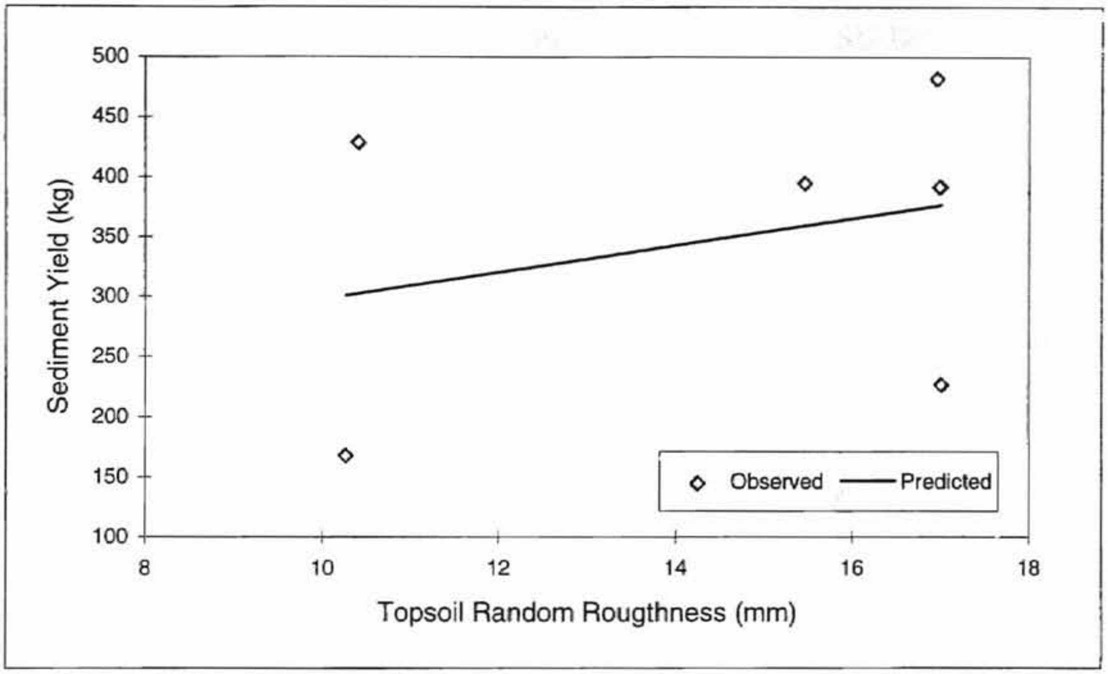


Figure 5.12: Topsoil Random Roughness and Sediment Yield for the UK Data

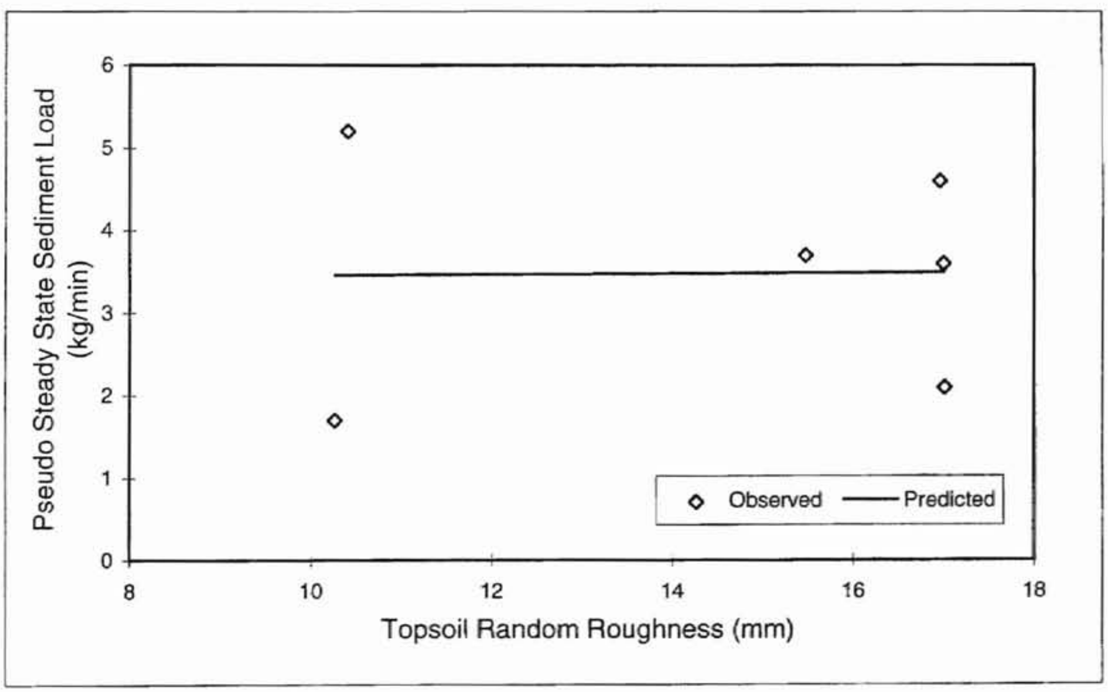


Figure 5.13: Topsoil Random Roughness and Pseudo Steady State Sediment Yield for the UK Data

(2) Topographic Parameters and Sediment Yield for the OSU Data

Table 5.7 lists topographic parameters for the OSU data. Because of the limited OSU data set, detailed statistics were not applied. Link length, rill density, and random roughness were compared graphically with sediment yield. These plots are shown in Figures 5.14 and 5.15. The plots indicate that rill density may be positively correlated with sediment yield, but the link length and random roughness have no clear tendency with sediment yield.

Table 5.7: Topographic Parameters for the OSU Data

ID Code	Random Roughness (mm)	Rill Density (m/m^2)	Mean Link Length (m)
AAA	9.5	0.98	1.65
ABA	8.2	0.90	3.02
ACA	12.4	0.80	1.88

For the UK data, it was also found that there are significant linear relationships between pseudo steady-state sediment load and total link length, and subsoil surface random roughness and sediment yield. The remaining parameters have no linear relationships with sediment yield or pseudo steady state sediment load. However, Mosley (1974) found that sediment yield from 112 rill systems were significant affected by slope

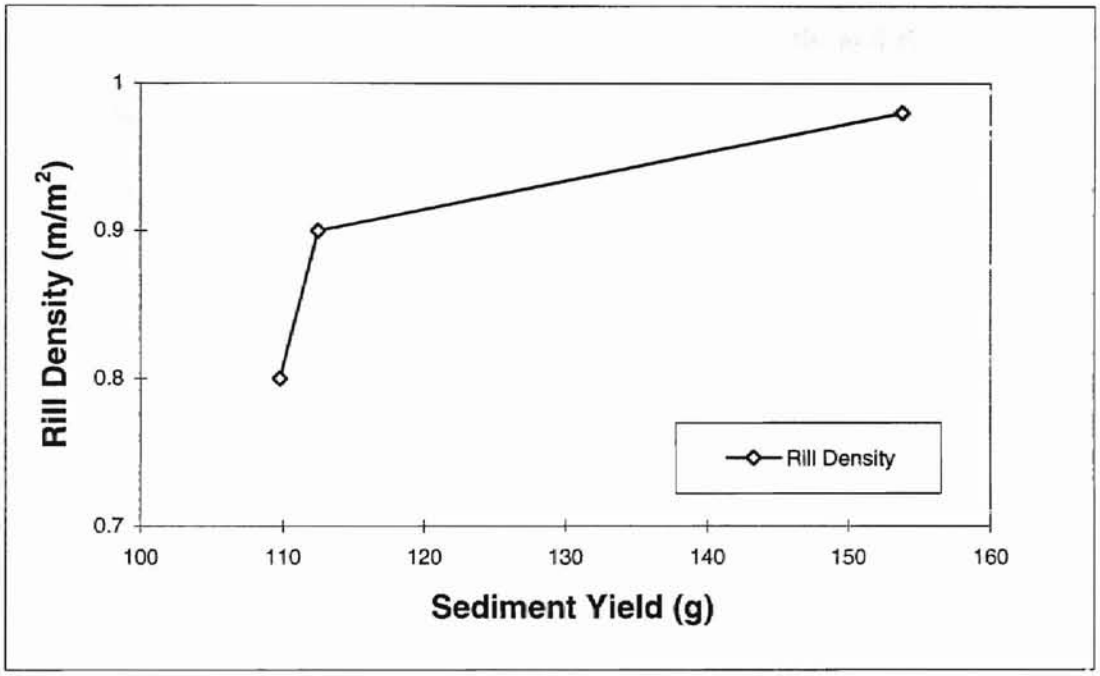


Figure 5.14: Sediment Yield vs Rill Density

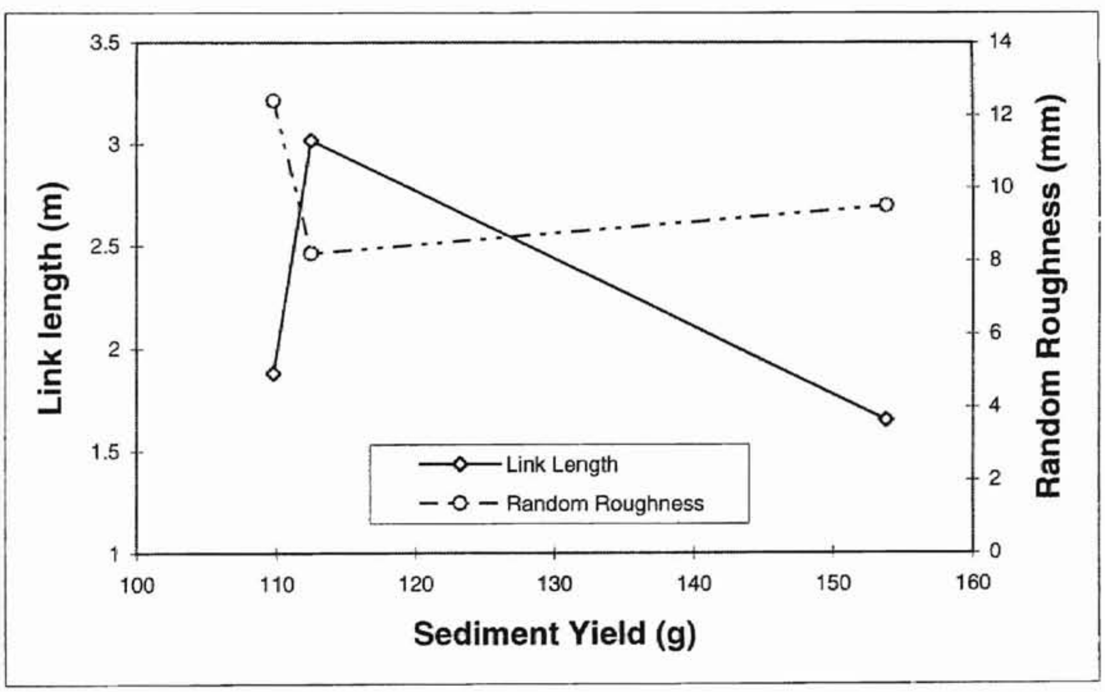


Figure 5.15: Sediment Yield vs Link Length and Random Roughness

shape, and were positively related to slope angle, slope length, and rill density per unit area. In the present study, rill density was not positively related with sediment yield. This reasons may be due in part to not considering different slopes in the analysis. From these results, it appears that a) the remaining parameters do not have a simple linear relationship with sediment yield or pseudo steady state sediment yield, b) the data variance is too great, c) the variables are not related, d) the range of data should be increased. More data are needed to evaluate these relationships further.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary

In this study, statistical characteristics of topographic parameters and their relationships with sediment yield were analyzed. A Digital Terrain Model (DTM) was used to extract topographic parameters from gridded digital elevation data and to generate rill networks. Data from the University of Kentucky erosion plots and the Oklahoma State University erosion table study were used to generate rill networks using a DTM model. First, the original gridded elevation data was transferred into a depressionless digital elevation model (DEM); Second, the processed data set was used to generate files defining the flow direction and flow accumulation values for each cell; Third, rill networks were delineated and watershed boundaries were outlined based on these two files, and the parameters of cells and watersheds characteristics were calculated. Finally, the information generated by the DTM were imported into the GRASS GIS for graphical display.

Four topological parameter, link length including total, exterior and interior link length, link drainage area, rill density and random roughness were computed for this study. For the University of Kentucky of link length statistical analysis, a Storm Water Management Program (SWAMP) was employed to estimate link length probability density functions. Normal, Log Normal, Extreme Value Type I, and Log Pearson Type III probability density functions were considered. Link length, including total, exterior, and interior link length, fit the Log-Normal distribution. A Chi-square goodness of test was used to judge the fit for this distribution. For the relationship of link length and link drainage area in the UK rill networks, the Student-T test shown that there are significant relationship with the 95% confidence level for all cases (Total, Exterior and Interior) with both power and linear functions. Linear regression equations were found to predict link drainage area as a function of exterior and total link length. A power equation was estimated to predict link drainage area for interior link lengths.

In order to investigate the possible relationships of sediment yield and topographic parameters, a linear regression was performed for three topographic parameters (mean total link length, random roughness and rill density) with pseudo steady state sediment load and sediment yield for the UK rill networks. The analysis results show that only link length is significant to explain the variation in pseudo steady sate sediment load, and random roughness for subsoil surface plots was significant to represent the variation in sediment yield. Other parameters have no significant relationship with sediment yield or pseudo steady state sediment yield. The OSU rill networks visually show a potential relationship for rill density and sediment yield, but link length and random roughness have no clear tendency with sediment yield.

Conclusions

The following points can be concluded from this research:

1. Most total link length, exterior link length, and interior link length for the UK rill networks fit a Log-Normal probability density function, which agree with previous research both rivers and small-scale drainage basins.

2. For the UK rill networks, link length and pseudo steady state sediment load are linearly related, and random roughness for the subsoil plots are linearly related with sediment yield. Rill density and random roughness, with the exception of the subsoil plots, have no significant relationship with sediment yield and pseudo steady state sediment yield.

3. For the UK data, total and exterior Link length and link drainage area are linearly related, and interior link length and link drainage area can be described by a power function. The results are similar to previous river basins research and especially close to previous small-scale drainage basin research.

Recommendation for Further Research

This research represents a preliminary study for the relationship of sediment yield and topographic parameters. There is still more work to be done. The following topics are suggested as deserving of further investigation:

1. Relationships between sediment yield and topographic parameters should be tested using more erosion and sediment data.

2. More complex interactions between topographic parameters and sediment yield and pseudo steady sate sediment load need to be evaluated. In addition, other topographic parameters may need to be investigated.

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APPENDIXES

APPENDIX A

Summary Rill Network Data

Summary Rill Network Data for the UK Data

Table A. 1: Summary Rill Network Data for the UK (S1R2.CHN)

T.R.	T.S.
7	37

(T.R. = Total Number of Rills, T.S. = Total Number of Subshed)

Number of Rill	Total # of Branch	Number of Bran. Cell	Number of Branch	Number of Interill Cell	Upstream Branch Numbers							
1	3	158	1	4555	0	0	0	0	0	0	0	0
1	3	194	2	5301	0	0	0	0	0	0	0	0
1	3	58	3	958	0	1	2	0	0	0	0	0
2	1	89	1	3623	0	0	0	0	0	0	0	0
3	11	22	1	3043	0	0	0	0	0	0	0	0
3	11	87	2	3349	0	0	0	0	0	0	0	0
3	11	274	3	6040	0	0	0	0	0	0	0	0
3	11	326	4	11138	0	0	0	0	0	0	0	0
3	11	284	5	9202	0	0	0	0	0	0	0	0
3	11	297	6	10430	0	0	0	0	0	0	0	0
3	11	263	7	7021	0	3	4	0	0	0	0	0
3	11	146	8	1987	0	5	6	0	0	0	0	0
3	11	133	9	1978	0	2	8	0	0	0	0	0
3	11	185	10	2014	0	9	7	0	0	0	0	0
3	11	35	11	316	0	10	1	0	0	0	0	0
4	5	13	1	2746	0	0	0	0	0	0	0	0
4	5	220	2	7001	0	0	0	0	0	0	0	0
4	5	197	3	7373	0	0	0	0	0	0	0	0
4	5	58	4	255	0	2	3	0	0	0	0	0
4	5	275	5	5506	0	1	4	0	0	0	0	0
5	1	252	1	6940	0	0	0	0	0	0	0	0
6	1	43	1	3459	0	0	0	0	0	0	0	0
7	7	534	1	14066	0	0	0	0	0	0	0	0
7	7	124	2	3451	0	0	0	0	0	0	0	0
7	7	100	3	3575	0	0	0	0	0	0	0	0
7	7	362	4	12109	0	0	0	0	0	0	0	0
7	7	97	5	1572	0	1	2	0	0	0	0	0
7	7	308	6	6747	0	3	4	0	0	0	0	0
7	7	84	7	1736	0	5	6	0	0	0	0	0
0	8	0	1	12267	0	0	0	0	0	0	0	0
0	8	0	2	12267	0	0	0	0	0	0	0	0
0	8	0	3	12267	0	0	0	0	0	0	0	0
0	8	0	4	12267	0	0	0	0	0	0	0	0
0	8	0	5	12267	0	0	0	0	0	0	0	0
0	8	0	6	12267	0	0	0	0	0	0	0	0
0	8	0	7	12267	0	0	0	0	0	0	0	0
0	8	0	8	12267	0	0	0	0	0	0	0	0

Table A. 2: Summary Rill Network Data for the UK (S2R2.CHN)

T.R.	T.S.	
8	51	(T.R. = Total Number of Rills, T.S. = Total Number of Subshed)

Number of Rill	Total # of Branch	Number of Bran. Cell	Number of Branch	Number of Interrill Cell	Upstream Branch Numbers						
1	9	464	1	6955	0	0	0	0	0	0	0
1	9	113	2	4689	0	0	0	0	0	0	0
1	9	125	3	2804	0	0	0	0	0	0	0
1	9	512	4	10108	0	0	0	0	0	0	0
1	9	30	5	2689	0	0	0	0	0	0	0
1	9	201	6	2439	1	2	0	0	0	0	0
1	9	8	7	130	6	3	0	0	0	0	0
1	9	76	8	889	7	4	0	0	0	0	0
1	9	26	9	199	8	5	0	0	0	0	0
2	7	269	1	7480	0	0	0	0	0	0	0
2	7	170	2	6808	0	0	0	0	0	0	0
2	7	79	3	4860	0	0	0	0	0	0	0
2	7	39	4	2412	0	0	0	0	0	0	0
2	7	126	5	3154	1	2	0	0	0	0	0
2	7	256	6	4306	5	3	0	0	0	0	0
2	7	142	7	2171	6	4	0	0	0	0	0
3	3	152	1	3464	0	0	0	0	0	0	0
3	3	18	2	2816	0	0	0	0	0	0	0
3	3	75	3	861	1	2	0	0	0	0	0
4	3	699	1	14021	0	0	0	0	0	0	0
4	3	25	2	2450	0	0	0	0	0	0	0
4	3	61	3	908	1	2	0	0	0	0	0
5	3	299	1	6196	0	0	0	0	0	0	0
5	3	104	2	3066	0	0	0	0	0	0	0
5	3	459	3	8489	1	2	0	0	0	0	0
6	1	195	1	5151	0	0	0	0	0	0	0
7	1	140	1	3706	0	0	0	0	0	0	0
8	15	162	1	4160	0	0	0	0	0	0	0
8	15	174	2	3988	0	0	0	0	0	0	0
8	15	197	3	4045	0	0	0	0	0	0	0
8	15	60	4	2740	0	0	0	0	0	0	0
8	15	50	5	2711	0	0	0	0	0	0	0
8	15	15	6	2203	0	0	0	0	0	0	0
8	15	375	7	5032	0	0	0	0	0	0	0
8	15	11	8	2168	0	0	0	0	0	0	0
8	15	81	9	966	1	2	0	0	0	0	0
8	15	60	10	639	3	4	0	0	0	0	0
8	15	133	11	1688	9	10	0	0	0	0	0
8	15	42	12	1110	5	6	0	0	0	0	0
8	15	113	13	1280	11	12	0	0	0	0	0
8	15	165	14	3185	13	7	0	0	0	0	0
8	15	98	15	585	14	8	0	0	0	0	0
0	9	0	1	7730	0	0	0	0	0	0	0
0	9	0	2	7730	0	0	0	0	0	0	0
0	9	0	3	7730	0	0	0	0	0	0	0
0	9	0	4	7730	0	0	0	0	0	0	0
0	9	0	5	7730	0	0	0	0	0	0	0
0	9	0	6	7730	0	0	0	0	0	0	0
0	9	0	7	7730	0	0	0	0	0	0	0
0	9	0	8	7730	0	0	0	0	0	0	0
0	9	0	9	7730	0	0	0	0	0	0	0

Table A. 3: Summary Rill Network Data for the UK (S3R2.CHN)

T.R.	T.S.	
8	47	(T.R. = Total Number of Rills, T.S. = Total Number of Subshed)

Number of Rill	Total # of Branch	Number of Bran. Cell	Number of Branch	Number of Interrill Cell	Upstream Branch Numbers							
1	1	238	1	6123	0	0	0	0	0	0	0	0
2	15	14	1	3369	0	0	0	0	0	0	0	0
2	15	17	2	3581	0	0	0	0	0	0	0	0
2	15	245	3	8238	0	0	0	0	0	0	0	0
2	15	101	4	3545	0	0	0	0	0	0	0	0
2	15	134	5	5955	0	0	0	0	0	0	0	0
2	15	60	6	2963	0	0	0	0	0	0	0	0
2	15	160	7	5608	0	0	0	0	0	0	0	0
2	15	252	8	8915	0	0	0	0	0	0	0	0
2	15	62	9	861	0	5	6	0	0	0	0	0
2	15	236	10	4026	0	7	8	0	0	0	0	0
2	15	252	11	9239	0	3	9	0	0	0	0	0
2	15	223	12	1786	0	4	10	0	0	0	0	0
2	15	225	13	6372	0	11	1	0	0	0	0	0
2	15	16	14	55	0	12	2	0	0	0	0	0
2	15	72	15	1068	0	13	14	0	0	0	0	0
3	1	50	1	3063	0	0	0	0	0	0	0	0
4	1	283	1	5803	0	0	0	0	0	0	0	0
5	1	98	1	3614	0	0	0	0	0	0	0	0
6	9	43	1	4808	0	0	0	0	0	0	0	0
6	9	48	2	3511	0	0	0	0	0	0	0	0
6	9	131	3	4306	0	0	0	0	0	0	0	0
6	9	269	4	5314	0	0	0	0	0	0	0	0
6	9	409	5	11131	0	0	0	0	0	0	0	0
6	9	36	6	229	0	4	5	0	0	0	0	0
6	9	12	7	120	0	3	6	0	0	0	0	0
6	9	115	8	970	0	7	2	0	0	0	0	0
6	9	176	9	2089	0	8	1	0	0	0	0	0
7	1	53	1	3442	0	0	0	0	0	0	0	0
8	9	161	1	4929	0	0	0	0	0	0	0	0
8	9	176	2	4646	0	0	0	0	0	0	0	0
8	9	41	3	2744	0	0	0	0	0	0	0	0
8	9	238	4	4393	0	0	0	0	0	0	0	0
8	9	69	5	3593	0	0	0	0	0	0	0	0
8	9	17	6	92	0	4	5	0	0	0	0	0
8	9	94	7	817	0	3	6	0	0	0	0	0
8	9	241	8	3284	0	2	7	0	0	0	0	0
8	9	178	9	1471	0	8	1	0	0	0	0	0
0	9	0	1	13685	0	0	0	0	0	0	0	0
0	9	0	2	13685	0	0	0	0	0	0	0	0
0	9	0	3	13685	0	0	0	0	0	0	0	0
0	9	0	4	13685	0	0	0	0	0	0	0	0
0	9	0	5	13685	0	0	0	0	0	0	0	0
0	9	0	6	13685	0	0	0	0	0	0	0	0
0	9	0	7	13685	0	0	0	0	0	0	0	0
0	9	0	8	13685	0	0	0	0	0	0	0	0
0	9	0	9	13685	0	0	0	0	0	0	0	0

Table A. 4: Summary Rill Network for the UK Data (S1S2.CHN)

T.R.	T.S.
9	55

(T.R. = Total Number of Rills, T.S. = Total Number of Subshed)

Number of Rill	Total # of Branch	Number of Bran. Cell	Number of Branch	Number of Interrill Cell	Upstream Branch Numbers							
1	3	123	1	3484	0	0	0	0	0	0	0	0
1	3	208	2	3902	0	0	0	0	0	0	0	0
1	3	36	3	212	0	1	2	0	0	0	0	0
2	5	530	1	10580	0	0	0	0	0	0	0	0
2	5	145	2	3367	0	0	0	0	0	0	0	0
2	5	220	3	3910	0	0	0	0	0	0	0	0
2	5	238	4	2859	0	2	3	0	0	0	0	0
2	5	264	5	4663	0	1	4	0	0	0	0	0
3	11	646	1	9902	0	0	0	0	0	0	0	0
3	11	225	2	4915	0	0	0	0	0	0	0	0
3	11	184	3	5458	0	0	0	0	0	0	0	0
3	11	33	4	1963	0	0	0	0	0	0	0	0
3	11	264	5	6244	0	0	0	0	0	0	0	0
3	11	215	6	5917	0	0	0	0	0	0	0	0
3	11	176	7	1928	0	5	6	0	0	0	0	0
3	11	33	8	463	0	7	4	0	0	0	0	0
3	11	146	9	2348	0	3	8	0	0	0	0	0
3	11	44	10	539	0	2	9	0	0	0	0	0
3	11	128	11	1981	0	10	1	0	0	0	0	0
4	1	99	1	2314	0	0	0	0	0	0	0	0
5	1	19	1	2018	0	0	0	0	0	0	0	0
6	1	202	1	5124	0	0	0	0	0	0	0	0
7	1	78	1	3004	0	0	0	0	0	0	0	0
8	21	21	1	1845	0	0	0	0	0	0	0	0
8	21	103	2	2777	0	0	0	0	0	0	0	0
8	21	121	3	3179	0	0	0	0	0	0	0	0
8	21	16	4	1789	0	0	0	0	0	0	0	0
8	21	72	5	3124	0	0	0	0	0	0	0	0
8	21	136	6	3215	0	0	0	0	0	0	0	0
8	21	104	7	2916	0	0	0	0	0	0	0	0
8	21	38	8	2153	0	0	0	0	0	0	0	0
8	21	103	9	2998	0	0	0	0	0	0	0	0
8	21	4	10	1575	0	0	0	0	0	0	0	0
8	21	88	11	3620	0	0	0	0	0	0	0	0
8	21	126	12	1582	0	3	4	0	0	0	0	0
8	21	273	13	6416	0	5	6	0	0	0	0	0
8	21	444	14	4579	0	7	8	0	0	0	0	0
8	21	36	15	1043	0	10	11	0	0	0	0	0
8	21	288	16	6684	0	9	15	0	0	0	0	0
8	21	111	17	3411	0	13	14	0	0	0	0	0
8	21	251	18	3399	0	16	2	0	0	0	0	0
8	21	18	19	166	0	18	12	0	0	0	0	0
8	21	55	20	749	0	19	17	0	0	0	0	0
8	21	105	21	1298	0	20	1	0	0	0	0	0
9	1	250	1	5526	0	0	0	0	0	0	0	0
0	10	0	1	8619	0	0	0	0	0	0	0	0
0	10	0	2	8619	0	0	0	0	0	0	0	0
0	10	0	3	8619	0	0	0	0	0	0	0	0
0	10	0	4	8619	0	0	0	0	0	0	0	0
0	10	0	5	8619	0	0	0	0	0	0	0	0
0	10	0	6	8619	0	0	0	0	0	0	0	0
0	10	0	7	8619	0	0	0	0	0	0	0	0
0	10	0	8	8619	0	0	0	0	0	0	0	0
0	10	0	9	8619	0	0	0	0	0	0	0	0
0	10	0	10	8619	0	0	0	0	0	0	0	0

Table A. 5: Summary Rill Network Data for the UK (S2S2.CHN)

T.R.	T.S.	
7	51	(T.R. = Total Number of Rills, T.S. = Total Number of Subshed)

Number of Rill	Total # of Branch	Number of Bran. Cell	Number of Branch	Number of Interrill Cell	Upstream Branch Numbers							
1	1	34	1	1991	0	0	0	0	0	0	0	0
2	5	95	1	2609	0	0	0	0	0	0	0	0
2	5	400	2	11156	0	0	0	0	0	0	0	0
2	5	7	3	1535	0	0	0	0	0	0	0	0
2	5	223	4	4236	0	2	3	0	0	0	0	0
2	5	144	5	3490	0	1	4	0	0	0	0	0
3	9	86	1	2635	0	0	0	0	0	0	0	0
3	9	236	2	5177	0	0	0	0	0	0	0	0
3	9	241	3	5725	0	0	0	0	0	0	0	0
3	9	207	4	4843	0	0	0	0	0	0	0	0
3	9	204	5	5192	0	0	0	0	0	0	0	0
3	9	234	6	4121	0	1	2	0	0	0	0	0
3	9	61	7	615	0	4	5	0	0	0	0	0
3	9	436	8	6513	0	7	3	0	0	0	0	0
3	9	69	9	970	0	6	8	0	0	0	0	0
4	3	43	1	2104	0	0	0	0	0	0	0	0
4	3	322	2	4569	0	0	0	0	0	0	0	0
4	3	187	3	3863	0	1	2	0	0	0	0	0
5	1	108	1	2812	0	0	0	0	0	0	0	0
6	7	5	1	1510	0	0	0	0	0	0	0	0
6	7	523	2	8337	0	0	0	0	0	0	0	0
6	7	45	3	3076	0	0	0	0	0	0	0	0
6	7	249	4	5378	0	0	0	0	0	0	0	0
6	7	106	5	3029	0	3	4	0	0	0	0	0
6	7	201	6	3304	0	2	5	0	0	0	0	0
6	7	40	7	225	0	1	6	0	0	0	0	0
7	17	288	1	7690	0	0	0	0	0	0	0	0
7	17	725	2	14845	0	0	0	0	0	0	0	0
7	17	10	3	1547	0	0	0	0	0	0	0	0
7	17	128	4	3753	0	0	0	0	0	0	0	0
7	17	102	5	2413	0	0	0	0	0	0	0	0
7	17	2	6	1579	0	0	0	0	0	0	0	0
7	17	6	7	1566	0	0	0	0	0	0	0	0
7	17	71	8	2341	0	0	0	0	0	0	0	0
7	17	152	9	3379	0	0	0	0	0	0	0	0
7	17	18	10	172	0	1	2	0	0	0	0	0
7	17	166	11	2356	0	6	7	0	0	0	0	0
7	17	45	12	779	0	8	9	0	0	0	0	0
7	17	57	13	1202	0	11	12	0	0	0	0	0
7	17	185	14	1995	0	13	5	0	0	0	0	0
7	17	220	15	3621	0	4	14	0	0	0	0	0
7	17	76	16	1029	0	3	15	0	0	0	0	0
7	17	57	17	797	0	10	16	0	0	0	0	0
0	8	0	1	9679	0	0	0	0	0	0	0	0
0	8	0	2	9679	0	0	0	0	0	0	0	0
0	8	0	3	9679	0	0	0	0	0	0	0	0
0	8	0	4	9679	0	0	0	0	0	0	0	0
0	8	0	5	9679	0	0	0	0	0	0	0	0
0	8	0	6	9679	0	0	0	0	0	0	0	0
0	8	0	7	9679	0	0	0	0	0	0	0	0
0	8	0	8	9679	0	0	0	0	0	0	0	0

Table A. 6: Summary Rill Network Data for the UK (S3S2.CHN)

T.R.	T.S.	
8	43	(T.R. = Total Number of Rills, T.S. = Total Number of Subshed)

Number of Rill	Total # of Branch	Number of Bran. Cell	Number of Branch	Number of Interrill Cell	Upstream Branch Numbers							
1	3	3	1	2007	0	0	0	0	0	0	0	0
1	3	301	2	8111	0	0	0	0	0	0	0	0
1	3	431	3	8633	0	1	2	0	0	0	0	0
2	7	16	1	2067	0	0	0	0	0	0	0	0
2	7	37	2	2514	0	0	0	0	0	0	0	0
2	7	67	3	3621	0	0	0	0	0	0	0	0
2	7	31	4	3563	0	0	0	0	0	0	0	0
2	7	102	5	1396	0	3	4	0	0	0	0	0
2	7	474	6	10542	0	5	2	0	0	0	0	0
2	7	146	7	1014	0	1	6	0	0	0	0	0
3	5	127	1	3154	0	0	0	0	0	0	0	0
3	5	168	2	6213	0	0	0	0	0	0	0	0
3	5	266	3	4700	0	0	0	0	0	0	0	0
3	5	77	4	1888	0	2	3	0	0	0	0	0
3	5	413	5	9579	0	1	4	0	0	0	0	0
4	5	63	1	3198	0	0	0	0	0	0	0	0
4	5	37	2	2401	0	0	0	0	0	0	0	0
4	5	270	3	8931	0	0	0	0	0	0	0	0
4	5	79	4	771	0	2	3	0	0	0	0	0
4	5	2	5	25	0	4	1	0	0	0	0	0
5	5	183	1	4833	0	0	0	0	0	0	0	0
5	5	207	2	5278	0	0	0	0	0	0	0	0
5	5	272	3	6960	0	0	0	0	0	0	0	0
5	5	255	4	4261	0	2	3	0	0	0	0	0
5	5	264	5	4636	0	4	1	0	0	0	0	0
6	5	167	1	5583	0	0	0	0	0	0	0	0
6	5	105	2	3358	0	0	0	0	0	0	0	0
6	5	349	3	10615	0	0	0	0	0	0	0	0
6	5	92	4	1568	0	2	3	0	0	0	0	0
6	5	362	5	6066	0	4	1	0	0	0	0	0
7	3	282	1	6476	0	0	0	0	0	0	0	0
7	3	16	2	2044	0	0	0	0	0	0	0	0
7	3	16	3	114	0	1	2	0	0	0	0	0
8	1	102	1	2986	0	0	0	0	0	0	0	0
0	9	0	1	10652	0	0	0	0	0	0	0	0
0	9	0	2	10652	0	0	0	0	0	0	0	0
0	9	0	3	10652	0	0	0	0	0	0	0	0
0	9	0	4	10652	0	0	0	0	0	0	0	0
0	9	0	5	10652	0	0	0	0	0	0	0	0
0	9	0	6	10652	0	0	0	0	0	0	0	0
0	9	0	7	10652	0	0	0	0	0	0	0	0
0	9	0	8	10652	0	0	0	0	0	0	0	0
0	9	0	9	10652	0	0	0	0	0	0	0	0

Table A. 7: Summary Rill Network Data for the UK (T1R2.CHN)

T.R.	T.S.	
7	57	(T.R. = Total Number of Rills, T.S. = Total Number of Subshed)

Number of Rill	Total # of Branch	Number of Bran. Cell	Number of Branch	Number of Interrill Cell	Upstream Branch Numbers							
1	9	59	1	2709	0	0	0	0	0	0	0	0
1	9	172	2	4175	0	0	0	0	0	0	0	0
1	9	36	3	1908	0	0	0	0	0	0	0	0
1	9	83	4	2803	0	0	0	0	0	0	0	0
1	9	76	5	3161	0	0	0	0	0	0	0	0
1	9	141	6	2519	0	4	5	0	0	0	0	0
1	9	300	7	4675	0	3	6	0	0	0	0	0
1	9	174	8	2988	0	2	7	0	0	0	0	0
1	9	84	9	2125	0	1	8	0	0	0	0	0
2	1	60	1	2409	0	0	0	0	0	0	0	0
3	11	60	1	2521	0	0	0	0	0	0	0	0
3	11	127	2	3570	0	0	0	0	0	0	0	0
3	11	1	3	2021	0	0	0	0	0	0	0	0
3	11	34	4	1794	0	0	0	0	0	0	0	0
3	11	55	5	2121	0	0	0	0	0	0	0	0
3	11	78	6	2533	0	0	0	0	0	0	0	0
3	11	394	7	5793	0	2	3	0	0	0	0	0
3	11	347	8	4483	0	5	6	0	0	0	0	0
3	11	155	9	2506	0	8	4	0	0	0	0	0
3	11	138	10	1781	0	7	9	0	0	0	0	0
3	11	83	11	850	0	1	10	0	0	0	0	0
4	3	306	1	5773	0	0	0	0	0	0	0	0
4	3	188	2	3440	0	0	0	0	0	0	0	0
4	3	240	3	3600	0	1	2	0	0	0	0	0
5	15	192	1	4711	0	0	0	0	0	0	0	0
5	15	165	2	4157	0	0	0	0	0	0	0	0
5	15	130	3	3404	0	0	0	0	0	0	0	0
5	15	196	4	3902	0	0	0	0	0	0	0	0
5	15	437	5	11106	0	0	0	0	0	0	0	0
5	15	25	6	1566	0	0	0	0	0	0	0	0
5	15	165	7	3133	0	0	0	0	0	0	0	0
5	15	97	8	3362	0	0	0	0	0	0	0	0
5	15	294	9	4055	0	7	8	0	0	0	0	0
5	15	5	10	30	0	6	9	0	0	0	0	0
5	15	62	11	371	0	5	10	0	0	0	0	0
5	15	39	12	402	0	4	11	0	0	0	0	0
5	15	188	13	2420	0	3	12	0	0	0	0	0
5	15	8	14	134	0	2	13	0	0	0	0	0
5	15	51	15	838	0	1	14	0	0	0	0	0
6	1	378	1	7307	0	0	0	0	0	0	0	0
7	9	3	1	1509	0	0	0	0	0	0	0	0
7	9	35	2	2475	0	0	0	0	0	0	0	0
7	9	98	3	2794	0	0	0	0	0	0	0	0
7	9	98	4	2423	0	0	0	0	0	0	0	0
7	9	66	5	3449	0	0	0	0	0	0	0	0
7	9	120	6	1614	0	4	5	0	0	0	0	0
7	9	34	7	216	0	3	6	0	0	0	0	0
7	9	385	8	7197	0	7	2	0	0	0	0	0
7	9	177	9	4735	0	8	1	0	0	0	0	0
0	8	0	1	10190	0	0	0	0	0	0	0	0
0	8	0	2	10190	0	0	0	0	0	0	0	0
0	8	0	3	10190	0	0	0	0	0	0	0	0
0	8	0	4	10190	0	0	0	0	0	0	0	0
0	8	0	5	10190	0	0	0	0	0	0	0	0
0	8	0	6	10190	0	0	0	0	0	0	0	0
0	8	0	7	10190	0	0	0	0	0	0	0	0
0	8	0	8	10190	0	0	0	0	0	0	0	0

Table A. 8: Summary Rill Network Data for the UK (T2R2.CHN)

T.R.	T.S.
9	83

(T.R. = Total Number of Rills, T.S. = Total Number of Subshed)

Number of Rill	Total # of Branch	Number of Bran. Cell	Number of Branch	Number of Interrill Cell	Upstream Branch Numbers							
1	13	70	1	1608	0	0	0	0	0	0	0	0
1	13	37	2	1464	0	0	0	0	0	0	0	0
1	13	77	3	1813	0	0	0	0	0	0	0	0
1	13	12	4	1137	0	0	0	0	0	0	0	0
1	13	25	5	1497	0	0	0	0	0	0	0	0
1	13	134	6	2653	0	0	0	0	0	0	0	0
1	13	1	7	1319	0	0	0	0	0	0	0	0
1	13	2	8	9	0	2	3	0	0	0	0	0
1	13	171	9	3376	0	6	7	0	0	0	0	0
1	13	85	10	1303	0	5	9	0	0	0	0	0
1	13	127	11	1923	0	10	4	0	0	0	0	0
1	13	136	12	1583	0	1	11	0	0	0	0	0
1	13	78	13	1403	0	12	8	0	0	0	0	0
2	1	49	1	2128	0	0	0	0	0	0	0	0
3	13	437	1	8181	0	0	0	0	0	0	0	0
3	13	138	2	2952	0	0	0	0	0	0	0	0
3	13	149	3	3697	0	0	0	0	0	0	0	0
3	13	104	4	2276	0	0	0	0	0	0	0	0
3	13	180	5	2951	0	0	0	0	0	0	0	0
3	13	107	6	3402	0	0	0	0	0	0	0	0
3	13	39	7	1379	0	0	0	0	0	0	0	0
3	13	95	8	1931	0	4	5	0	0	0	0	0
3	13	107	9	1600	0	6	7	0	0	0	0	0
3	13	68	10	950	0	9	3	0	0	0	0	0
3	13	151	11	3068	0	10	8	0	0	0	0	0
3	13	380	12	6342	0	2	11	0	0	0	0	0
3	13	41	13	234	0	12	1	0	0	0	0	0
4	1	38	1	1362	0	0	0	0	0	0	0	0
5	5	109	1	1715	0	0	0	0	0	0	0	0
5	5	184	2	2951	0	0	0	0	0	0	0	0
5	5	53	3	2085	0	0	0	0	0	0	0	0
5	5	431	4	6961	0	2	3	0	0	0	0	0
5	5	137	5	2420	0	4	1	0	0	0	0	0
6	21	9	1	1049	0	0	0	0	0	0	0	0
6	21	110	2	2222	0	0	0	0	0	0	0	0
6	21	90	3	2236	0	0	0	0	0	0	0	0
6	21	33	4	1441	0	0	0	0	0	0	0	0
6	21	51	5	1809	0	0	0	0	0	0	0	0
6	21	55	6	1739	0	0	0	0	0	0	0	0
6	21	16	7	1210	0	0	0	0	0	0	0	0
6	21	45	8	2784	0	0	0	0	0	0	0	0
6	21	41	9	1390	0	0	0	0	0	0	0	0
6	21	78	10	2029	0	0	0	0	0	0	0	0
6	21	36	11	1462	0	0	0	0	0	0	0	0
6	21	117	12	1038	0	8	9	0	0	0	0	0
6	21	122	13	1643	0	10	11	0	0	0	0	0
6	21	52	14	300	0	6	12	0	0	0	0	0
6	21	82	15	528	0	13	7	0	0	0	0	0
6	21	121	16	860	0	4	14	0	0	0	0	0
6	21	56	17	867	0	15	5	0	0	0	0	0
6	21	60	18	498	0	16	17	0	0	0	0	0
6	21	60	19	1636	0	18	3	0	0	0	0	0
6	21	251	20	2683	0	2	19	0	0	0	0	0
6	21	124	21	1624	0	1	20	0	0	0	0	0
7	7	14	1	1102	0	0	0	0	0	0	0	0
7	7	194	2	3790	0	0	0	0	0	0	0	0
7	7	8	3	1054	0	0	0	0	0	0	0	0
7	7	103	4	2335	0	0	0	0	0	0	0	0
7	7	141	5	2547	0	3	4	0	0	0	0	0
7	7	61	6	903	0	2	5	0	0	0	0	0
7	7	36	7	450	0	1	6	0	0	0	0	0
8	3	3	1	1038	0	0	0	0	0	0	0	0
8	3	31	2	1360	0	0	0	0	0	0	0	0
8	3	29	3	176	0	1	2	0	0	0	0	0
9	9	51	1	2325	0	0	0	0	0	0	0	0
9	9	537	2	8992	0	0	0	0	0	0	0	0
9	9	70	3	2335	0	0	0	0	0	0	0	0
9	9	35	4	1141	0	0	0	0	0	0	0	0
9	9	162	5	3249	0	0	0	0	0	0	0	0
9	9	206	6	3387	0	4	5	0	0	0	0	0
9	9	42	7	436	0	6	3	0	0	0	0	0
9	9	132	8	2026	0	2	7	0	0	0	0	0
9	9	148	9	3468	0	8	1	0	0	0	0	0
0	10	0	1	6923	0	0	0	0	0	0	0	0
0	10	0	2	6923	0	0	0	0	0	0	0	0
0	10	0	3	6923	0	0	0	0	0	0	0	0
0	10	0	4	6923	0	0	0	0	0	0	0	0
0	10	0	5	6923	0	0	0	0	0	0	0	0
0	10	0	6	6923	0	0	0	0	0	0	0	0
0	10	0	7	6923	0	0	0	0	0	0	0	0
0	10	0	8	6923	0	0	0	0	0	0	0	0
0	10	0	9	6923	0	0	0	0	0	0	0	0
0	10	0	10	6923	0	0	0	0	0	0	0	0

Table A. 9: Summary Rill Network Data for the UK (T3R2.CHN)

T.R.	T.S.
12	97

(T.R. = Total Number of Rills, T.S. = Total Number of Subshed)

Number of Rill	Total # of Branch	Number of Bran. Cell	Number of Branch	Number of Interill Cell	Upstream Branch Numbers						
1	1	286	1	5126	0	0	0	0	0	0	0
2	15	95	1	2527	0	0	0	0	0	0	0
2	15	88	2	2137	0	0	0	0	0	0	0
2	15	164	3	2196	0	0	0	0	0	0	0
2	15	42	4	1227	0	0	0	0	0	0	0
2	15	267	5	5011	0	0	0	0	0	0	0
2	15	12	6	1046	0	0	0	0	0	0	0
2	15	49	7	2092	0	0	0	0	0	0	0
2	15	21	8	1067	0	0	0	0	0	0	0
2	15	148	9	827	1	2	0	0	0	0	0
2	15	22	10	198	9	3	0	0	0	0	0
2	15	190	11	4113	10	4	0	0	0	0	0
2	15	47	12	938	5	6	0	0	0	0	0
2	15	87	13	1171	12	7	0	0	0	0	0
2	15	168	14	1335	11	13	0	0	0	0	0
2	15	192	15	1443	14	8	0	0	0	0	0
3	1	32	1	1193	0	0	0	0	0	0	0
4	19	101	1	3251	0	0	0	0	0	0	0
4	19	33	2	1236	0	0	0	0	0	0	0
4	19	37	3	2015	0	0	0	0	0	0	0
4	19	187	4	2999	0	0	0	0	0	0	0
4	19	44	5	1678	0	0	0	0	0	0	0
4	19	163	6	2424	0	0	0	0	0	0	0
4	19	2	7	1017	0	0	0	0	0	0	0
4	19	50	8	1606	0	0	0	0	0	0	0
4	19	320	9	4758	0	0	0	0	0	0	0
4	19	170	10	2891	0	0	0	0	0	0	0
4	19	76	11	1347	1	2	0	0	0	0	0
4	19	104	12	821	11	3	0	0	0	0	0
4	19	39	13	425	12	4	0	0	0	0	0
4	19	108	14	1877	13	5	0	0	0	0	0
4	19	85	15	687	14	6	0	0	0	0	0
4	19	34	16	264	15	7	0	0	0	0	0
4	19	16	17	108	16	8	0	0	0	0	0
4	19	139	18	2013	17	9	0	0	0	0	0
4	19	143	19	2418	18	10	0	0	0	0	0
5	1	67	1	1595	0	0	0	0	0	0	0
6	1	201	1	3735	0	0	0	0	0	0	0
7	5	451	1	5892	0	0	0	0	0	0	0
7	5	102	2	1766	0	0	0	0	0	0	0
7	5	7	3	1040	0	0	0	0	0	0	0
7	5	7	4	161	1	2	0	0	0	0	0
7	5	69	5	909	4	3	0	0	0	0	0
8	1	66	1	2451	0	0	0	0	0	0	0
9	27	132	1	2497	0	0	0	0	0	0	0
9	27	12	2	1150	0	0	0	0	0	0	0
9	27	99	3	2678	0	0	0	0	0	0	0
9	27	5	4	1431	0	0	0	0	0	0	0
9	27	69	5	1683	0	0	0	0	0	0	0
9	27	190	6	2173	0	0	0	0	0	0	0
9	27	15	7	1155	0	0	0	0	0	0	0
9	27	26	8	1255	0	0	0	0	0	0	0
9	27	201	9	3640	0	0	0	0	0	0	0
9	27	29	10	1227	0	0	0	0	0	0	0
9	27	53	11	1556	0	0	0	0	0	0	0
9	27	33	12	1309	0	0	0	0	0	0	0
9	27	75	13	1829	0	0	0	0	0	0	0
9	27	63	14	1781	0	0	0	0	0	0	0
9	27	115	15	2004	1	2	0	0	0	0	0
9	27	128	16	987	3	4	0	0	0	0	0
9	27	155	17	3043	15	16	0	0	0	0	0
9	27	51	18	566	17	5	0	0	0	0	0
9	27	38	19	482	6	7	0	0	0	0	0
9	27	97	20	1492	18	19	0	0	0	0	0
9	27	29	21	307	20	8	0	0	0	0	0
9	27	127	22	1154	9	10	0	0	0	0	0
9	27	18	23	214	22	11	0	0	0	0	0
9	27	83	24	1649	21	23	0	0	0	0	0
9	27	45	25	583	24	12	0	0	0	0	0
9	27	35	26	326	25	13	0	0	0	0	0
9	27	95	27	1115	26	14	0	0	0	0	0
10	1	55	1	1343	0	0	0	0	0	0	0
11	9	424	1	7740	0	0	0	0	0	0	0
11	9	399	2	6408	0	0	0	0	0	0	0
11	9	19	3	1119	0	0	0	0	0	0	0
11	9	44	4	1213	0	0	0	0	0	0	0
11	9	57	5	1591	0	0	0	0	0	0	0
11	9	119	6	995	1	2	0	0	0	0	0
11	9	40	7	426	6	3	0	0	0	0	0
11	9	5	8	6	7	4	0	0	0	0	0
11	9	243	9	2160	8	5	0	0	0	0	0
12	3	164	1	3223	0	0	0	0	0	0	0
12	3	9	2	1075	0	0	0	0	0	0	0
12	3	30	3	317	1	2	0	0	0	0	0
0	13	0	1	5696	0	0	0	0	0	0	0
0	13	0	2	5696	0	0	0	0	0	0	0
0	13	0	3	5696	0	0	0	0	0	0	0
0	13	0	4	5696	0	0	0	0	0	0	0
0	13	0	5	5696	0	0	0	0	0	0	0
0	13	0	6	5696	0	0	0	0	0	0	0
0	13	0	7	5696	0	0	0	0	0	0	0
0	13	0	8	5696	0	0	0	0	0	0	0
0	13	0	9	5696	0	0	0	0	0	0	0
0	13	0	10	5696	0	0	0	0	0	0	0
0	13	0	11	5696	0	0	0	0	0	0	0
0	13	0	12	5696	0	0	0	0	0	0	0
0	13	0	13	5696	0	0	0	0	0	0	0

Table A. 10: Summary Rill Network Data for the UK (T1V2.CHN)

T.R.	T.S.
12	95

(T.R. = Total Number of Rills, T.S. = Total Number of Subshed)

Number of Rill	Total # of Branch	Number of Bran. Cell	Number of Branch	Number of Interill Cell	Upstream Branch Numbers							
1	17	202	1	2752	0	0	0	0	0	0	0	0
1	17	97	2	1700	0	0	0	0	0	0	0	0
1	17	155	3	2204	0	0	0	0	0	0	0	0
1	17	130	4	2506	0	0	0	0	0	0	0	0
1	17	258	5	3814	0	0	0	0	0	0	0	0
1	17	72	6	1586	0	0	0	0	0	0	0	0
1	17	98	7	1919	0	0	0	0	0	0	0	0
1	17	220	8	2693	0	0	0	0	0	0	0	0
1	17	336	9	5066	0	0	0	0	0	0	0	0
1	17	52	10	483	0	6	7	0	0	0	0	0
1	17	41	11	285	0	8	9	0	0	0	0	0
1	17	581	12	6687	0	10	4	0	0	0	0	0
1	17	114	13	1017	0	11	5	0	0	0	0	0
1	17	91	14	1134	0	2	12	0	0	0	0	0
1	17	145	15	1350	0	3	13	0	0	0	0	0
1	17	153	16	1228	0	15	1	0	0	0	0	0
1	17	11	17	131	0	16	14	0	0	0	0	0
2	1	282	1	4431	0	0	0	0	0	0	0	0
3	1	37	1	1592	0	0	0	0	0	0	0	0
4	1	83	1	1531	0	0	0	0	0	0	0	0
5	15	15	1	854	0	0	0	0	0	0	0	0
5	15	483	2	8790	0	0	0	0	0	0	0	0
5	15	178	3	3079	0	0	0	0	0	0	0	0
5	15	47	4	1280	0	0	0	0	0	0	0	0
5	15	11	5	866	0	0	0	0	0	0	0	0
5	15	166	6	3607	0	0	0	0	0	0	0	0
5	15	32	7	1467	0	0	0	0	0	0	0	0
5	15	20	8	984	0	0	0	0	0	0	0	0
5	15	226	9	3805	0	2	3	0	0	0	0	0
5	15	223	10	3366	0	7	8	0	0	0	0	0
5	15	78	11	1127	0	6	10	0	0	0	0	0
5	15	324	12	6589	0	5	11	0	0	0	0	0
5	15	40	13	641	0	4	12	0	0	0	0	0
5	15	30	14	405	0	9	13	0	0	0	0	0
5	15	111	15	1178	0	1	14	0	0	0	0	0
6	1	167	1	3163	0	0	0	0	0	0	0	0
7	27	24	1	968	0	0	0	0	0	0	0	0
7	27	157	2	3488	0	0	0	0	0	0	0	0
7	27	64	3	1345	0	0	0	0	0	0	0	0
7	27	30	4	879	0	0	0	0	0	0	0	0
7	27	31	5	984	0	0	0	0	0	0	0	0
7	27	98	6	1462	0	0	0	0	0	0	0	0
7	27	52	7	1220	0	0	0	0	0	0	0	0
7	27	108	8	1864	0	0	0	0	0	0	0	0
7	27	94	9	2215	0	0	0	0	0	0	0	0
7	27	16	10	819	0	0	0	0	0	0	0	0
7	27	54	11	1614	0	0	0	0	0	0	0	0
7	27	124	12	2365	0	0	0	0	0	0	0	0
7	27	75	13	1489	0	0	0	0	0	0	0	0
7	27	2	14	761	0	0	0	0	0	0	0	0
7	27	83	15	951	0	5	6	0	0	0	0	0
7	27	66	16	1081	0	13	14	0	0	0	0	0
7	27	81	17	812	0	16	12	0	0	0	0	0
7	27	42	18	270	0	17	11	0	0	0	0	0
7	27	49	19	471	0	18	10	0	0	0	0	0
7	27	79	20	903	0	9	19	0	0	0	0	0
7	27	33	21	552	0	8	20	0	0	0	0	0
7	27	122	22	1515	0	21	7	0	0	0	0	0
7	27	19	23	431	0	15	22	0	0	0	0	0
7	27	113	24	1361	0	4	23	0	0	0	0	0
7	27	14	25	62	0	24	3	0	0	0	0	0
7	27	47	26	627	0	25	2	0	0	0	0	0
7	27	92	27	1139	0	1	26	0	0	0	0	0
8	1	8	1	799	0	0	0	0	0	0	0	0
9	1	269	1	3856	0	0	0	0	0	0	0	0
10	15	20	1	858	0	0	0	0	0	0	0	0
10	15	411	2	4579	0	0	0	0	0	0	0	0
10	15	33	3	892	0	0	0	0	0	0	0	0
10	15	138	4	2496	0	0	0	0	0	0	0	0
10	15	18	5	944	0	0	0	0	0	0	0	0
10	15	73	6	1266	0	0	0	0	0	0	0	0
10	15	6	7	1284	0	0	0	0	0	0	0	0
10	15	31	8	1374	0	0	0	0	0	0	0	0
10	15	113	9	2307	0	7	8	0	0	0	0	0
10	15	123	10	1936	0	9	6	0	0	0	0	0
10	15	130	11	1953	0	5	10	0	0	0	0	0
10	15	55	12	674	0	4	11	0	0	0	0	0
10	15	36	13	367	0	12	3	0	0	0	0	0
10	15	83	14	1833	0	13	2	0	0	0	0	0
10	15	274	15	4195	0	1	14	0	0	0	0	0
11	1	42	1	1319	0	0	0	0	0	0	0	0
12	1	257	1	3740	0	0	0	0	0	0	0	0
0	13	0	1	6108	0	0	0	0	0	0	0	0
0	13	0	2	6108	0	0	0	0	0	0	0	0
0	13	0	3	6108	0	0	0	0	0	0	0	0
0	13	0	4	6108	0	0	0	0	0	0	0	0
0	13	0	5	6108	0	0	0	0	0	0	0	0
0	13	0	6	6108	0	0	0	0	0	0	0	0
0	13	0	7	6108	0	0	0	0	0	0	0	0
0	13	0	8	6108	0	0	0	0	0	0	0	0
0	13	0	9	6108	0	0	0	0	0	0	0	0
0	13	0	10	6108	0	0	0	0	0	0	0	0
0	13	0	11	6108	0	0	0	0	0	0	0	0
0	13	0	12	6108	0	0	0	0	0	0	0	0
0	13	0	13	6108	0	0	0	0	0	0	0	0

Table A. 11: Summary Rill Network Data for the UK (T2V2.CHN)

T.R.	T.S.											
10	99	(T.R. = Total Number of Rills, T.S. = Total Number of Subshed)										

Number of Rill	Total # of Branch	Number of Bran. Cell	Number of Branch	Number of Interrill Cell	Upstream Branch Numbers							
1	1	49	1	1156	0	0	0	0	0	0	0	0
2	17	2	1	766	0	0	0	0	0	0	0	0
2	17	5	2	799	0	0	0	0	0	0	0	0
2	17	55	3	1337	0	0	0	0	0	0	0	0
2	17	221	4	3931	0	0	0	0	0	0	0	0
2	17	22	5	651	0	0	0	0	0	0	0	0
2	17	237	6	3601	0	0	0	0	0	0	0	0
2	17	141	7	1533	0	0	0	0	0	0	0	0
2	17	114	8	1527	0	0	0	0	0	0	0	0
2	17	151	9	3342	0	0	0	0	0	0	0	0
2	17	130	10	3363	0	8	9	0	0	0	0	0
2	17	108	11	1707	0	10	7	0	0	0	0	0
2	17	139	12	2479	0	6	11	0	0	0	0	0
2	17	42	13	1039	0	12	5	0	0	0	0	0
2	17	89	14	2043	0	4	13	0	0	0	0	0
2	17	65	15	1768	0	3	14	0	0	0	0	0
2	17	81	16	543	0	15	2	0	0	0	0	0
2	17	14	17	132	0	16	1	0	0	0	0	0
3	3	115	1	1701	0	0	0	0	0	0	0	0
3	3	4	2	805	0	0	0	0	0	0	0	0
3	3	28	3	280	0	1	2	0	0	0	0	0
4	7	2	1	774	0	0	0	0	0	0	0	0
4	7	42	2	995	0	0	0	0	0	0	0	0
4	7	92	3	1498	0	0	0	0	0	0	0	0
4	7	198	4	3095	0	0	0	0	0	0	0	0
4	7	26	5	692	0	3	4	0	0	0	0	0
4	7	186	6	2472	0	2	5	0	0	0	0	0
4	7	29	7	203	0	6	1	0	0	0	0	0
5	21	50	1	1213	0	0	0	0	0	0	0	0
5	21	24	2	979	0	0	0	0	0	0	0	0
5	21	161	3	2939	0	0	0	0	0	0	0	0
5	21	125	4	2420	0	0	0	0	0	0	0	0
5	21	199	5	2637	0	0	0	0	0	0	0	0
5	21	80	6	2035	0	0	0	0	0	0	0	0
5	21	116	7	2122	0	0	0	0	0	0	0	0
5	21	117	8	2165	0	0	0	0	0	0	0	0
5	21	16	9	799	0	0	0	0	0	0	0	0
5	21	44	10	1961	0	0	0	0	0	0	0	0
5	21	71	11	1422	0	0	0	0	0	0	0	0
5	21	78	12	669	0	7	8	0	0	0	0	0
5	21	20	13	429	0	10	11	0	0	0	0	0
5	21	163	14	1895	0	5	12	0	0	0	0	0
5	21	67	15	1006	0	9	13	0	0	0	0	0
5	21	152	16	1936	0	14	3	0	0	0	0	0
5	21	257	17	3557	0	6	15	0	0	0	0	0
5	21	119	18	1216	0	17	4	0	0	0	0	0
5	21	18	19	158	0	16	18	0	0	0	0	0
5	21	125	20	1234	0	19	2	0	0	0	0	0
5	21	155	21	2247	0	20	1	0	0	0	0	0
6	17	16	1	768	0	0	0	0	0	0	0	0
6	17	23	2	862	0	0	0	0	0	0	0	0
6	17	19	3	846	0	0	0	0	0	0	0	0
6	17	54	4	1310	0	0	0	0	0	0	0	0
6	17	122	5	2441	0	0	0	0	0	0	0	0
6	17	21	6	1351	0	0	0	0	0	0	0	0
6	17	72	7	2092	0	0	0	0	0	0	0	0
6	17	52	8	1941	0	0	0	0	0	0	0	0
6	17	9	9	795	0	0	0	0	0	0	0	0
6	17	70	10	1212	0	4	5	0	0	0	0	0
6	17	82	11	1242	0	8	9	0	0	0	0	0
6	17	114	12	1663	0	7	11	0	0	0	0	0
6	17	4	13	31	0	6	12	0	0	0	0	0
6	17	241	14	4292	0	3	13	0	0	0	0	0
6	17	244	15	3187	0	14	10	0	0	0	0	0
6	17	81	16	1296	0	2	15	0	0	0	0	0
6	17	24	17	168	0	1	16	0	0	0	0	0
7	3	217	1	3623	0	0	0	0	0	0	0	0
7	3	190	2	4615	0	0	0	0	0	0	0	0
7	3	136	3	1281	0	1	2	0	0	0	0	0
8	3	20	1	829	0	0	0	0	0	0	0	0
8	3	53	2	1386	0	0	0	0	0	0	0	0
8	3	33	3	174	0	1	2	0	0	0	0	0
9	15	39	1	1422	0	0	0	0	0	0	0	0
9	15	183	2	2874	0	0	0	0	0	0	0	0
9	15	59	3	1192	0	0	0	0	0	0	0	0
9	15	26	4	944	0	0	0	0	0	0	0	0
9	15	298	5	6251	0	0	0	0	0	0	0	0
9	15	109	6	2022	0	0	0	0	0	0	0	0
9	15	179	7	4150	0	0	0	0	0	0	0	0
9	15	195	8	3739	0	0	0	0	0	0	0	0
9	15	120	9	2492	0	4	5	0	0	0	0	0
9	15	118	10	919	0	7	8	0	0	0	0	0
9	15	175	11	2283	0	6	10	0	0	0	0	0
9	15	87	12	553	0	11	3	0	0	0	0	0
9	15	133	13	2098	0	12	9	0	0	0	0	0
9	15	54	14	219	0	2	13	0	0	0	0	0
9	15	66	15	1355	0	14	1	0	0	0	0	0
10	1	204	1	3535	0	0	0	0	0	0	0	0
0	11	0	1	6714	0	0	0	0	0	0	0	0
0	11	0	2	6714	0	0	0	0	0	0	0	0
0	11	0	3	6714	0	0	0	0	0	0	0	0
0	11	0	4	6714	0	0	0	0	0	0	0	0
0	11	0	5	6714	0	0	0	0	0	0	0	0
0	11	0	6	6714	0	0	0	0	0	0	0	0
0	11	0	7	6714	0	0	0	0	0	0	0	0
0	11	0	8	6714	0	0	0	0	0	0	0	0
0	11	0	9	6714	0	0	0	0	0	0	0	0
0	11	0	10	6714	0	0	0	0	0	0	0	0
0	11	0	11	6714	0	0	0	0	0	0	0	0

Table A. 12: Summary Rill Network Data for the UK (T3V2.CHN)

T.R.	T.S.	
12	75	(T.R. = Total Number of Rills, T.S. = Total Number of Subshed)

Number of Rill	Total # of Branch	Number of Bran. Cell	Number of Branch	Number of Interrill Cell	Upstream Branch Numbers							
1	1	92	1	1641	0	0	0	0	0	0	0	0
2	19	309	1	5069	0	0	0	0	0	0	0	0
2	19	525	2	7747	0	0	0	0	0	0	0	0
2	19	6	3	1019	0	0	0	0	0	0	0	0
2	19	25	4	1177	0	0	0	0	0	0	0	0
2	19	204	5	3830	0	0	0	0	0	0	0	0
2	19	25	6	1167	0	0	0	0	0	0	0	0
2	19	54	7	1552	0	0	0	0	0	0	0	0
2	19	22	8	1232	0	0	0	0	0	0	0	0
2	19	272	9	5176	0	0	0	0	0	0	0	0
2	19	34	10	1243	0	0	0	0	0	0	0	0
2	19	359	11	4901	0	6	7	0	0	0	0	0
2	19	69	12	327	0	9	10	0	0	0	0	0
2	19	116	13	1810	0	4	11	0	0	0	0	0
2	19	38	14	217	0	12	8	0	0	0	0	0
2	19	171	15	2964	0	2	13	0	0	0	0	0
2	19	175	16	1731	0	14	5	0	0	0	0	0
2	19	122	17	1852	0	16	3	0	0	0	0	0
2	19	33	18	328	0	15	17	0	0	0	0	0
2	19	86	19	1482	0	18	1	0	0	0	0	0
3	1	36	1	1387	0	0	0	0	0	0	0	0
4	3	72	1	1972	0	0	0	0	0	0	0	0
4	3	55	2	1623	0	0	0	0	0	0	0	0
4	3	27	3	407	0	1	2	0	0	0	0	0
5	3	126	1	3185	0	0	0	0	0	0	0	0
5	3	18	2	1126	0	0	0	0	0	0	0	0
5	3	153	3	2022	0	1	2	0	0	0	0	0
6	1	58	1	1419	0	0	0	0	0	0	0	0
7	7	564	1	9169	0	0	0	0	0	0	0	0
7	7	386	2	6522	0	0	0	0	0	0	0	0
7	7	32	3	1397	0	0	0	0	0	0	0	0
7	7	34	4	1541	0	0	0	0	0	0	0	0
7	7	277	5	2874	0	3	4	0	0	0	0	0
7	7	259	6	3766	0	5	2	0	0	0	0	0
7	7	208	7	1757	0	1	6	0	0	0	0	0
8	9	126	1	3648	0	0	0	0	0	0	0	0
8	9	226	2	5441	0	0	0	0	0	0	0	0
8	9	204	3	3852	0	0	0	0	0	0	0	0
8	9	23	4	1196	0	0	0	0	0	0	0	0
8	9	174	5	4647	0	0	0	0	0	0	0	0
8	9	239	6	3849	0	4	5	0	0	0	0	0
8	9	178	7	2068	0	3	6	0	0	0	0	0
8	9	205	8	3825	0	7	2	0	0	0	0	0
8	9	26	9	864	0	1	8	0	0	0	0	0
9	5	83	1	1752	0	0	0	0	0	0	0	0
9	5	105	2	1731	0	0	0	0	0	0	0	0
9	5	383	3	5782	0	0	0	0	0	0	0	0
9	5	243	4	2634	0	2	3	0	0	0	0	0
9	5	174	5	2018	0	4	1	0	0	0	0	0
10	1	74	1	1674	0	0	0	0	0	0	0	0
11	11	67	1	1321	0	0	0	0	0	0	0	0
11	11	15	2	1146	0	0	0	0	0	0	0	0
11	11	15	3	1525	0	0	0	0	0	0	0	0
11	11	36	4	1108	0	0	0	0	0	0	0	0
11	11	16	5	1311	0	0	0	0	0	0	0	0
11	11	80	6	2618	0	0	0	0	0	0	0	0
11	11	118	7	1772	0	5	6	0	0	0	0	0
11	11	65	8	687	0	7	4	0	0	0	0	0
11	11	139	9	2329	0	3	8	0	0	0	0	0
11	11	153	10	2348	0	9	2	0	0	0	0	0
11	11	284	11	4258	0	10	1	0	0	0	0	0
12	1	169	1	2302	0	0	0	0	0	0	0	0
0	13	0	1	5420	0	0	0	0	0	0	0	0
0	13	0	2	5420	0	0	0	0	0	0	0	0
0	13	0	3	5420	0	0	0	0	0	0	0	0
0	13	0	4	5420	0	0	0	0	0	0	0	0
0	13	0	5	5420	0	0	0	0	0	0	0	0
0	13	0	6	5420	0	0	0	0	0	0	0	0
0	13	0	7	5420	0	0	0	0	0	0	0	0
0	13	0	8	5420	0	0	0	0	0	0	0	0
0	13	0	9	5420	0	0	0	0	0	0	0	0
0	13	0	10	5420	0	0	0	0	0	0	0	0
0	13	0	11	5420	0	0	0	0	0	0	0	0
0	13	0	12	5420	0	0	0	0	0	0	0	0
0	13	0	13	5420	0	0	0	0	0	0	0	0

Summary Rill Network Data for the OSU Data

Table A. 13: Summary Rill Network Data for the OSU Erosion Study(AAA.CHN)

T.R.	T.S.
2	13

(T.R. = Total Number of Rills, T.S. = Total Number of Subshed)

Number of Rill	Total # of Branch	Number of Bran. Cell	Number of Branch	Number of Interrill Cell	Upstream Branch Numbers							
1	3	23	1	11992	0	0	0	0	0	0	0	0
1	3	50	2	13374	0	0	0	0	0	0	0	0
1	3	34	3	1268	0	1	2	0	0	0	0	0
2	9	39	1	12200	0	0	0	0	0	0	0	0
2	9	11	2	9952	0	0	0	0	0	0	0	0
2	9	392	3	23921	0	0	0	0	0	0	0	0
2	9	146	4	30615	0	0	0	0	0	0	0	0
2	9	96	5	9625	0	0	0	0	0	0	0	0
2	9	27	6	4987	0	4	5	0	0	0	0	0
2	9	610	7	24355	0	6	3	0	0	0	0	0
2	9	303	8	23997	0	2	7	0	0	0	0	0
2	9	142	9	10109	0	1	8	0	0	0	0	0
0	1	0	1	20032	0	0	0	0	0	0	0	0

Table A. 14: Summary Rill Network Data for the OSU (ABA.CHN)

T.R.	T.S.
3	10

(T.R. = Total Number of Rills, T.S. = Total Number of Subshed)

Number of Rill	Total # of Branch	Number of Bran. Cell	Number of Branch	Number of Interrill Cell	Upstream Branch Numbers							
1	3	25	1	9089	0	0	0	0	0	0	0	0
1	3	12	2	8611	0	0	0	0	0	0	0	0
1	3	174	3	8573	0	1	2	0	0	0	0	0
2	1	88	1	9934	0	0	0	0	0	0	0	0
3	5	582	1	14531	0	0	0	0	0	0	0	0
3	5	312	2	21817	0	0	0	0	0	0	0	0
3	5	385	3	25764	0	0	0	0	0	0	0	0
3	5	462	4	20724	0	2	3	0	0	0	0	0
3	5	203	5	2878	0	4	1	0	0	0	0	0
0	1	0	1	26286	0	0	0	0	0	0	0	0

Table A. 15: Summary Rill Network Data for the OSU (ACA.CHN)

T.R.	T.S.
2	11

(T.R. = Total Number of Rills, T.S. = Total Number of Subshed)

Number of Rill	Total # of Branch	Number of Bran. Cell	Number of Branch	Number of Interrill Cell	Upstream Branch Numbers							
1	1	214	1	26791	0	0	0	0	0	0	0	0
2	9	117	1	22075	0	0	0	0	0	0	0	0
2	9	45	2	10330	0	0	0	0	0	0	0	0
2	9	67	3	18443	0	0	0	0	0	0	0	0
2	9	284	4	22662	0	0	0	0	0	0	0	0
2	9	69	5	22863	0	0	0	0	0	0	0	0
2	9	495	6	29355	0	4	5	0	0	0	0	0
2	9	75	7	3290	0	6	3	0	0	0	0	0
2	9	83	8	8462	0	2	7	0	0	0	0	0
2	9	432	9	31861	0	8	1	0	0	0	0	0
0	1	0	1	6571	0	0	0	0	0	0	0	0

APPENDIX B

C Program Code For Calculating Random Roughness for the UK Plot Data

```
#include <stdio.h>
#include <conio.h>
#include <stdlib.h>
#include <string.h>
#include <process.h>
#include <errno.h>
#include <math.h>
#include <time.h>
#include <dos.h>
#include <conio.h>

#define XMAX 353
#define YMAX 37
#define CRT 0.0000765
#define CEF 1

FILE *ifp, *ofp, *sfp, *ifpx, *ifpy, *ifpz,*ifff;


void main()

{

int i,j,k,zdata[40][400],id;
float xdata[400],ydata[40];
double xmean,zmean[40],xsum,zsum[400],xzsum[400],xxsum,c,rr;
double a[40],b[40],delz[40],zsqsum[40],zsq[40],rrsq,xmx,zmz[40];
char x_file[20],y_file[20], z_file[20],line[10];


    ifp = fopen("xdata.out","w");
    ofp = fopen("ydata.out","w");
    sfp = fopen("zdata.out","w");
    ifff= fopen("reg.out","w");
   //printf("Enter X file name !\n\n");
   //scanf("%s",x_file);
   //ifpx= fopen(x_file,"r");
ifpx= fopen("RMX.ELE","r");     /* read X data FILE */
if(ifpx== NULL){
printf("X data file <%s> not find!\n",x_file);
exit(0);
}
    //printf("Enter Y file name !\n\n");
   //scanf("%s",y_file);
      ifpy= fopen("RMY.ELE","r");     /* read Y data file */
if(ifpy== NULL){
printf("Y data file not find!\n");
exit(0);
}
printf("\nPlease Enter Z Data File Name !\n\n");
scanf("%s", z_file);
```

```
ifpz= fopen(z_file,"r");     /* read Z data file */
 //     ifpz= fopen("RMT2V2A.ELE","r");     /* read Z data file */
        if(ifpz== NULL){
        printf("Z data file not find!\n");
        exit(0);
         }
/* read x,y,z data files.*/
                xsum =0;
        for (i=0;i<XMAX;i++){
                fscanf(ifpx,"%f",&xdata[i]); /* get x data */
            //  printf("i=%d, xdata=%d\n",i,xdata[i]);
                fprintf(ifp,"%f\n", xdata[i]);
                xsum += xdata[i];
            xmean= xsum / (i+1);
                }
            //  printf("i=%d, xmean=%f\n",i,xmean);
        for (i=0;i<YMAX;i++){
                fscanf(ifpy,"%d",&ydata[i]); /* get y data */
           //   printf("i=%d, ydata=%d\n",i,ydata[i]);
                fprintf(ofp,"%d\n", ydata[i]);
                }
        for (i=0;i<YMAX;i++){
                zsum[i] =0;
                if (i>0){
                        fscanf(ifpz,"%d",&id);
                  //    printf("id=%d\n",id);
                        }
                for (j=0;j<XMAX;j++){
                    fscanf(ifpz,"%d",&zdata[i][j]); /* get z data */
                 // printf("i=%d,j=%d, zdata=%d\n",i,j, zdata[i][j]);
                    fprintf(sfp,"%d\n", zdata[i][j]);
                zsum[i] += zdata[i][j];
                    zmean[i]=zsum[i]/(j+1);
                }
                  // printf("i=%d,zmean[%d]=%f\n",i,i, zmean[i]);
        }

/* regression */

        for (i=0;i<YMAX;i++){
             xzsum[i] =0;
             xxsum =0;
            for (j=0;j<XMAX;j++){
                  xmx=xdata[j]-xmean;
                  zmz[i]=zdata[i][j]-zmean[i];
                  xzsum[i] += xmx*zmz[i];
                  xxsum += xmx*xmx;
                  }
                  b[i]=xzsum[i]/xxsum;
                  a[i]=zmean[i]-b[i]*xmean;
           // printf("i=%d,a=%13.5f,b=%13.5f\n",i,a[i],b[i]);
```

```
                fprintf(ifff,"%d a=%13.5f b=%13.5f zmean=%f\n", i,a[i],b[i],zmean[i]);
        }

/* calculation for RR.*/
                rrsq=0;
            for (i=0;i<YMAX;i++){
                    zsqsum[i]=0;
                for (j=0;j<XMAX;j++){
                        delz[i] = (zdata[i][j]-b[i]*xdata[j]-a[i])*CEF;
                      // printf("i=%d,delz=%f\n",i,delz[i]);
                        zsq[i] = delz[i]*delz[i];
                     //  printf("i=%d,zsq=%f\n",i,zsq[i]);
                        zsqsum[i] +=zsq[i];
                    //   printf("i=%d,zsqsum[i]=%f\n",i,zsqsum[i]);
                        }
                        rrsq +=zsqsum[i];
                    //   printf("i=%d,RRSQ=%f\n",i,rrsq);
                        c=CRT*rrsq;
                        rr=sqrt(c);
            }
            printf("\nc=%f\n",c);
            printf("\nRRSQ=%f\n",rrsq);
            printf("\nRR=%f for <%s>.\n",rr, z_file);
            fprintf(ifff,"\nRandom Roughness RR=%13.5f in Data File <%s>\n", rr, z_file);
            fclose(ifff);
            fclose(ifp);
            fclose(ofp);
            fclose(sfp);
            fclose(ifpx);
            fclose(ifpy);
            fclose(ifpz);
            printf("\n********Programm is normal stop, Thank You!******\n");
}
```

C Program Code for Calculating Random Roughness for the OSU Erosion Table Data

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <errno.h>
#include <math.h>
#include <time.h>


#define XMAX 1000
#define YMAX 220
#define CRT 0.00000455
#define CEF 1
FILE *ifp, *ofp, *sfp, *ifpx, *ifpy, *ifpz,*ifff;


void main()

{

        int i,j,k,id;
        float xdata[1000],zdata[220][1000],ydata[220];
        double xmean,zmean[220],xsum,zsum[1000],xzsum[1000],xxsum,c,rr;
        double a[220],b[220],delz[220],zsqsum[220],zsq[220],rrsq,xmx,zmz[220];
        char x_file[20],y_file[20], z_file[20],line[80];


   ifp = fopen("xosu.out","w");
   ofp = fopen("yosu.out","w");
   sfp = fopen("zosu.out","w");
   ifff= fopen("reosu.out","w");
  /*    printf("Enter X file name !\n\n");
        scanf("%s",x_file);
        ifpx= fopen(x_file,"r"); */
        ifpx= fopen("osunx.dat","r");     /* read X data FILE */
                if(ifpx== NULL){
                printf("X data file <%s> not find!\n",x_file);
                exit(0);
                }
    /*  printf("Enter Y file name !\n\n");
        scanf("%s",y_file); */
             ifpy= fopen("osuny.dat","r");     /* read Y data file */
                if(ifpy== NULL){
                printf("Y data file not find!\n");
                exit(0);
                }
        /* printf("\nPlease Enter Z Data File Name !\n\n"); */
/*      scanf("%s", z_file); */
/*      ifpz= fopen(z_file,"r");      read Z data file */
        ifpz= fopen("aca.xyz","r");     /* read Z data file */
        if(ifpz== NULL){
        printf("Z data file not find!\n");
        exit(0);
```

```
        }
/* read x,y,z data files.*/
                xsum =0;
        for (i=0;i<XMAX;i++){
                fscanf(ifpx,"%f",&xdata[i]); /* get x data */
            /*  printf("i=%d, xdata=%d\n",i,xdata[i]); */
                fprintf(ifp,"%f\n", xdata[i]);
                xsum += xdata[i];
            xmean= xsum / (i+1);
                }
            /*  printf("i=%d, xmean=%f\n",i,xmean); */
        for (i=0;i<YMAX;i++){
                fscanf(ifpy,"%d",&ydata[i]); /* get y data */
           /*   printf("i=%d, ydata=%d\n",i,ydata[i]); */
                fprintf(ofp,"%d\n", ydata[i]);
                }
        for (i=0;i<YMAX;i++){
                zsum[i] =0;
                if (i>0){
                        fscanf(ifpz,"%d",&id);
                  /*    printf("id=%d\n",id);  */
                        }
                for (j=0;j<XMAX;j++){
                    fscanf(ifpz,"%f",&zdata[i][j]); /* get z data */
                 /* printf("i=%d,j=%d, zdata=%d\n",i,j, zdata[i][j]); */
                    fprintf(sfp,"%d\n", zdata[i][j]);
                zsum[i] += zdata[i][j];
                    zmean[i]=zsum[i]/(j+1);
                 }
                  /* printf("i=%d,zmean[%d]=%f\n",i,i, zmean[i]); */
        }

/* regression */

        for (i=0;i<YMAX;i++){
             xzsum[i] =0;
             xxsum =0;
            for (j=0;j<XMAX;j++){
                 xmx=xdata[j]-xmean;
                 zmz[i]=zdata[i][j]-zmean[i];
                 xzsum[i] += xmx*zmz[i];
                 xxsum += xmx*xmx;
                 }
                 b[i]=xzsum[i]/xxsum;
                 a[i]=zmean[i]-b[i]*xmean;
             /* printf("i=%d,a=%13.5f,b=%13.5f\n",i,a[i],b[i]); */
                 fprintf(ifff,"%d a=%13.5f b=%13.5f zmean=%f\n", i,a[i],b[i],zmean[i]);
         }

/* calculation for RR.*/
                 rrsq=0;
            for (i=0;i<YMAX;i++){
```

```
            zsqsum[i]=0;
      for (j=0;j<XMAX;j++){
            delz[i] = (zdata[i][j]-b[i]*xdata[j]-a[i])*CEF;
         /* printf("i=%d,delz=%f\n",i,delz[i]); */
            zsq[i] = delz[i]*delz[i];
         /* printf("i=%d,zsq=%f\n",i,zsq[i]); */
            zsqsum[i] +=zsq[i];
         /* printf("i=%d,zsqsum[i]=%f\n",i,zsqsum[i]); */
            }
            rrsq +=zsqsum[i];
         /* printf("i=%d,RRSQ=%f\n",i,rrsq); */
            c=CRT*rrsq;
            rr=sqrt(c);
   }
   printf("\nc=%f\n",c);
   printf("\nRRSQ=%f\n",rrsq);
   printf("\nRR=%f for <%s>.\n",rr, z_file);
   fprintf(ifff,"\nRandom Roughness RR=%13.5f in Data File <%s>\n", rr, z_file);
   fclose(ifff);
   fclose(ifp);
   fclose(ofp);
   fclose(sfp);
   fclose(ifpx);
   fclose(ifpy);
   fclose(ifpz);
   printf("\n********Programm is normal stop, Thank You!******\n");
}
```

C Program Code for Changing Font of the OSU Erosion Table Data

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#define MAX1 215160

int main(argc,argv)
int argc;
char *argv[];
{
    FILE *infp,*outfp;
    char token[20];
    double number;
    int i, j, k,n=0;

    infp=fopen(argv[1],"r");
    outfp=fopen(argv[2],"w");

  for (k=0; k<222; k++){
     fprintf(outfp,"0 ");
     }
     fprintf(outfp,"\n9999 ");

    for(i=0; i < MAX1; i++){
       fscanf(infp,"%s",token);
       fscanf(infp,"%s",token);
       fscanf(infp,"%s",token);
       number=atof(token);
       n++;
       fprintf(outfp,"%d ",(int)number);

      if(n==220){
            fprintf(outfp,"9999 \n 9999 ");
            n=0;
       }

    }

    for (k=0; k<222; k++){
        fprintf(outfp,"9999 ");
        }
        fprintf(outfp,"\n");

    fclose(infp);
    fclose(outfp);
}
```

APPENDIX C

Total Link Length Distribution

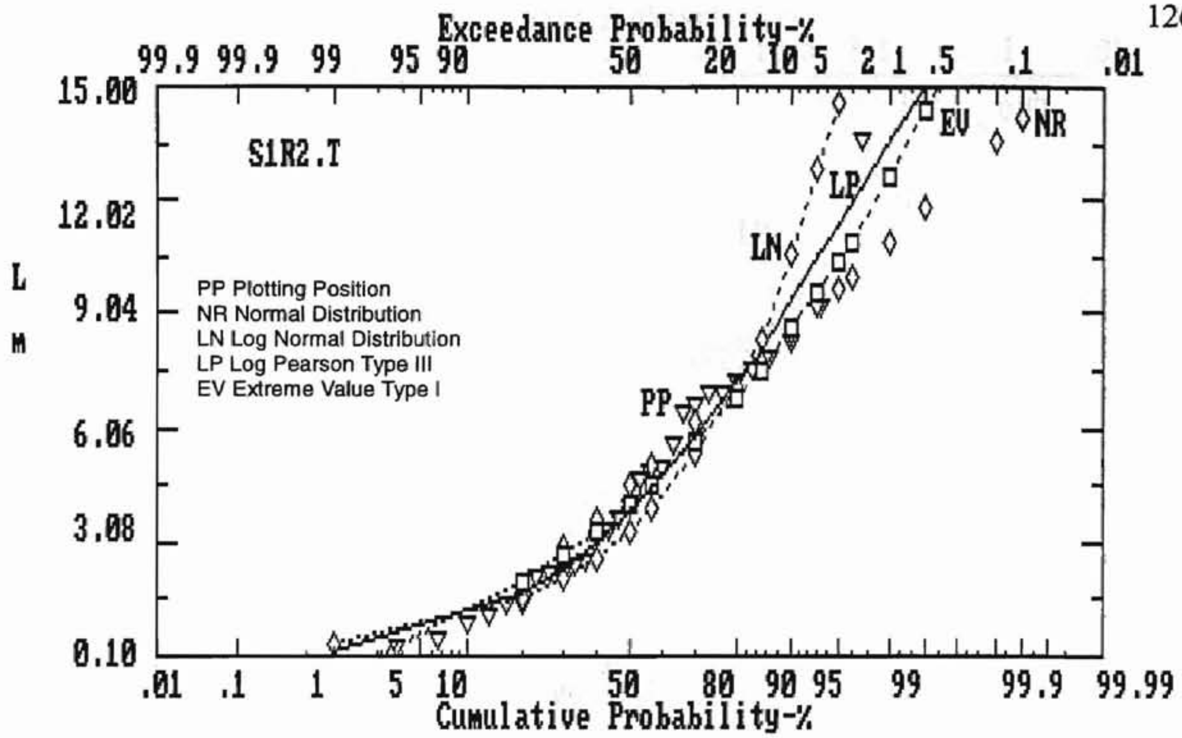

Figure 1. S1R2 Total Link Length Distribution

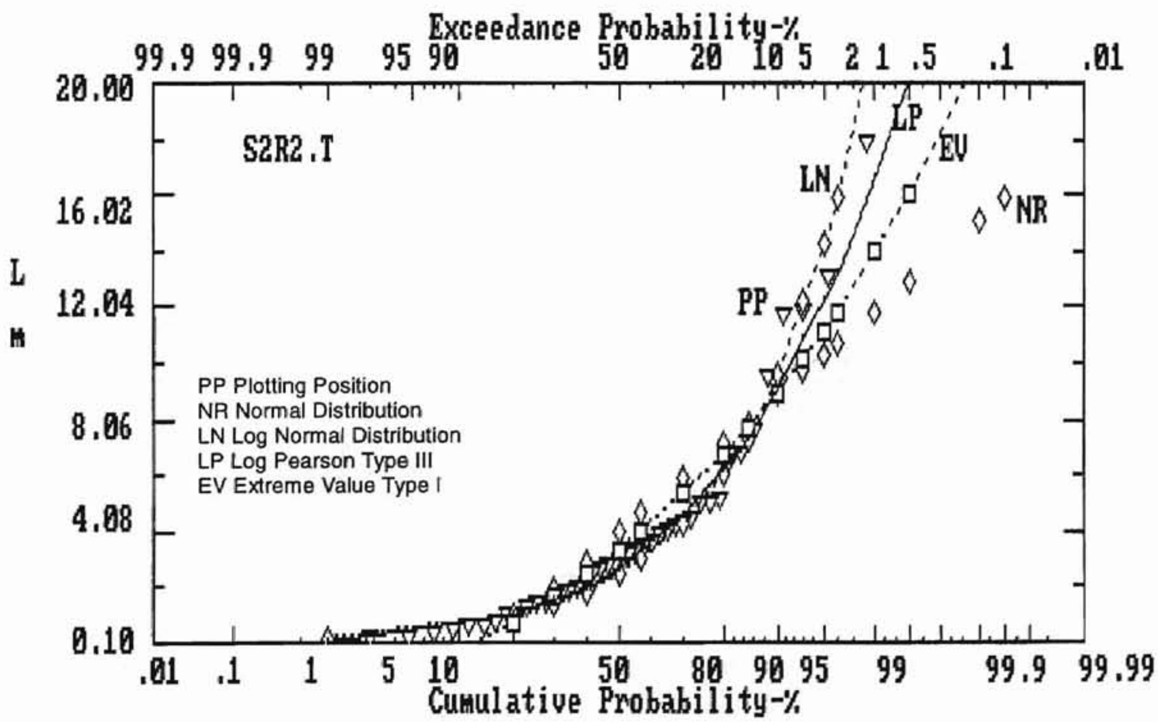

Figure 2. S2R2 Total Link length Distribution

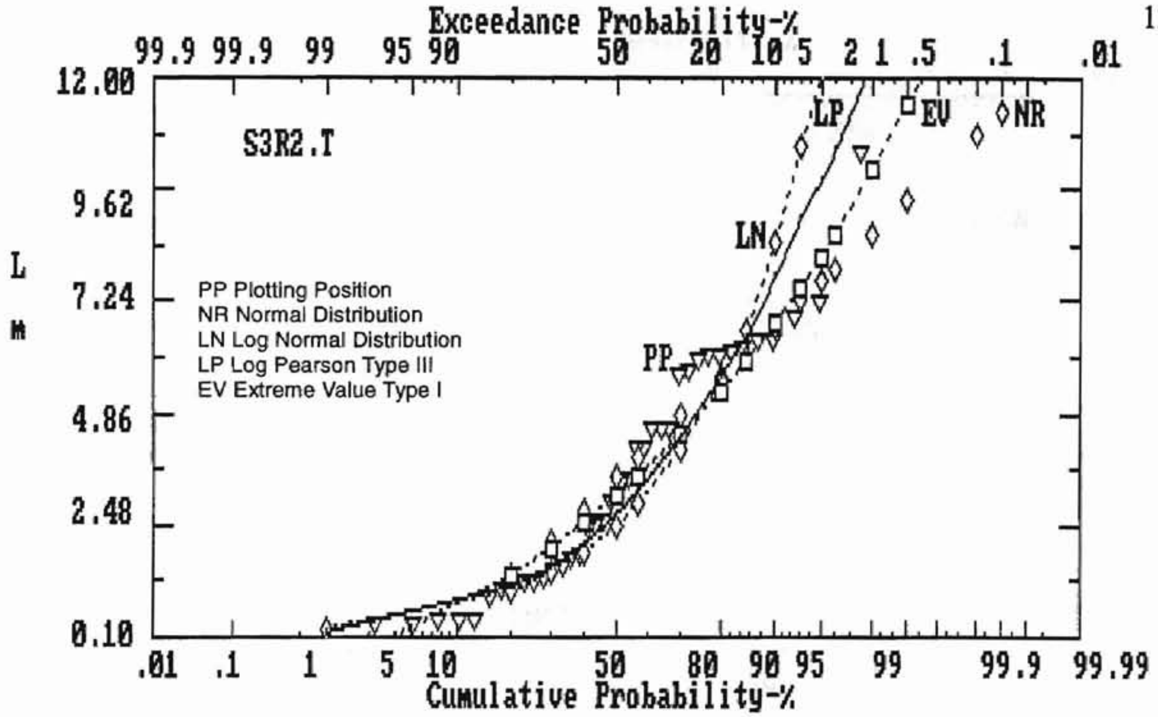

Figure 3. S3R2 Total Link Length Distribution

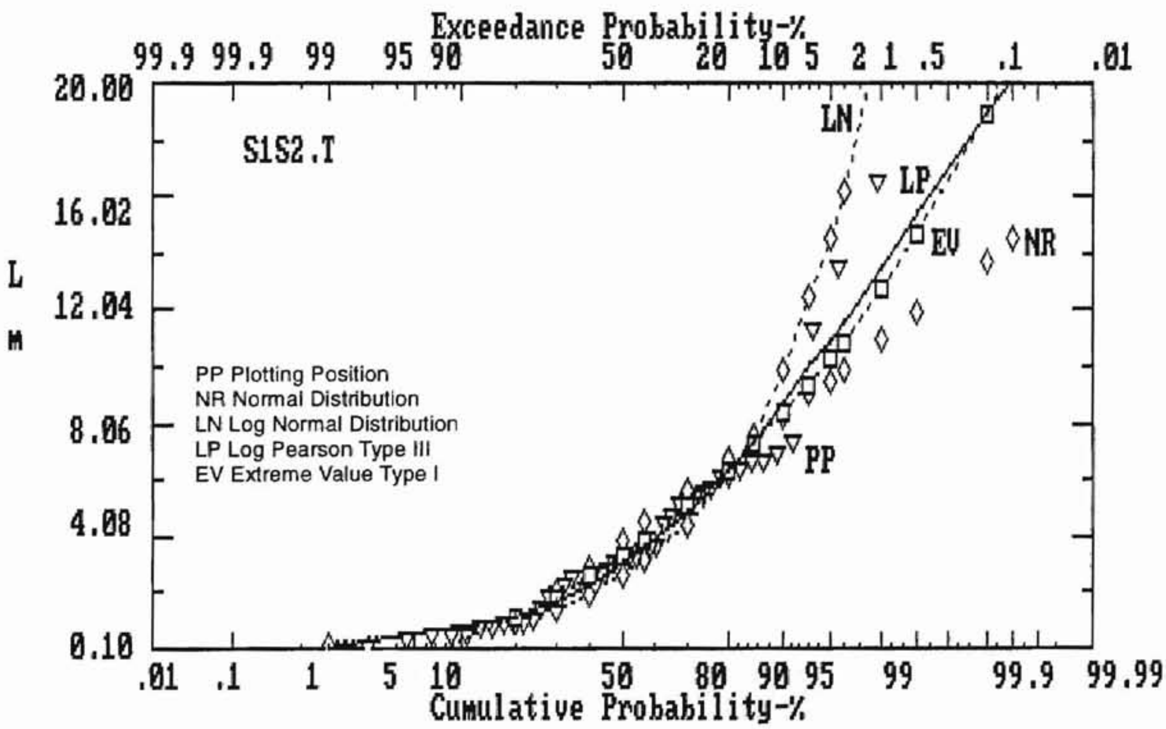

Figure 4. S1S2 Total Link Length Distribution

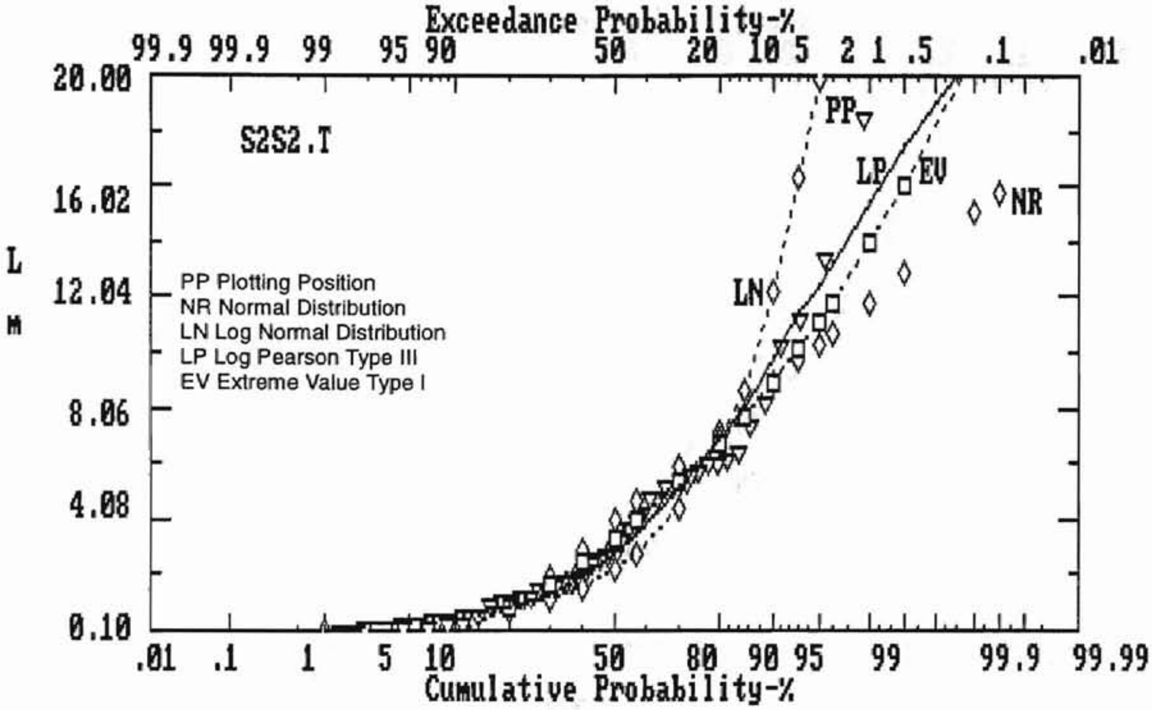

Figure 5. S2S2 Total Link Length Distribution

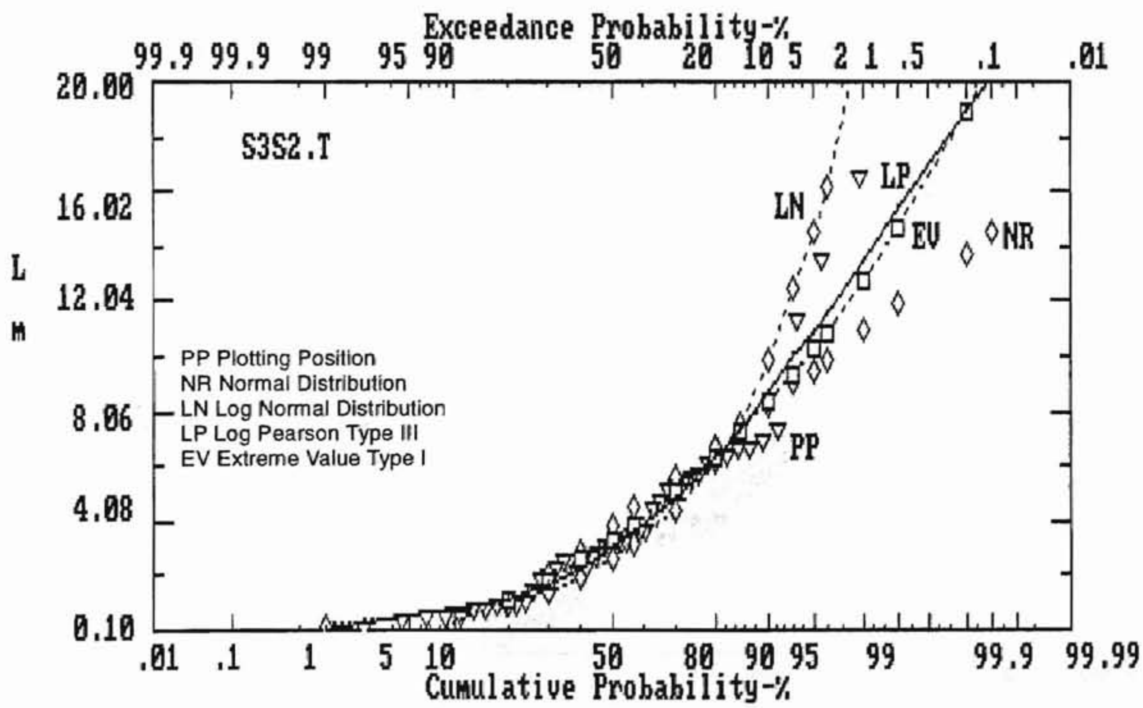

Figure 6. S3S2 Total Link Length Distribution

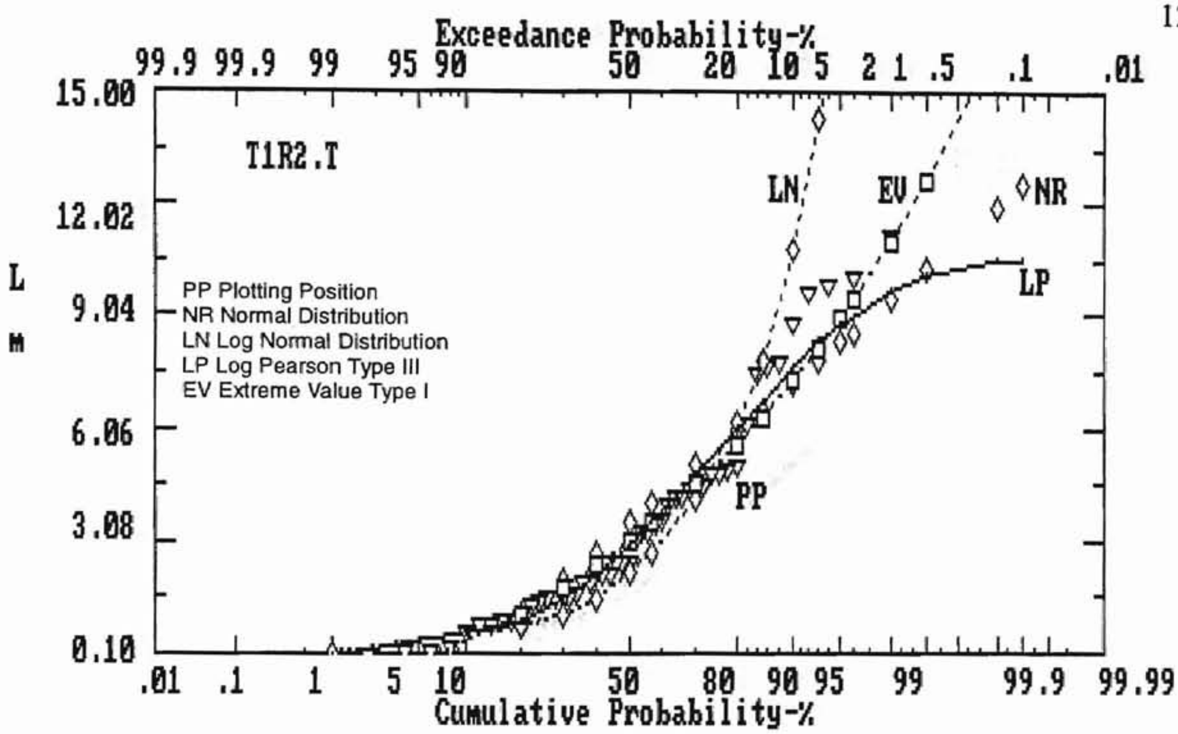

Figure 7. T1R2 Total Link Length Distribution

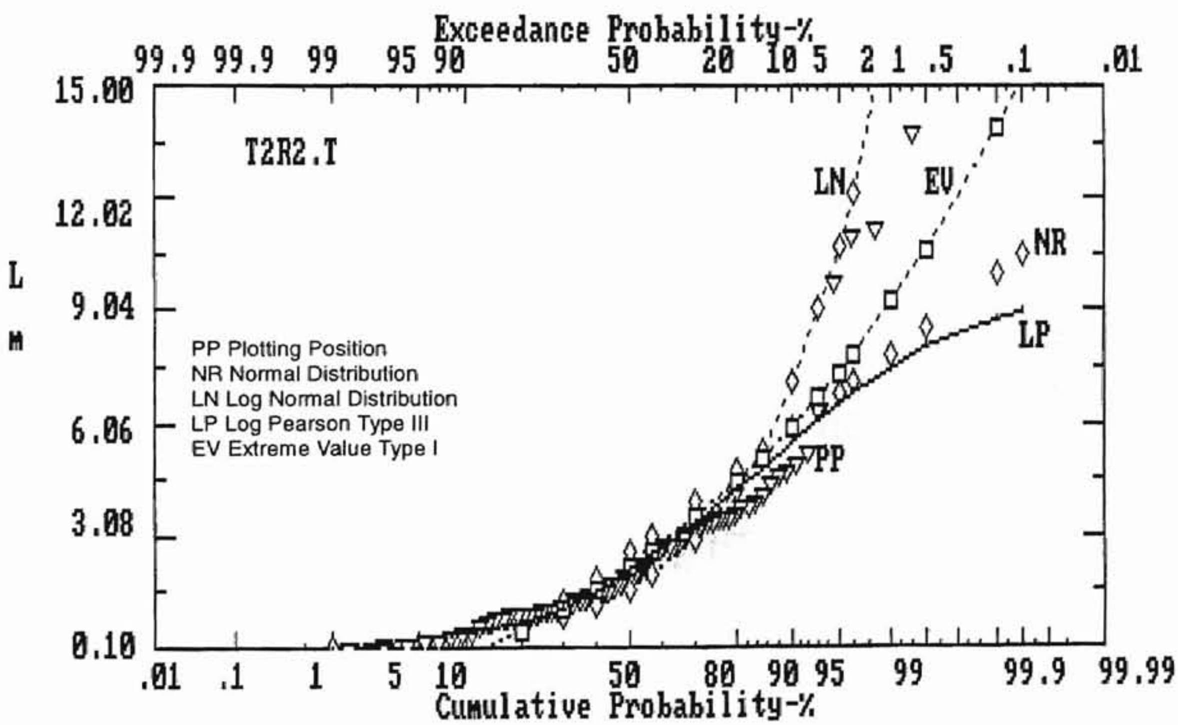

Figure 8. T2R2 Total Link Length Distribution

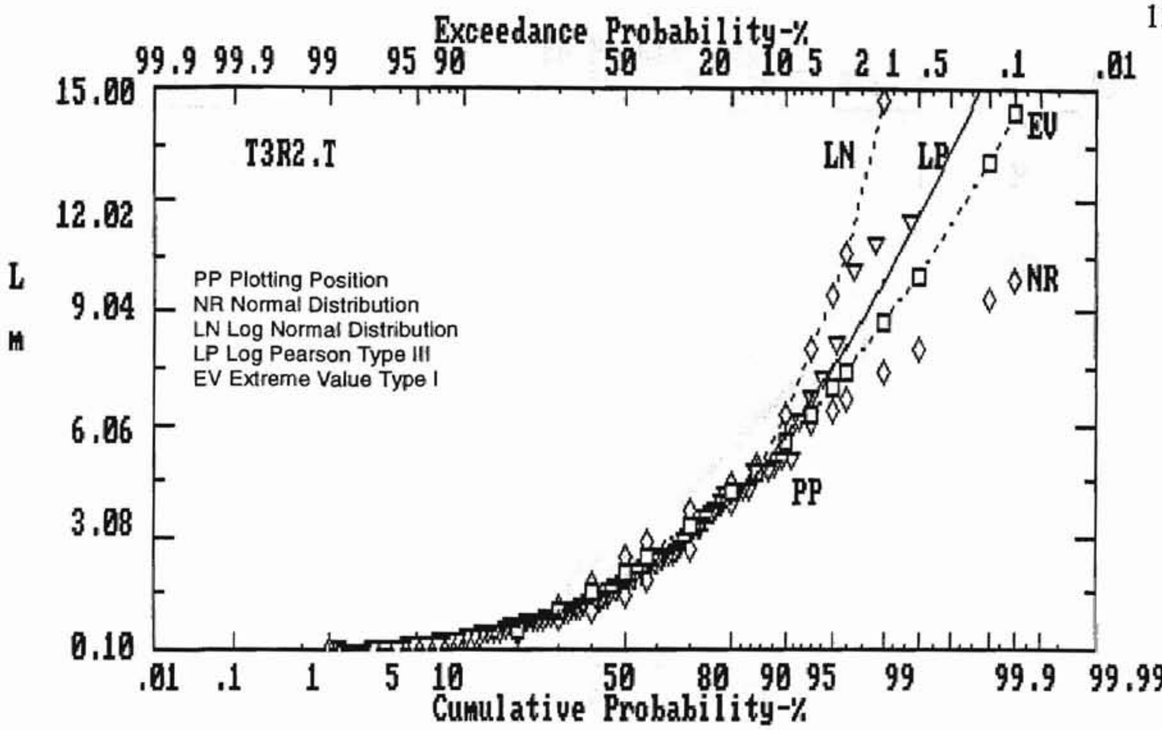

Figure 9. T3R2 Total Link Length Distribution

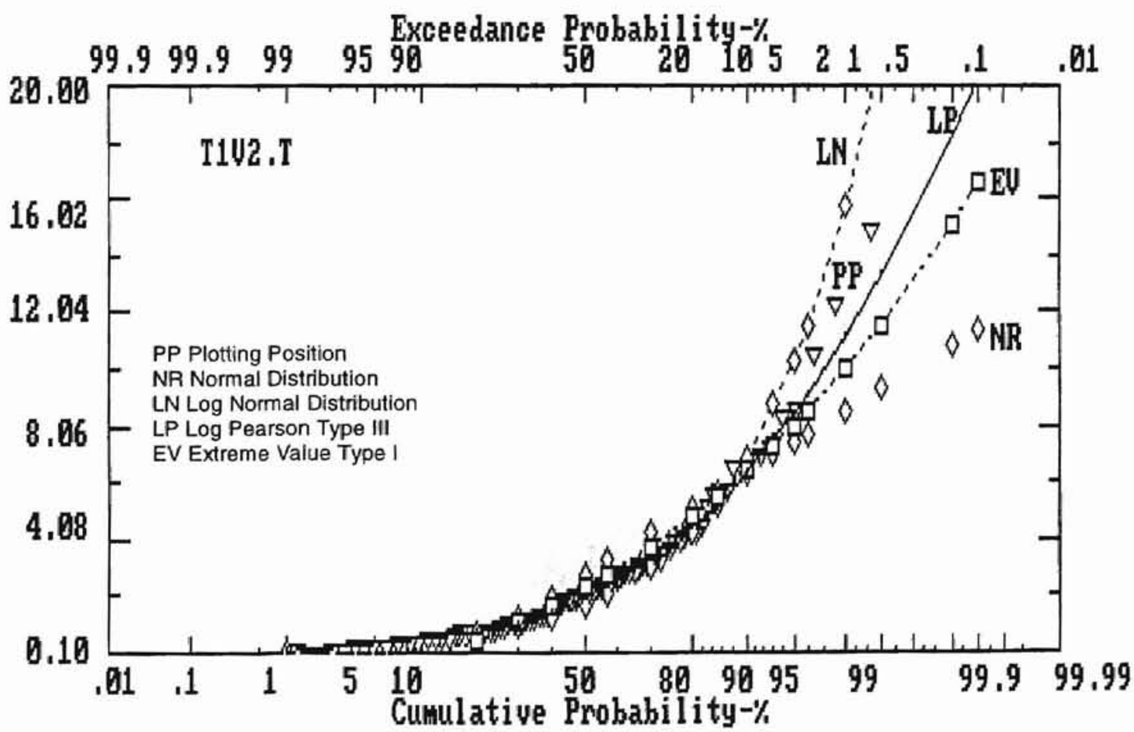

Figure 10. T1V2 Total Link Length Distribution

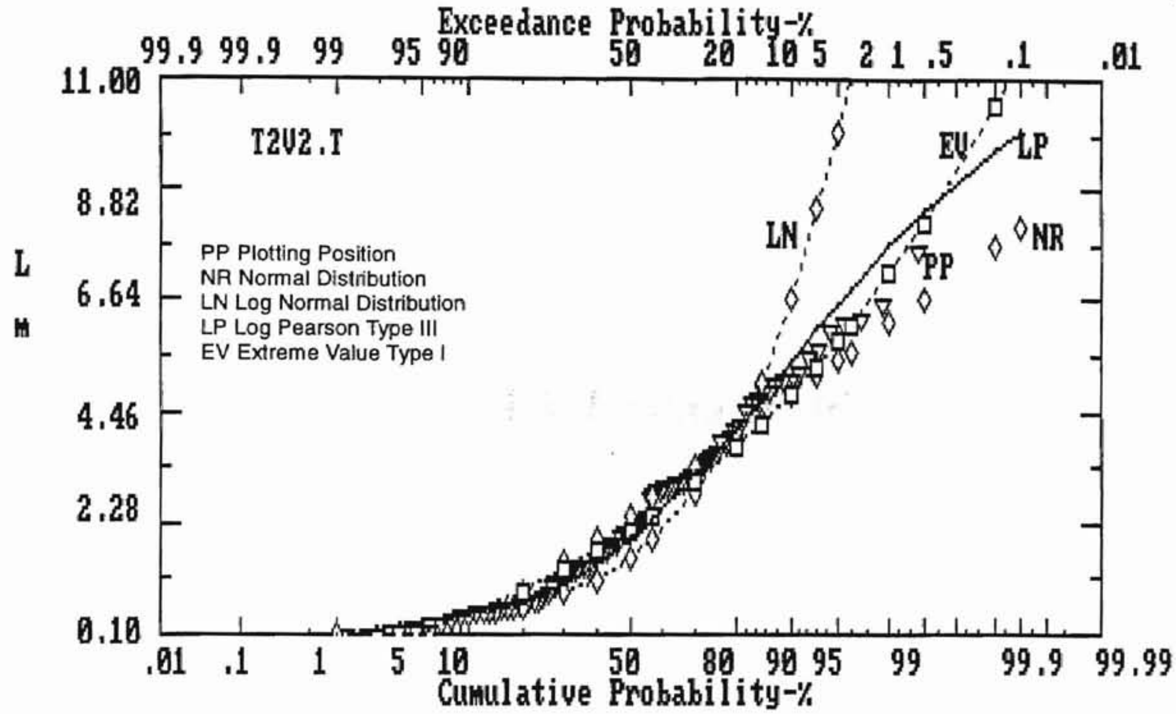

Figure 11. T2V2 Total Link Length Distribution

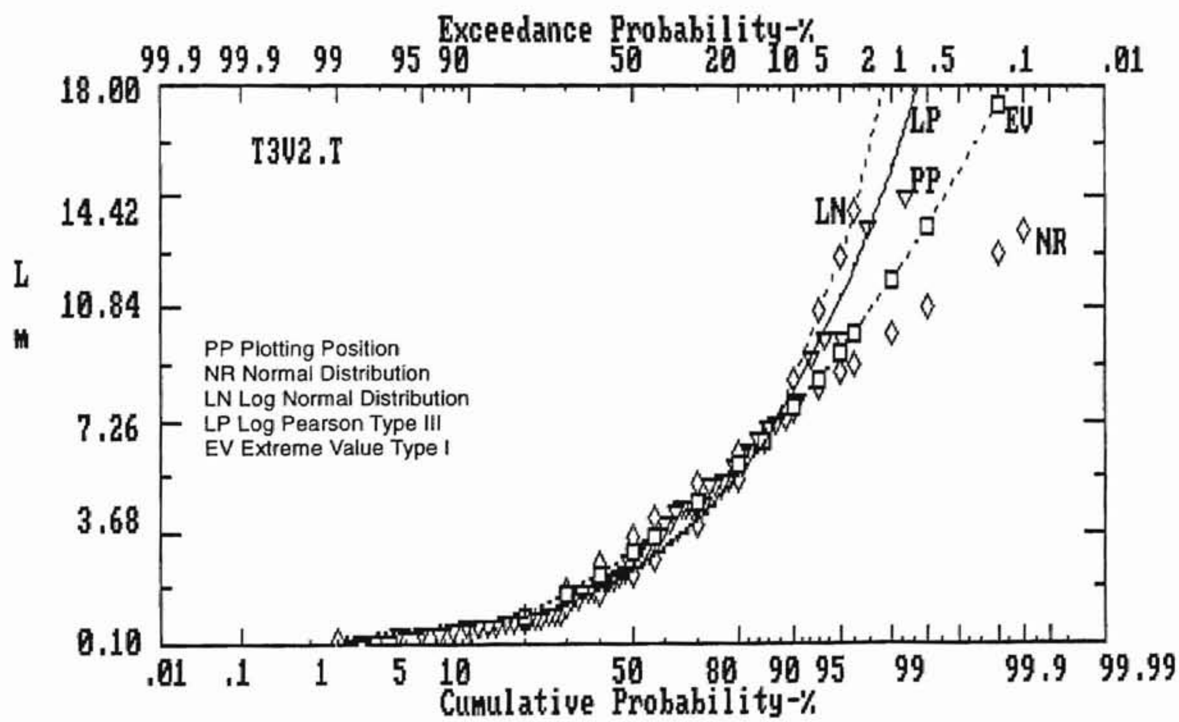

Figure 12. T3V2 Total Link Length Distribution

Exterior Link Length Distribution

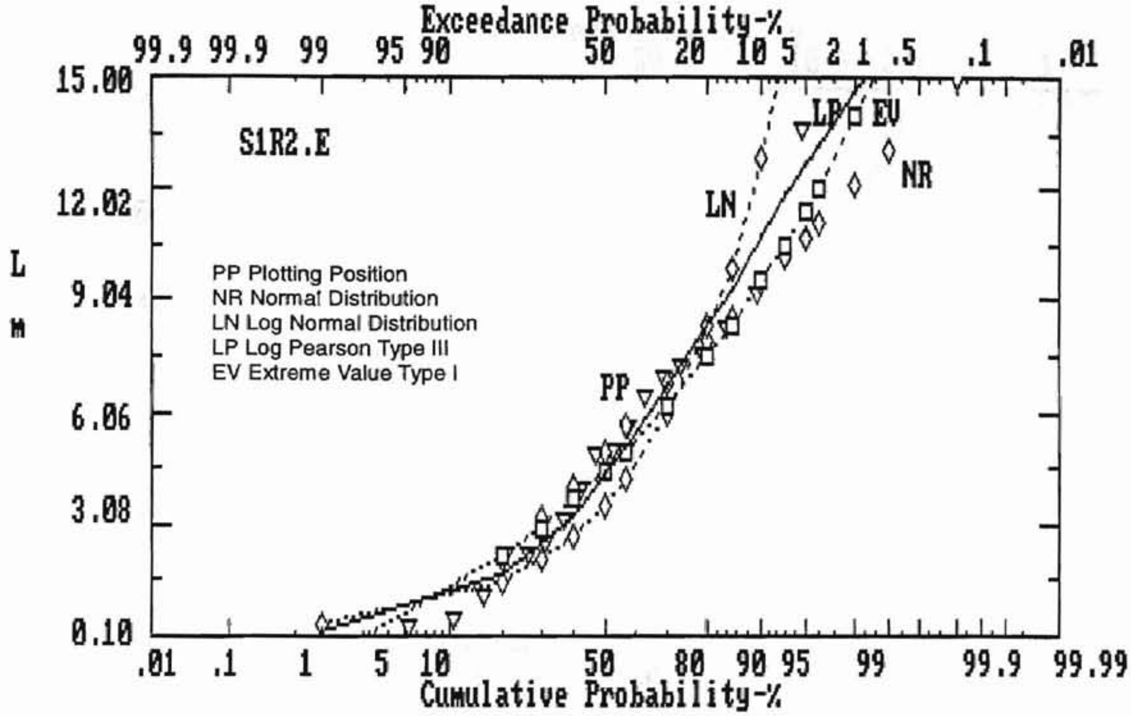

Figure 13. S1R2 Exterior Link Length Distribution

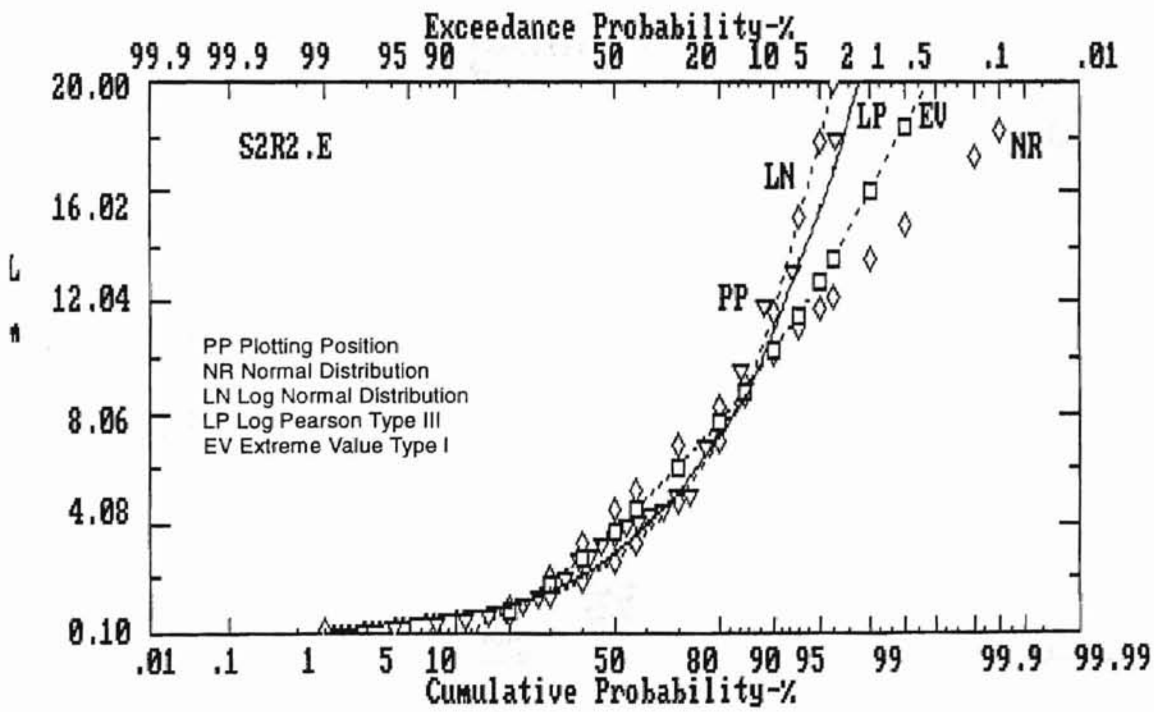

Figure 14. S2R2 Exterior Link Length Distribution

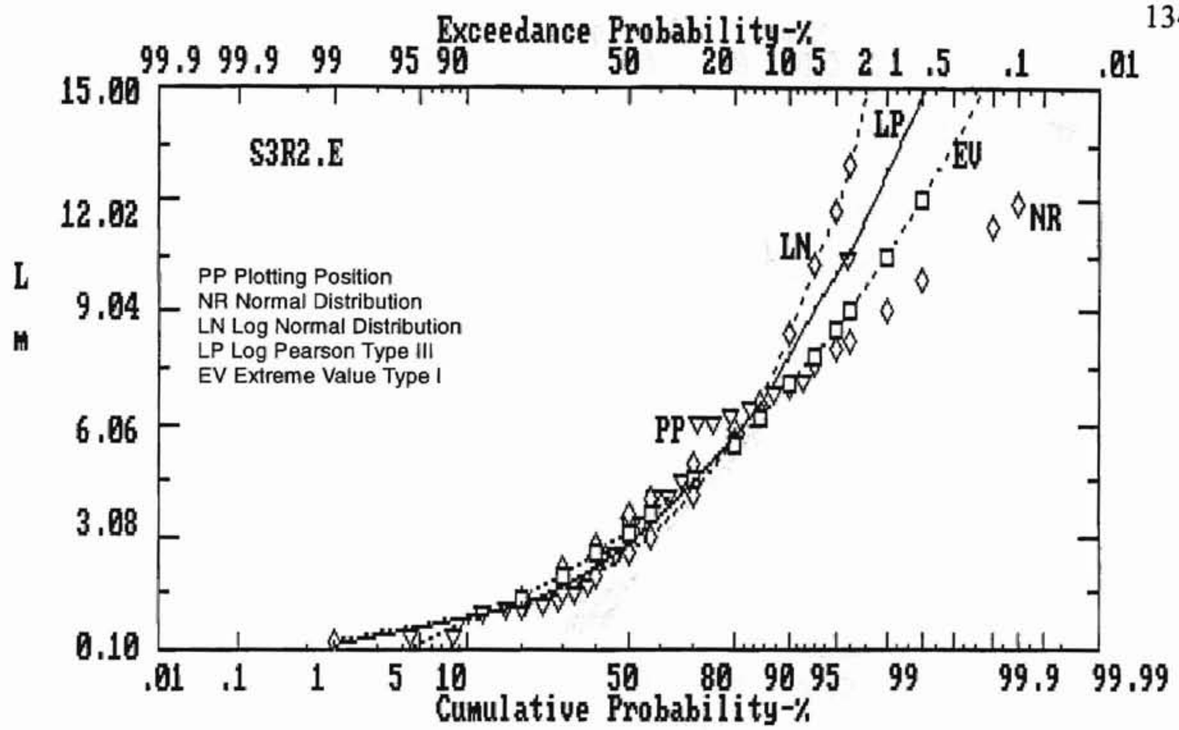

Figure 15. S3R2 Exterior Link Length Distribution

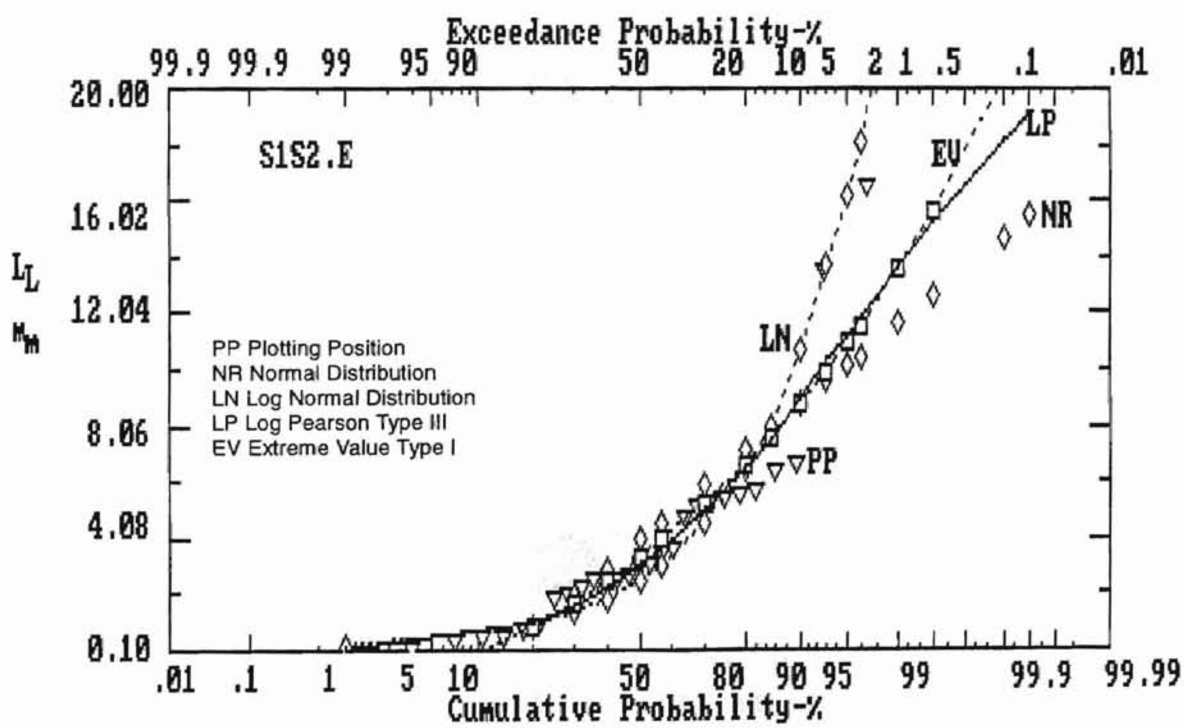

Figure 16. S1S2 Exterior Link Length Distribution

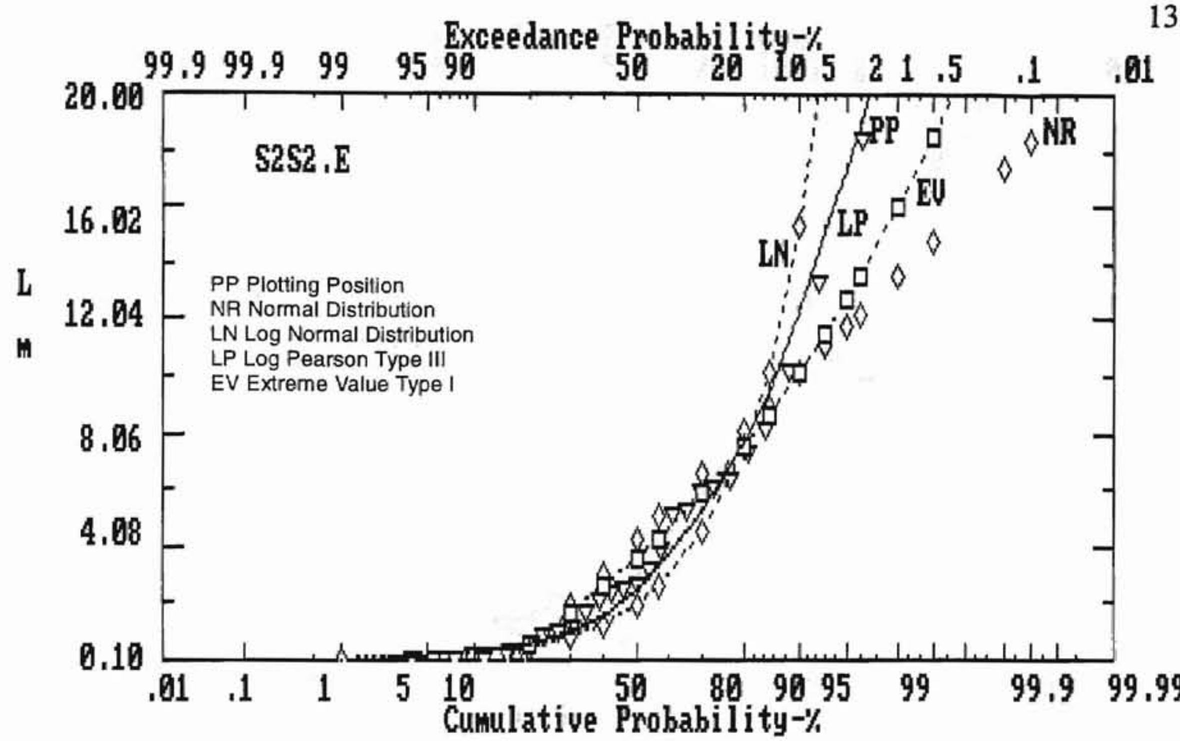

Figure 17. S2S2 Exterior Link Length Distribution

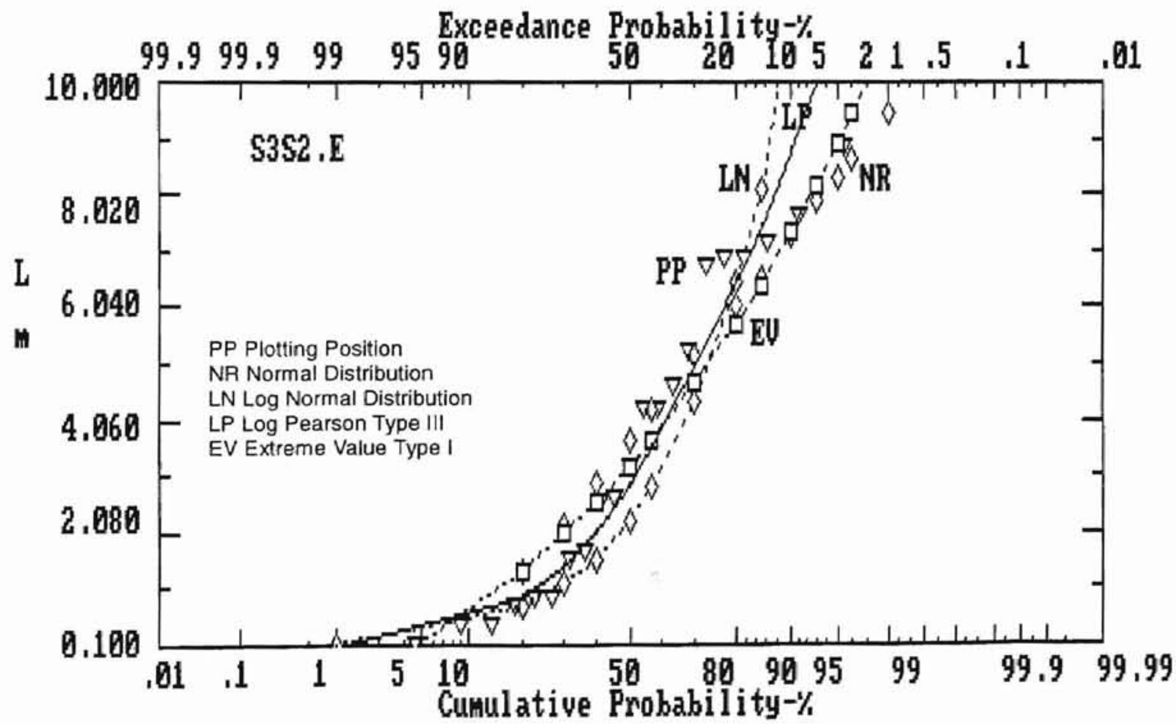

Figure 18. S3S2 Exterior Link Length Distribution

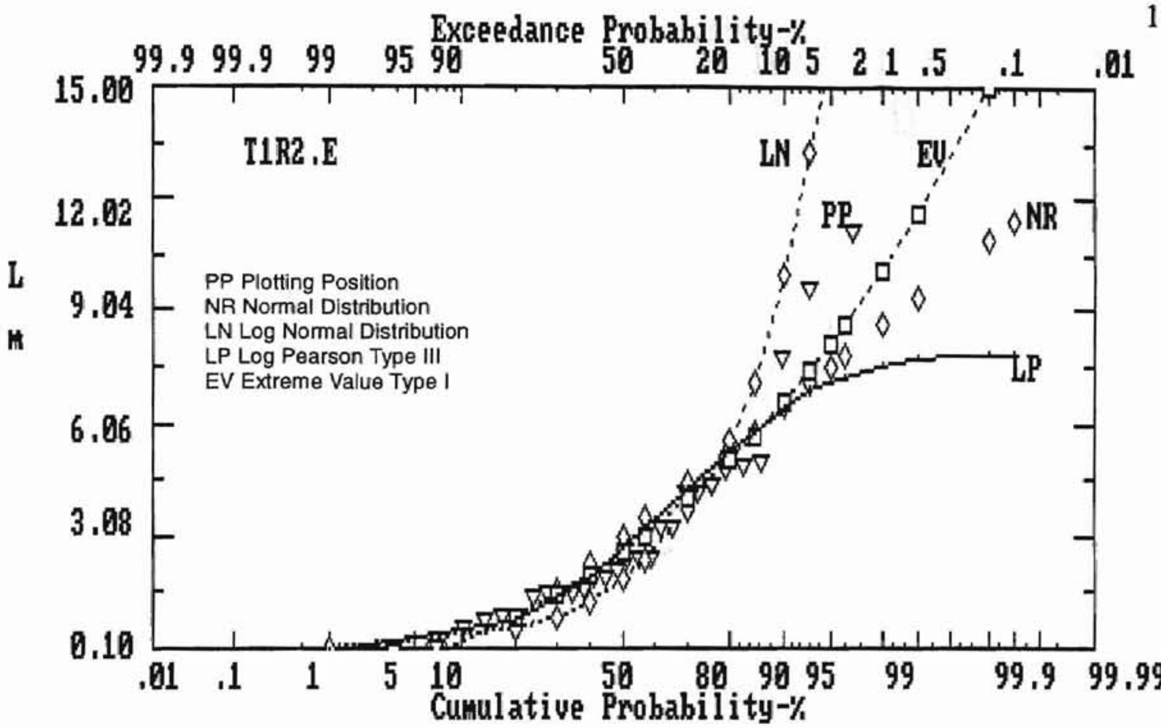

Figure 19. T1R2 Exterior Link Length Distribution

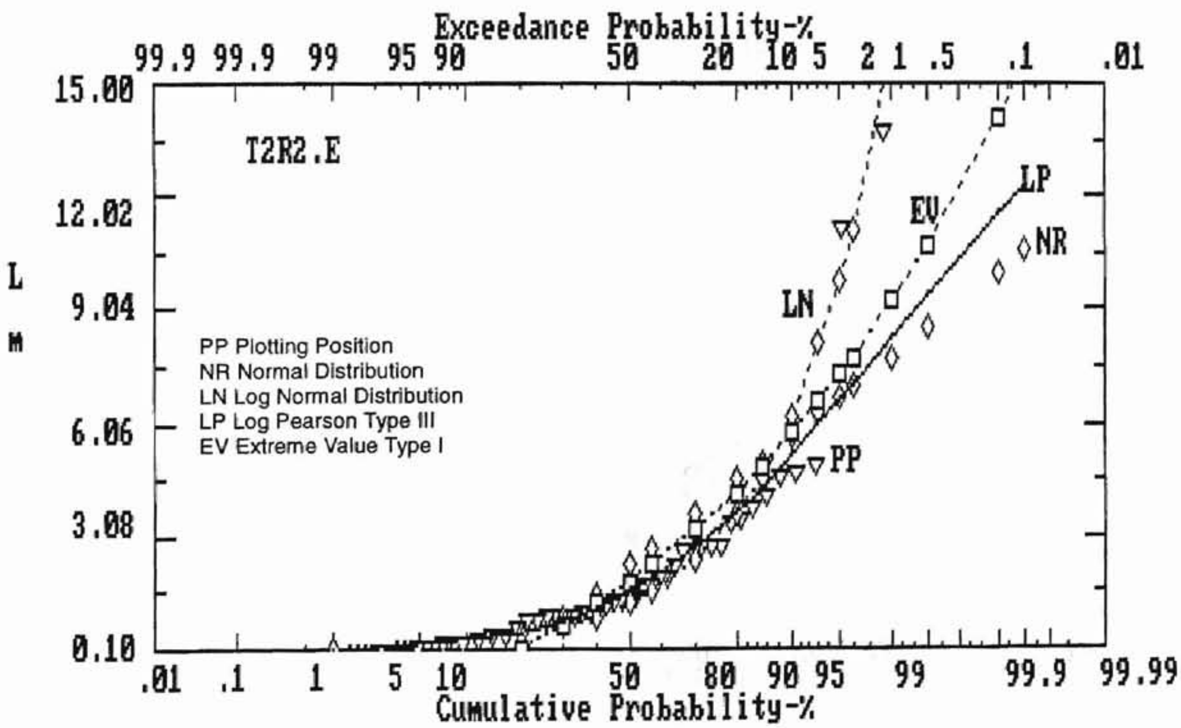

Figure 20. T2R2 Exterior Link Length Distribution

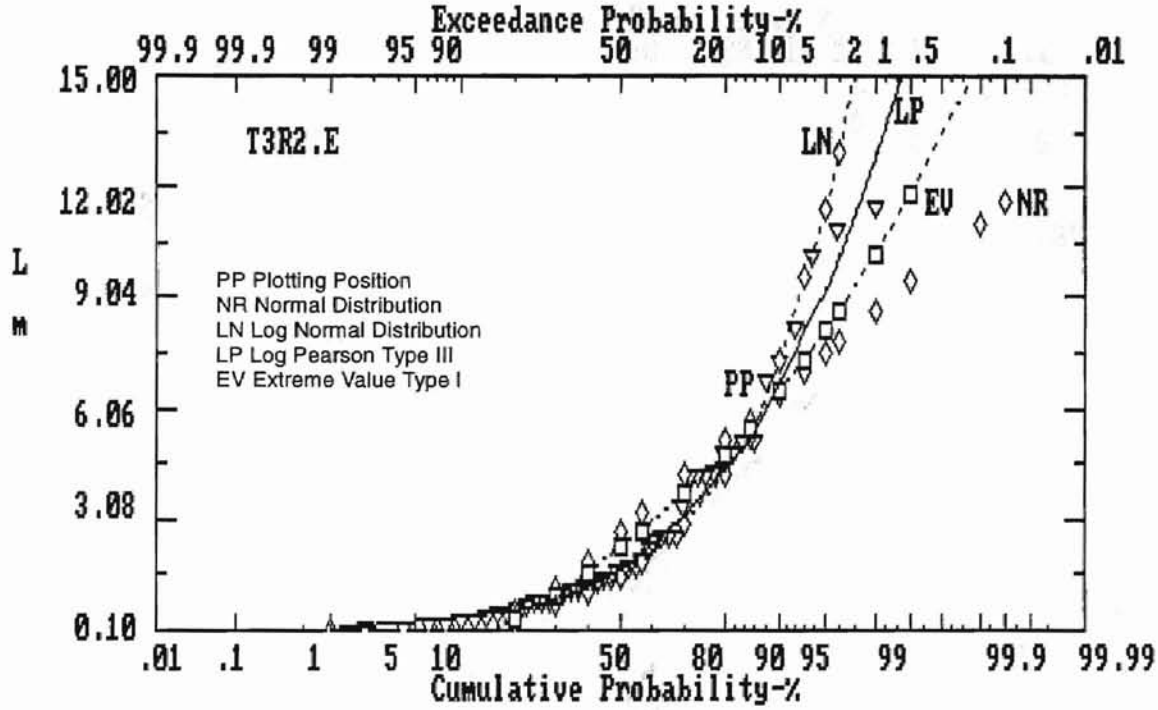

Figure 21. T3R2 Exterior Link Length Distribution

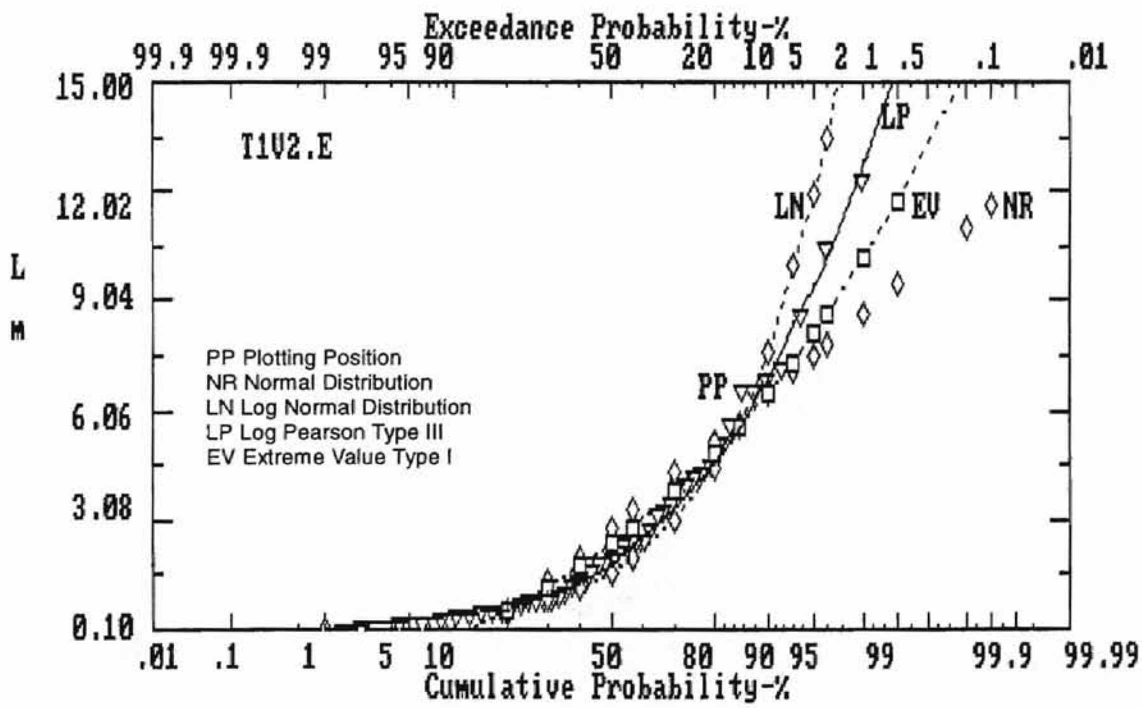

Figure 22. T1V2 Exterior Link Length Distribution

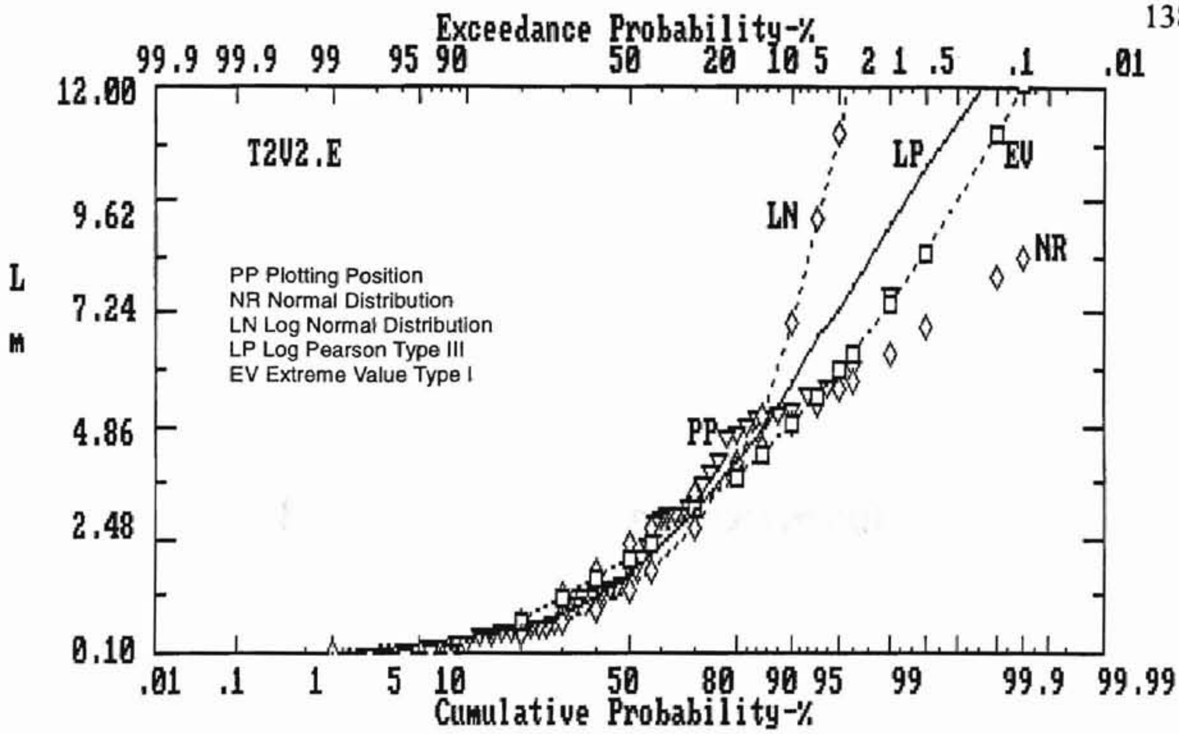

Figure 23. T2V2 Exterior Link Length Distribution

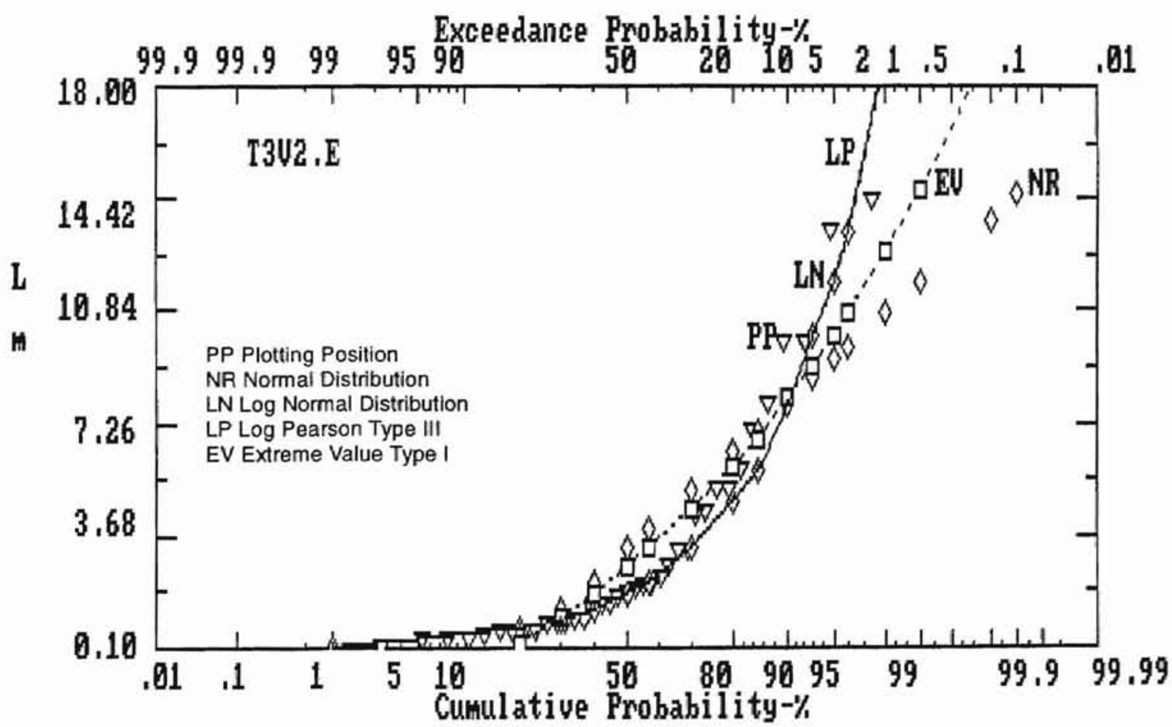

Figure 24. T3V2 Exterior Link Length Distribution

Interior Link Length Distribution

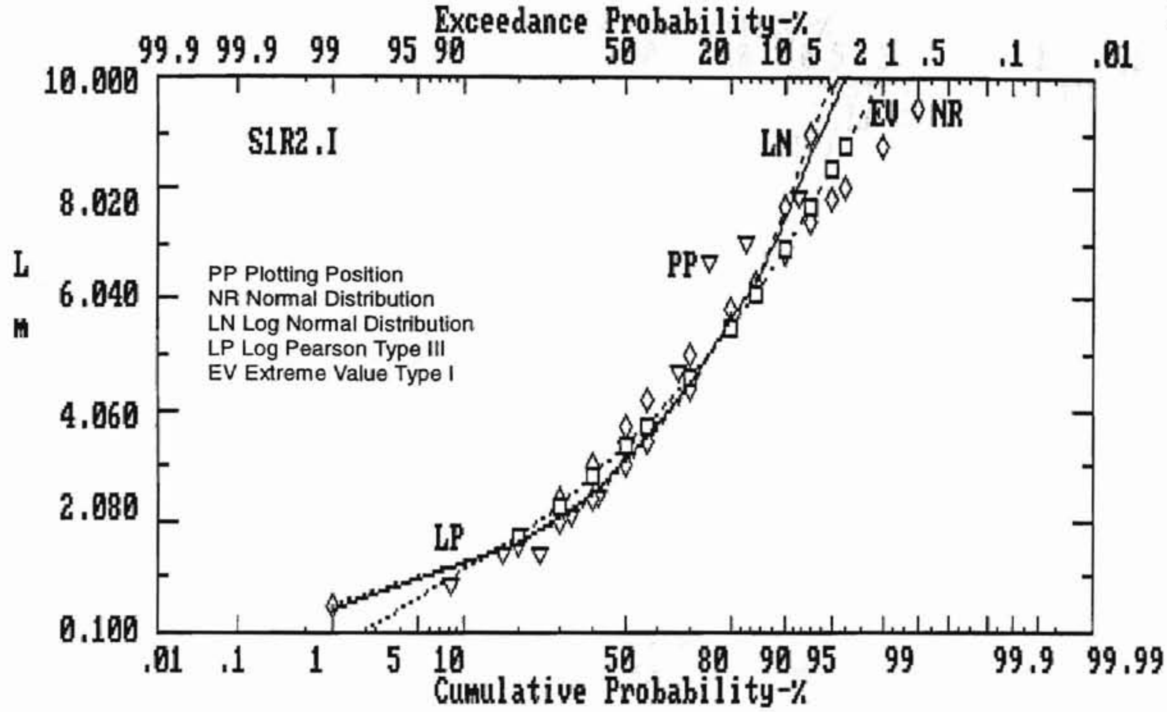

Figure 25. S1R2 Interior Link Length Distribution

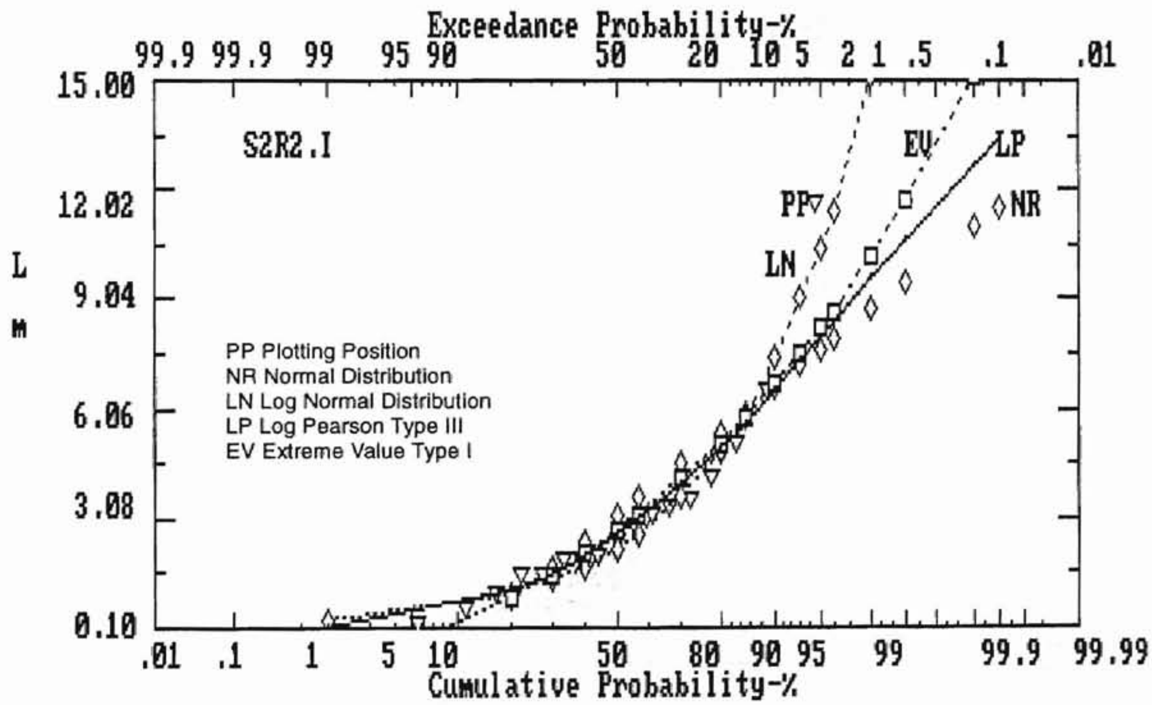

Figure 26. S2R2 Interior Link Length Distribution

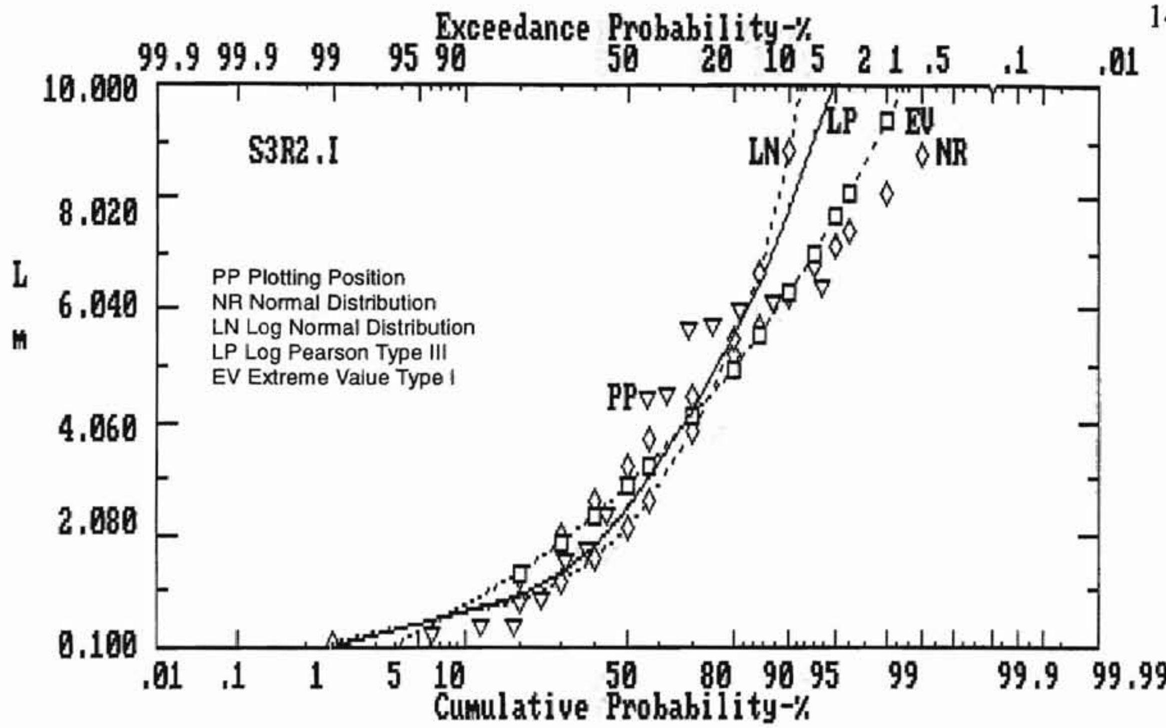

Figure 27. S3R2 Interior Link Length Distribution

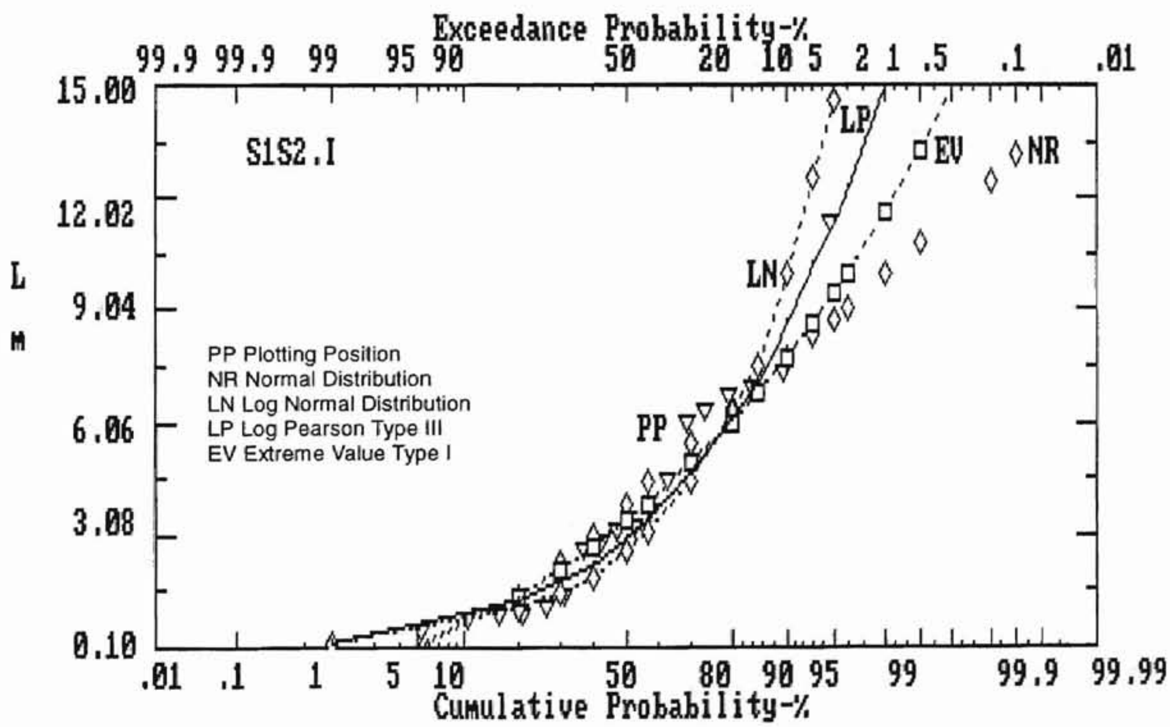

Figure 28. S1S2 Interior Link Length Distribution

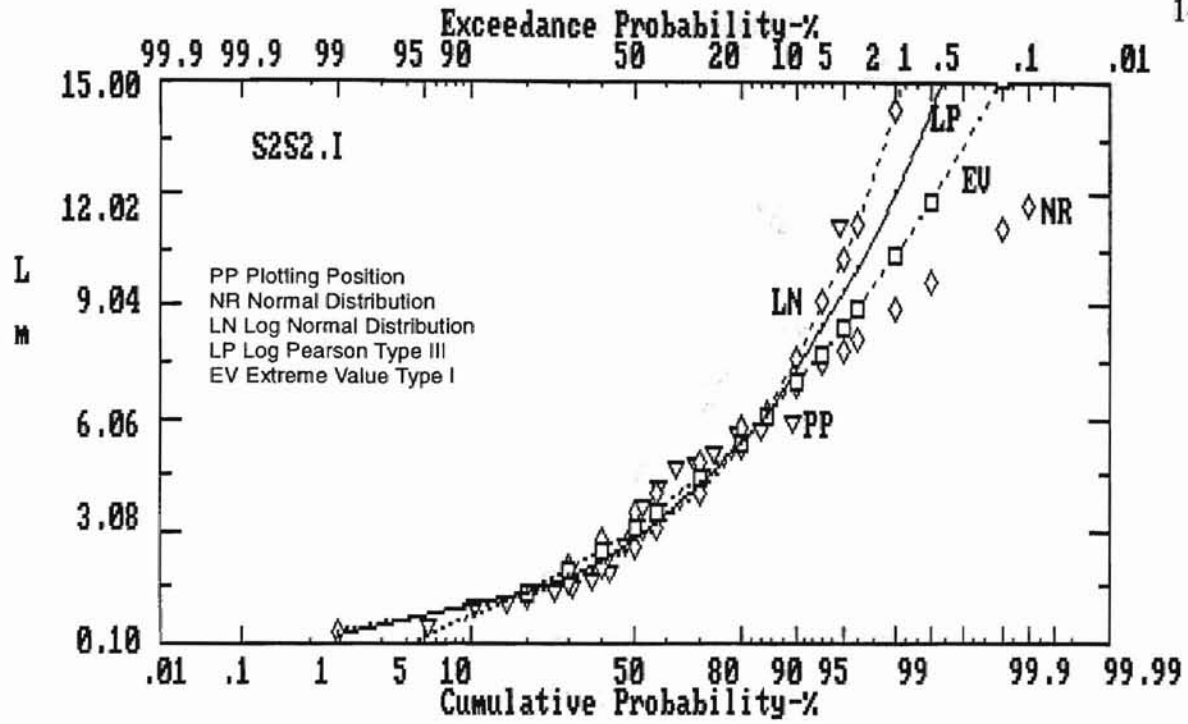

Figure 29. S2S2 Interior Link Length Distribution

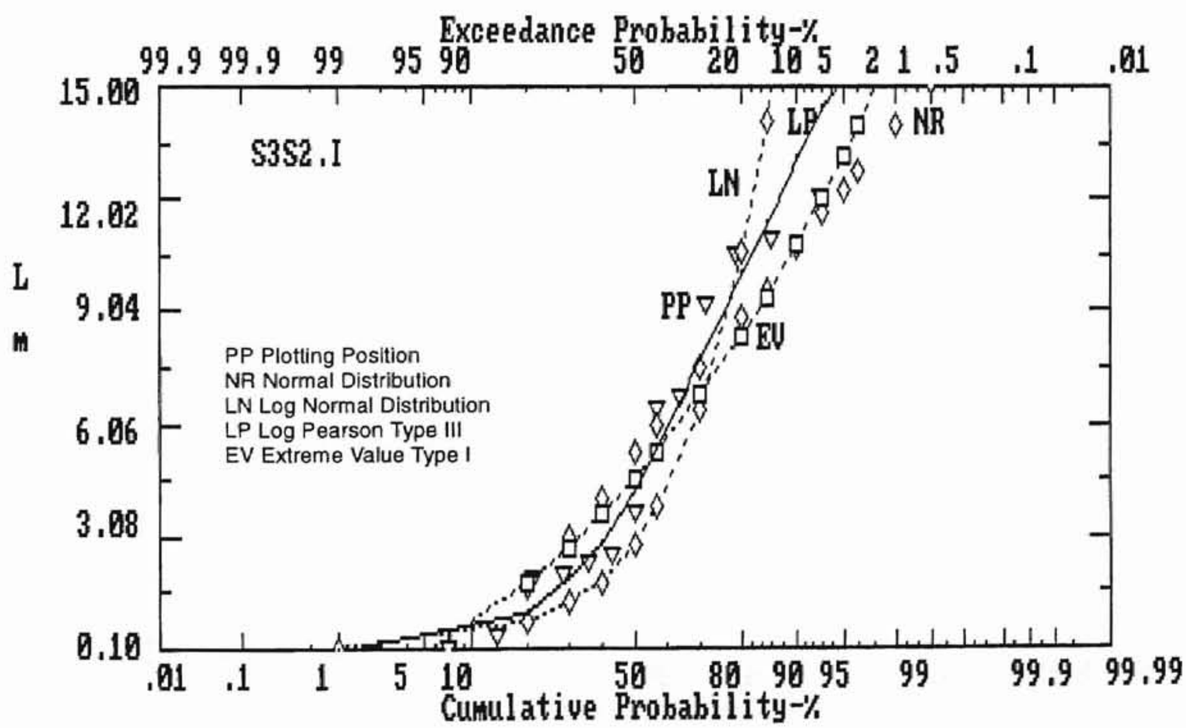

Figure 30. S3S2 Interior Link Length Distribution

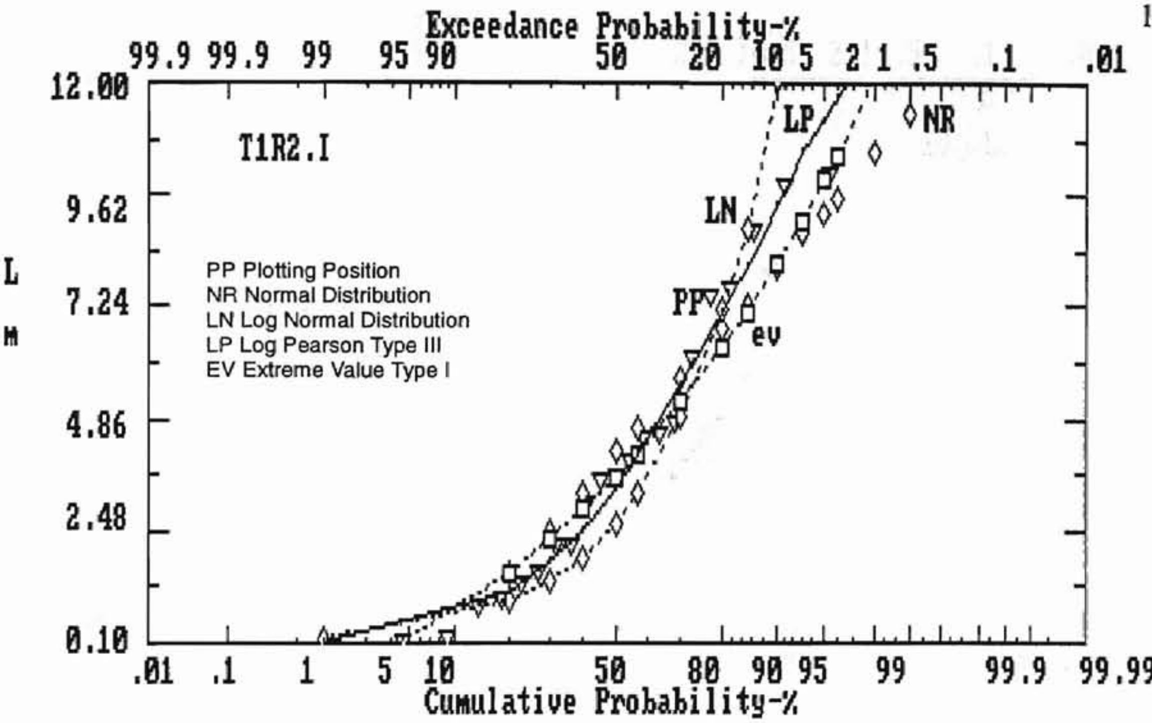

Figure 31. T1R2 Interior Link Length Distribution

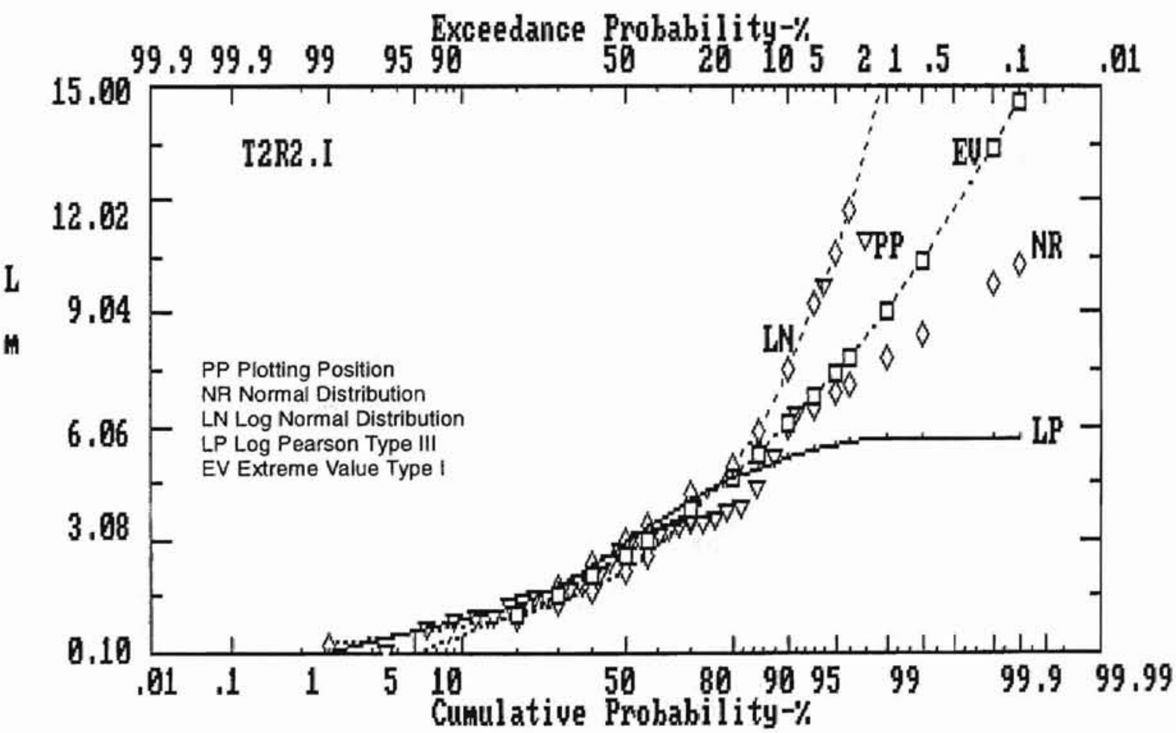

Figure 32. T2R2 Interior Link Length Distribution

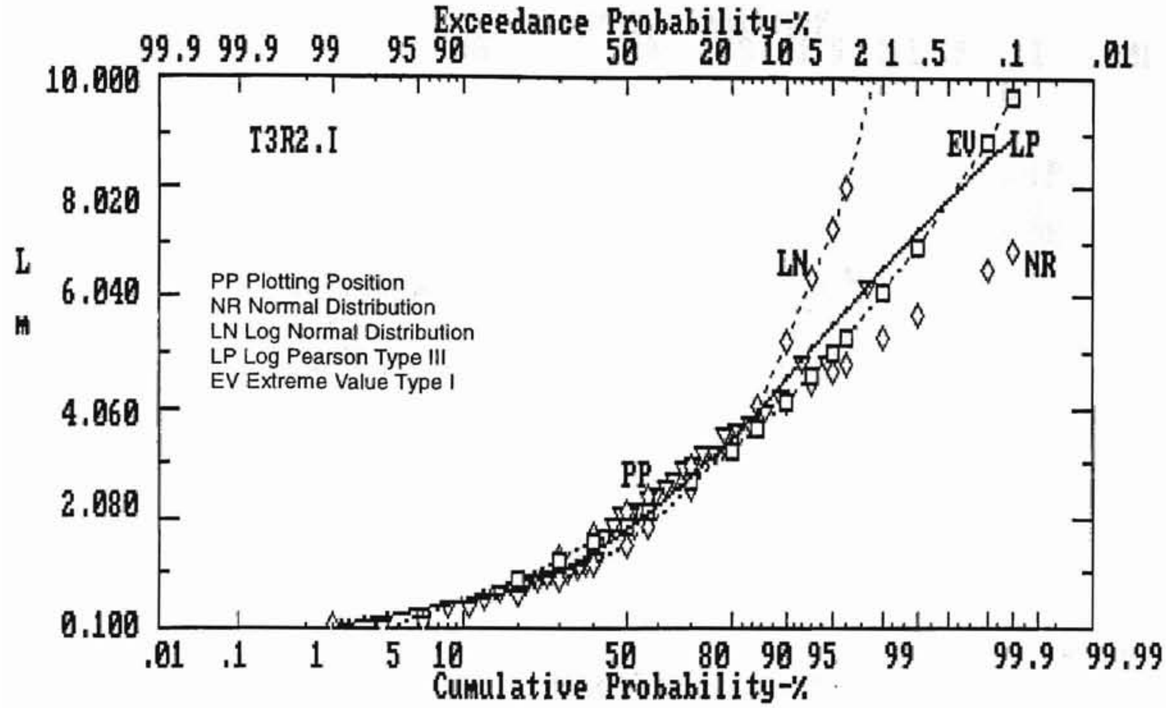

Figure 33. T3R2 Interior Link Length Distribution

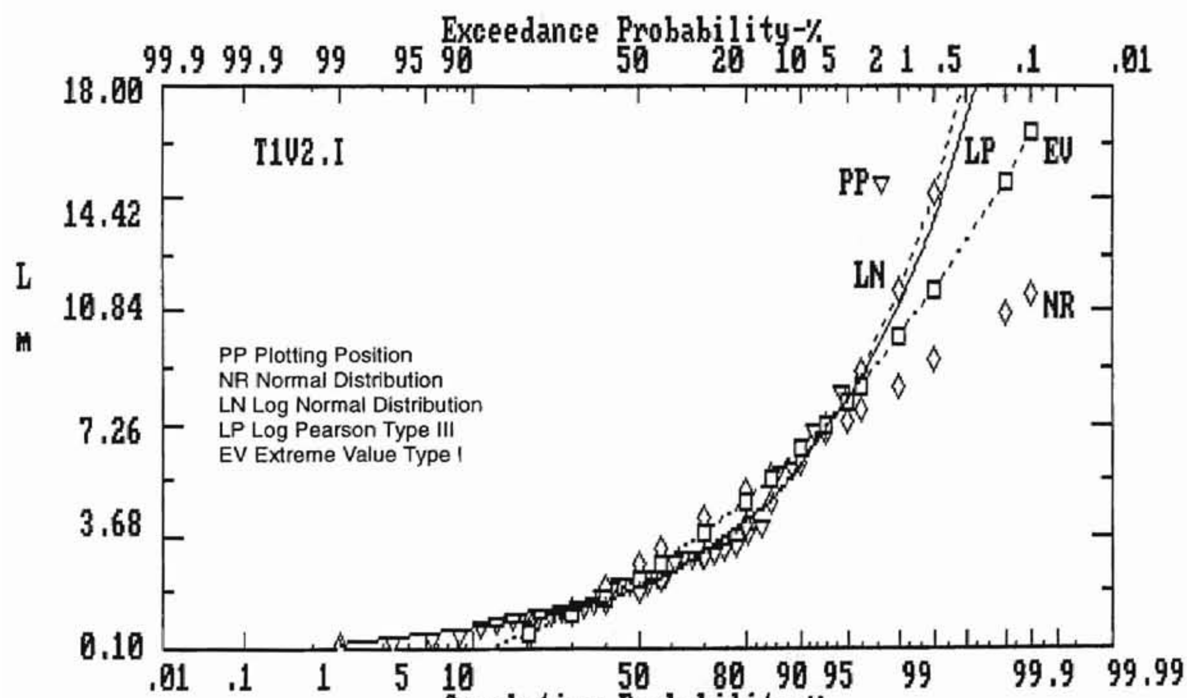

Figure 34. T1V2 Interior Link Length Distribution

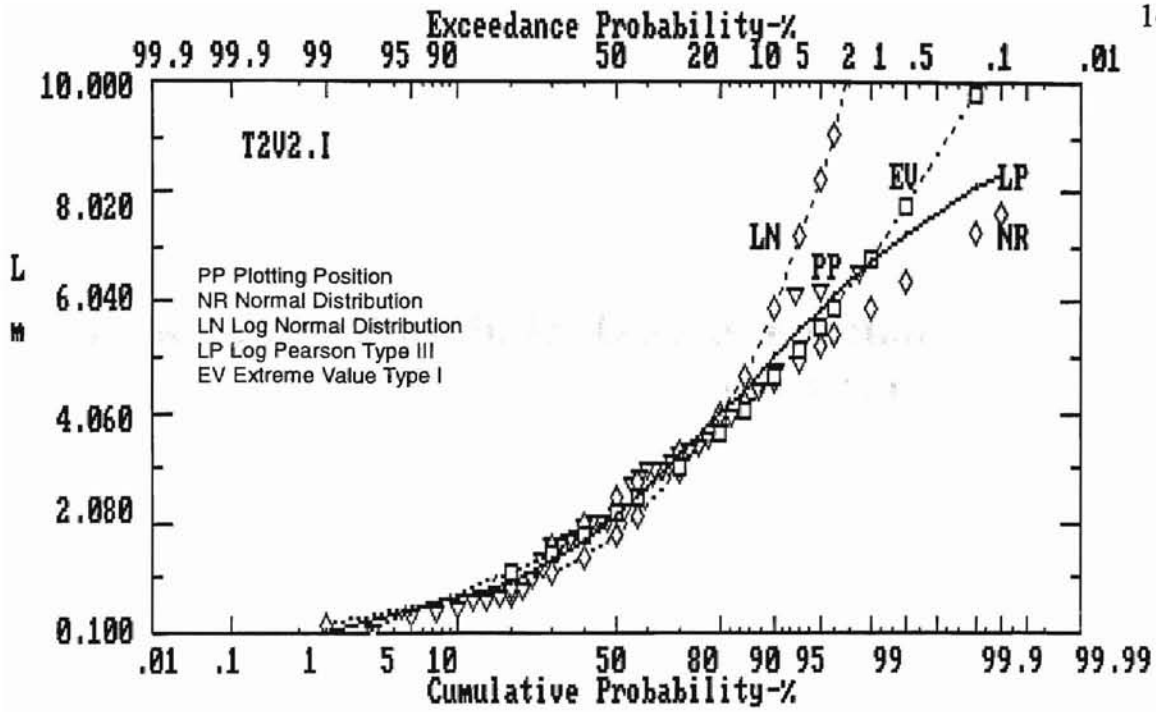

Figure 35. T2V2 Interior Link Length Distribution

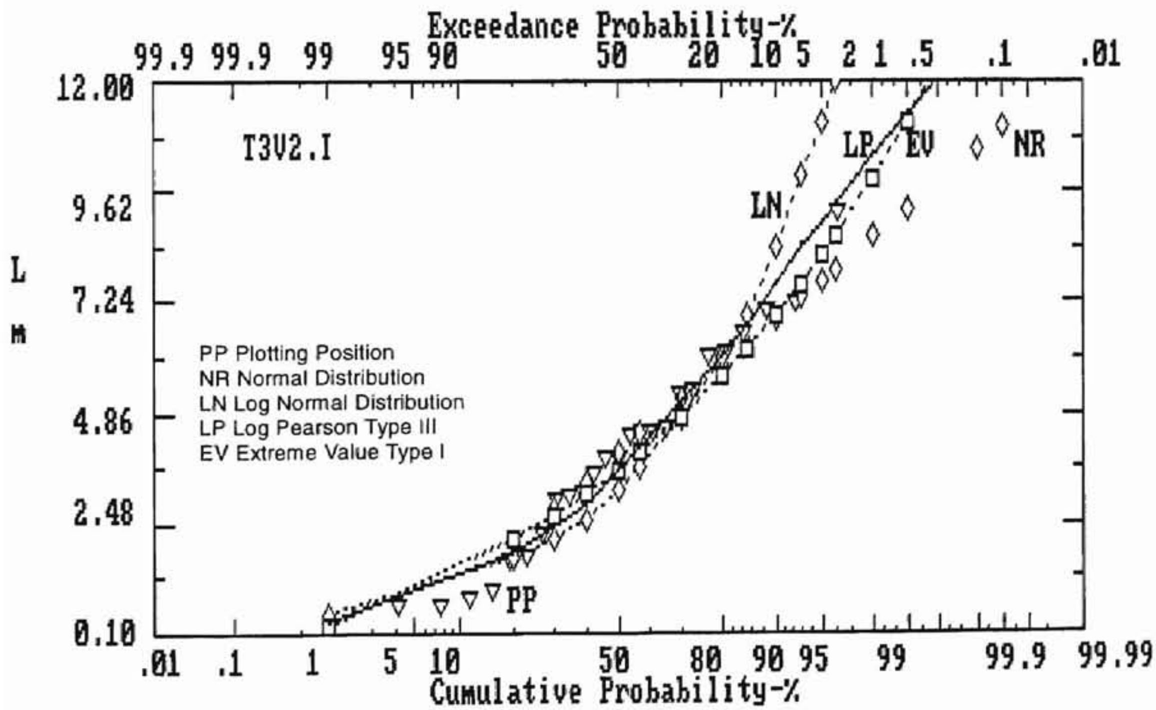

Figure 36. T3V2 Interior Link Length Distribution

Link Length Probability Density Function Estimated Parameters for the UK Data

Table C.1: Total Link Length Probability Density Function Estimated Parameters for the UK Data

ID Name	Normal		Log-Normal		Extreme Value I	
	Mean (m)	Standard Deviation (m)	Mean	Standard Deviation	Alpha	Beta
S1R2	4.57	3.12	1.22	0.89	2.43	3.17
S2R2	3.99	3.85	0.93	1.05	3.00	2.26
S3R2	3.51	2.52	0.89	0.97	1.96	2.37
S1S2	3.96	3.41	0.97	1.04	2.66	2.43
S2S2	4.03	3.82	0.82	1.32	2.98	2.30
S3S2	4.32	3.45	0.92	1.35	2.69	2.77
T1R2	3.55	2.90	0.79	1.25	2.26	2.24
T2R2	2.63	2.55	0.51	1.13	1.99	1.48
T3R2	2.53	2.40	1.19	1.09	1.87	1.45
T1V2	2.85	2.78	0.58	1.06	2.17	1.60
T2V2	2.45	1.82	0.48	1.11	1.42	1.63
T3V2	3.55	3.16	0.82	1.03	2.47	2.13

Table C.2: Exterior Link Length Probability Density Function Estimated Parameters for the UK Data

ID Name	Normal		Log-Normal		Extreme Value I	
	Mean (m)	Standard Deviation (m)	Mean	Standard Deviation	Alpha	Beta
S1R2	5.05	3.44	1.29	0.99	2.69	3.50
S2R2	4.55	4.42	1.00	1.14	3.45	2.56
S3R2	3.63	2.67	0.96	0.84	2.08	2.43
S1S2	4.00	3.73	0.93	1.12	2.90	2.32
S2S2	4.36	4.52	0.70	1.59	3.52	2.33
S3S2	3.71	2.80	0.83	1.24	2.19	2.45
T1R2	3.10	2.71	0.64	1.30	2.11	1.88
T2R2	2.30	2.68	0.27	1.22	2.09	1.09
T3R2	2.77	2.88	0.44	1.21	2.25	1.47
T1V2	2.88	2.82	0.51	1.20	2.20	1.61
T2V2	2.39	1.96	0.35	1.25	1.53	1.51
T3V2	3.26	3.65	0.59	1.14	2.84	1.62

Table C.3: Interior Link Length Probability Density Function Estimated Parameters for the UK Data

ID Name	Normal		Log-Normal		Extreme Value I	
	Mean (m)	Standard Deviation (m)	Mean	Standard Deviation	Alpha	Beta
S1R2	3.79	2.44	1.12	0.72	1.90	2.69
S2R2	3.17	2.72	0.82	0.92	2.12	1.95
S3R2	3.31	2.34	0.79	1.08	1.82	2.26
S1S2	3.91	2.98	1.02	0.93	2.32	2.57
S2S2	3.56	2.63	0.99	0.81	2.05	2.38
S3S2	5.30	4.23	1.06	1.55	3.30	3.40
T1R2	4.14	3.10	0.98	1.18	2.42	2.74
T2R2	3.06	2.34	0.82	0.94	1.83	2.00
T3R2	2.21	1.51	0.48	0.92	1.18	1.53
T1V2	2.81	2.77	0.68	0.86	2.16	1.56
T2V2	2.52	1.66	0.63	0.90	1.29	1.78
T3V2	3.98	2.27	1.16	0.76	1.77	2.96

APPENDIX D

Residual Plots For The UK Data

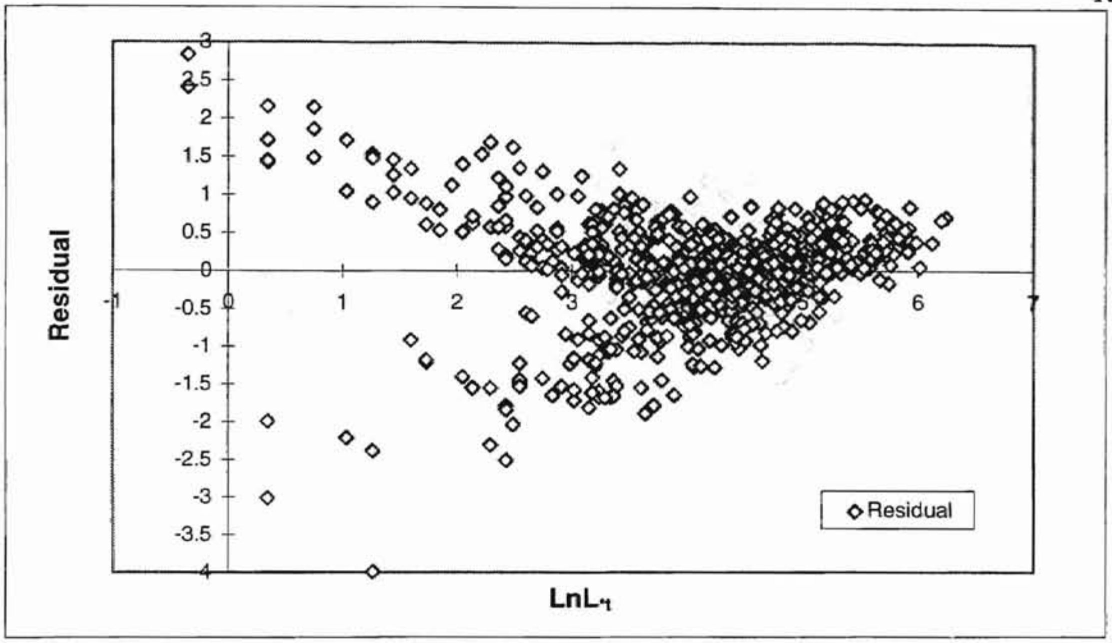

Figure D.1: Residual of Total Link Area for Natural Logarithm Transformed UK Data

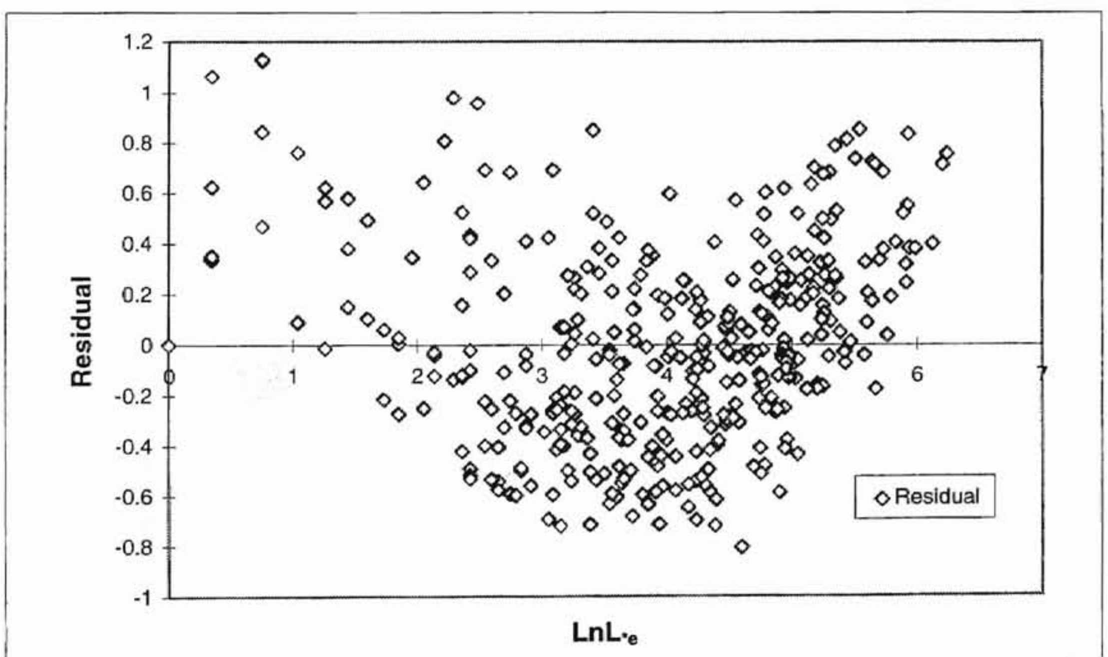

Figure D.2: Residual of Exterior Link Area for Natural Logarithm Transformed UK Data

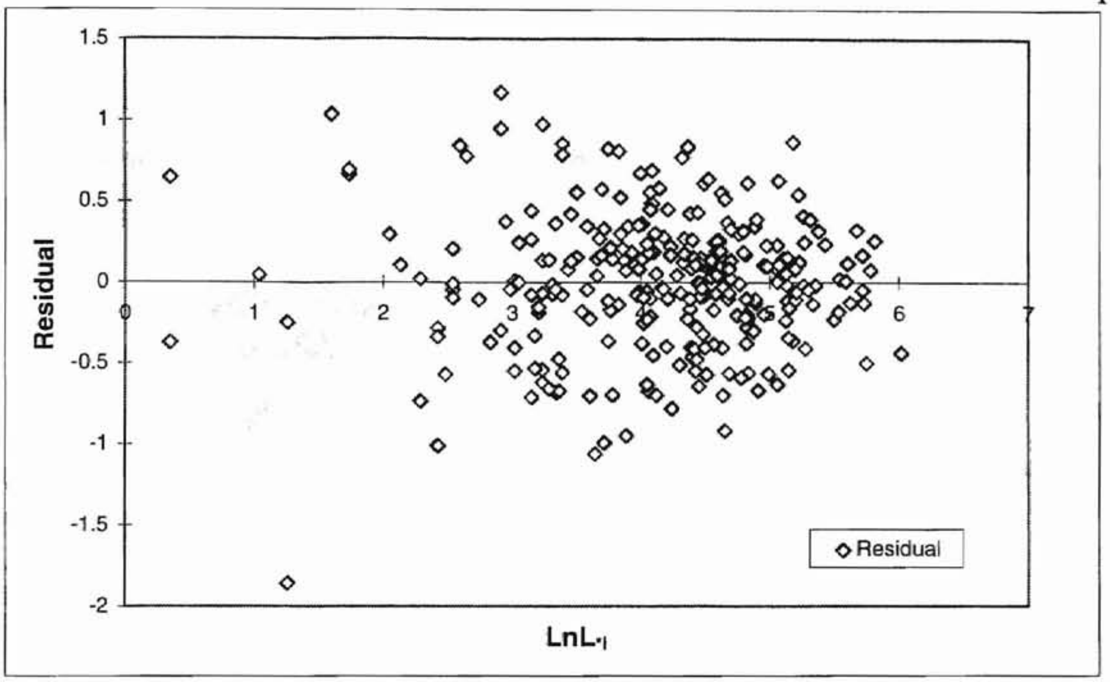

Figure D.3: Residual of Interior Link Area for Natural Logarithm Transformed UK Data

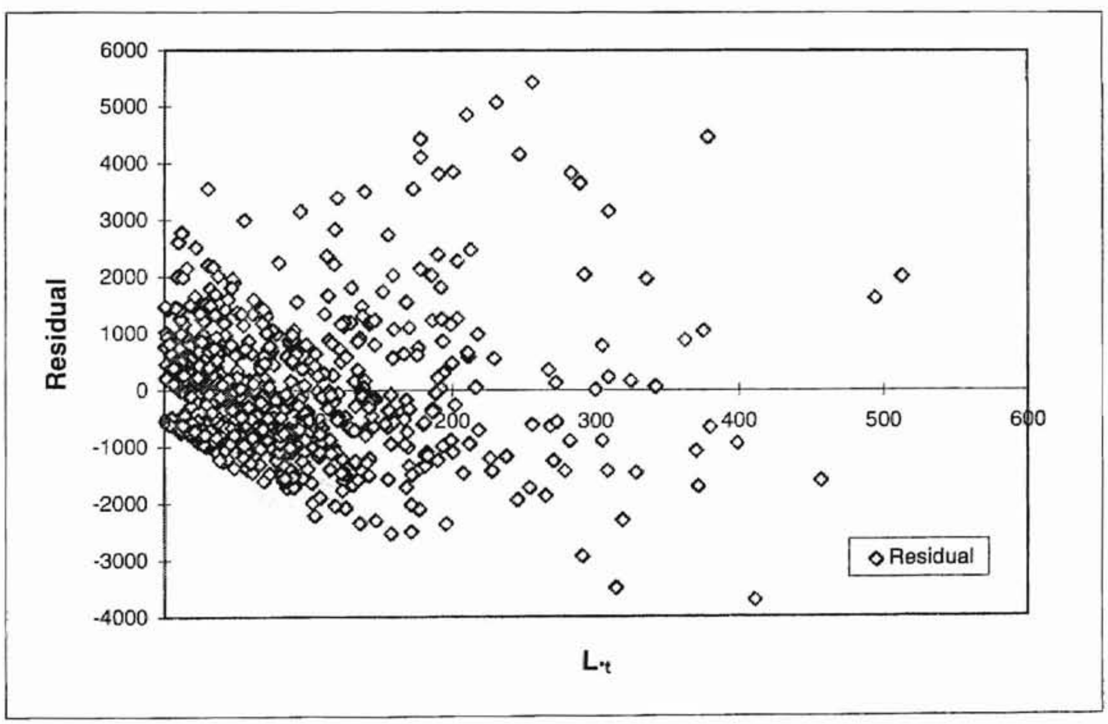

Figure D.4: Residual of Total Link Area for the UK Data

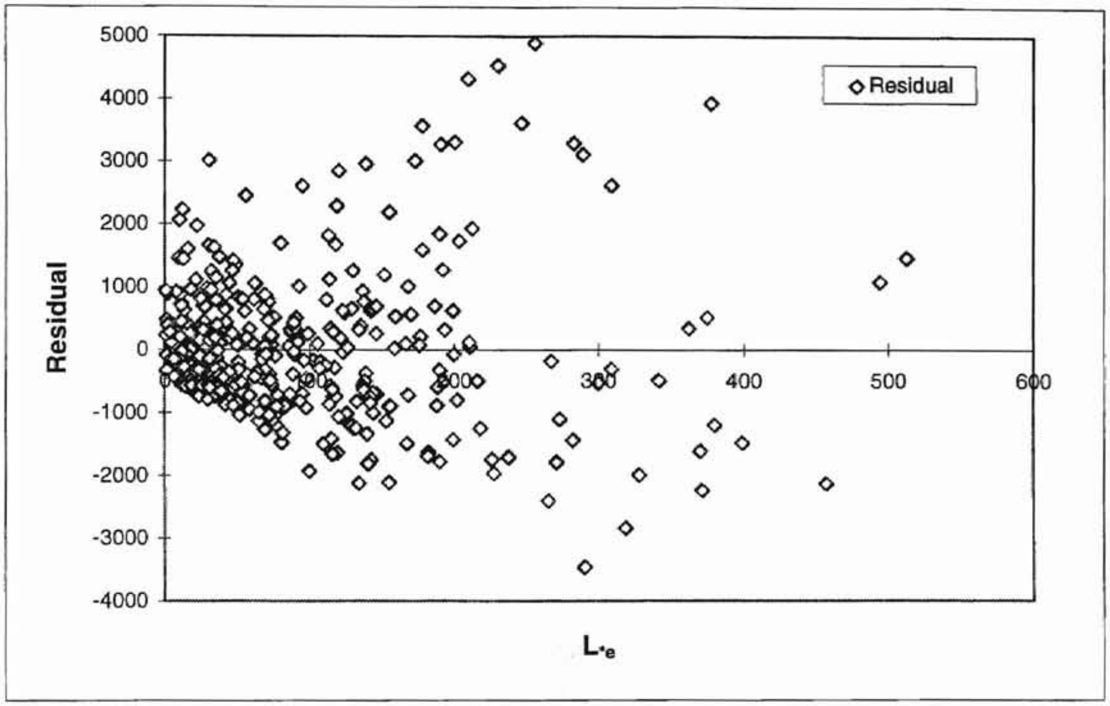

Figure D.5: Residual of Exterior Link Area for the UK Data

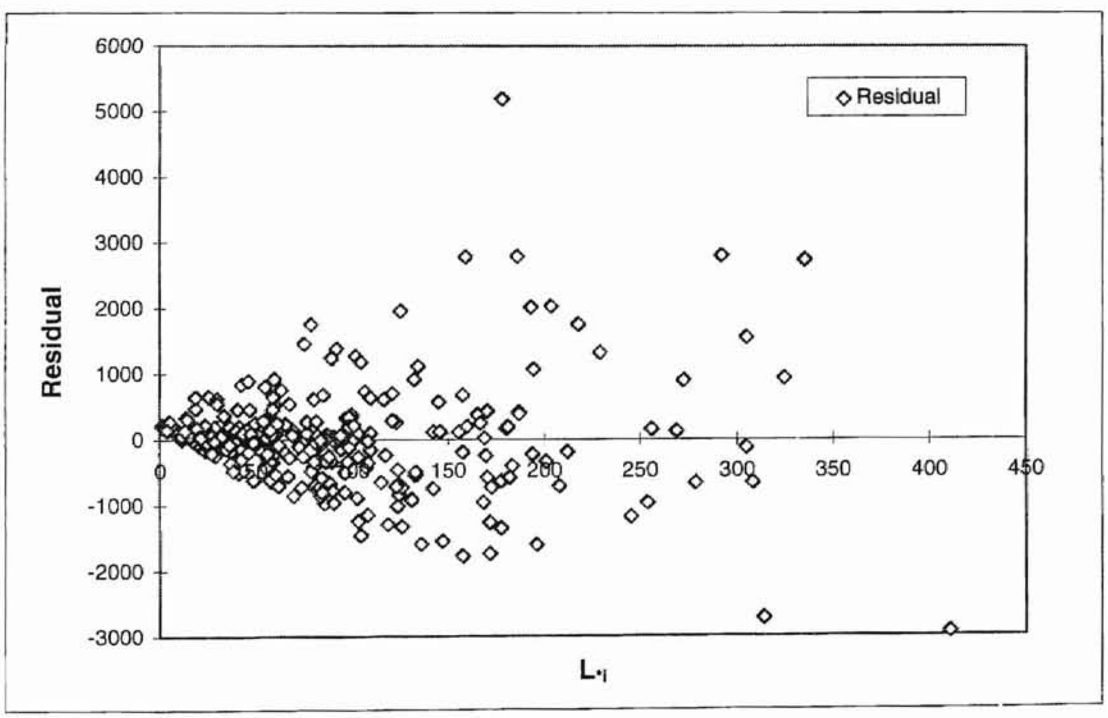

Figure D.6: Residual of Interior Link Area for the UK Data

2

VITA

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