Using Accumulation Based Network Identification Methods to Identify Hill Slope Scale Drainage Networks in a Raster GIS

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Abstract

The simple accumulation-based network identification method (ANIM) in a raster Geographic Information System (GIS) posed by O'Callaghan and Mark (1984) has been criticized for producing a spatially uniform drainage density (Tarboton 2002) at the watershed scale. This criticism casts doubt on the use of ANIMs for deriving properties such as overland flow length for non-point source pollution models without calibrating the accumulation threshold value. However, the basic assumption that underlies ANIMs is that convergent topography will yield a more rapid accumulation of cells, and thus, more extensive flow networks, with divergent or planar terrain yielding sparser networks. Previous studies have focused on networks that are coarser than the hill-slope scale, and have relied upon visual inspection of drainage networks to suggest that ANIMs lack the ability to produce diverse networks. In this study overland flow lengths were calculated on a sub-watershed basis, with standard deviation, and range calculated for sub-watershed populations as a means of quantifying the diversity of overland flow lengths produced by ANIM at the hill slope scale. Linear regression and Spearman ranking analyses were used to determine if the methods represented trends in overland flow length as suggested by manual delineation of contour lines. Three ANIMs were analyzed: the flow accumulation method (O'Callaghan and Mark, 1984), the terrain curvature method (Tarboton, 2000) and the ridge accumulation method (introduced in this study). All three methods were shown to produce non-zero standard deviations and ranges using a single support area threshold, with the terrain curvature method producing the most diverse networks, followed by the ridge accumulation method, and then the flow accumulation method. At an analysis unit size of 20 ha, the terrain curvature method produced a standard deviation that was most similar to those suggested by the contour crenulations, -13.5%, followed by the ridge accumulation method, -21.5%, and the flow accumulation method, -61.6%. The ridge accumulation produced the most similar range, -19.1%, followed by terrain curvature, -24.9%, and flow accumulation, -65.4%. While the flow accumulation networks had a much narrower range of predicted flow lengths, they had the highest Spearman ranking coefficient, R_s=0.722, and linear regression coefficient, R^2=0.602. The terrain curvature method was second, R_s=0.641, R^2=0.469, and then ridge accumulation, R_s=0.602, R^2=0.490. For all methods, as threshold values were varied, areas of dissimilar morphology (as evidenced by the common stream metric, stream frequency) experienced changes in overland flow lengths at different rates. This results in an inconsistency in ranking of sub-watersheds at different thresholds. When thresholds were varied to produce average overland flow lengths from 75 m to 150 m, the terrain curvature method showed the lowest incidence of rank change, 16.05%, followed by the ridge accumulation method, 16.73%, then flow accumulation, 25.18%. The results of this investigation suggest that for all three methods, a causal relationship exists between threshold area, underlying morphology, and predicted overland flow length. This causal relationship enables ANIMs to represent contour network trends in overland flow length with a single threshold value, but also results in the introduction of rank change error as

threshold values are varied. Calibration of threshold value (varying threshold in order to better match observed overland flow lengths) is an effective means of increasing the accuracy of ANIM predictions, and may be necessary when comparing areas with different stream frequencies. It was shown that the flow accumulation method produces less diverse networks than the terrain curvature and ridge accumulation methods. However, the results of rank and regression analyses suggest that further investigation is required to determine if these more diverse ANIM are in fact more accurate than the flow accumulation method.

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Introduction

NPS pollution models are often used to determine the potential effects of changes in land use, or the application or absence of certain conservation management practices (Haan et al, 1994). They may also be used for the purpose of prioritizing areas of land for the receipt of human and financial conservation resources, or for choosing the type of best management practice to be implemented in order to meet conservation goals (Tomer et al, 2003). An accurate representation of the drainage network is essential for the reliable performance of NPS models, as transport processes differ greatly between overland and channelized flow (Thiekken et al, 1999). Knowledge of the extent of flow concentration in ephemeral channels, at the "hill slope" scale, is essential for predicting the performance of riparian buffers (Dillaha and Hayes, 1992; Inamdar and Dillaha, 2000), and in using empirical methods for predicting erosion and sediment yields (Jain and Kothyari, 2001). Widely used models such as HSPF, AGNPS, TR-55, GLEAMS, USLE/RUSLE and ANSWERS2000 require either an estimate of overland flow length (distance of overland flow before concentration) or a cell based representation of the drainage network at the hill slope scale, where flow through a cell is distinguished as either sheet or channel flow. The purpose of this research is to evaluate the use of Accumulation-based Network Identification Methods (ANIM) in Geographic Information Systems (GIS) for supplying the overland flow length parameter for non-point source pollution models. In order to evaluate these methods based on ease of use and accuracy, a set of general-purpose performance criteria and a standard evaluation procedure will be outlined. In order to inform the choice of evaluation criteria, the basic concepts behind flow accumulation and its relationship to topography will also be explored.

Accumulation-based network identification methods (ANIM) are based on determining the contributing area flowing (or *accumulating*) into every point in a watershed and partitioning flow into overland and channelized flow based on the exceedence of a source area threshold. In order to realize the potential efficiency gains in NPS model input parameterization promised by GIS, network identification methods must be simple to implement, processor efficient, and make use of readily available data sets. The chosen methods must also be able to make accurate predictions with minimal effort (e.g. threshold value calibration) on the part of modelers. ANIM are widely used because they employ readily available rectangular gridded digital elevation model (DEM) data, have relatively small processor demands, and operate on algorithms that are available in virtually all GIS. With regards to accuracy, however, these methods have been widely criticized based on their dependence on an arbitrary choice of threshold value, the resultant need for calibration of this value, artifacts in network representation due to systematic deficiencies (such as parallel flow paths), and spatial homogeneity in overland flow length when using a single threshold. Three ANIM's, the simple source area threshold method (flow accumulation), the terrain curvature method (terrain curvature), and the ridge accumulation method (ridge accumulation), will be evaluated based on their ability to provide estimates of overland flow length that reflect variations in terrain without calibration of the threshold value.

While previous studies have suggested that the original ANIM, the flow accumulation method, is unable to represent spatial diversity, there has been little attempt to outline evaluation criteria to support these claims. For that matter, there has been little investigation into the practical implications of the fundamentals upon which all ANIM rely, i.e., that convergent terrain will yield denser drainage networks (shorter overland flow lengths) and that divergent or planar terrain will yield sparser networks (longer overland flow lengths). This study will explore the fundamental principles that underlay ANIM and also outline a process for evaluating spatial diversity at the hill-slope scale. The following questions will shape this investigation:

1. Do the mechanisms that underlay Accumulation-based Network Identification Methods (ANIM) provide for the *possibility* of spatial variation in overland flow length with a single threshold? Also, are there any negative implications inherent in these mechanisms?
2. Do ANIM exhibit spatial variation with a single threshold when analyzing real terrain forms, and can this variation be quantified simply (i.e. standard deviation)?
3. Do ANIM represent trends in variation of overland flow length as suggested by tracing contours lines using: a) a locally calibrated threshold value, b) a regionally calibrated threshold value?
4. What is the sensitivity to changes in threshold value, and can this sensitivity be predicted?

1. Literature Review

Early investigations into defining overland flow length / ephemeral drainage networks were performed by manually defining the channels on contour maps (Smith, 1950; Leopold, 1964; Mark, 1983; Dillaha and Hayes, 1992). More recently, attention has turned to the use of GIS to define these drainage-ways (Inamdar et al, 1993; Bren, 1998; Helmers et al, 2001). While GIS based network identification methods (NIM) can be much faster than manual methods, their accuracy has been questioned due to deficiencies in the methods themselves, and due to the accuracy of the input data sets (Caiado et al, 2003; Edreny and Wood, 2001). Furthermore, due to the scarcity of data at a resolution sufficient to discern hill-slope drainage networks, little is known about the performance of common GIS based NIM at this scale.

Accumulation-based network identification methods, ANIM, are computed by assigning each cell in the grid a weight and flow direction, then computing the sum, or *accumulation*, of all upland cell weights flowing through each cell in the grid (O'Callaghan and Mark, 1984). The operator then chooses a threshold value for channel initiation, and applies this as a filter over the flow accumulation grid. Cells whose accumulation values exceed the threshold value are considered to be part of the channelized flow network.

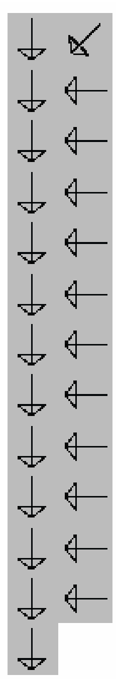

Figure 1.1: Sample flow direction grid.

0	0
3	0
5	0
7	0
9	0
11	0
13	0
15	0
17	0
19	0
21	0
23	0
24	

Figure 1.2: Sample Flow accumulation grid.

The most significant change to this common method since its inception has been the introduction of a procedure to fill pits or depressions in the source DEM, and for routing flow over the resulting flat areas (Jensen and Domingue, 1988). The D8 flow direction method (Jenson and Domingue, 1988) creates parallel flow patterns in large areas of flat terrain. The simple flow accumulation method produces parallel channels in these areas. Numerous solutions to this problem have been proposed, from slight alteration of the DEM, to the introduction of alternate algorithms for defining flow direction (Fairfield 1991, Tribe 1992, and Garbrecht and Martz, 1997; Tarboton, 1997). These changes facilitate the construction of a continuous stream network.

ANIM, as defined in this study, differ primarily in their choice of weighting scheme. The most common accumulation-based method is the one introduced by O'Callaghan and Mark, the source area threshold, or flow accumulation method, which features a weight of 1 for each cell. Other weighting schemes have been proposed, based on local slope (Montgomery and Dietrich, 1989; Leopold et al, 1992; Inamdar and Dillaha, 2000), erosion thresholds (Dietrich et al, 1993), using vector contours (Bren, 1998) and upwardly curved cells (Tarboton, 2001). The terrain curvature weighting scheme introduced by Tarboton (Tarboton, 2001), combines one of the earliest network identification algorithms – identifying upwardly curved cells (Peucker and Douglas, 1975), which produced non-continuous networks, with the standard flow accumulation algorithm. By combining these two approaches – accumulation and curvature – this method produces continuous networks that are a reflection of observed terrain features.

While drainage network identification has been studied extensively, due to the scarcity of high-resolution data, much of the work has focused on the use of threshold values that produce networks beyond the hill-slope scale. Furthermore, there have been few attempts to set down standard procedures for evaluating the accuracy of drainage network predictions at the hill-slope scale. One study that did attempt to evaluate hill slope scale networks, an evaluation of predicting concentrated flow through riparian buffers using 30m DEMs (Brothers et al., 2002) was more an exercise in evaluating the accuracy of 30m DEMs, than it was an evaluation of the ANIM. They concluded that 30m DEM are insufficient to discern hill-slope scale networks. This agreed with a previous study that concluded that DEM's with a 10m resolution would be necessary to represent networks with overland flow lengths as small as 50m (Zhang and Montgomery 1994).

Many investigators have raised questions pertaining to DEM accuracy, and the potential for DEM errors to propagate to NPS models has been shown to be significant (Mark, 1984; Edreny and Wood, 2001; Brothers et al, 2002). Due to these uncertainties, it is difficult to locate instances where investigators actually utilize an ANIM for determining the actual drainage network characteristics employed in predictive NPS models. More common is the use of accumulation values for consideration of loading (Xiang, 1996; Bren, 1998), or in an empirical equation to generate overland flow length factor for use in various implementations of the USLE (Jain and Kothyari, 2000; Tomers, et al, 2002). The USLE and its variants have been shown to be highly sensitive to the overland flow length, or LS factor (Gertner, et al, 2002). The use of ANIM for producing a digital drainage network for NPS models is fairly widespread, perhaps the most prominent being in the integrated GIS and modeling environment BASINS (U.S. EPA, 2003). Although the integrated toolkit provides a facility for employing the flow accumulation method for drainage network identification, it does not necessarily recommend its use, nor does it provide guidance for threshold value choice. Indeed, it also provides for the use of other methods, and the inclusion of the flow accumulation method in the BASIN's toolkit is more an acknowledgement of its ubiquity than its usefulness. While the use of ANIM is widespread, the usefulness of the networks they produce for derivation of overland flow length has not been validated.

While many authors have commented on the influence that the choice of threshold value has on the length of the resulting network (Morris and Heerdegen, 1986; Tarboton et al 1991, Helmlinger et al 1993), few have been able to suggest robust, easy to use guidelines for threshold choice (Helmlinger et al, 1993). Tarboton suggests the use of the constant stream drop parameter, an empirical characteristic of stream networks (Broscoe, 1959), to guide the choice of threshold value. However, preliminary results in this investigation suggest that this method was not suitable for producing networks at the hill slope scale; the resulting networks were too coarse. Helmlinger reported on the relationship between threshold value

(T) and drainage density (D), establishing that an increase in threshold value over the range 5 ha < T < 92 ha, resulted in an exponential decrease in drainage density for 3 watersheds, sizes ranging from 113 km^2 to 600 km^2. Tarboton (2001), comparing drainage densities in 3 separate watersheds (watershed area not reported) at values of threshold area between 1 ha and 100 ha, found a consistent functional dependence between source area threshold, T, and the resultant drainage density. He concluded that networks defined with the flow accumulation technique suffered from a spatially uniform drainage density. The results of Gandolfi and Bischetti (1997), however, showed significant variation in drainage density between 3 watersheds (areas between 4.5 km^2 to 7.0 km^2) when using the same threshold values over a range of 1 ha <= T <= 10 ha. Their results also showed a variation in the rate of change in D as a function of T, with one watershed having a greater D at lower values of T, and a second watershed having a greater D at higher T levels.

The impact of threshold value on the morphometric characteristics of the resulting networks, such as total network order, drainage density, drainage frequency and bifurcation ratio has been shown to be substantial (Morris and Heerdegen, 1988, Helmlinger et al, 1993, and Gandolfi and Bischetti, 1997). Despite the widespread investigation into the effects of threshold value on stream morphometrics, there has been little investigation into the role that variation in the underlying topography plays on these metrics when networks are generated with a constant support area threshold; excepting, of course, the extensive discussion of parallel flow paths. This problem of parallel flow paths over flat surfaces is perhaps the most extensively studied example of the interaction between an ANIM and the underlying landform represented by the DEM. The effect of resolution aggregation of input DEM has also been shown to significantly alter the resulting drainage network (Wang and Yin, 1998, Thiekken et al, 1999). Additionally, the effects of DEM smoothing on determination of flow direction has been shown to be significant (Caiado et al, 2003), in essence demonstrating the potential impact that changes in landform may have on the interpretation of the drainage network.

The parallel flow problem is particularly interesting in that the flow accumulation method produces an erroneously high drainage density due to a misinterpretation of an artificial landform, i.e. the perfectly flat surface with all drainage pathways flowing parallel to one another. As a result of these observations, it is not unthinkable that there may exist cases wherein naturally occurring landforms that are accurately represented in a DEM might be misinterpreted by the flow accumulation method. However, there seems to be a scarcity of investigation into the role of terrain morphology and ANIM. The lone example of a mention of the impacts of the underlying morphology (other than parallel flow paths) noted in this review is the mention of stream frequency in the sensitivity analysis performed by O'Callaghan and Mark (1984) in their initial paper introducing flow accumulation.

Previous investigations have used 3 basic sources of ground truth to evaluate the veracity of the predicted drainage networks, and/or to guide the choice of accumulation threshold values:

1. Comparing the digital network against a field survey of the area in question (Montgomery and Dietrich, 1989; Inamdar and Dillaha, 2000; Brothers et al, 2001).
2. Comparing the properties of the digital network against the corresponding properties of real networks as based on empirical relationships (Tarboton, 1992; Ijjasz-Vasquez and Bras, 1995).
3. Comparison with ephemeral channels mapped on existing USGS 7.5' topographical maps through the interpretation of contour crenulations (Tarboton, 2001).

The first method would undoubtedly yield the most precise evaluation of the digital network, but is impractical if the area in question were very large. Such field surveys are also expensive, time-consuming, and consequently, rarely available to the investigator. The use of empirical methods (such as drainage density, stream frequency or overland flow length) is much more practical in the case of a large watershed wide assessment, however, data for estimating empirical quantities for a given watershed must be readily available in order to facilitate the comparison of the proposed ephemeral drainage networks. While a number of investigations have been performed using accepted "laws" of stream network characteristics (Ijjasz-Vasquez and Bras, 1995; Tarboton, 1992), the universality of these laws has been questioned (Helmlinger et al, 1993; Montgomery and Foufoula-Georgiou, 1993), and the resolution of these studies was not extended to the hill-slope scale. The third method, comparison with ephemeral channels interpreted from contour crenulations on USGS topographic maps (generally referred to as the contour crenulation, or CC method), while less precise and still time consuming, is readily accessible. There are two different approaches to evaluating contour crenulations: manual delineation and texture ratio measurement.

Manual delineation is a common method of producing a drainage network, based on interpreting the contours on a topographic map. The basic method, as defined by Lubowe (1964) is to extend the drainage net along a series of cusps in successive contour lines if there are 3 consecutive contours of 150 degrees or less, or if there are two consecutive contours of 100 degrees or less. The USGS topographic DEMs are based on a common form of topographic map that can provide contour networks for such an analysis. When constructing a contour map, USGS topographers begin by sketching in all channels in an area, and then drawing contours based on this channel network. Channels that do not have perennial flow are then eliminated from the final map (Mark, 1983). The CC method involves interpreting the significance of bends, or crenulations, in the contour lines that are drawn upon a topographical map, effectively restoring the drainage features detected by the original topographer (Mark, 1984). Mark (1983) showed that 24 out of 25 drainage pathways predicted by the CC method existed in the field. The main limitation to this method is the resolution of the contour map employed. Comparison of drainage networks predicted by topographic maps with field surveys performed by Morisawa (1961) and Mark (1983) both determined that actual drainage paths are more numerous in the field than those predicted from contour analysis. However, Mark (1983) found that the channels not predicted by the contour analysis were smaller than those that *were* predicted. Morisawa (1961), Leopold (1964) and Mark (1983) all found that the CC method provided a more detailed picture of the actual drainage network than the did the maps of blue line streams on USGS 7.5 minute topographic quads.

The texture ratio is determined by first summing the number of crenulations in the most crenulated contour of a watershed, then, this sum is divided by the length of the watershed perimeter (in km or miles). The resulting number, the *texture ratio*, has been shown by Smith (1950) and Leopold (1964) to be highly correlated with drainage density. While this method is less time consuming than the manual delineation method for a large area, it is limited in that it provides only a surrogate of a single measurement, drainage density, and may obscure variations in terrain as the size of the watershed being measured increases.

2. Materials and Methods

2.1 Introduction to accumulation based methods and evaluation criteria

Evaluating the characteristics of ANIM networks requires knowledge of not only the *extent* of the drainage network, but also the *location*. Overland flow length is well suited to this pursuit, as it may be evaluated on a watershed-wide basis, effectively yielding the *extent* of the drainage network (i.e. how dissected is the overall terrain), as well as on a sub-watershed scale, where it then reports on the *location* or *diversity* of the drainage network (i.e. how are the channels distributed along the landscape). In order to evaluate extent, ANIM overland flow lengths for larger watersheds will be compared with contour crenulation overland flow lengths. In order to evaluate location, the watersheds will be divided into smaller sub-watersheds, and overland flow lengths for the sub-watersheds in the digital network will be compared to those in the contour network. Sub-watersheds will be divided into units occupying the minimum permissible area; agreements or disagreements with contour crenulation networks in these small areas should quantify the accuracy in spatial distribution. Central to this process will involve determining the appropriate DEM types, appropriate study areas, software for performing analysis, and methods of comparison.

2.2 Choice of DEM Resolution

Inherent in the evaluation of any drainage network is a central question: "What scale of drainage network is sought?" This question imposes an unavoidable subjectivity on the discussion. The drainage network desired may be as coarse as the "blue line streams", or may extend all the way up the hillside, as overland flow separates into rills (Chorley et al, 1984). While the choice of drainage network extent is arbitrary, the resolution of the input grid will limit the ability to accurately locate channel heads (Dietrich et al, 1993). This study will use the concept of hill-slope scale, or ephemeral channel network, situated somewhere between the rill network, and the perennial stream network. This network is considered to consist of permanent terrain features that concentrate runoff, which cannot be obliterated by tillage, and which are discernable by crenulated contours on topographic maps. The characterization of the 'hill-slope' scale used in this study will follow the results of a survey of riparian hill-slopes in southwestern Virginia's Ridge and Valley province by Inamdar and Dillaha (2000), which focused on ephemeral channels, and found overland flow lengths between 30-100 m. Zhang and Montgomery (1994) concluded that 10m DEM's were of a sufficient resolution to represent a highly dissected sub-watershed with overland flow lengths of between 30 and 50m, provided that the DEM were sufficiently free of errors.

2.3 Description of the Area of Study and Selected DEM Source

The source data for these study areas are USGS 10m Level 2 DEMs for Louisa, Craigville, Briery Branch and Surry Virginia, (GIS Data Depot, 2003). . The DEM themselves were generated from 1:24,000 scale contour maps, through an automated process which interpolates elevation values smoothly between adjacent contours, and are produced at a resolution of 10m. It will be assumed that these maps, despite topographical generalization in their creation (Mark, 1983) accurately represent a range of morphologic patterns. This does not imply an assumption that these maps are in fact accurate representations of the terrain that they depict. In truth, the resulting map is only as accurate as the contour source, which were generated by human cartographers. Also, the interpolation process may smooth features between contours. However, this data is free of some of the artifacts and noise common to earlier DEM. Even in the case of comparison with ground truth, the ground truth is generated from the maps themselves using contour crenulation, outlined in section 2.5. These quad sheets were selected in order to provide a diversity of terrain forms, however, all study areas are within the Chesapeake Bay watershed in Virginia. These areas span 6 eco-regions (Omernik, 1987), Northern Inner Piedmont, Rolling Chesapeake Inner Coastal Plain, Dissected Ridge and Knob, Northern Shale Valleys, Northern Sandstone Ridges and Northern Limestone/Dolomite Valleys.

2.4 GIS Software for delineating overland flow networks and calculating flow lengths

The goal of this research is to use the most recent advances in network delineation in an “off the shelf” fashion. ArcView GIS 3.1 and Spatial Analyst (ESRI, 1997) were used delineate networks for the ridge-weight method and the flow accumulation method. The stand-alone version of MapWindow 2.7 (Ames, 2001), with the TauDEM plug-in (Tarboton, 2002), was used to generate the terrain curvature networks, although the plug-in version of MapWindow for ESRI ArcGIS 8.x could also be used for deriving these networks. Values for diagonal and adjacent cell weightings for the terrain curvature method recommended in the literature were used exclusively, with the only adjustments made to the cell threshold values (see section 2.10.1). Terrain curvature networks were then imported into ArcView for further analysis. All calculations of overland flow length were performed using ArcView GIS 3.1. All analyses of flow network properties were carried out through the use of ArcView 3.1, with Spatial Analyst and the Hydrologic Modeling extension version 1.1. Appendix B contains the map algebra statements and Avenue scripts for ArcView GIS 3.1 that were used to perform the analyses listed below. Microsoft Excel, with the Data Analysis ToolPak was used for computing linear regression coefficients and Spearman ranking coefficients (Microsoft, 2000). The MS-DOS program R2 (Steiger and Fouladi, 1992) was used to compute confidence intervals for the R^2 values, in order to determine the signifcane of small differences in R^2 between two different methods.

2.5 Watershed partitioning

Ultimately, all analyses boiled down to a calculation of overland flow length in the small sub-watershed components of a larger watershed. The DEM's used in this study were partitioned into watershed units of various sizes, depending on the minimum or maximum sub-watershed size required for a given analysis. The sub-watersheds units were determined in ArcView GIS 3.1, using the following procedure:

1. Create a simple flow accumulation flow accumulation grid using the "Flow Accumulation" menu item.
2. Determine a coarse drainage network by reclassifying flow accumulation grid based on a cell threshold equal to the desired minimum unit size, 500 cells for a 5 ha unit, 1,000 cells for a 10 ha cell unit, 2,000 cells for a 20 ha cell unit.
3. Assign each reach in the resulting flow networks a unique ID by employing the StreamLink function.
4. Create a raster grid of sub-watersheds using the watershed function, with the stream link theme as the outlet theme.

The resulting theme contained sub-watersheds with a variety of sizes, with all headwater sub-watersheds guaranteed to have a minimum size equivalent to the threshold used to delineate the base network. Figure 2.1 shows the Craigville 3 watershed, partitioned by a 500-cell network. Figure 2.2 shows the contour network for sub-watershed 4, and figures 2.3-5 show the flow accumulation, terrain curvature and ridge accumulation networks, respectively, for this sub-watershed.

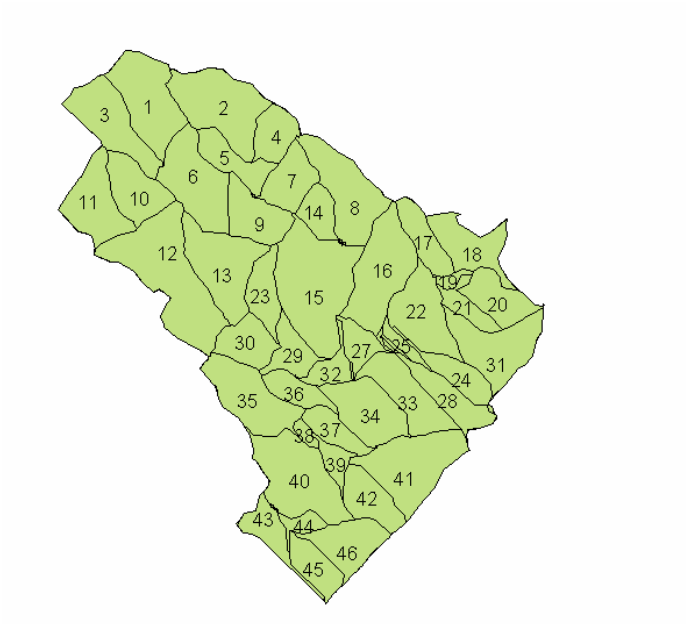

Figure 2.1: Sub-watersheds in Craigville 3 quad, based on a minimum analysis unit size of 5 ha.

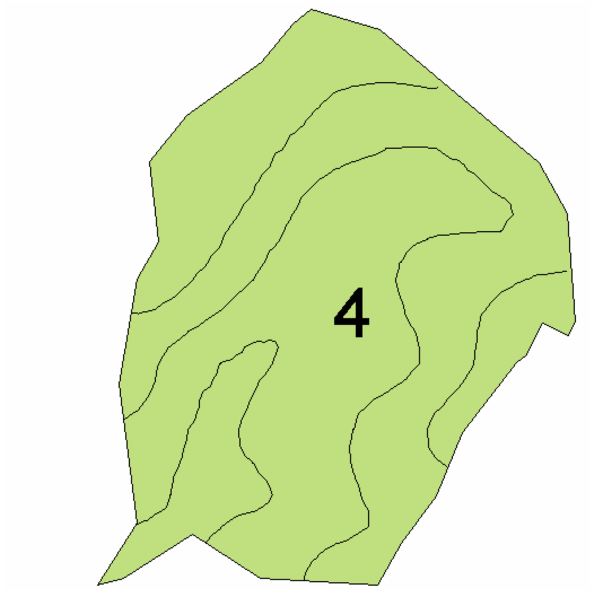

Figure 2.2: Sub-watershed 4 (6.8 ha) in the Craigville 3 quad, based on a minimum analysis unit size of 5 ha.

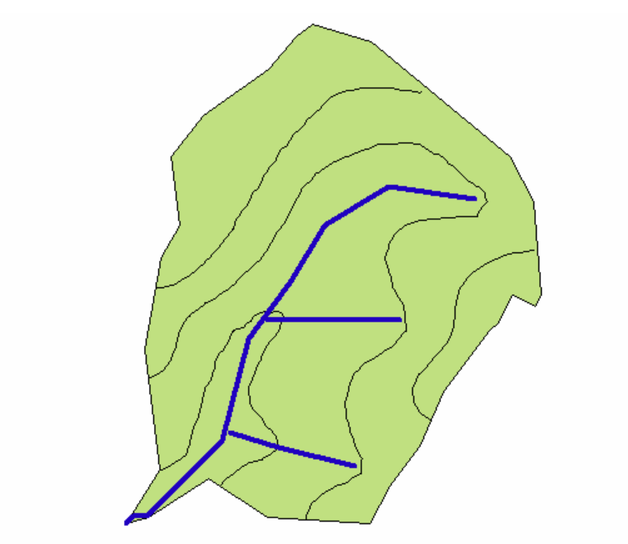

Figure 2.3: Channelized flow network in sub-watershed 4 in the Craigville 3 quad using the contour crenulation method of network delineation.

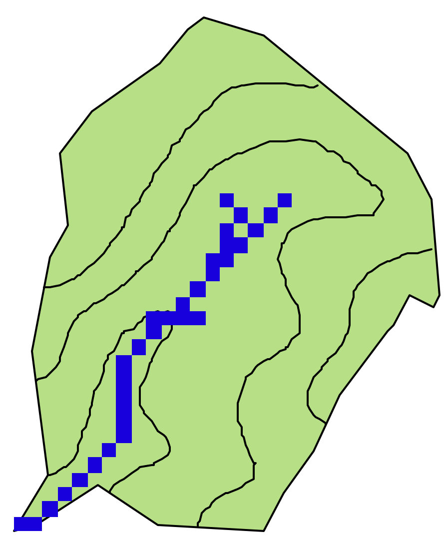

Figure 2.4: Channelized flow network in sub-watershed 4 in the Craigville 3 quad using the flow accumulation method of network delineation.

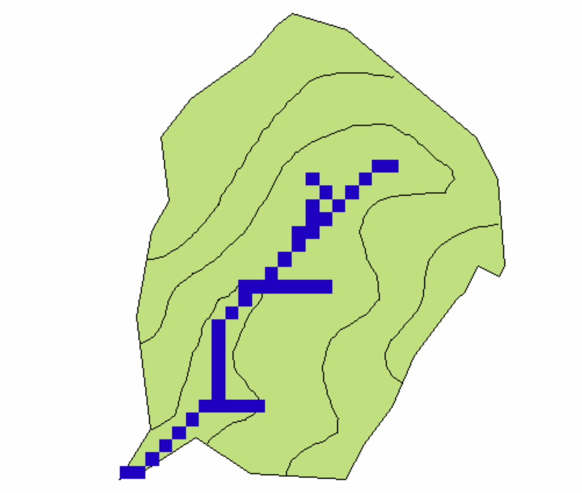

Figure 2.5: Channelized flow network in sub-watershed 4 in the Craigville 3 quad using the terrain curvature method of network delineation.

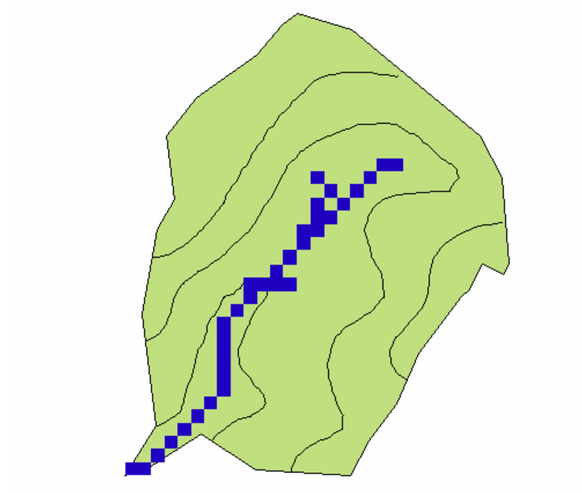

Figure 2.6: Channelized flow network in sub-watershed 4 in the Craigville 3 quad using the ridge accumulation method of network delineation.

2.6 Overland flow length calculations

Following Leopold (1964, p.146), who defined the distance between two adjacent channels, or overland flow length, as the reciprocal of drainage density, we may relate drainage density and overland flow length as follows:

$D = S / A$; [Eq. 2.1]

$D = 1 / (2 * L)$; [Eq. 2.2]

and therefore, $L = 1 / (2 * D)$; [Eq. 2.3]

where D = drainage density, S = stream length and L is the average overland flow length, and assumes a ridge situated equidistant from two adjacent channels. Therefore, if stream length and sub-watershed area are known an average overland flow length can be computed.

In order to facilitate the rapid calculation of overland flow length for these sub-watersheds, an automated method was developed using a raster drainage network and the "Summarize Zones" function. For determining the length of a given raster stream network in the larger study area, it was assumed that an equal number of cells flowed diagonally, flow distance 14.14 m, and vertically/horizontally, flow distance 10 m, for an average flow distance of 12.07 m. The average stream length for any given reach was then estimated as the number of cells, multiplied by the average flow distance. In order to insure the validity of this assumption, the average cell lengths for the five study areas used in analysis parts 1-2 were computed by converting raster flow networks into vector networks then dividing the total length of the resulting vectors by the total number of cells in the original raster networks. This computed average cell length was within 0.5% the estimated average flow length of 12.07 m. The overland flow length was then calculated by re-arranging Leopold's formula.

$L = (A / (2 * S))$; [Eq. 2.4]

2.7 Graphs of overland flow length versus threshold value

In order to produce graphs of overland flow length versus threshold value (Figure 3.9) the data table from the flow accumulation grid, containing accumulation values and number of cells at a given accumulation value, was imported into Microsoft Excel, and sorted by accumulation value. An additional column was created for each accumulation level showing drainage network length at the given threshold. This drainage network length is computed by first performing a cumulative sum from the last row up to the first row yielding the total number of cells in the network at any given threshold. This cell count is then multiplied by the average length of flow through a cell (approximately 12.07 m in the case of these 10m DEM's) to give a close approximation for length of the flow network:

$$L = \overline{L} \cdot \sum_{i=n}^{T} C_i$$

; [Eq. 2.5]

Where C_T = the number of cells with an accumulation value equal to threshold i, n is the largest accumulation value in the grid, and T is the accumulation value at any given row. The overland flow length at each point was then computed as in section 2.6. Microsoft Excel's plot function was then used to create a graph of L as a function of T for the study areas.

Strahler defined stream frequency (F) as the number of stream reaches per unit area (as reported by Chorley et al, 1948, 1984). The StreamLink function was used to segment this network into reaches, giving each link a unique ID. Stream frequency was then determined by applying the Spatial Analysts' "zonal summary" to the stream networks and watershed themes. The result of the variety statistic yielded a count of individual reaches in each watershed. The value for stream frequency at a given threshold value was then determined by dividing the number of reaches by the area of the watershed in question.

2.8 Quantifying spatial diversity in overland flow length

The ability or inability of an ANIM to represent spatial variation in overland flow length limits its usefulness as a basis for NPS model parameters. It has been suggested in at least two studies that the flow accumulation method requires the use of multiple, or 'calibrated' values to represent spatial diversity in overland flow length (Tarboton, 2001;Morris and Heerdegen, 1998). However, the result of Section 3, and the results of a study in Italy (Gandolfi and Bischetti, 1997) imply that spatial diversity with the flow accumulation method is at least possible, if not common. This suggests that either the flow accumulation method is capable of displaying only a limited diversity, which is practically indiscernible in reality, or that there were factors in the previous studies that biased the results toward homogeneity, or perhaps a combination of both. Large analysis units – a minimum size of 11,300 ha, and large threshold values – a minimum T of 5 ha, characterized the study by Morris and Heerdegen (1998). These threshold values are too large to capture the hill slope channels, and the analysis unit is of a size that might lead to averaging of terrain features. Tarboton (2001) compared networks produced by simple flow accumulation and terrain curvature concluding that the flow accumulation networks were spatially homogeneous, and that the terrain curvature networks were spatially diverse. While it appeared that this was in fact the case, these observations were only substantiated graphically, and not quantitatively. Thus, the factors that might bias an analysis towards homogeneity must be identified, and a procedure must be constructed such that these biases can be avoided. Finally, it is not sufficient to simply perform an analysis and proclaim "diversity is present" – some attempt must be made to evaluate the extent to which diversity is present. This portion of the analysis will then attempt to outline a procedure for describing the spatial variability in overland flow length and apply it to networks produced by three ANIM – the flow accumulation method, the terrain curvature method and the ridge accumulation method.

There are several possible reasons (other than ANIM deficiencies) why a drainage network produced by a given ANIM might lack spatial diversity:

1. The threshold value might be too large to capture the hill-slope scale variations in morphology that characterize the variations in different regions
2. The analysis units (i.e. watersheds being compared) are too large to reflect the regional variations within them, resulting in comparisons of watersheds that are aggregates of smaller, more diverse units, and that consequently display an "average" overland flow length.
3. The different analysis units being compared are, in fact, homogeneous.

This first cause is simple to overcome – a threshold value must be chosen such that hill-slope scale overland flow lengths are produced. The second potential problem may be overcome by choosing an analysis unit that is sufficiently small to capture the regional variations. The third problem might be somewhat more difficult, given that the absence of ground truth overland flow lengths describing an area might make it difficult to determine analysis units that one would *expect* to display some diversity. In this case, the EPA's level IV ecoregions (USEPA, 2004) are chosen, as they are based in part on differences in "bedrock and surficial geology, soils, land use, hydrology, physiography" (Omernik 1995), and include in them descriptions of variation in drainage density (USEPA, 2003).

In assessing the degree to which diversity, if present, is represented by a given ANIM, simple descriptive statistics will be applied to the sample populations. The minimum and maximum of the population will represent the extremes, while the standard deviation of overland flow lengths will be counted as the measure of diversity. Using these measures it would follow that a method which fails entirely to produce spatially varying overland flow length would show a standard deviation of zero, and no difference between minimum and maximum values, whereas a method which succeeds in producing variation would show some positive value in these measures. This portion of the analysis does not attempt to identify a "correct" level of variation, but simply to establish a numerical measure of spatial homogeneity or diversity for a given ANIM. In addition to the application of these statistics as measures of a given methods performance, they will also be used in order to evaluate the degree to which analysis unit size biases a result towards homogeneity. Finally, networks will be analyzed to determine if there are differences in predicted overland flow length by eco-region for any of the methods.

2.9 Quantitative Comparison of Contour Crenulation and ANIM Networks

When comparing overland flow lengths in ANIM networks to the those generated by manual contour delineation, there are two crucial considerations: 1) means of comparison, and 2) choice of threshold value. Previous investigations have used a qualitative method: the visual comparison with contours (Tarboton, 2001), and a quantitative method: using a least squares regression between predicted and observed OFLs for unique and independent hydrologic units (i.e. headwater sub-watersheds), to calculate a coefficient of multiple determination, or R^2 value (Montgomery and Dietrich, 1989; Inamdar and Dillaha, 2000). This investigation will use a qualitative evaluation, and two quantitative methods – Spearman's Rank Correlation Coefficient (R_s), and the linear regression coefficient (R^2). A variety of threshold values will be chosen such that they all yield overland flow lengths at the hill-slope scale (as determined by manual contour delineation). The effects of the degree to which these thresholds are calibrated will be varied to explore the impacts of threshold calibration.

The quantitative method – least squares regression – is an attractive alternative due to its ability to assign a numerical value to the predictive abilities of one method or another, it relies upon some fundamental assumptions that may not hold true in all cases: a normal distribution, and a linear relationship between the observed (in this case contour crenulation) and predicted (a given ANIM) values. In cases where these assumptions are in doubt, one may use a "Rank Correlation Coefficient", sometimes referred to as Spearman's Rank Correlation Coefficient, or $\mathbf{R_s}$. In the computation of this coefficient, a numerical rank is assigned to each sub-watershed based on its overland flow length. A rank is assigned for the flow length yielded by the contour crenulation method, and the flow length given by each ANIM, then the correlation coefficient is computed based on the distance of the predicted rank versus the observed rank based on the following formula:

$$R_s = 1 - \frac{6 ? d_i^2}{n(n^2 - 1)}$$

Where the term d_i = (predicted rank – observed rank). As for the choice of threshold value, there has been considerable discussion with regard to the identification of an optimum threshold value for use with a given ANIM.

Generally speaking, the choice of threshold has been found to be dependent upon the extent of the drainage network being analyzed, e.g., if one were attempting to mimic the blue line stream network, one would choose a certain threshold that yielded a suitable network, whereas if one were dealing with hill-slope scale networks (as in this investigation) a different threshold value (considerably lower) would be appropriate. The identification of a "universal threshold" for hill-slope scale networks, if such a thing exists, is beyond the scope of this investigation, so "locally calibrated" and "regionally calibrated" thresholds will be employed. The locally calibrated threshold value be chosen such that the OFL closely matches the OFL for a larger watershed area as given by the contour crenulation method, then the larger watershed will be divided into unique and independent hydrologic units in order to compare the fidelity of the ANIM networks to the contour crenulation networks, using the methods outlined in section 2.5. This local calibration will be repeated for each larger watershed study area (see section 5 for the results of this analysis), resulting in a total of 5 thresholds for each method. Figure 2.7 shows the 20 ha sub-watershed analysis units for the Craigville 3 quad, and figure 2.8 shows the 10 ha sub-watershed analysis unit in that same quad (See Appendix A for all watersheds). In order to examine the effects of threshold calibration, but still remain within the hill slope scale, the analysis will be repeated using an arithmetic mean of the "locally calibrated" threshold values from the five larger watersheds. This will be referred to as the "regionally calibrated" threshold value.

It may be noted that the methods of section 2.5 yields a set of sub-watersheds that is a mixture of headwater and downstream sub-watersheds, however, the criteria for identifying "unique and independent" hydrologic units is interpreted as referring to only headwater sub-watersheds (Inamdar and Dillaha, 2000), as the OFD of downstream sub-watersheds will be influenced by those watersheds flowing into them. Therefore, the choice of threshold value will be based on the entire watershed, but the analysis will be completed for the subset of headwater sub-watersheds only. In an attempt to observe the effects of analysis unit size, the larger watershed areas will be divided based on a minimum sub-watershed unit size of 10 ha and 20 ha, and the analysis will be repeated at both unit sizes and the results compared.

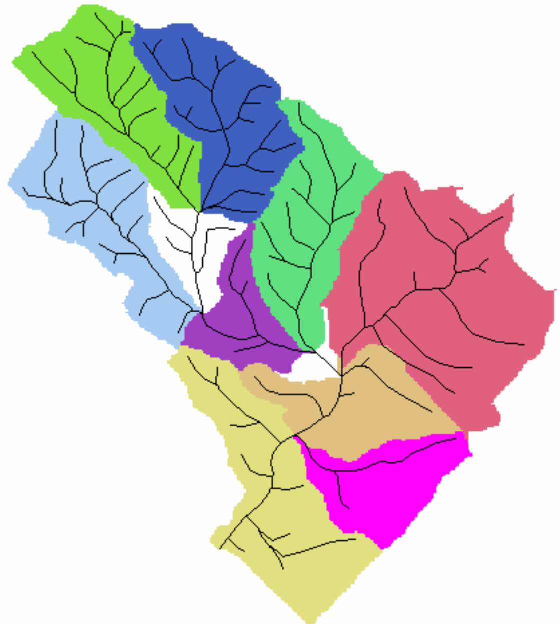

Figure 2.7: Craigville 3 quad divided into sub-watershed units based on a minimum unit size of 20 ha.

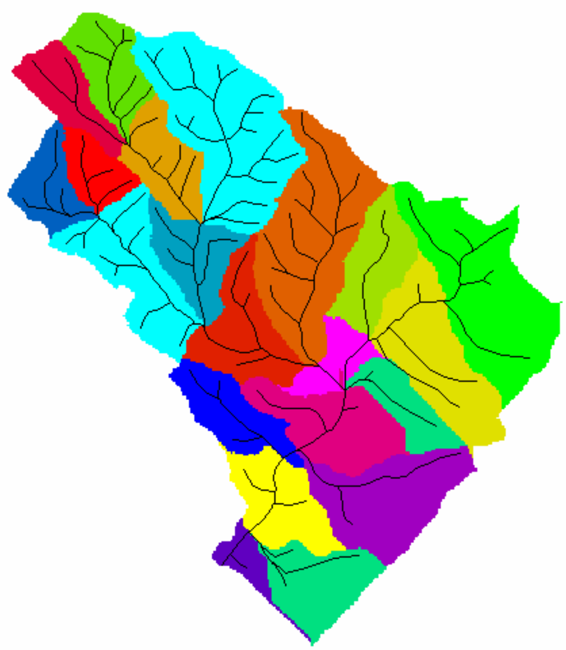

Figure 2.8: Craigville 3 quad divided into sub-watershed units based on a minimum unit size of 10 ha.

2.10 Description of selected Accumulation-based Network Identification Methods

The ANIM as outlined by O'Callaghan and Mark (1984) begins with a gridded digital elevation matrix, from which a flow direction is derived, based on the assumption that runoff from any cell will flow to only one of its eight neighbors. This is often referred to as the D-8 method of flow partitioning. A flow accumulation matrix, representing the sum of all cells draining into each cell is then derived from this flow direction matrix and a weighting matrix. A weight of one will yield an accumulation grid that represents the total area draining to each individual cell (O'Callaghan and Mark, 1984), this will be referred to as the flow accumulation method. Differing combinations of diverging and converging landforms will govern flow direction and concentration, and this should lead to spatial variations in overland flow length.

The other methods used in this analysis will be the terrain curvature method, and the ridge weight method. Each of these methods differs from the flow accumulation method in the choice of weighting grid values, and were devised with the intent of producing a greater spatial variation in drainage network distribution. The terrain curvature method also may differ slightly in its handling of flat terrain. The algorithm that it employs routes flow in flat areas towards the nearest downstream cell, helping to eliminate parallel flow paths. Watershed areas that are used for comparison in this study will be chosen such that the incidence of parallel flow paths is minimized, helping to insure that the comparison between ANIMs is based on channel initiation not flow path.

2.10.1 Terrain Curvature Method

The terrain curvature method is an accumulation based method, which assigns a weight of 1 to all cells which represent a local minimum in a 4 square cell neighborhood, and are therefore concave upward, and a weight of 0 to all other cells. Also, the user is able to specify a weight for cells that are situated adjacent to the upwardly curved cell on the diagonal (the suggested values are between 0.01 and 0.1). This method is based on the terrain curvature algorithm outlined by Peucker and Douglas (1975), and employs the accumulation method to correct network discontinuities present in the original method (Tarboton, 2001). The curvature method (terrain curvature) marks a distinct difference in approach to that of the flow accumulation method. Whereas the flow accumulation method attempts to *predict* the occurrence of channelization based on the exceedence of a certain threshold, the terrain curvature method in essence *interprets* the occurrence of a specific landform type, which is likely to concentrate overland flow. The ability of this method to identify upwardly curved cells is only limited by the vertical resolution of the input data set. The reader is referred to Peucker and Douglas (1975), and Tarboton (2001) for a detailed description of the curvature algorithm. MapWindow 2.7 was used to delineate these networks using a pit-filled DEM that was prepared within ArcView GIS 3.1. The default values for adjacent cell weighting suggested in the TauDEM delineation wizard (side=0.1, center=0.4, diagonal = 0.05) in MapWindow 2.7 were used to delineate all flow networks in this study. Figure 2.9 shows the terrain curvature network for the Briery Branch watershed.

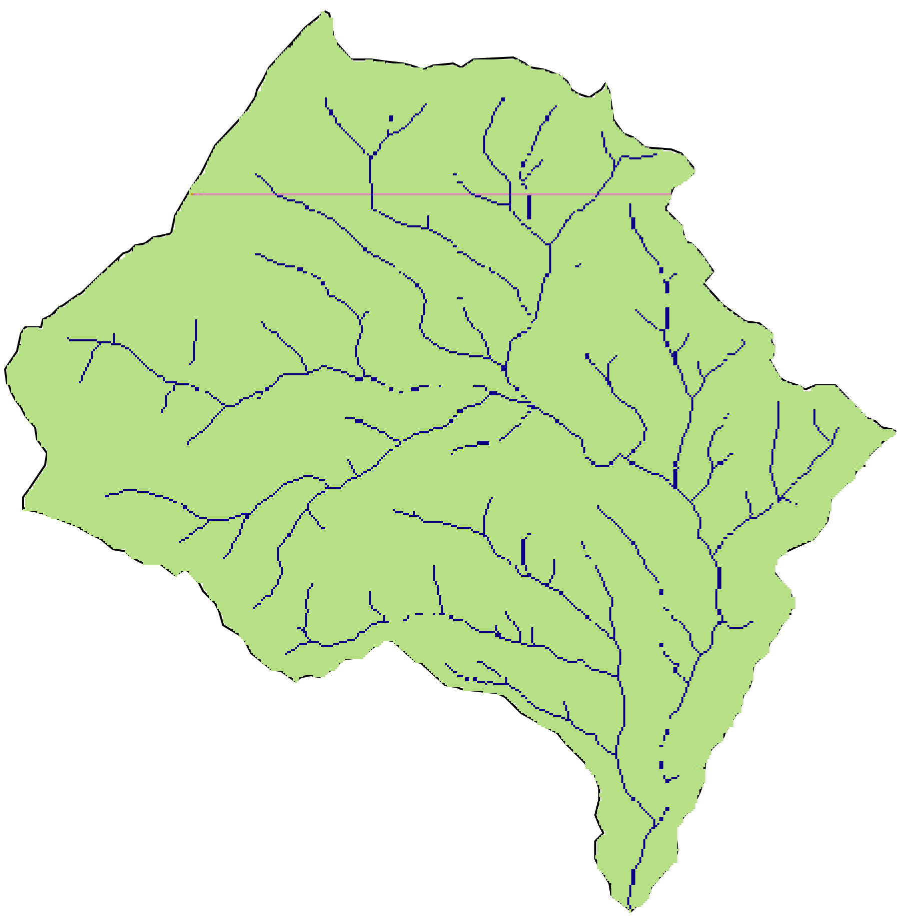

Figure 2.9: Terrain curvature flow network for the Briery Branch 2 sub-watershed. A threshold value of 7 cells was used to produce this flow network.

2.10.2 Ridge Accumulation

The ridge accumulation method is introduced in this study as a new alternative ANIM. This method involves assigning a weight of 1 to all ridge cells, and a weight of 0 to all other cells. Ridge cells are defined as being any cell whose upslope contributing area is equal to 0. First, a simple, flow accumulation grid is derived, then a map algebra formula is applied to convert cells with a zero accumulation values to 1, and all other values to zero. This new grid is referred to as the "ridge grid". A new accumulation grid is then computed using this ridge grid as its weight. Figure 2.10 shows the ridge weight grid, and figure 2.11 shows the resulting drainage network when a threshold value of 27 cells is applied as a channel initiation criteria. (ArcView 3.1 Map Calculator commands can be found in Appendix B.)

This method attempts to identify convergent landforms through the accumulation of maxima, thereby producing networks with a greater spatial diversity. It is also hoped that in large flat areas, a lower instance of ridge cells will result in this method producing a lower incidence of stream channel initiation along parallel flow paths. It is also hoped that this might prove useful in areas where the vertical resolution is insufficient to show distinct upwardly curved cells as required by the terrain curvature method.

Figure 2.10: A ridge weight grid for the Briery Branch 2 sub-watershed. Cells in blue are cells whose flow accumulation value is zero (0) or "ridge " cells, and are assigned a weight of one (1).

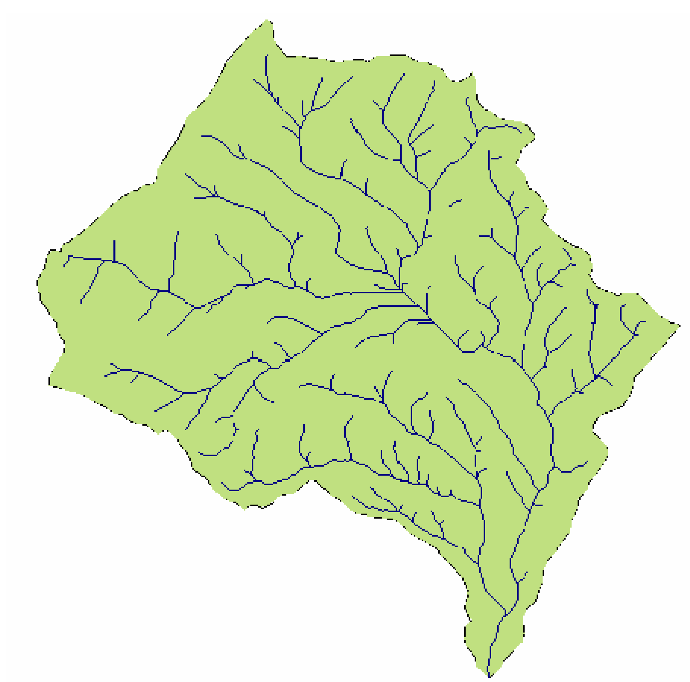

Figure 2.11: The stream network yielded with a threshold value of 27 for the ridge accumulation weighting grid for Briery Branch 2.

2.11 Differences in flow paths between terrain curvature and other ANIM

While all three methods use a common flow direction grid, the flow paths that are produced by the terrain curvature method are not always identical to those produced by other ANIMs. Figures 2.12-14 depict a detail view of flow paths derived by the flow accumulation, ridge accumulation, and terrain curvature methods over the same area. While the ridge accumulation method and flow accumulation methods share the same flow paths, in some instances the terrain curvature method produces an entirely different path. This is a result of the complex weighting scheme employed by the terrain curvature method, which provides for the weighting of cells next to those identified as "upwardly curved", as well as the procedure used to determine flow direction in flat areas. Watershed areas in this study were chosen to minimize the incidence of parallel flow paths. Figure 2.15 contains flow networks from all three methods superimposed on one another in order to highlight the divergences.

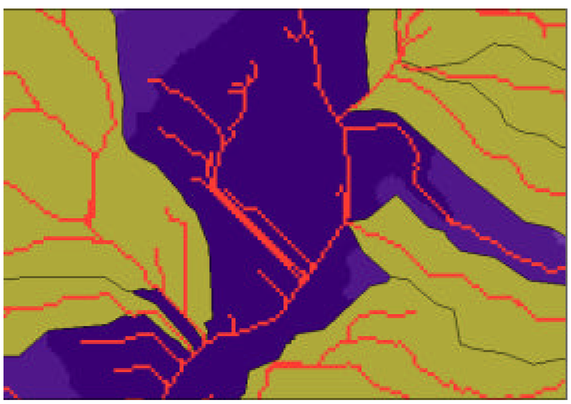

Figure 2.12: Flow paths as determined by the flow accumulation method.

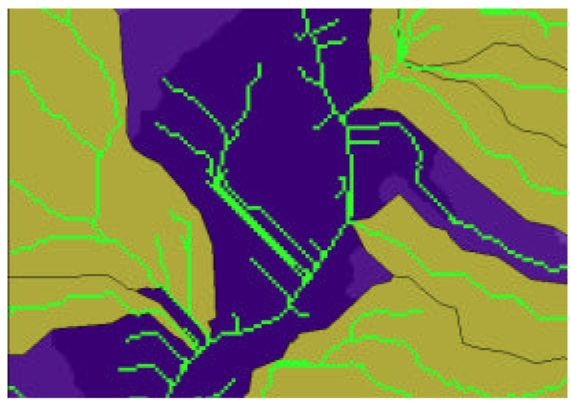

Figure 2.13: Flow paths as determined by the ridge accumulation method.

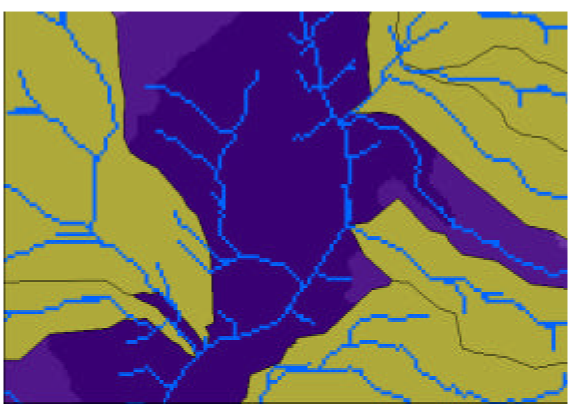

Figure 2.14: Flow paths as determined by the terrain curvature method.

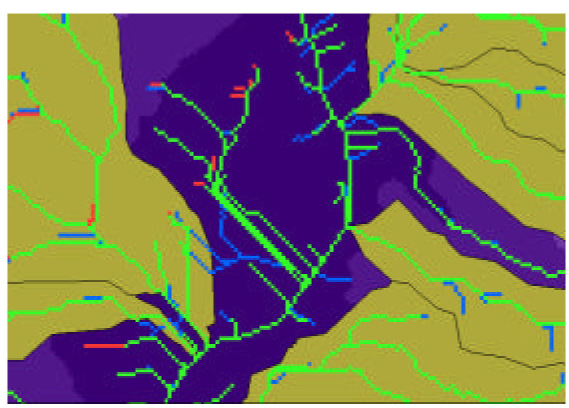

Figure 2.15: Flow paths as determined by all 3 methods overlaid to illustrate divergences in predicted flow paths.

2.12 Contour Crenulation Methodology and Selected Watersheds

Manual delineation, since it yields an actual drainage network, will be used to provide the basis for comparison of ANIM networks for this analysis. Based on the previous research regarding this method, it is reasonable to assume that it will most likely yield a conservative estimate of the actual drainage network. While it will not be possible to determine the extent of this underestimation of the drainage network, it does at least indicate that the CC network will be more complete than the one depicted by blue line streams, while not over estimating its extent. Most importantly, it should provide a good measure of overall spatial trends in overland flow length.

ArcView GIS 3.1 was used to trace the contour network through the creation of a vector theme. The contour intervals were selected based on the contour interval used in the original source 1:24,000 scale quad sheet. The blue line stream network on the original contour map was used to provide the base network. The base network was extended along the adjacent contours provided that the contour line met one of the following criterion:

- It was bent at less than 100 degrees (clearly crenulated);
- Or, it was less than 150 degrees, and had a 100-degree bend on a down slope contour;
- Or, three consecutive 150-degree crenulations occurred, in which case all three would be included.

CC networks were traced for five watersheds (sizes ranging from 49 to 466 ha), selected from the Briery Branch, Craigville, Louisa, and Surry quads (see figures 2.16 through 2.20). The watersheds were selected in order to provide a diversity of terrain forms, as identified by the Eco-Region, to avoid large flat areas which would be rendered with parallel flow paths, and also to reflect areas in the DEM that appeared to be free of many of the defects that are commonly associated with DEMs, such as artifacts and banding. Subsequently, the watershed delineated in the Rolling Coastal Plain area, Surry quad, is considerably smaller than the others, due to large flat areas and considerable quality issues encountered in this and other Virginia coastal plain DEMs. Two watersheds were selected from the Craigville quad, as it contained a high diversity of Eco-Regions, and one each was chosen from the Briery Branch, Louisa and Surry quads. In all, six (6) Eco-Regions were represented in the data set:

Northern Inner Piedmont, Rolling Chesapeake Inner Coastal Plain, Dissected Ridge and Knob, Northern Shale Valleys, Northern Sandstone Ridges and Northern Limestone/Dolomite Valleys.

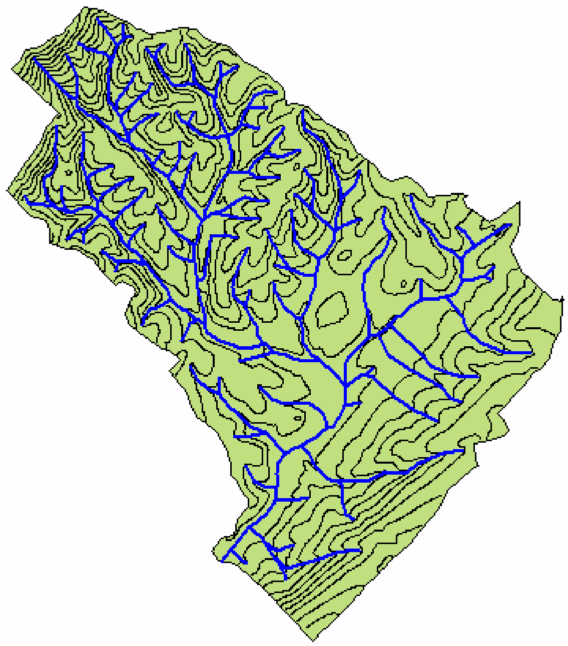

Figure 2.16: Contour crenulation (CC) stream network derived for sub-watershed Craigville 3, used for comparison with the networks derived by selected ANIM.

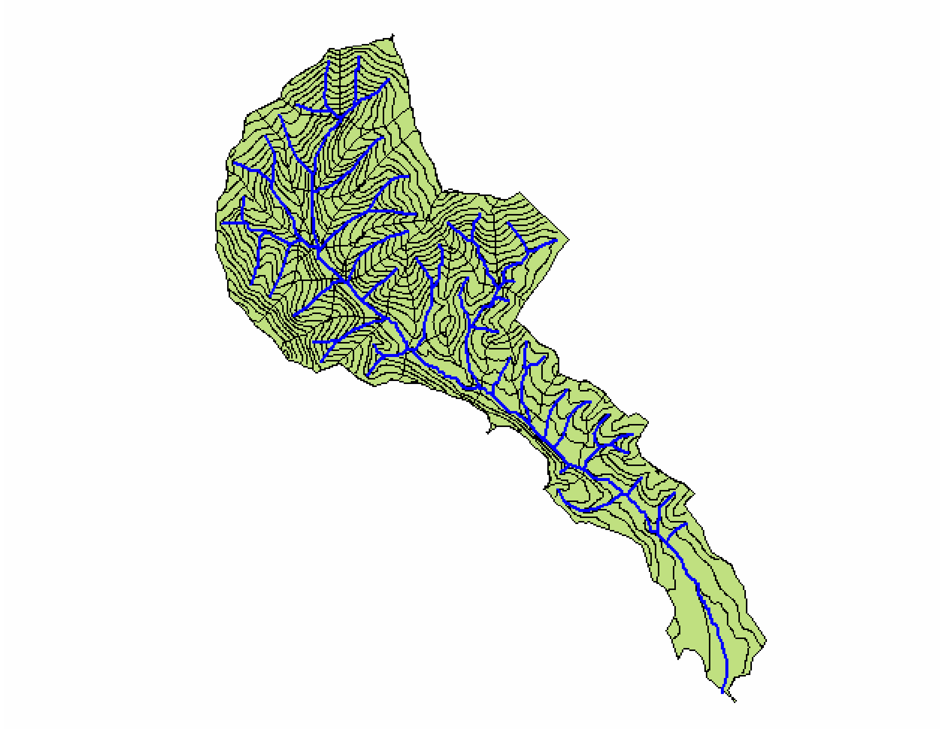

Figure 2.17: Contour crenulation (CC) stream network derived for sub-watershed Craigville 4, used for comparison with the networks derived by selected ANIM.

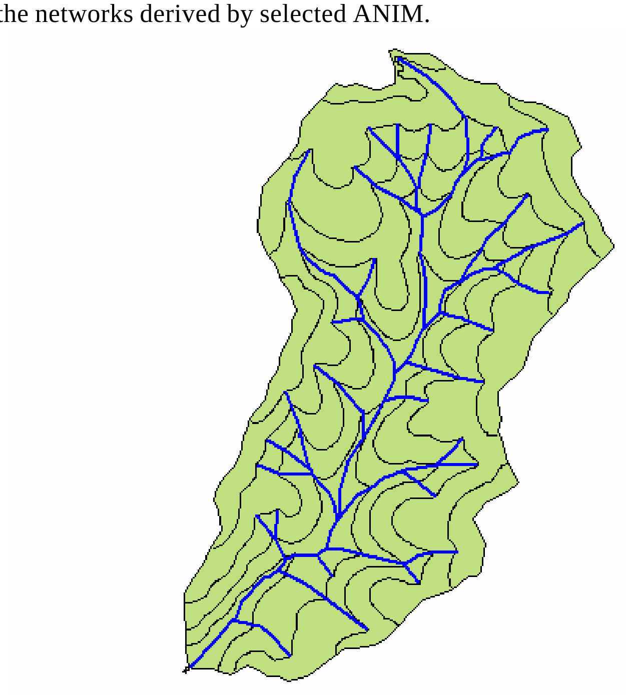

Figure 2.18: Contour crenulation (CC) stream network derived for sub-watershed Louisa 5, used for comparison with the networks derived by selected ANIM.

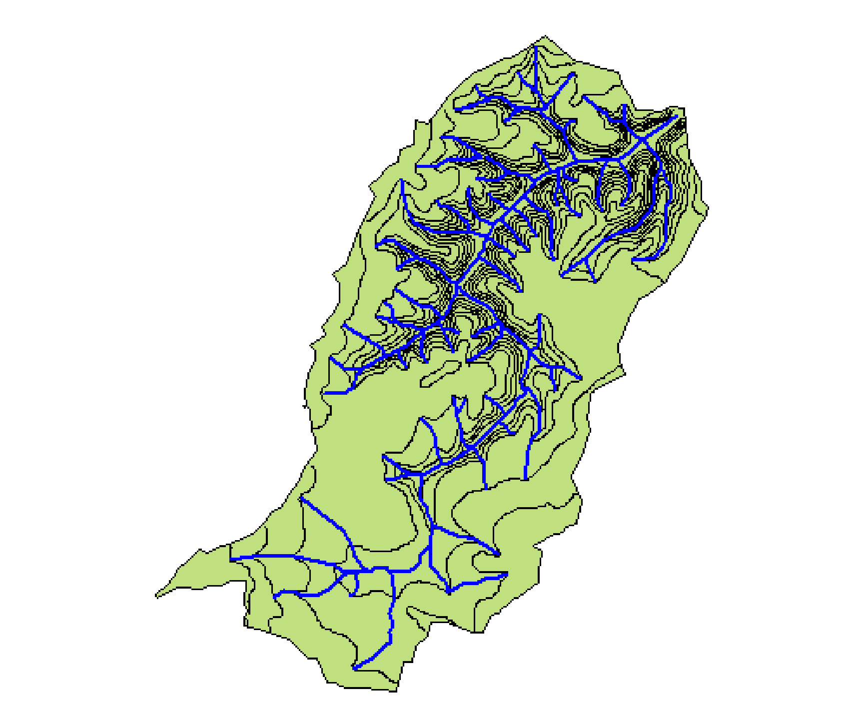

Figure 2.19: Contour crenulation (CC) stream network derived for sub-watershed Surry 3, used for comparison with the networks derived by selected ANIM.

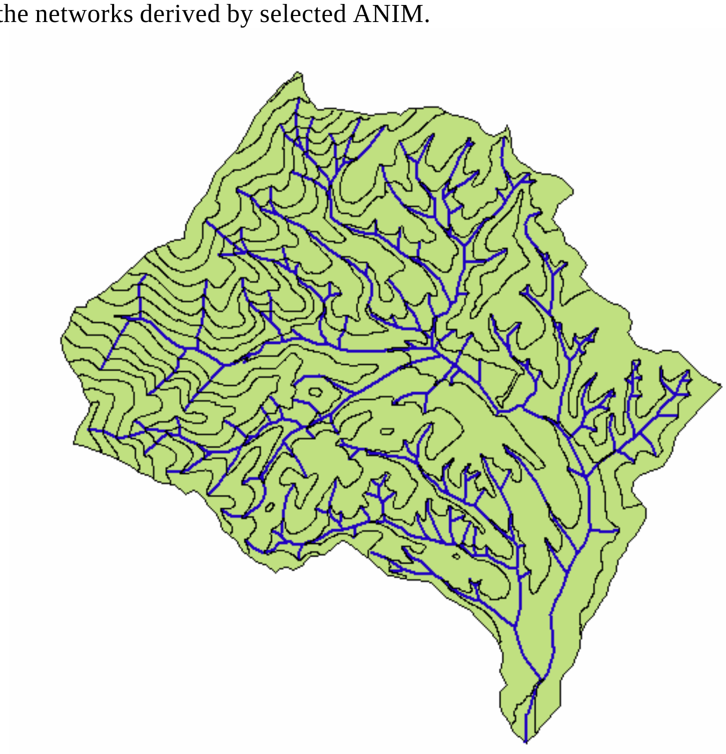

Figure 2.20: Contour crenulation (CC) stream network derived for sub-watershed Briery Branch 2, used for comparison with the networks derived by selected ANIM.

3. Preliminary Analysis: Terrain Morphology and Accumulation-based NIM

This portion of the investigation attempts to lay some conceptual groundwork for the sections that follow. Given the apparent scarcity of information regarding the interaction between terrain morphology and ANIM, an exploration of the fundamental processes that underlie ANIM was undertaken. The basic assumption that seems to underlie the flow accumulation method (and by association, all other ANIM), is that convergent topography will yield a more rapid accumulation of cells, and thus, more extensive flow networks. Divergent, or planar terrain will likewise yield more sparse networks. Thus, two watersheds with similar areas, but different morphologies should have different overland flow lengths when evaluated at the same source area threshold. If this underlying assumption proves to be true, the role played by the morphological structure of this network and the impact of applying an arbitrary threshold onto this surface remains to be determined. The use of stream frequency (F) as a potential predictor for changes in overland flow length as a result of changing threshold value ($\Delta L / \Delta T$) becomes apparent during this analysis, and is later utilized in analysis chapter 7, as a further criteria for evaluating ANIM.

3.1 Idealized drainage network forms, threshold and overland flow length

Figures 3.1-4 present flow direction and flow accumulation grids (10 m unit size) for idealized sub-watersheds with the same area, but different drainage network forms. Sub-watershed A is long and narrow, with a single main channel (a morphology that can be described as “parallel”), and sub-watershed B is short and wide, with 5 main flow paths converging at the outlet (“dendritic” morphology). Their difference can also be quantified in terms of stream frequency (F); sub-watershed A has a frequency of 4/ ha, while sub-watershed B has 20/ ha. Evaluating overland flow length (L) at a threshold value of T = 5 cells we have L_a = 22.7 m, and L_b = 83.3 m – a difference of 267%. While this is an extreme example, it demonstrates that landform may influence the length of the drainage network when using a constant threshold value with the support area threshold method.

Table 3.1: Drainage network characteristics for two idealized sub-watershed forms. Stream length (l) and overland flow length (L) are shown to be highly variable at a single threshold value.

	Area (ha)	Stream Frequency (F)	Stream Length (m)	Overland Flow Length (m)
Sub-watershed A	0.25	4	110	22.7
Sub-watershed B	0.25	20	30	83.3

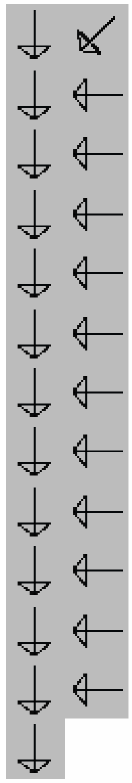

Figure 3.1: Sub-watershed “A”. Flow direction grid for an idealized surface with a high D.

0	0
3	0
5	0
7	0
9	0
11	0
13	0
15	0
17	0
19	0
21	0
23	0
24	

Figure 3.2: Sub-watershed “A”. Flow accumulation grid for an idealized surface with a high D.

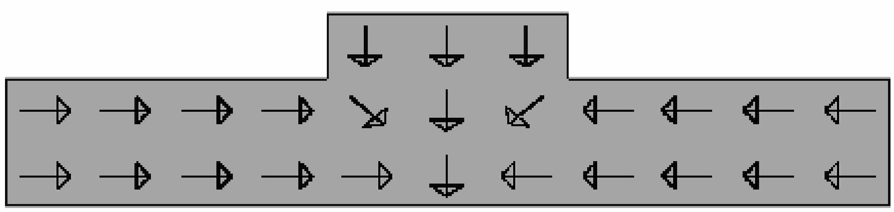

Figure 3.3: Sub-watershed “B”. Flow direction grid for an idealized surface with a low D.

				0	0	0				
0	1	2	3	5	1	5	3	2	1	0
0	1	2	3	4	24	4	3	2	1	0

Figure 3.4: Sub-watershed “B”. Flow accumulation grid for an idealized surface with a low D.

3.2 Idealized Drainage Network Forms, Threshold and Stream Frequency

The stream frequency metric describes the number of branches per unit area in a given watershed. It is hypothesized that as the value of T increases, those areas with a high value for stream frequency (F) at a given threshold will experience increases in overland flow length at a greater rate than those whose value of F is low. This occurs because the shortening of the drainage network occurs at the ends of headwater reaches, and the number of headwater reaches will be less than or equal to the total number of branches, thus it follows that the change in drainage network length should occur at a rate not to exceed:

$$\Delta L / \Delta T = FnA \qquad \textbf{\textit{Eq. 3.1}}$$

Where F is the stream frequency at the previous value of T, n is the change in threshold value, and A is the area of the watershed of interest and $\Delta L/\Delta T$ is measured in DEM cells. The idealized set of landforms in figures 3.1-4 will be used to explore the potential for variation in $\Delta L/\Delta T$ and the use of F as a predictor of this variation.

Evaluating L at a value of T = 3 cells we have a flow network in sub-watershed A of 9 cells, with L_a = 12.7 m, F_a = 4/ha and sub-watershed B has a flow network of 12 cells, with L_b = 10.4 m, and F_b = 20/ha. If the proposed relationship between F and $\Delta L/\Delta T$ is valid it should follow that as T is increased, $\Delta L_b/\Delta T > \Delta L_a/\Delta T$. At a threshold value of 5 cells, the overland flow length computed for the sub-watershed “A” (L_a) in Figure 3.3 is 11.4 m, an increase of approximately 11% while that for the sub-watershed in “B” (L_b) in Figure 3.4 has grown to 38.3 m, an increase of 213%. The flow network in sub-watershed A decreased by 1 unit, or 1 stream cell/threshold cell, and the network in sub-watershed B decreased by 6 units, or 3 stream cell/threshold cell. The inequality in equation 3.1 predicts that for sub-watershed A, the maximum rate of decrease in stream length per unit increase in T is 1 cell/cell, and for sub-watershed B this rate is 5 cell/cell.

Table 3.2: Drainage network characteristics for two idealized sub-watershed forms. A relationship between stream frequency (F) and ?L are implied.

		T = 3 cells (0.03 ha)			T = 5 cells (0.03 ha)		
	Area (ha)	**F (n/ha)**	**l (m)**	**L (m)**	**l**	**L (m)**	**?L**
Sub-watershed A	0.25	4	120	12.7	110 m	11.4	11 %
Sub-watershed B	0.25	20	98.3	10.4	38.3 m	32.6	213 %

This example demonstrates that $\Delta L / \Delta T$ may vary greatly between sub-watersheds, and suggests a possible relationship between F and $\Delta L / \Delta T$. It should noted that the values for F and L in these idealized sub-watersheds were contrived in order to demonstrate a point, it remains to be seen whether this trend is evident in actual watersheds. Further analysis using actual terrain data are necessary in order to extend this observation.

3.3 Analysis of Actual Networks

Howard (1967) posed eight basic drainage patterns: dendritic, parallel, trellis, rectangular, radial, annular, multi-basinal and contorted. Strahler (1964) noted that due to differences in drainage pattern, drainage density (D) and stream frequency (F) are independent of one another. Given that drainage density and overland flow length are inversely proportional to one another (equation 2.3), therefore it stands to reason that overland flow length and stream frequency are similarly independent. Figures 3.5-6 show drainage networks for two watersheds in Virginia, Craigville 7 and Surry 3. Craigville 7 is characterized by parallel drainage patterns, while Surry 3 is predominantly dendritic with some parallel patterns visible in its southern reaches. These two watersheds have nearly identical values for overland flow length, L_{c7} = 81.9 m and L_{s3} = 79.2 m, a difference of approximately 3%. The contrasts posed by Strahler are in evidence here, as their stream frequencies differ by a factor greater than 2, with F_{c7} = 26.6 and F_{s3} = 62.2 despite a similar drainage density (and consequently, overland flow length).

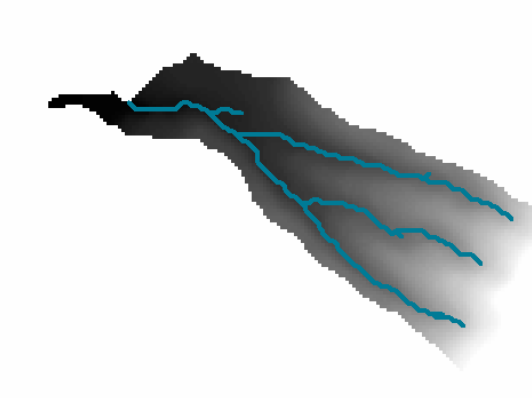

Figure 3.5: Craigville 7 watershed, displaying a parallel drainage network form. At T = 85 cells stream frequency (F) = 26.6, L = 81.9 m.

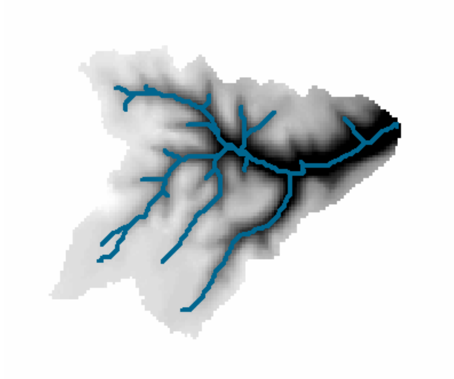

Figure 3.6: Surry 3 watershed, displaying a dendritic drainage network form. At T = 85 cells stream frequency (F) = 62.6, L = 79.2 m.

To examine the behavior of ? L/?T for these two sub-watersheds, overland flow lengths were calculated within the range of 0.5 ha < T < 3.0 ha for these two sub-watersheds; the results are plotted in Figure 7. Table 2 provides a summary of these plots, showing L values for Surry 3 and Craigville 7 at values of T = 0.5, 1.0, 2.0 and 3.0 ha. The % change in L between T = 0.5 ha and T = 3.0 ha differs by a factor of nearly 3 between these two sub-watersheds. Due to this variation, a drainage network delineation that employed a threshold value of 0.5 ha would conclude that overland flow length in Surry 3 exceeded that of Craigville 7, by approximately 35%. Conversely, network delineation employing a threshold value of 3.0 ha would conclude that the overland flow length of Craigville 7 exceeded that of Surry 3 by 42%. Figure 3.7 shows a plot of overland flow length versus threshold value for these two sub-watersheds.

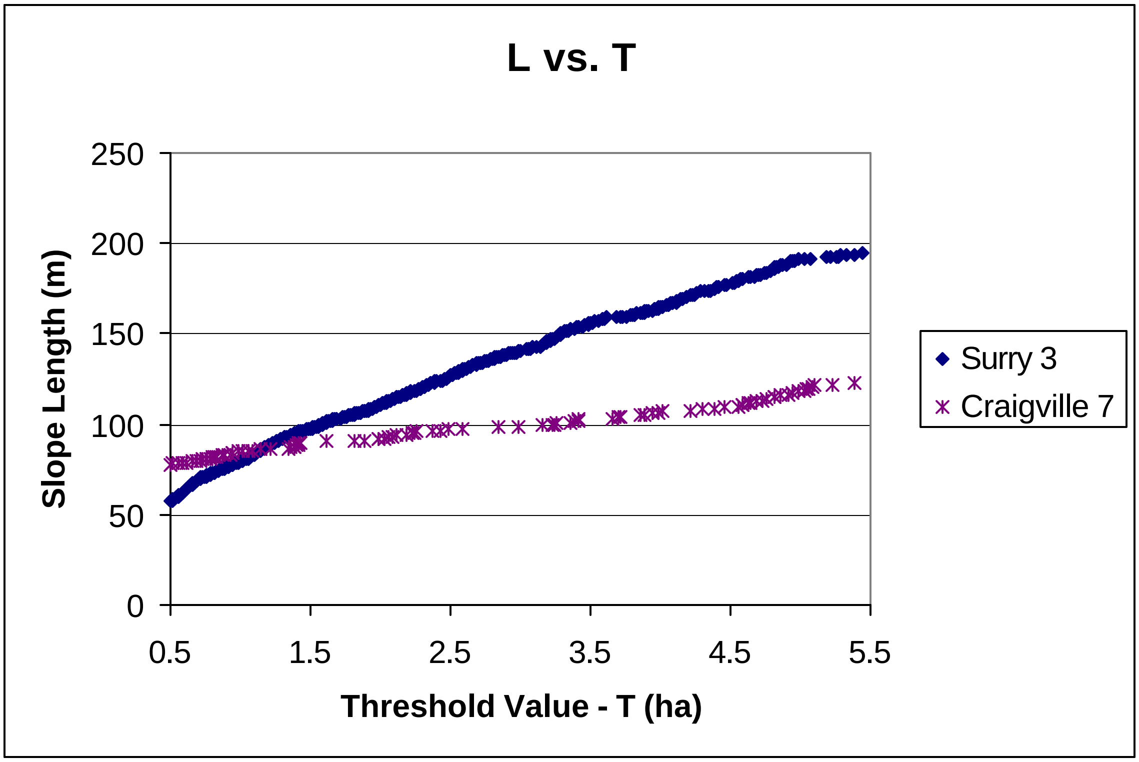

Figure 3.7: Plot of overland flow length vs. Threshold area for Surry 3 and Craigville 7 sub-watersheds between source area threshold values of 0.5 ha < T < 3.0 ha.

Table 3.3: Values of stream frequency and overland flow length (in meters) for Surry 3 and Craigville 7 at values of T = 0.5, 1.0, 2.0 and 3.0 ha. Threshold values used to compute L are given in parentheses. The value for F is at a threshold value of 0.5 ha.

	F	**L** (0.5 ha)	**L** (1.0 ha)	**L** (2.0 ha)	**L** (3.0 ha)	**%** D **L**
Surry 3	62.6	57.01	79.49	111.11	140.45	59.41%
Craigville 7	26.6	77.28	85.03	91.91	98.62	21.64%

The comparison of these two sub-watersheds further demonstrates the potential for the expression of varying drainage network morphology based on the choice of an arbitrary threshold value. Specifically, this change in relative calculated overland flow length or “rank change” between sub-watersheds might be particularly troubling for hydrologic models. However, for this to significantly impact a wide range of hydrologic studies, the type of variability seen between Surry 3 and Craigville 7 would have to be widespread. Section 7 will explore this issue further, examining and comparing the flow accumulation, terrain curvature and ridge accumulation methods.

4. Spatial Diversity at a Single Threshold, Analysis Unit Size, and Measures of Diversity

The results of section 3 confirm the possibility that ANIM networks may display spatial diversity in overland flow length, based on the underlying terrain morphology, and that this possibility is realized in both contrived flow networks and actually occurring networks. This section attempts to identify an appropriate unit size for analysis of diversity, to determine if this diversity is widespread, and to explore the use of standard deviation as a means for quantifying diversity. Finally, networks will be analyzed to determine if there are differences in predicted overland flow length by eco-region for any of the methods.

4.1 The effect of analysis unit size on measures of diversity in overland flow length

In order to explore the impact that analysis unit size has on spatial diversity, networks were generated for the Craigville quad using flow accumulation, terrain curvature and ridge accumulation methods. This analysis was limited to a single quad in order to eliminate variation that might occur as a result of differences in quad sheet preparation. A single threshold value was chosen for each method such that the average overland flow length over the whole quad was approximately 100m. Then, sub-watershed analysis units at five different scales were partitioned using the methods explained in section 2.5 corresponding to 500 , 1,000, 2,000, 5,000 and 10,000 cell threshold networks. A minimum sub-watershed size was set for each analysis scale of 10 ha, 20 ha, 50 ha, 100 ha and 200 ha, respectively. Sub-watersheds that extended into an adjacent quad were omitted from the analysis. Figures 4.1-5 show the sub-watershed units at each of these scales. The resulting calculations of minimum, maximum, and standard deviations of overland flow lengths are presented in Tables 4.1-3.

It can be seen that for all three methods, standard deviations decrease as the size of the analysis units increase, and that similarly, minimum and maximum overland flow lengths become less extreme as the analysis unit size increases. In addition to the apparent effects of the large analysis unit in reducing diversity, the effects of smaller analysis units are interesting in the range of maximum overland flow lengths predicted. At the minimum 10 ha analysis unit level, the flow accumulation method predicts a maximum overland flow length of 316 m, while the ridge accumulation method predicts a maximum overland flow length of 465.7 m, and the terrain curvature method predicts a maximum of 1,023.2 m.

Table 4.1: Average, minimum, maximum and standard deviation of overland flow lengths calculated for watersheds at five different scales using the flow accumulation method of network identification.

Threshold	# of units	Minimum Unit Size (ha)	Avg. Unit Size (ha)	Avg. Flow Length (m)	Minimum Flow Length (m)	Maximum Flow Length (m)	Std. Dev. (m)
178	614	10	23.1	109.2	51.3	316.0	27.5
178	302	20	46.4	106.7	62.2	175.4	18.5
178	115	50	118.3	104.4	75.8	175.4	16.1
178	47	100	282.6	107.5	88.5	150.5	13.2
178	26	200	515.6	105.5	93.1	121.5	8.0

Table 4.2: Average, minimum, maximum and standard deviation of overland flow lengths calculated for watersheds at five different scales using the terrain curvature method of network identification.

Threshold	# of units	Minimum Unit Size (ha)	Avg. Unit Size (ha)	Avg. Flow Length (m)	Minimum Flow Length (m)	Maximum Flow Length (m)	Std. Dev. (m)
9	614	10	23.1	120.5	50.1	1,023.2	77.8
9	302	20	46.4	111.1	59.5	584.9	41.4
9	115	50	118.3	104.0	63.7	191.9	24.3
9	47	100	282.6	105.9	74.1	157.9	21.2
9	26	200	515.6	106.1	78.4	144.7	18.5

Table 4.3: Average, minimum, maximum and standard deviation of overland flow lengths calculated for watersheds at five different scales using the ridge accumulation method of network identification.

Threshold	# of units	Minimum Unit Size (ha)	Avg. Unit Size (ha)	Avg. Flow Length (m)	Minimum Flow Length (m)	Maximum Flow Length (m)	Std. Dev. (m)
29	614	10	23.1	116.2	51.3	465.7	46.0
29	302	20	46.4	110.0	63.3	199.9	27.6
29	115	50	118.3	106.0	66.2	186.7	22.8
29	47	100	282.6	108.5	80.5	166.1	19.7
29	26	200	515.6	107.3	87.1	141.8	13.7

Despite the trend toward more homogeneous overland flow lengths with increasing watershed size, all three methods still maintain a measure of spatial diversity in their predictions up to an analysis unit size of 200 ha. Comparing the measure of standard deviation between the three methods it is apparent that the terrain curvature method retains more diversity than the others (a minimum standard deviation of 18.5) followed by the ridge accumulation method (13.7) and finally the flow accumulation method (8.0).

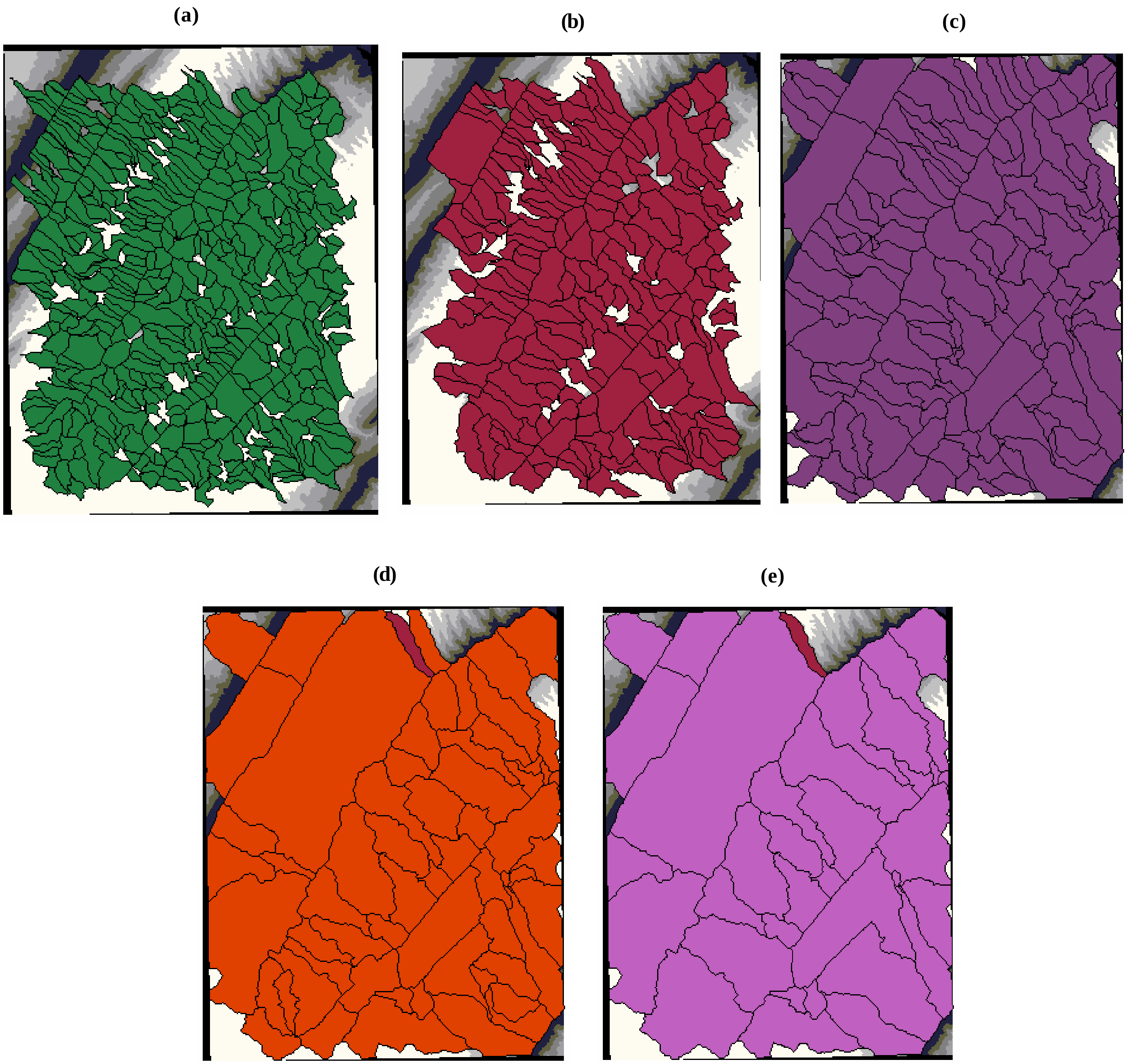

Figure 4.1: Sub-watershed units at five different scales used to examine the effects of watershed unit size on the spatial diversity in overland flow length reported by the flow accumulation, terrain curvature and ridge accumulation methods. (a) average unit size 23.1 ha, (b) average unit size 46.4 ha, (c) average unit size 118.3 ha, (d) average unit size 282.6 ha, (e) average unit size 515.6 ha.

4.2 Comparisons of predicted overland flow lengths by digital orthoquad

The effect of spatial aggregation is also evident when considering an entire quad sheet as the analysis unit. Table 4.4 presents the results of average overland flow lengths calculated for three USGS quad sheets (in the form of 10 m DEMs), Craigville, Louisa and Surry, which encompass seven (7) ecoregions. The analysis unit size is approximately 15,200 ha in the case of the Craigville and Louisa quads, and approximately 8,300 ha in the case of the Surry quad. The thresholds values used were the same as those that yielded a network with an approximate average overland flow length of 100 m in the Craigville quad in the previous section. In this case the ridge accumulation predicts the widest degree of variation (a range of 29.11 m), followed by the curvature method (a range of 27.58 m), and then the flow accumulation method, which predicts little variation whatsoever (a range of 3.71 m). The differences in the networks yielded by the terrain curvature method and the ridge accumulation method are particularly striking, as these methods predicted a much larger range of overland flow lengths than did the flow accumulation method. Also, the terrain curvature and ridge accumulation methods agree as to the relative ranking of these quads on the basis of overland flow length. The trend towards decreasing diversity with larger analysis unit size, seen in the previous analysis, seems to have continued, with all methods showing a decrease in range with the quad sheet sized analysis unit, however, this effect was much more pronounced in the case of the flow accumulation method, while the ridge accumulation and terrain curvature methods managed to maintain a much larger range of variation.

Table 4.4: Overland flow lengths (in meters) predicted by the flow accumulation, terrain curvature, and ridge accumulation methods for three (3) digital orthoquad 10 m DEMs in Virginia.

Quad Name	Flow Accumulation Overland Flow Length	Terrain Curvature Overland Flow Length	Ridge Accumulation Overland Flow Length
Craigville	104.36	103.60	104.36
Louisa	106.94	92.63	89.76
Surry	103.23	76.02	75.25

4.3 Variation in overland flow length by Eco-Region

If the spatial diversity that is predicted by these methods is considered to genuinely reflect natural variation, rather than simply being random errors in the method, it would be expected that trends between various ecoregions would be evident. Table 4.5 shows a summary of predicted overland flow length by quad sheet for all three methods, summarized by ecoregion. Drainage networks were calculated for the quad as a whole, and then average overland flow lengths were calculated by ecoregion using the method presented in section 2.5. All three methods show variation by ecoregion. Figures 4.2-4 show the networks predicted by the flow accumulation method, the ridge accumulation method, and the terrain curvature method, with eco-regions overlaid for the Craigville quad. The variation in the density of the predicted networks by eco-region is evident by visual inspection. The contrast between the drainage networks predicted for the Northern Sandstone Ridges (with the longest predicted overland flow length, and hence the most sparsely populated network) and that for the Northern Shale Valleys (with the shortest overland flow length) is particularly apparent. The terrain curvature method predicted the greatest amount of variation with a maximum overland flow length of 141.77 m in the Northern Sandstone Ridges, located in the Craigville quad, and a minimum overland flow length of 74.09 m in the Rolling Chesapeake Inner Coastal Plain located in the Surry quad, a range of 67.68 m. The ridge accumulation method shows less variation, with a range of 59.39 m between the maximum and minimum predicted overland flow lengths. The flow accumulation method shows the least amount of variation, 30.22 m between the maximum and minimum values. Comparing these ranges it can be seen that they agree with the standard deviation measure in the previous section, terrain curvature being largest, followed by ridge accumulation, followed by flow accumulation. The methods were all in agreement as to the ecoregion with the largest overland flow length – the Northern Sandstone Ridges, but they disagreed in their prediction of the ecoregion with the shortest overland flow length. The terrain curvature predicted the Rolling Chesapeake Inner Coastal Plain, while ridge accumulation method predicted the Mid-Atlantic Flatwoods as having the shortest overland flow length, and the flow accumulation method predicted the Northern Shale Valleys as shortest. Arguably, overland flow length predicted by the ridge accumulation method for the Mid-Atlantic Flatwoods did not differ significantly from the overland flow length it predicted for the Rolling Chesapeake Inner Coastal Plain, a difference of less than 0.51%. Given that the original source for 10m DEMs is a hand drawn topographic map, comparisons between different quads may be inherently problematic. However, in the Craigville quad (which spans four ecoregions), all three methods agreed on their ranking of ecoregion by overland flow length, ranking them in ascending order as: Northern Shale Valleys, Northern Limestone/Dolomite Valleys, Northern Dissected Ridges and Knobs and Northern Sandstone Ridges. Interestingly, in the Surry quad, the ridge accumulation method discerned little difference between ecoregions, while both the terrain curvature flow accumulation methods predicted the Mid-Atlantic Flatwoods to have a longer overland flow length than the Rolling Chesapeake Inner Coastal Plain.

Table 4.5: Overland flow lengths (in meters) predicted by the flow accumulation, terrain curvature, and ridge accumulation methods for seven (7) ecoregions in Virginia.

USEPA Ecoregion	Quad	Ecoregion Area	Flow Accumulation Overland Flow Length	Terrain Curvature Overland Flow Length	Ridge Accumulation Overland Flow Length
Rolling Chesapeake Inner Coastal Plain	Surry	5,973 ha	101.51	74.09	75.36
Mid-Atlantic Flatwoods	Surry	2,319 ha	107.92	81.50	74.98
Northern Inner Piedmont	Louisa	15,234 ha	106.93	92.65	89.75
Northern Limestone/Dolomite Valleys	Craigville	2,695 ha	97.83	103.87	99.58
Northern Shale Valleys	Craigville	4,598 ha	89.37	80.12	81.28
Northern Dissected Ridges and Knobs	Craigville	3,297 ha	117.24	106.71	118.88
Northern Sandstone Ridges	Craigville	4,626 ha	119.59	141.77	134.37
Maximum – Minimum			**30.22**	**67.68**	**59.39**

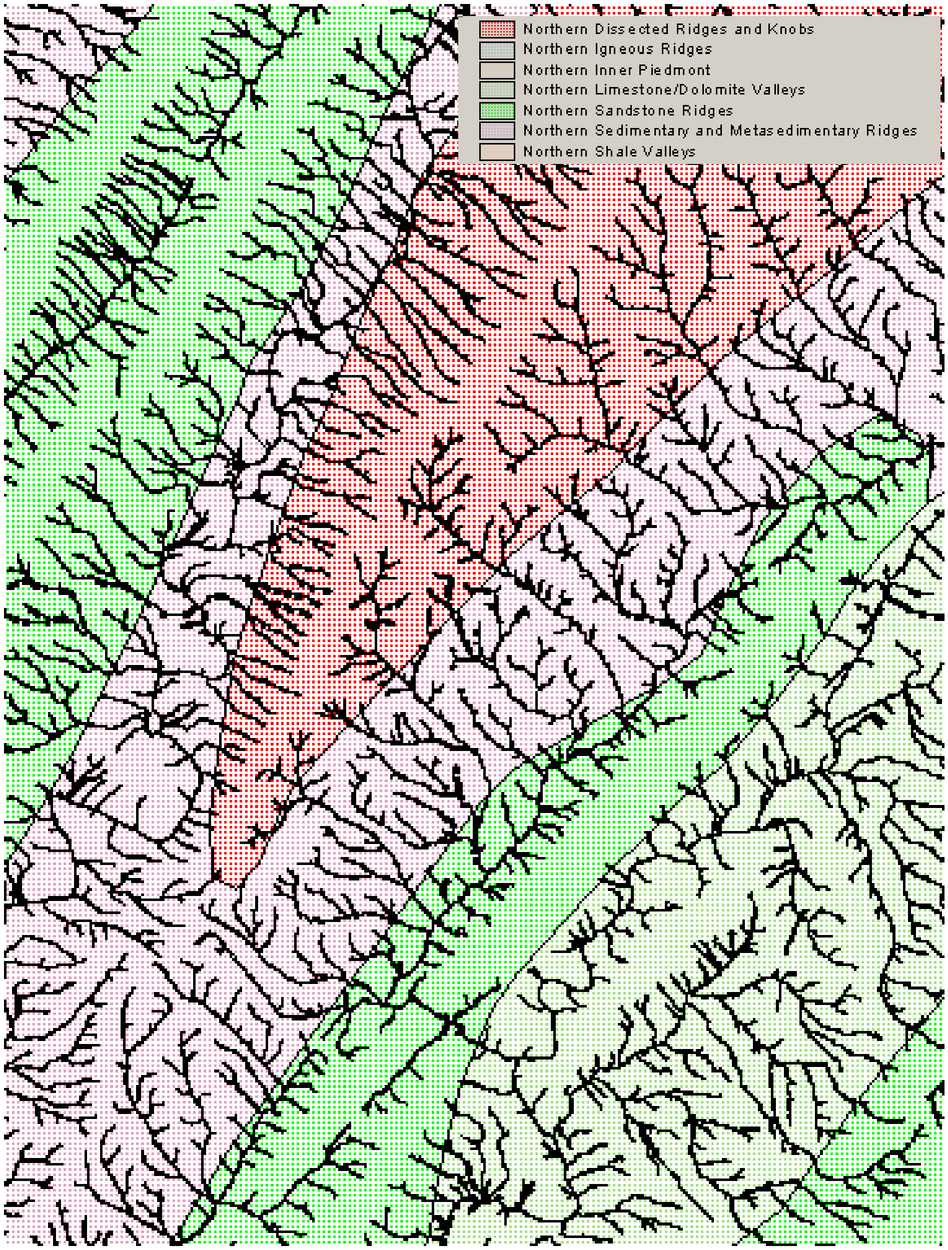

Figure 4.2: The networks predicted by the Flow Accumulation method with eco-regions overlaid for the Craigville quad. Longest overland flow lengths are predicted in the Northern Sandstone Ridges (in green), which the shortest lengths are predicted in the Northern Shale Valleys (light tan, occupying the diagonal from the bottom left to the upper right of this figure).

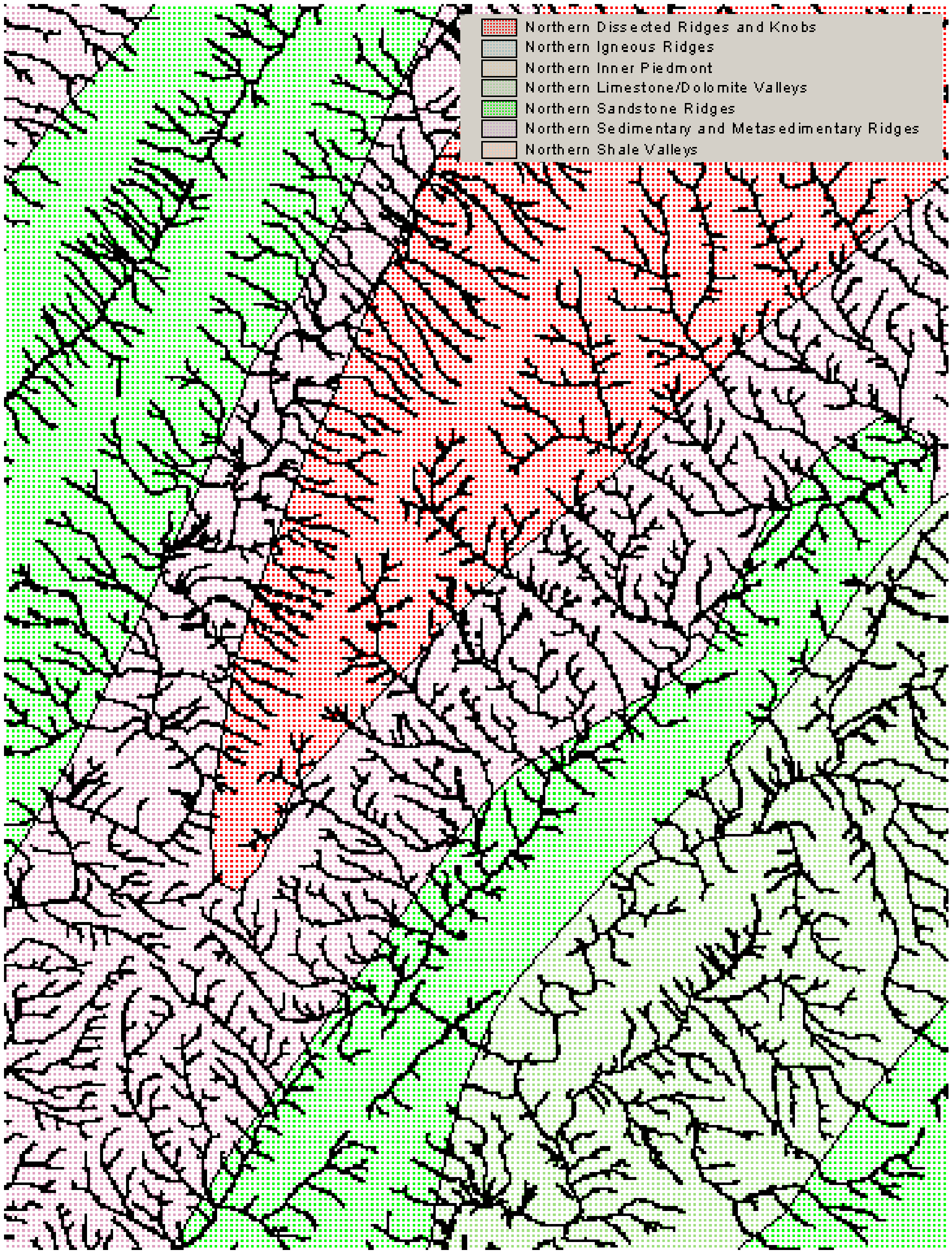

Figure 4.3: The networks predicted by the Ridge Accumulation method with eco-regions overlaid for the Craigville quad. Longest overland flow lengths are predicted in the Northern Sandstone Ridges (in green), which the shortest lengths are predicted in the Northern Shale Valleys (light tan, occupying the diagonal from the bottom left to the upper right of this figure).

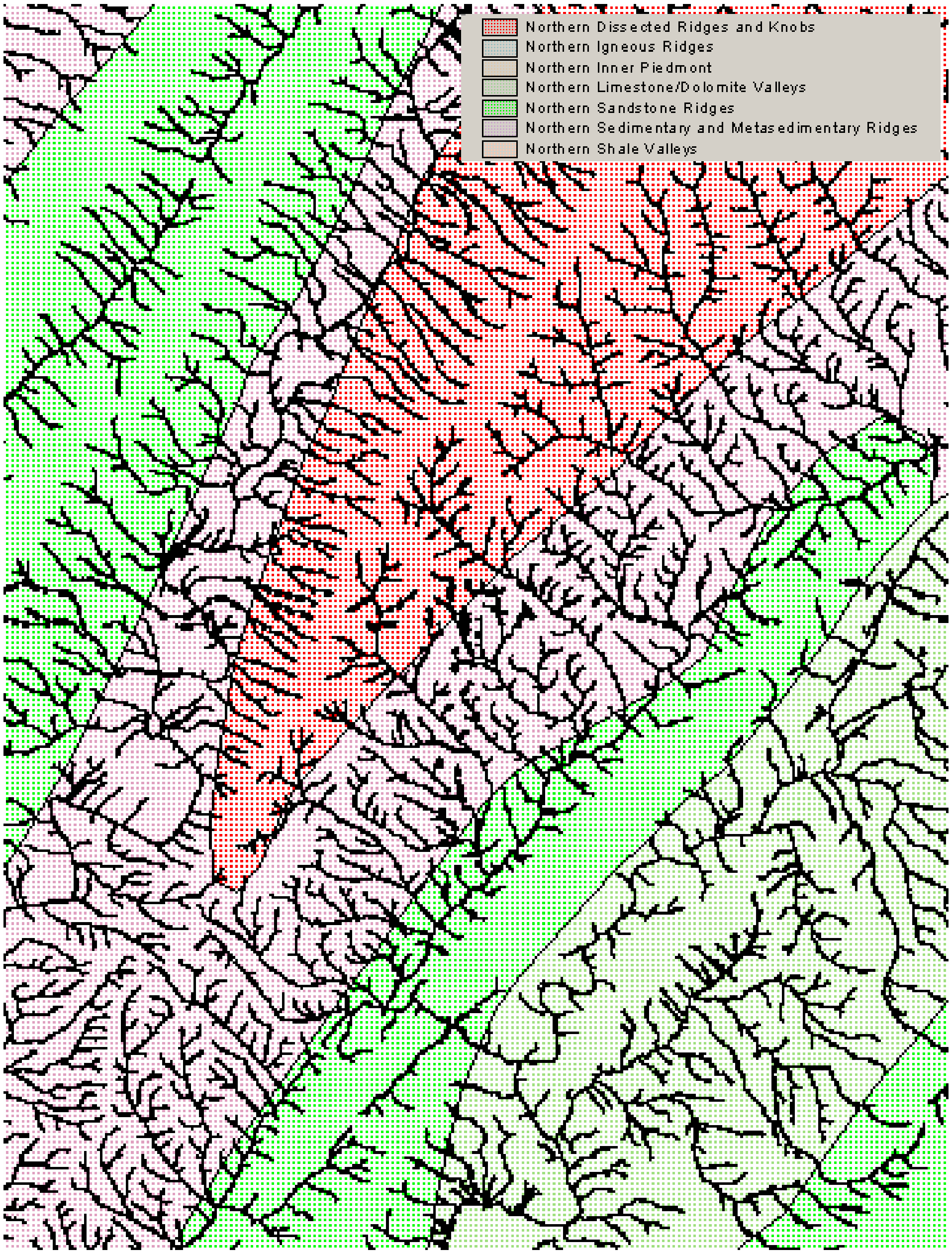

Figure 4.4: The networks predicted by the Terrain Curvature method with eco-regions overlaid for the Craigville quad. Longest overland flow lengths are predicted in the Northern Sandstone Ridges (in green), which the shortest lengths are predicted in the Northern Shale Valleys (light tan, occupying the diagonal from the bottom left to the upper right of this figure).

In summary, all three methods demonstrated the ability to produce a measurable variation in overland flow length when evaluated at a single threshold that produced a hill-slope scale drainage network. This variation was evidenced by a non-zero standard deviation in the population of analysis units. All three methods showed a decrease in the diversity of overland flow lengths predicted as the minimum analysis unit went from 10 to 200 ha, when analysis units were based on sub-watersheds. Standard deviation decreased most rapidly as the unit size went from 10 ha to 20 ha for all methods, and leveled off somewhat at a unit size of 50 ha. When evaluating overland flow lengths by quad sheet as a whole (analysis unit size 8,300 to 15,200 ha), little variation was predicted by the flow accumulation method; however, the terrain curvature and ridge accumulation methods both predicted a measurable amount of diversity between different quad sheets. When analysis units were based on ecoregions, a measurable amount of diversity was discernible for all three methods, even as the minimum analysis unit size was 2,319 ha, although the range of variation for the flow accumulation method was considerably smaller, 30.22 m, as compared to the terrain curvature and ridge accumulation methods, 67.68 m and 59.39 m respectively. It is concluded that it is not correct to say that the flow accumulation method produces spatially homogeneous networks, but more precisely, that the networks produced by this method fall into a relatively narrow range. Furthermore, the range of overland flow lengths predicted by the flow accumulation method was less than the range produced by the ridge accumulation and terrain curvature methods. Also, the range of variation predicted by each of these methods tends to decrease with increasing analysis unit size, although the ridge accumulation and terrain curvature methods were less sensitive to the analysis unit size than was the flow accumulation method. This robustness in the face of analysis unit aggregation may be indicated by the measure of standard deviation.

5. Matching DEM Contours

The results of previous sections suggests that three ANIM, flow accumulation (A_f), terrain curvature (A_c), and ridge accumulation (A_r), produce flow networks that contain a measurable amount of variation in overland flow length with a single threshold value, and that these methods differ in the breadth of the range of overland flow lengths that they produce. However, these results have not suggested which, if any, of these three methods most "accurately" predicts these values, although it might be reasonable to hypothesize that a method that is capable of displaying a greater range of overland flow lengths, might be more adept at predicting the flow paths in an area with a large range of overland flow lengths. Comparisons against actual field measurements of overland flow lengths would be necessary to truly evaluate the relative abilities of these methods. In absence of field data, it has long been suggested that tracing the contour crenulations of a topographic map is an acceptable surrogate to field measurement of drainage pathways (Smith, 1950; Mark, 1983; Hayes and Dillaha, 1992; Tarboton, 2001). Therefore, in this part of the analysis, ANIM will be evaluated based on their ability to mimic the networks produced by manual contour crenulation (CC method).

Contour crenulation networks were traced for five larger watershed areas, as described in section 2.8. The areas, average slopes, average overland flow lengths and a summary of eco-regions represented in each watershed are given in table 5.1. Figures 2.28-32 show the contour crenulation networks for each watershed.

Table 5.1: Watershed area, number of sub-watersheds and mean overland flow length (m) for 5 watersheds in Briery Branch, Craigville, Louisa and Surry quads in Virginia, for a contour crenulation flow network. The number of sub-watersheds given corresponds to using a 10 and 20 ha minimum sub-watershed size.

Watershed	Area (ha)	Sub-watersheds (10ha/20ha)	Mean OFL(m)	Eco-Region Summary
Briery Branch 2	986.3	45/25	101.8	Northern Limestone/Dolomite Valleys, Northern Dissected Ridges and Knobs, Northern Shale Valleys
Craigville 3	466.0	24/11	79.8	Dissected Ridge and Knob, Northern Shale Valleys, Northern Sandstone Ridges
Craigville 4	271.0	13/5	80.3	Dissected Ridge and Knob, Northern Shale Valleys
Louisa 5	196.4 ha	12/5	88.8	Northern Inner Piedmont
Surry 3	67.2 ha	5/1*	57.3	Rolling Chesapeake Inner Coastal Plain

* Regression and rank analysis at 20 ha unit size was not performed for Surry 3, as the sub-division process yielded only 1 sub-watershed at that threshold.

5.1 Characteristics of ANIM Networks and Contour Crenulation Networks

After manually delineating the networks according to the procedures outlined in section 2.5, an average overland flow length was calculated for each of these five watersheds based on the CC network. Using this overland flow length as a guide, a threshold value was chosen for each ANIM via a process of trial and error in order to yield an average overland flow length for each watershed that closely matched the value given by the CC method for each watershed, within the constraints of the given ANIM's resolution. This threshold value will be referred to as a "locally calibrated" threshold value. This calibration resulted in an OFL for each method that was within a maximum difference of 3.5% of the CC methods overland flow length, and are presented in table 5.2. The resulting flow networks for the Craigville 3 watershed are presented in Figures 5.1-4. The networks for the remaining 4 watersheds are presented in Appendix A.

Table 5.2: Overland flow lengths (OFL) for networks predicted by manual contour crenulation, flow accumulation, terrain curvature and ridge accumulation, using locally calibrated threshold values (in meters).

Watershed	Contour Network OFL (m)	Flow Accum. T	Flow Accum. OFL (m)	Terrain Curvature T	Terrain Curvature OFL (m)	Ridge Accum. T	Ridge Accum. OFL (m)
Briery Branch 2	90.5	101	90.4	9	92.2	19	89.6
Craigville 3	76.9	81	77.0	5	74.2	16	76.4
Craigville 4	77.8	66	77.7	4	76.5	13	77.6
Louisa 5	85.6	80	85.4	6	87.0	20	85.6
Surry 3	54.2	39	54.1	6	55.0	15	53.7
Mean Values	**82.9**	**73**	**82.8**	**6**	**82.8**	**17**	**82.3**

These five watersheds were then partitioned into sub-watershed units obtained by the method in section 2.5, using 1,000 cell and 2,000 cell threshold accumulation networks – yielding minimum sub-watershed units of approximately 10 ha and 20 ha (see figures 5.1 and 5.2). The sub-watershed unit size of 10 ha was chosen because below a unit size of 10 ha, some sub-watersheds had no stream cells, and therefore an infinite overland flow length. The 20 ha unit size was chosen because the previous section showed that the decline in diversity due to unit aggregation leveled off after 20 ha. Overland flow lengths were then calculated for predicted (ANIM) and observed (CC) networks for each sub-watershed (see Appendix A, table A.1 and A.2 for a list of all sub-watershed units and the OFL yielded by each method).

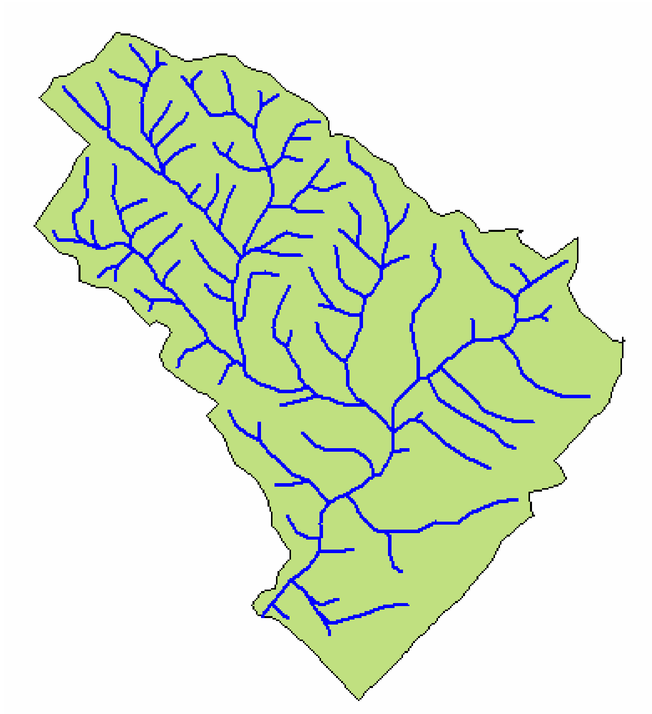

Figure 5.1 : Contour Crenulation network for the Craigville 3 watershed.

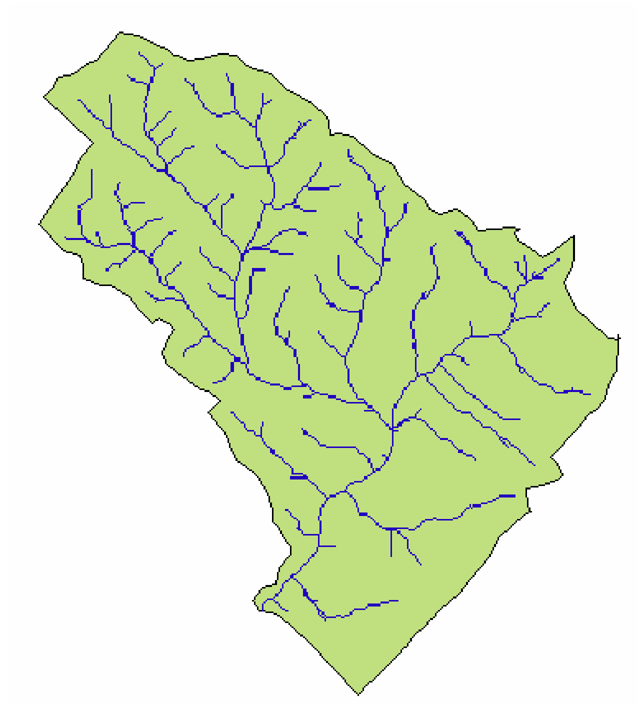

Figure 5.2: Ridge accumulation network with a locally calibrated threshold value, T = 16, for Craigville 3 watershed.

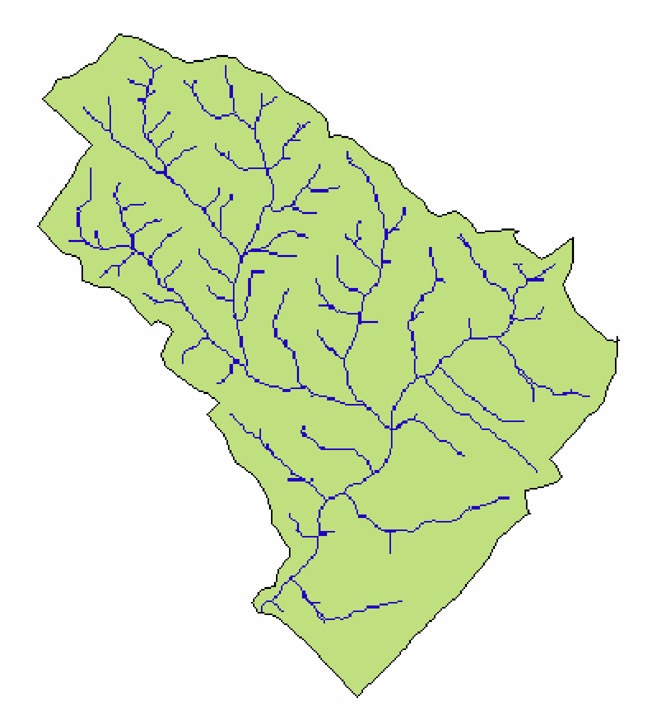

Figure 5.3: Terrain curvature network with a locally calibrated threshold value, T = 5, for Craigville 3 watershed.

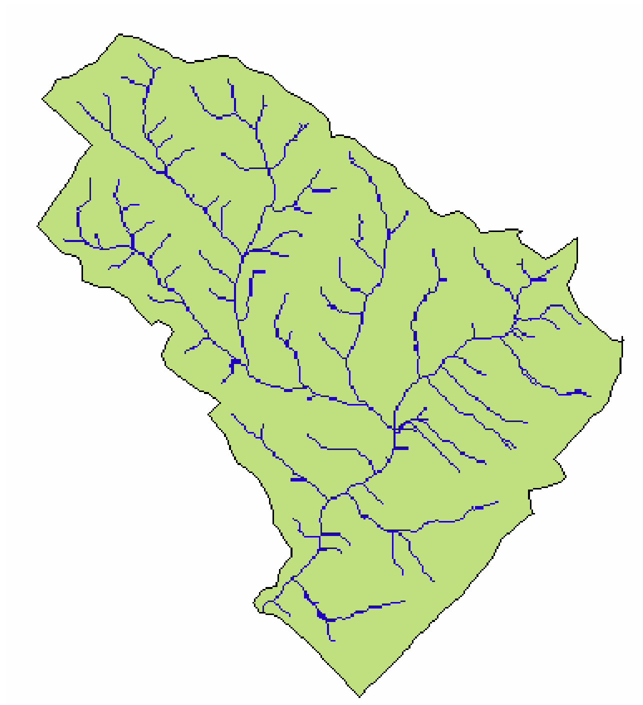

Figure 5.4: Flow accumulation network with a locally calibrated threshold value, T = 81, for Craigville 3 watershed.

5.2 Diversity in overland flow length of ANIM versus contour crenulation networks

Table 5.3 shows mean, median, standard deviation, range, minimum and maximum of OFL for the 10 ha headwater sub-watershed populations, using a locally calibrated threshold value for each of the five larger watershed units. As in the previous chapter, the standard deviation and range for OFL varied by method, with the flow accumulation (14.51 m) method producing the lowest standard deviation, followed by the ridge accumulation method (20.05 m) and then the terrain curvature method (32.16 m) for headwater sub-watersheds. While the terrain curvature may have produced a standard deviation considerably higher than the other ANIM's, none of the three methods examined produced a standard deviation at 10 ha analysis unit size that approached that of the contour crenulation method, which had a standard deviation of 86.77.

Table 5.3: Standard deviation and range statistics (in meters) for flow networks predicted for 53 headwater sub-watersheds with a minimum size of 10 ha in the Briery Branch, Craigville, Louisa, and Surry quads in Virginia. ANIM networks were generated using a locally calibrated threshold value.

	Contour	Flow Accumulation	% Error	Terrain Curvature	% Error	Ridge Accumulation	% Error
Mean	94.75	82.88	--	86.57	--	82.88	--
Standard Deviation	86.77	14.51	-83%	32.16	-63%	20.05	-77%
Range	650.6	77.46	-88%	221.42	-66%	108.45	-83%
Minimum	47.58	50.78	7%	51.78	9%	48.64	2%
Maximum	698.18	128.24	-82%	273.2	-61%	157.09	-78%

Table 5.4 shows the mean, median, standard deviation, range, minimum and maximum for headwater sub-watersheds at a 20 ha minimum unit sizes using a locally calibrated threshold value. As in the previous chapter, the standard deviation and range for OFL decreased for each ANIM method as the analysis unit size increased. At least part of this may be assumed to be due to the averaging of terrain forms that occurs with a larger analysis unit, as is evidenced by the dramatic decrease in standard deviation in the networks produced by the Contour Crenulation method – decreasing from a maximum of 86.77 m at 10 ha to 19.57 m at a 20 ha minimum unit size. The terrain curvature method displays the largest standard deviations, followed by the Ridge Accumulation, and then Flow Accumulation methods. In a comparison of ANIM standard deviations to contour crenulation, the flow accumulation method fared worst with a standard deviation of 9.75 m (-50% of contour crenulation) at the 20 ha unit size. The terrain curvature and ridge accumulation methods produced standard deviations that were considerably larger, with values of 20.37 m (+4%) and 16.61 m (-15%),

respectively. The range of values was also closely matched by the terrain curvature method (-5%), as were the minimum (-2%) and maximum values (-4%). The ridge accumulation method was next closest, with range –14%, minimum at +7% and maximum at –5%. The flow accumulation performed worst in this regard, with –52%, +21% and –22% in range, minimum and maximum values.

Table 5.4: Standard deviation and range statistics (in meters) for flow networks predicted for 25 headwater sub-watersheds with a minimum unit size of 20 ha in the Briery Branch, Craigville, Louisa, and Surry quads in Virginia. ANIM networks were generated using a locally calibrated threshold value.

	Contour	**Flow Accumulation**	**% Error**	**Terrain Curvature**	**% Error**	**Ridge Accumulation**	**% Error**
Mean	84.78	84.79	--	84.80	--	84.28	--
Standard Deviation	19.57	9.75	-50	20.37	+4	16.61	-15
Range	83.21	39.24	-52	79.11	-5	71.88	-14
Minimum	57.88	70.35	+21	56.80	-2	61.94	+7
Maximum	141.1	109.59	-22	135.92	-4	133.82	-5

5.3 Qualitative Comparison of observed versus predicted networks

Figures 5.5 through 5.36 show contour crenulation and ANIM networks for selected sub-watersheds along with a percent error in overland flow estimation for each sub-watershed and method (see table 5.14 and 5.15 for all sub-watersheds used in this analysis). For this calculation of percent error the sub-watershed overland flow lengths yielded by the CC method were considered as the baseline. There are 4 sub-watersheds selected from the 10 ha analysis unit set, and 4 from the 20 ha analysis unit set, selected such that each method is represented by instances of "good" prediction and "poor" prediction. For each method, there are 4 cases where its predicted OFL is within 10% error (a good match) and 4 cases where the predicted OFL has an error greater than 15% (a poor match). Five out of eight cases include at least one method with an error <10% and at least one method with an error of >15%, two cases have all methods <10% error, and one case shows all methods with a >10% error.

It is difficult to discern a clearly superior method given these examples, however, the terrain curvature method appears less likely to produce extraneous flow paths, and overall produces more "realistic" networks than the other two methods, adhering to the contours. That said, there is at least one example where the terrain curvature method has an error <4%, yet predicts a significant flow path *not* included in the CC network, and misses a major tributary that *is* in the CC net (figures 5.17 and 5.18). By and large, none of the methods matches the CC network exactly, although each method seems to generally succeed in matching the main stem. In the prediction of tributaries to the main stem, all methods produce additional tributaries in some cases, and also miss minor tributaries in other cases, even in when the percent error indicates a "good" match of OFL. Some of the disparity between a small error and a good "visual fit" may be attributable to comparing a discrete method, contour crenulation, to continuous methods, ANIM. In these examples, the contour interval of the original quad sheets was used, resulting in a contour interval of between 20 and 40 m. A smaller contour interval would create a more continuous network, potentially minimizing this source of error. Analysis unit size may also play a role in these disparities. Additional accuracy could be obtained by using a smaller minimum analysis unit size, however, this would benefit from a more detailed CC network as well.

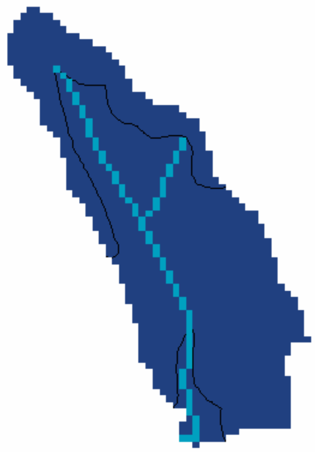

Figure 5.5: Contour Crenulation network in sub-watershed 38 (13.3 ha) in the Briery Branch 2 quad, with a minimum analysis unit of 10 ha. Sub-watershed size is

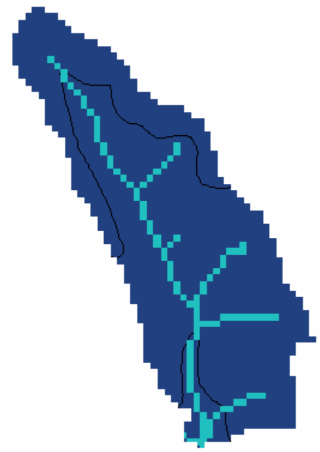

Figure 5.6: Terrain curvature in sub-watershed 38 in the Briery Branch 2 quad, with a minimum analysis unit of 10 ha. Percent error +12.5%.

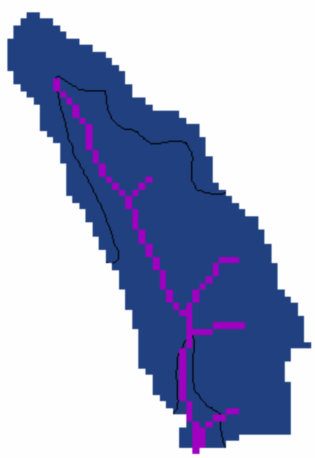

Figure 5.7: Flow Accumulation network in sub-watershed 38 in the Briery Branch 2 quad, with a minimum analysis unit of 10 ha. Percent error +11.2%.

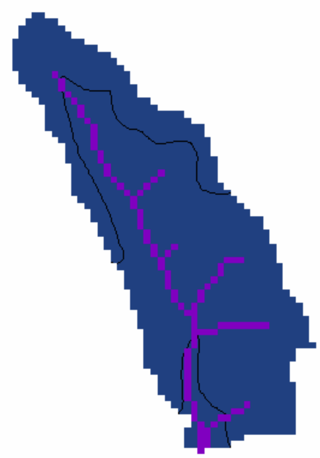

Figure 5.8: Ridge Accumulation network in sub-watershed 38 in the Briery Branch 2 quad, with a minimum analysis unit of 10 ha. Percent error +16.5%.

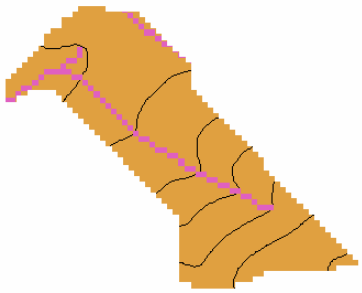

Figure 5.9: Contour Crenulation in sub-watershed 17(12.1 ha) in the Craigville 3 quad, with a minimum analysis unit of 10 ha.

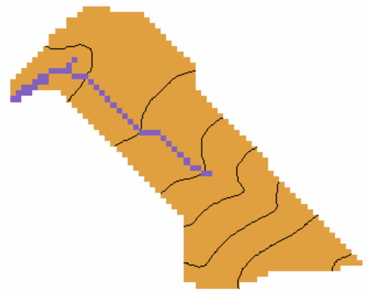

Figure 5.10: Terrain curvature network in sub-watershed 17 in the Craigville 3 quad, with a minimum analysis unit of 10 ha. Percent error +36.4%.

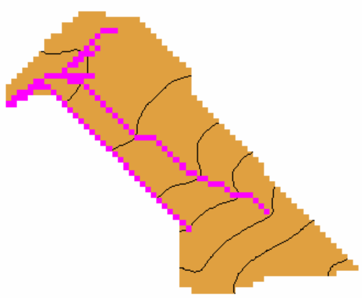

Figure 5.11: Flow Accumulation network in sub-watershed 17 in the Craigville 3 quad, with a minimum analysis unit of 10 ha. Percent error -39.4%.

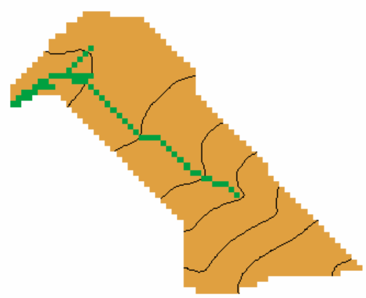

Figure 5.12: Ridge Accumulation network in sub-watershed 17 in the Craigville 3 quad, with a minimum analysis unit of 10 ha. Percent error +5.3%.

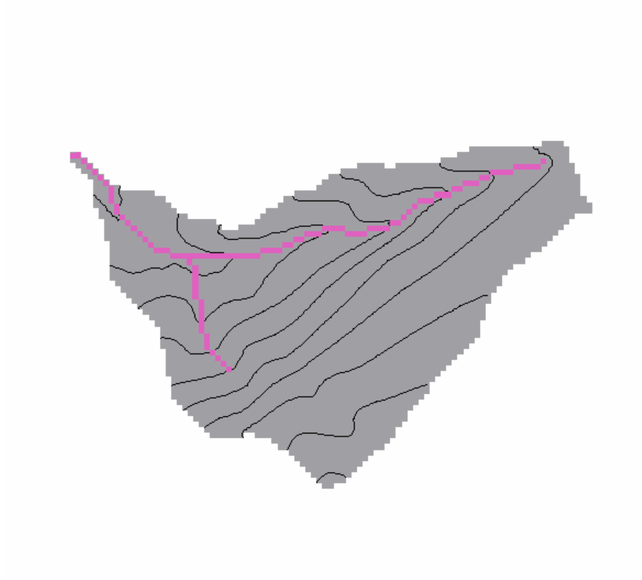

Figure 5.13: Contour Crenulation network in sub-watershed 22(30.1 ha) in the Craigville 3 quad, with a minimum analysis unit of 10 ha**.**

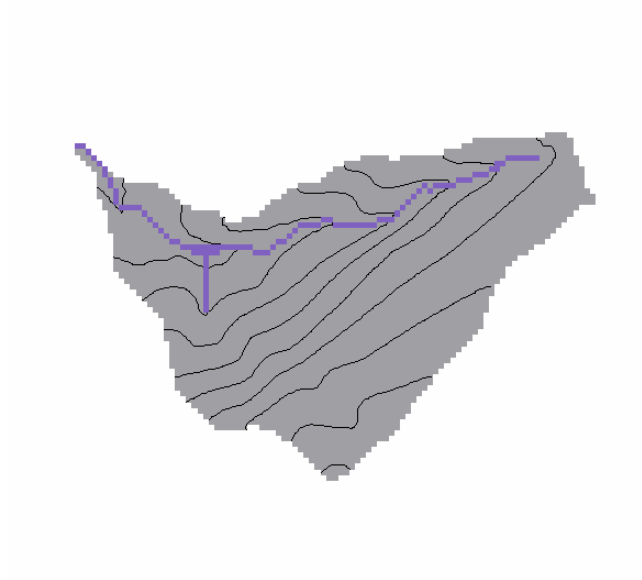

Figure 5.14: Terrain curvature network in sub-watershed 22 in the Craigville 3 quad, with a minimum analysis unit of 10 ha. Percent error +4.9%.

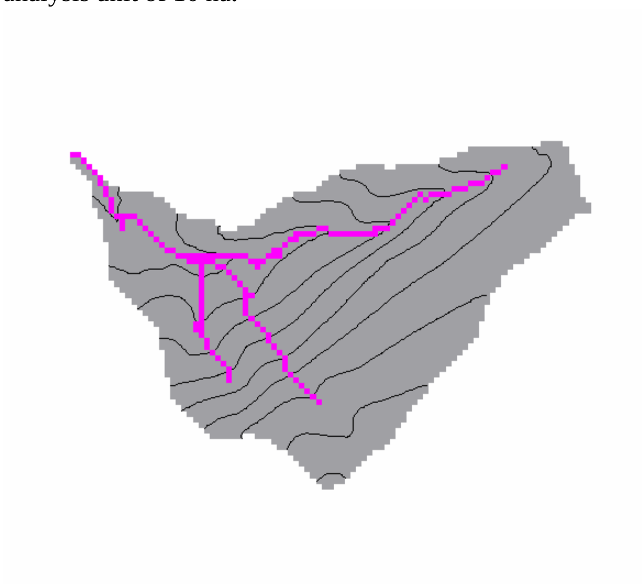

Figure 5.15: Flow Accumulation network in sub-watershed 22 in the Craigville 3 quad, with a minimum analysis unit of 10 ha. Percent error **-**25.0%.

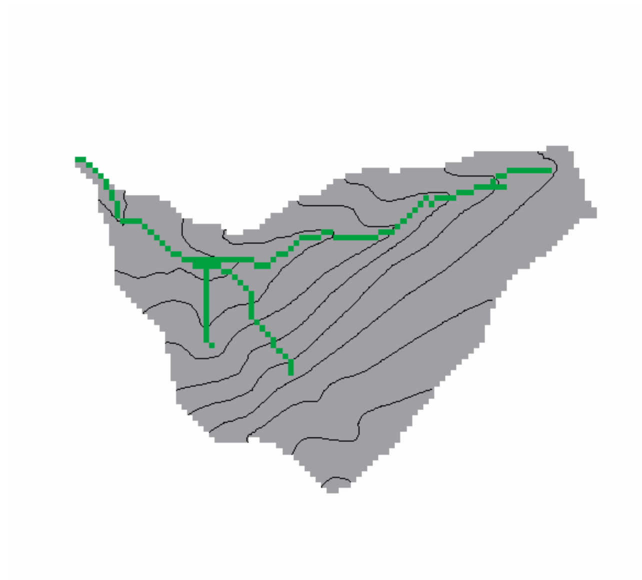

Figure 5.16: Ridge Accumulation network in sub-watershed 22 in the Craigville 3 quad, with a minimum analysis unit of 10 ha. Percent error -17.6 %.

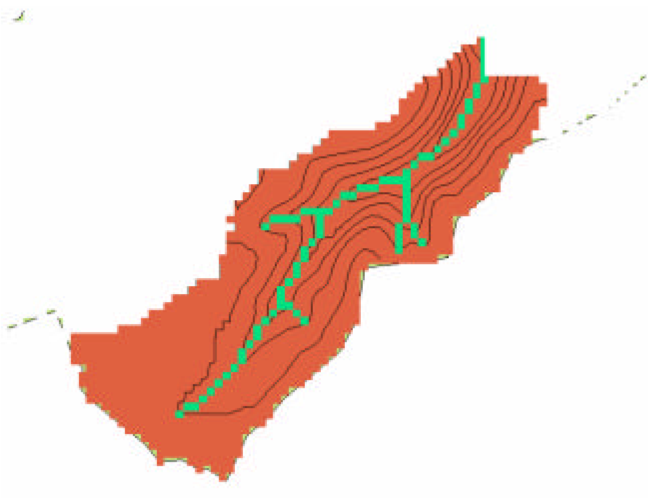

Figure 5.17: Contour Crenulation network in sub-watershed 5(12.5 ha) in the Surry 3 quad, with a minimum analysis unit of 10 ha.

Figure 5.18: Terrain curvature network in sub-watershed 5 in the Surry 3 quad, with a minimum analysis unit of 10 ha. Percent error -3.6%.

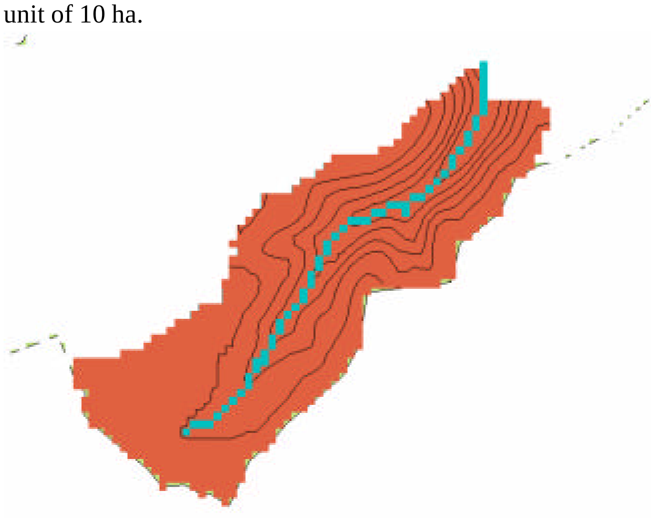

Figure 5.19: Flow Accumulation network in sub-watershed 5 in the Surry 3 quad, with a minimum analysis unit of 10 ha. Percent error +37.9 %.

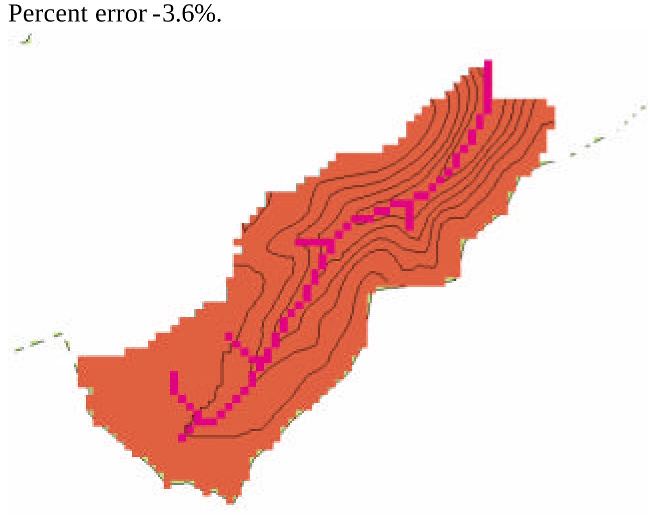

Figure 5.20: Ridge Accumulation network in sub-watershed 5 in the Surry 3 quad, with a minimum analysis unit of 10 ha. Percent error +6.7%.

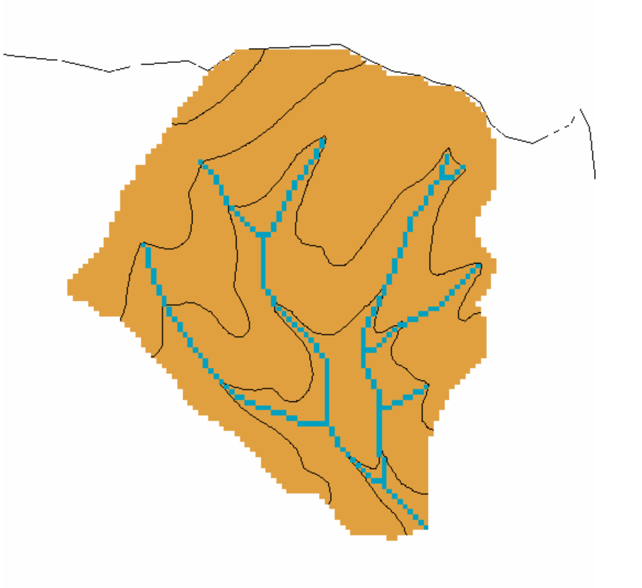

Figure 5.21: Contour Crenulation network in sub-watershed 2 (50.3 ha) in the Briery Branch 2 quad, with a minimum analysis unit of 20 ha.

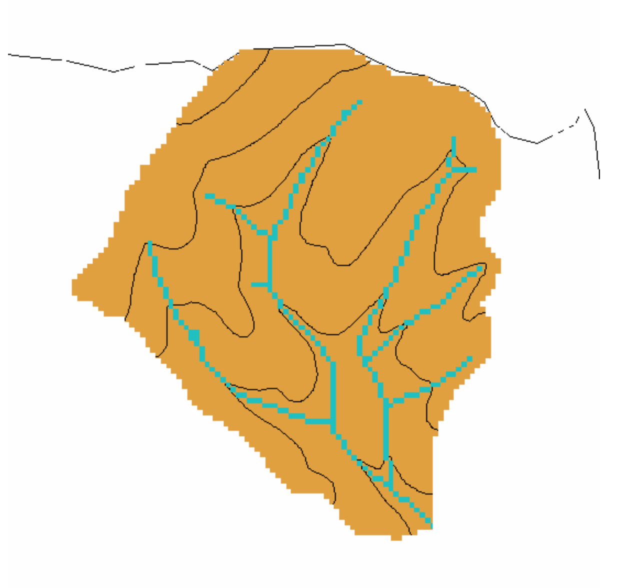

Figure 5.22: Terrain curvature network in sub-watershed 2 in the Briery Branch 2 quad, with a minimum analysis unit of 20 ha. Percent error -8.9%.

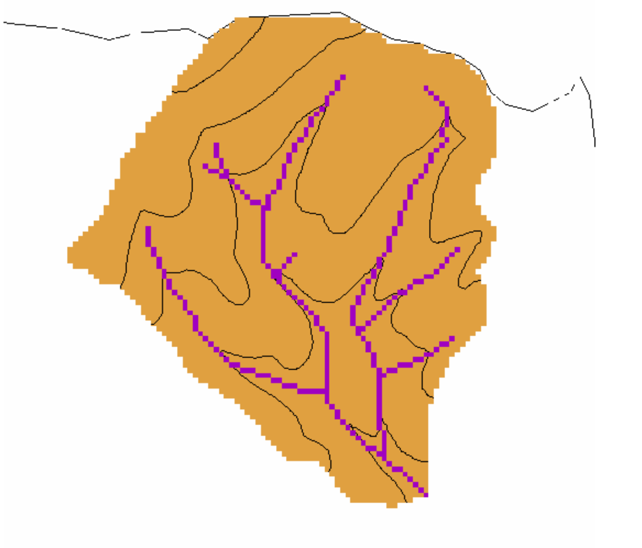

Figure 5.23: Flow Accumulation network in sub-watershed 2 in the Briery Branch 2 quad, with a minimum analysis unit of 20 ha. Percent error -7.1%.

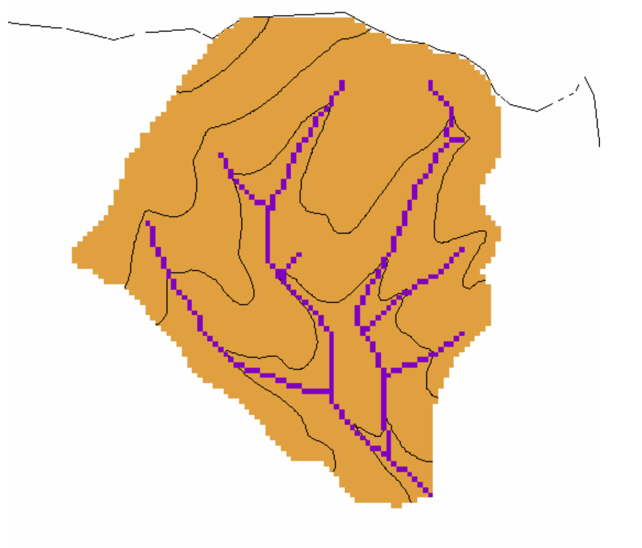

Figure 5.24: Ridge Accumulation network in sub-watershed 2 in the Briery Branch 2 quad, with a minimum analysis unit of 20 ha. Percent error -6.3%.

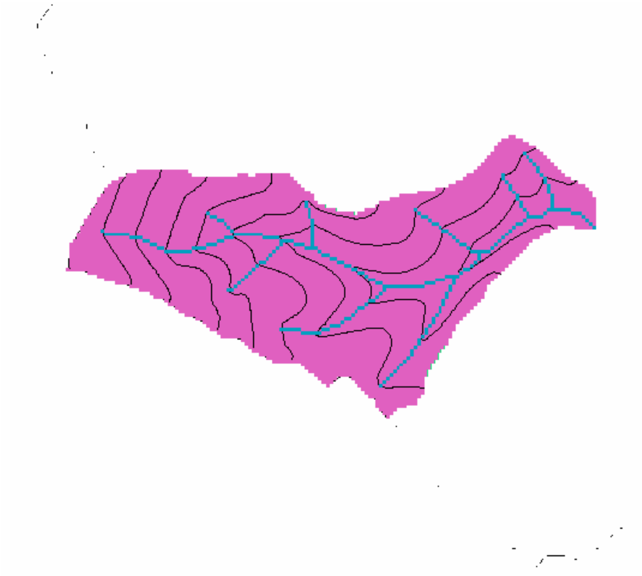

Figure 5.25: Contour Crenulation network in sub-watershed 15 (59.7 ha) in the Briery Branch 2 quad, with a minimum analysis unit of 20 ha.

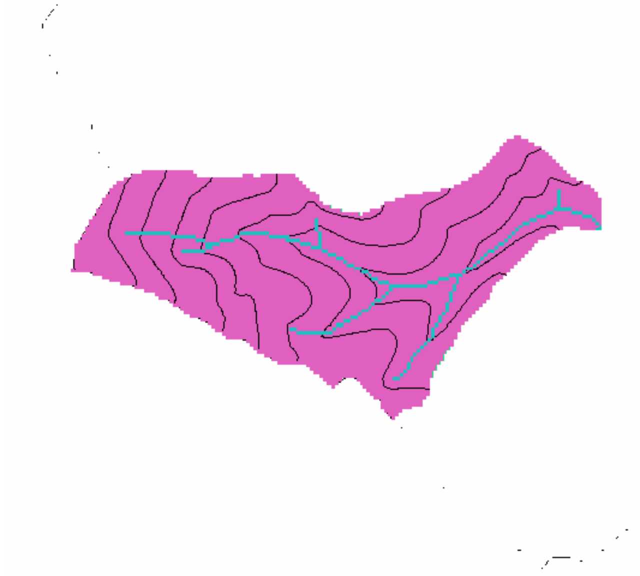

Figure 5.26: Terrain curvature network in sub-watershed 15 in the Briery Branch 2 quad, with a minimum analysis unit of 20 ha. Percent error +31.7%.

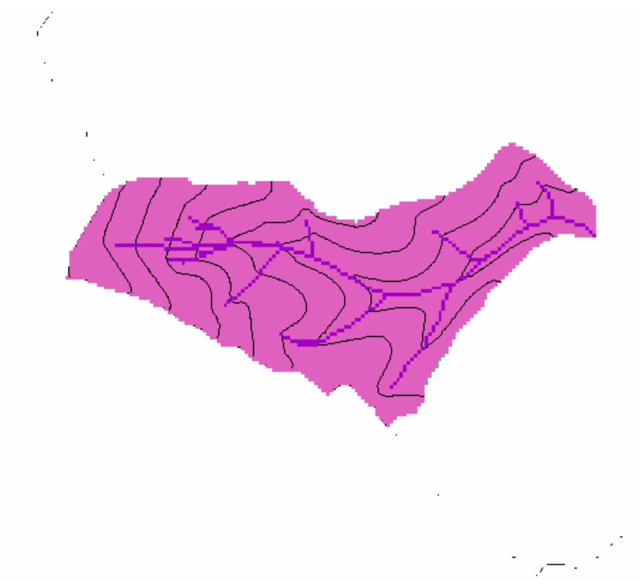

Figure 5.27: Flow Accumulation network in sub-watershed 15 in the Briery Branch 2 quad, with a minimum analysis unit of 20 ha. Percent error -9.2%.

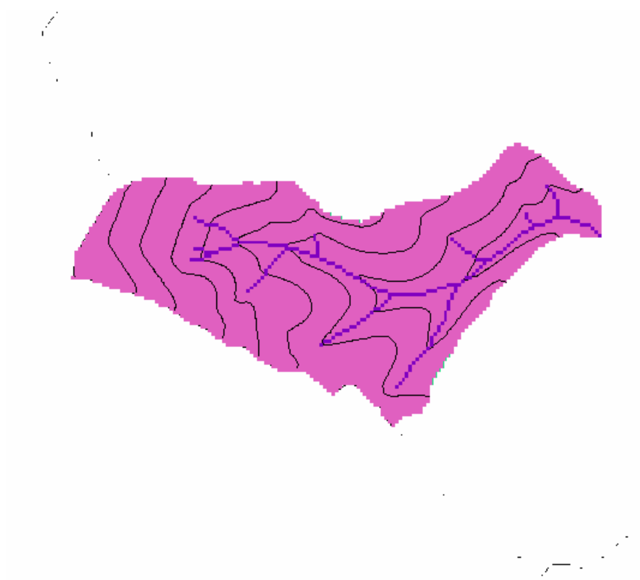

Figure 5.28: Ridge Accumulation network in sub-watershed 15 in the Briery Branch 2 quad, with a minimum analysis unit of 20 ha. Percent error +27.0%.

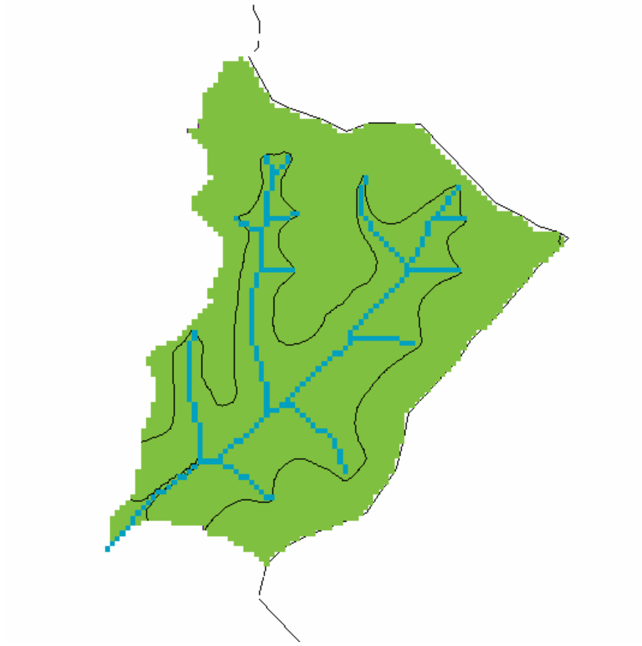

Figure 5.29: Contour Crenulation network in sub-watershed 18 (44.5 ha) in the Briery Branch 2 quad, with a minimum analysis unit of 20 ha.

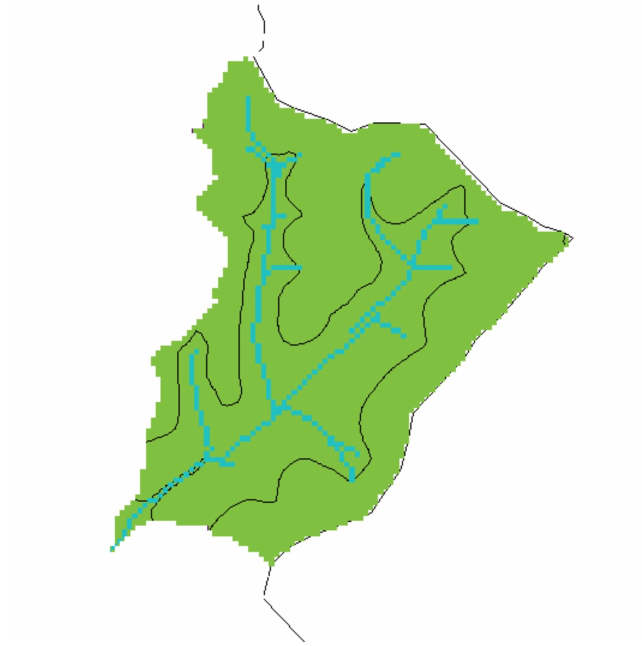

Figure 5.30: Terrain curvature network in sub-watershed 18 in the Briery Branch 2 quad, with a minimum analysis unit of 20 ha. Percent error -0.8%.

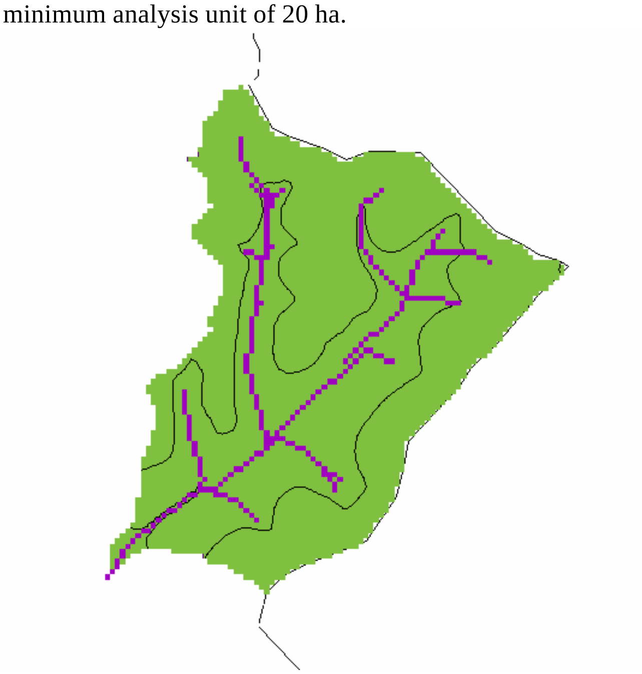

Figure 5.31: Flow Accumulation network in sub-watershed 18 in the Briery Branch 2 quad, with a minimum analysis unit of 20 ha. Percent error -5.0%.

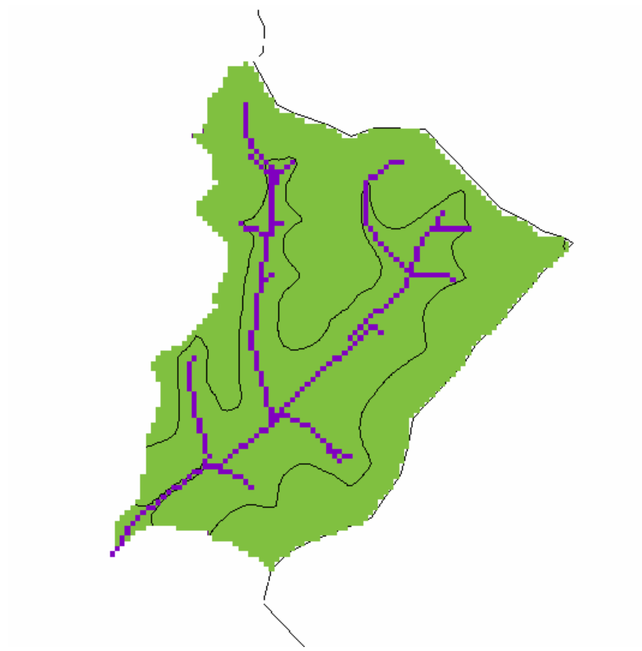

Figure 5.32: Ridge Accumulation network in sub-watershed 18 in the Briery Branch 2 quad, with a minimum analysis unit of 20 ha. Percent error -0.8 %.

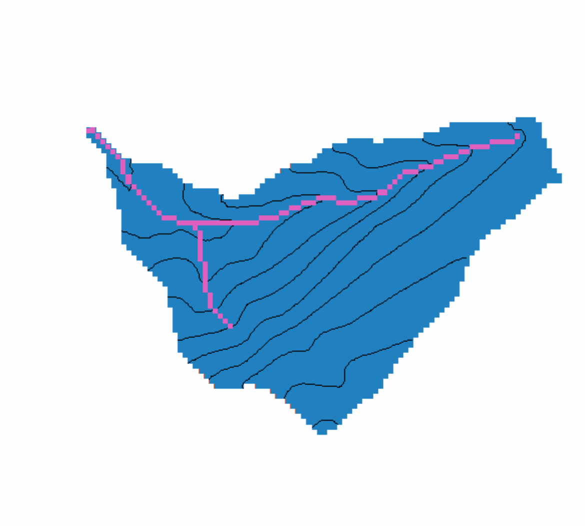

Figure 5.33: Contour Crenulation network in sub-watershed 11 (30.1 ha) in the Craigville 3 quad, with a minimum analysis unit of 20 ha.

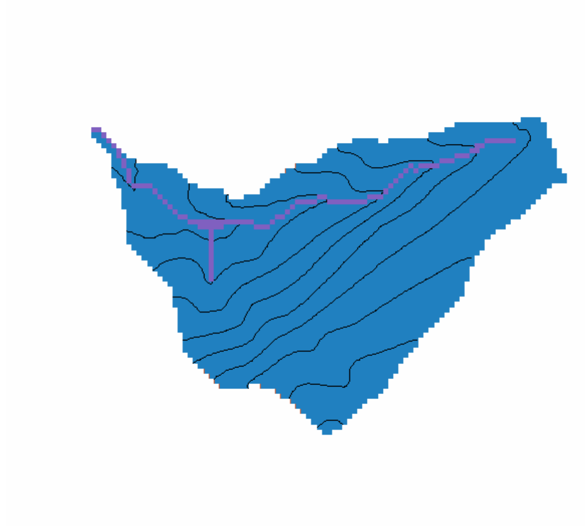

Figure 5.34: Terrain curvature network in sub-watershed 11 in the Craigville 3 quad, with a minimum analysis unit of 20 ha. Percent error +4.9%.

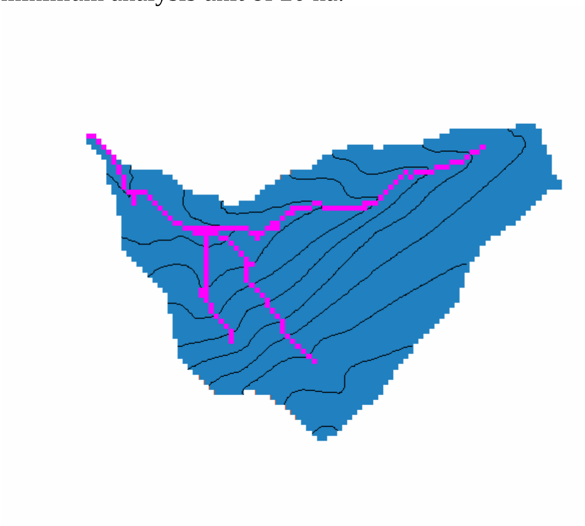

Figure 5.35: Flow Accumulation network in sub-watershed 11 in the Craigville 3 quad, with a minimum analysis unit of 20 ha. Percent error -25.0%.

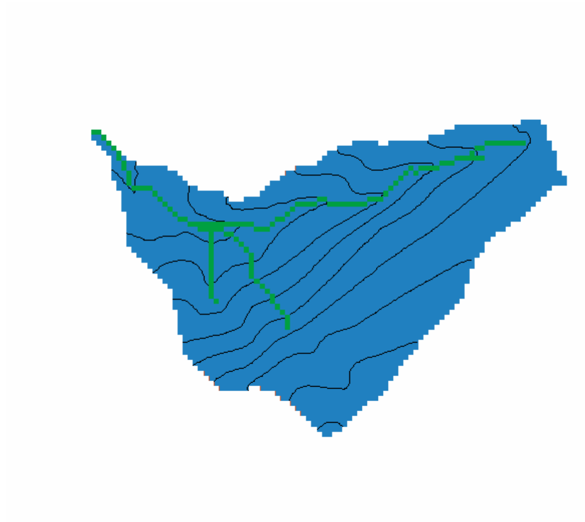

Figure 5.36: Ridge Accumulation network in sub-watershed 11 in the Craigville 3 quad, with a minimum analysis unit of 20 ha. Percent error -17.6 %.

5.4 Results of Rank Correlation / Regression Analysis

In order to evaluate the ANIM overland flow length as a predictor of CC overland flow length the sub-watershed overland flow lengths yielded by the CC method were considered as the independent variable and the overland flow length yielded by the three ANIM's as the dependent variable in the calculation of a Spearman Rank Correlation Coefficient (R_s) and a linear regression coefficient (R^2). The R_s values should show the ability of the ANIM to rank the overland flow lengths in a manner similar to that yielded by the CC method, thus representing the ability of the method to predict overall trends. The R^2 should evaluate the extent to which the overland flow lengths produced by each ANIM share a linear relationship to the overland flow lengths derived from the map contours. This analysis was performed using a minimum analysis unit size of 10 ha and then again for 20 ha.

Figures 5.37-39 show plots of the CC overland flow lengths versus the ANIM predicted flow lengths for headwater sub-watersheds of a minimum 10 ha unit size. A linear regression line is also plotted in these figures. The regression lines produced by all ANIM methods are considerably flatter than the 1:1 line (contour crenulation versus contour crenulation). This "flatness" might be expected, given the large differences in standard deviation between the ANIM sub-watershed populations and the CC populations (section 5.2, table 5.3). What these regression lines suggest is that at this analysis unit size, the ANIM methods in question are not capable of producing a strong linear relationship. The R^2 values for these curves are presented in table 5.5. Despite the flat regression lines, the terrain curvature method has an R^2 value of 0.747 – a fairly high value, given the uncertainties in this analysis, and the appearance of its regression line. Closer inspection of the data points for the terrain curvature method (figure 5.38) suggests that the regression line is heavily influenced by a handful of low predictions above 125 m, possibly accounting for the discrepancy between the regression line and R^2 values. The flow accumulation and ridge accumulation have much lower R^2 values that are more in accordance with what might be expected from looking at the regression lines – both measures indicating a weak linear relationship. Examining the confidence intervals of the R^2 for the flow and ridge accumulation suggests that there is no significant difference in their predictive abilities in this case. The results of Spearman ranking are also presented in table 5.5, and show a different performance ranking. In terms of R_s, the flow accumulation method has a slightly better score, although all methods are in a fairly narrow range. This suggests that while the narrow range of overland flow values predicted by these ANIMs prevents them from establishing a strong linear prediction of CC overland flow length, they are still capable of capturing overall trends in overland flow length. This is also supported by the slope of the regression lines in figures 5.37-39, while being much flatter than the 1:1 lines, they do in fact capture the proper directional trend.

Table 5.5: Result of regression analysis with Contour Crenulation network as observed variable, and ANIM network as predicted variable for 53 headwater sub-watersheds with a minimum size of 10 ha in the Briery Branch, Craigville, Louisa, and Surry quads in Virginia. ANIM networks were generated using a locally calibrated threshold value. P-value for all regressions was less than 0.01. a -values for each Spearman coefficient are < 0.005. 95% Confidence interval widths for R^2 estimate are also given.

	Flow Accumulation	**Terrain Curvature**	**Ridge Accumulation**
R^2	0.306	0.747	0.384
95% R^2 CI Width	0.37	0.33	0.37
Intercept / Slope	-179.3 / 3.3	-107.1 / 2.3	-127.5 / 2.7
Spearman R	0.691	0.686	0.661

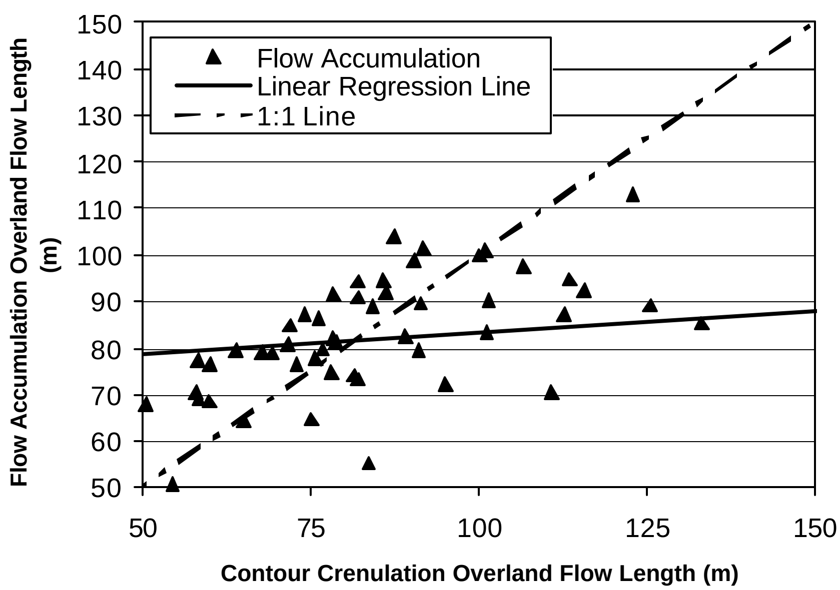

Figure 5.37: Plot of mean overland flow lengths for 53 headwater sub-watershed units of a minimum size of 10 ha. Values for mean overland flow length yielded by contour crenulation method are on the x-axis, with values predicted by the flow accumulation method are on the y-axis. Watersheds are from the Briery Branch, Craigville, Surry and Louisa quads in Virginia. ANIM networks were generated using a locally calibrated threshold value. The solid line is the linear regression line for the ridge accumulation method.

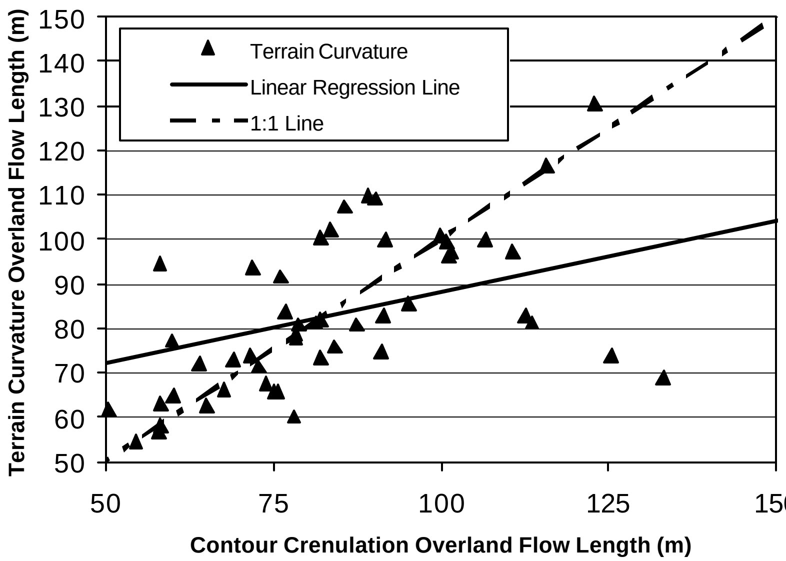

Figure 5.38: Plot of mean overland flow lengths for 53 headwater sub-watershed units of a minimum size of 10 ha. Values for mean overland flow length yielded by contour crenulation method are on the x-axis, with values predicted by the terrain curvature method are on the y-axis. Watersheds are from the Briery Branch, Craigville, Surry and Louisa quads in Virginia. ANIM networks were generated using a locally calibrated threshold value. The solid line is the linear regression line for the ridge accumulation method.

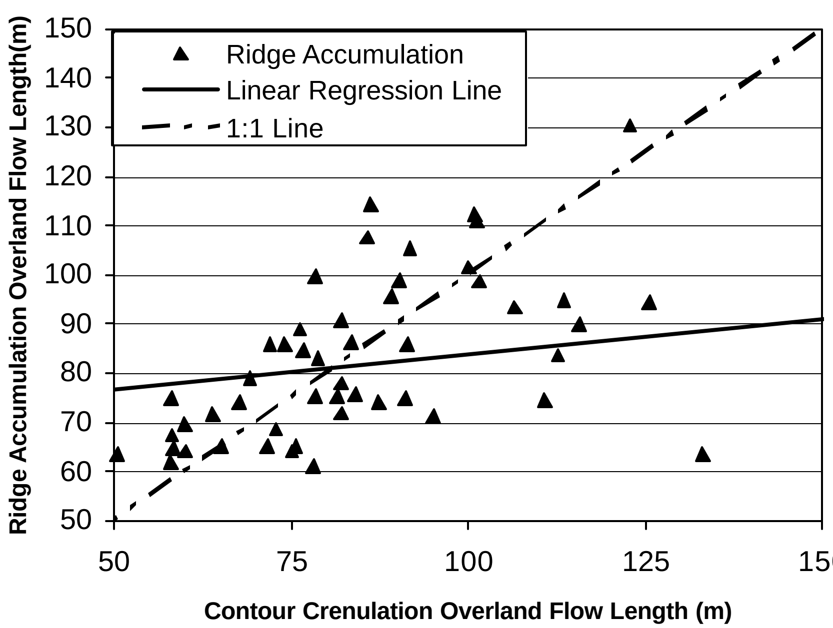

Figure 5.39: Plot of mean overland flow lengths for 53 headwater sub-watershed units of a minimum size of 10 ha. Values for mean overland flow length yielded by contour crenulation method are on the x-axis, with values predicted by the ridge accumulation method are on the y-axis. Watersheds are from the Briery Branch, Craigville, Surry and Louisa quads in Virginia. ANIM networks were generated using a locally calibrated threshold value. The solid line is the linear regression line for the ridge accumulation method.

Figures 5.40-42 show plots of the CC overland flow lengths versus the ANIM predicted mean overland flow lengths for headwater sub-watersheds of a minimum 20 ha unit size. At this analysis unit size the regression lines produced by all ANIM methods draw closer to the 1:1 line (contour crenulation versus contour crenulation), particularly the terrain curvature method. In fact, the slope of regression lines conforms to what might be predicted by from the standard deviations at this unit size (section 5.2, table 5.4). The terrain curvature, with a standard deviation and range almost identical to those of the CC method, matches the slope of the 1:1 line quite well. The ridge accumulation method, with values in the neighborhood of -15% of the CC method, has the next closest regression line slope. The flow accumulation method, with a range -50% of the CC method, has the flattest regression line. Given the slope of the regression lines, it might be expected that the terrain curvature method would have the best regression score (table 5.6). However, this is not the case. At the 20 ha analysis unit size, the flow accumulation method has the highest R^2, followed by terrain curvature and then ridge accumulation, although all fall into a narrow range (<0.1), considerably smaller than the confidence intervals calculated for each of the R^2 values, suggesting that the difference in R^2 may not be significant. For the flow accumulation and ridge accumulation methods, R^2 values increase by a large amount, while the score for the terrain curvature method decreases. It is not clear why this performance decline occurred for the terrain curvature method. Looking at the distribution of points around the regression line for these methods, it is clear that the flow accumulation methods predictions are more tightly clustered around the regression line, suggesting that while it does not display the range of the CC method, it represents the trends from lowest to highest more faithfully. This conclusion is also supported by the Spearman ranking scores. Although all methods occupy a relatively small range of R_s values, the flow accumulation method once again has the highest. Given the uncertainty involved in manual delineation, these R_s values are encouraging for all methods. Both the Spearman ranking and the trend lines (and to a lesser extent the R^2) seem to support the hypothesis that as the analysis unit size increases, and the standard deviation of contour crenulation overland flow lengths decreases, that the ANIM methods are able to better represent the variation in flow lengths present in the watersheds in this study area. They does not necessarily support the hypothesis that an ANIM that produces a wider standard deviation in predicted overland flow lengths will better represent trends in flow length, as the flow accumulation method has the highest ranking at both analysis unit sizes.

Table 5.6: Result of regression analysis with Contour Crenulation network as observed variable, and ANIM network as predicted variable for 25 headwater sub-watersheds with a minimum size of 20 ha from the Briery Branch, Craigville, Louisa, and Surry quads in Virginia. ANIM networks were generated using a locally calibrated threshold value. p-value for all regressions was less than 0.01. a-values for each Spearman coefficient are < 0.005. 95% Confidence interval widths for R^2 estimate are also given.

	Flow Accumulation	Terrain Curvature	Ridge Accumulation
R^2	0.603	0.563	0.521
95% R^2 CI Width	0.48	0.52	0.51
Intercept / Slope	-47.3 / 1.55	23.7 / 0.72	13.1 / 0.85
Spearman R	0.797	0.788	0.745

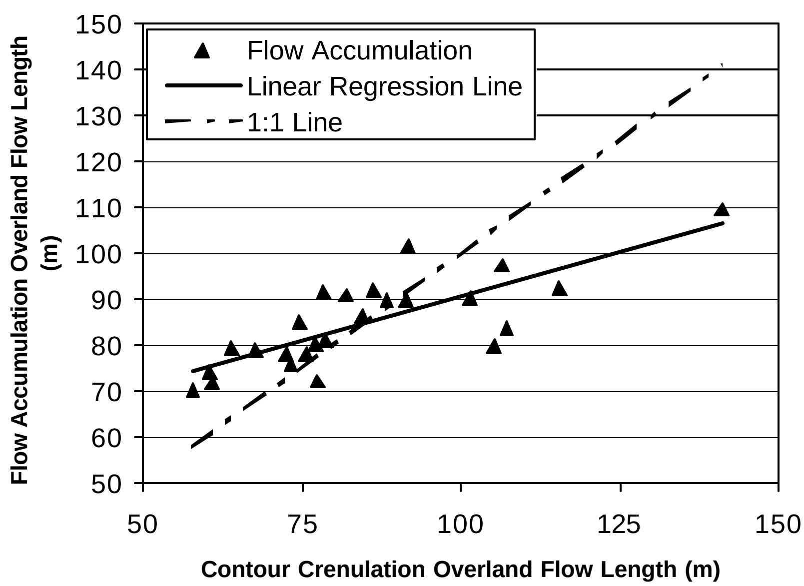

Figure 5.40: Plot of mean overland flow lengths for 35 headwater sub-watershed units of a minimum size of 20 ha. Values for mean overland flow length yielded by contour crenulation method are on the x-axis, with values predicted by the flow accumulation method are on the y-axis. Watersheds are from the Briery Branch, Craigville, and Louisa quads in Virginia. ANIM networks were generated using a locally calibrated threshold value. The solid line is the linear regression line for the ridge accumulation method.

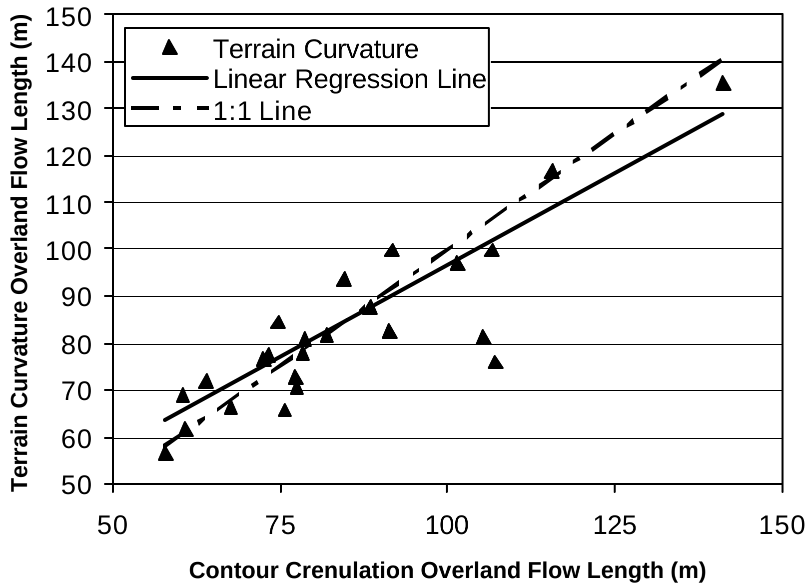

Figure 5.41: Plot of mean overland flow lengths for 35 headwater sub-watershed units of a minimum size of 20 ha. Values for mean overland flow length yielded by contour crenulation method are on the x-axis, with values predicted by the terrain curvature method are on the y-axis. Watersheds are from the Briery Branch, Craigville, and Louisa quads in Virginia. ANIM networks were generated using a locally calibrated threshold value. The solid line is the linear regression line for the ridge accumulation method.

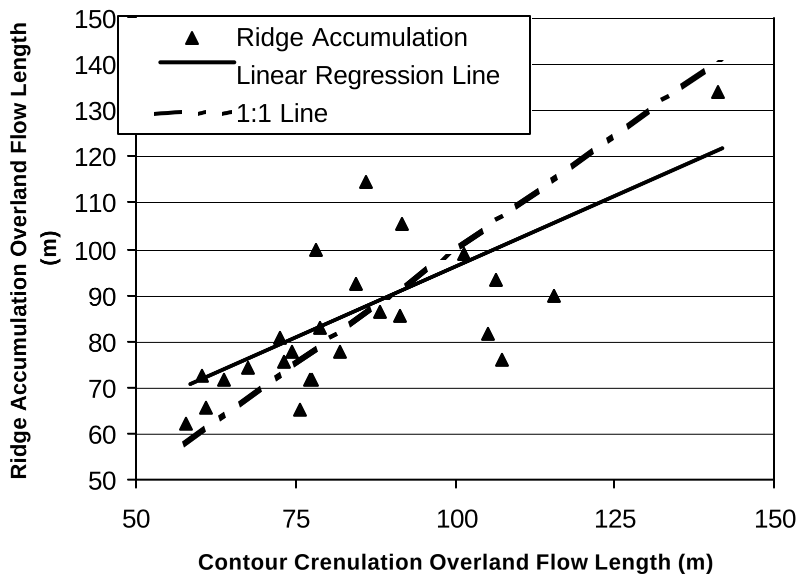

Figure 5.42: Plot of mean overland flow lengths for 35 headwater sub-watershed units of a minimum size of 20 ha. Values for mean overland flow length yielded by contour crenulation method are on the x-axis, with values predicted by the ridge accumulation method are on the y-axis. Watersheds are from the Briery Branch, Craigville, and Louisa quads in Virginia. ANIM networks were generated using a locally calibrated threshold value. The solid line is the linear regression line for the ridge accumulation method.

The results of this section suggest that there exists a wider range of overland flow lengths in these areas than any of the ANIMs studied are capable of producing – provided that the CC networks accurately reflect the range of overland flow lengths in the study areas. This was despite the use of threshold values calibrated to the watershed level. This is evidenced by the large differences in overland flow length standard deviation between ANIM and CC networks at a 10 ha analysis unit size. However, at a unit size of 20 ha, the terrain curvature method produced comparable range and standard deviation (+4% and -5% respectively). The ridge accumulation method was slightly less diverse (-15, -14), and the flow accumulation was considerably less diverse (-50%, -52%) at this unit size. While there were considerable differences in the ability of the different ANIM to produce comparable spatial diversity, this did not carry over into performance in ranking sub-watersheds on a basis of overland flow length. All methods fell within a fairly narrow range when calculating a Spearman Ranking (R_s), however the flow accumulation method had the highest R_s at both analysis unit sizes. Analysis unit aggregation from 10 ha to 20 ha improved the R_s value for all methods. The results of linear regression were less straightforward, with the terrain curvature method producing a considerably higher R^2 at 10 ha, but failing to produce a trend line that showed evidence of a truly linear relationship. At an analysis unit size of 20 ha, all methods had a similar R^2 value, with the flow accumulation method being highest, although the differences between methods was far smaller than the 95% confidence interval for their R^2 values. However, the terrain curvature method still had the most similar slope. On the whole, ANIM performance was positively affected by analysis unit aggregation, suggesting that there may be a lower analysis unit threshold in the neighborhood of 20 ha, above which the terrain curvature and ridge accumulation methods are capable of sharing a linear relationship with contour crenulation networks, given the range of expected overland flow lengths in these study areas. The flow accumulation methods predictions were too narrowly constrained to make this possible. That said, errors were considerably larger for both terrain curvature and ridge accumulation predictions than for flow accumulation predictions. One reason for the higher incidence of error for these methods might be the difference in magnitude of threshold values needed by each method. The flow accumulation method works on rather large thresholds, between 39 and 101 in cells for this group of watersheds. This is 3 to 5 times the thresholds used by the ridge accumulation method (13 to 20 ridge cells) and 10 times those used by the terrain curvature method (4 to 9 cells). Small numbers of erroneous cells in a DEM would most likely affect the terrain curvature method most, and to a smaller degree, the ridge accumulation method. In all of these comparisons, a great uncertainty is the error or bias introduced into the analysis by the contour crenulation method. It would require further research, with considerably larger data sets, preferably the field survey data, to determine the nature and extent of possible errors. In sum, the results of this analysis are encouraging for the use of the terrain curvature ridge accumulation methods as tools to predict realistic networks and/or rank networks, while the flow accumulation method shows potential as a ranking tool only.

Table 5.7: Predictions of overland flow length (in meters) by contour crenulation, flow accumulation, terrain curvature and ridge accumulation methods in 53 headwater sub-watersheds, with a minimum analysis unit size of 10 ha.

			Contour Crenulation Network		Flow Accumulation Network			Terrain Curvature Network			Ridge Accumulation Network		
Watershed	ID	Area (m^2)	Stream Length	Flow Length	Stream Length	Flow Length	% Error	Stream Length	Flow Length	% Error	Stream Length	Flow Length	% Error
Craigville 3	2	512900	4430.1	57.9	3645.5	70.3	22%	4514.6	56.8	2%	4140.4	61.9	7%
Craigville 3	5	473700	3500.6	67.7	2993.6	79.1	17%	3573.0	66.3	2%	3198.8	74.0	9%
Craigville 3	10	312700	1412.3	110.7	2221.1	70.4	36%	1605.5	97.4	12%	2100.4	74.4	33%
Craigville 3	22	301400	1303.7	115.6	1629.6	92.5	20%	1291.6	116.7	1%	1677.9	89.8	22%
Craigville 3	24	192900	953.6	101.1	1158.8	83.2	18%	1001.9	96.3	5%	869.1	111.0	10%
Craigville 3	11	180800	796.7	113.5	953.6	94.8	16%	1110.5	81.4	28%	953.6	94.8	16%
Craigville 3	1	166900	1653.7	50.5	1231.2	67.8	34%	1352.0	61.7	22%	1315.7	63.4	26%
Craigville 3	19	150200	893.3	84.1	845.0	88.9	6%	989.8	75.9	10%	989.8	75.9	10%
Craigville 3	13	148400	591.5	125.4	832.9	89.1	29%	1001.9	74.1	41%	784.6	94.6	25%
Craigville 3	3	139600	917.4	76.1	808.8	86.3	13%	760.5	91.8	21%	784.6	89.0	17%
Craigville 3	7	126500	1086.4	58.2	917.4	68.9	18%	1001.9	63.1	8%	977.8	64.7	11%
Craigville 3	17	121000	724.3	83.5	1098.5	55.1	34%	591.5	102.3	22%	700.1	86.4	3%
Craigville 3	6	102400	881.2	58.1	663.9	77.1	33%	881.2	58.1	0%	760.5	67.3	16%
Craigville 4	1	440900	2800.5	78.7	2716.0	81.2	3%	2728.1	80.8	3%	2655.6	83.0	5%
Craigville 4	5	194500	1267.5	76.7	1219.2	79.8	4%	1158.8	83.9	9%	1146.8	84.8	11%
Craigville 4	3	165200	869.1	95.0	1146.8	72.0	24%	965.7	85.5	10%	1158.8	71.3	25%
Craigville 4	8	126400	700.1	90.3	639.8	98.8	9%	579.4	109.1	21%	639.8	98.8	9%
Craigville 4	2	120100	869.1	69.1	760.5	79.0	14%	820.8	73.2	6%	760.5	79.0	14%
Craigville 4	11	102600	857.0	59.9	748.4	68.5	15%	663.9	77.3	29%	736.3	69.7	16%
Craigville 4	9	100200	615.6	81.4	676.0	74.1	9%	615.6	81.4	0%	663.9	75.5	7%
Louisa 5	4	274200	1750.3	78.3	1496.8	91.6	17%	1762.4	77.8	1%	1376.1	99.6	27%
Louisa 5	5	272600	1279.5	106.5	1400.2	97.3	9%	1364.0	99.9	6%	1460.6	93.3	12%
Louisa 5	1	190300	1267.5	75.1	1472.7	64.6	14%	1448.5	65.7	13%	1484.7	64.1	15%
Louisa 5	8	168000	832.9	100.9	832.9	100.9	0%	845.0	99.4	1%	748.4	112.2	11%
Louisa 5	2	153500	1038.1	73.9	881.2	87.1	18%	1134.7	67.6	9%	893.3	85.9	16%
Louisa 5	12	105400	603.6	87.3	507.0	103.9	19%	651.8	80.8	7%	712.2	74.0	15%

Louisa 5	9	105000	905.3	58.0	748.4	70.1	21%	555.3	94.5	63%	700.1	75.0	29%
Surry 3	4	218400	2003.8	54.5	2148.7	50.8	7%	2003.8	54.5	0%	2245.2	48.6	11%
Surry 3	1	127500	1339.9	47.6	1255.4	50.8	7%	1231.2	51.8	9%	1279.5	49.8	5%
Surry 3	5	125600	965.7	65.0	977.8	64.2	1%	1001.9	62.7	4%	965.7	65.0	0%
Briery Branch 2	39	730900	5721.7	63.9	4599.1	79.5	24%	5069.8	72.1	13%	5106.1	71.6	12%
Briery Branch 2	29	597200	3464.4	86.2	3247.1	92.0	7%	2196.9	135.9	58%	2607.4	114.5	33%
Briery Branch 2	7	531500	2619.4	101.5	2945.3	90.2	11%	2740.1	97.0	4%	2691.8	98.7	3%
Briery Branch 2	35	438800	2800.5	78.3	2679.8	81.9	5%	2788.4	78.7	0%	2921.2	75.1	4%
Briery Branch 2	11	407300	2221.1	91.7	2003.8	101.6	11%	2040.0	99.8	9%	1931.4	105.4	15%
Briery Branch 2	10	399500	1774.4	112.6	2293.5	87.1	23%	2414.2	82.7	27%	2390.1	83.6	26%
Briery Branch 2	3	311300	1557.2	100.0	1557.2	100.0	0%	1545.1	100.7	1%	1533.0	101.5	2%
Briery Branch 2	43	253800	1677.9	75.6	1629.6	77.9	3%	1931.4	65.7	13%	1943.4	65.3	14%
Briery Branch 2	5	233700	1279.5	91.3	1303.7	89.6	2%	1412.3	82.7	9%	1364.0	85.7	6%
Briery Branch 2	31	223700	1364.0	82.0	1231.2	90.8	11%	1364.0	82.0	0%	1436.5	77.9	5%
Briery Branch 2	1	212700	1195.0	89.0	1291.6	82.3	7%	965.7	110.1	24%	1110.5	95.8	8%
Briery Branch 2	25	182100	1110.5	82.0	965.7	94.3	15%	905.3	100.6	23%	1001.9	90.9	11%
Briery Branch 2	6	174000	1195.0	72.8	1134.7	76.7	5%	1219.2	71.4	2%	1267.5	68.6	6%
Briery Branch 2	2	171900	1195.0	71.9	1014.0	84.8	18%	917.4	93.7	30%	1001.9	85.8	19%
Briery Branch 2	22	168300	1026.0	82.0	1146.8	73.4	11%	1146.8	73.4	11%	1170.9	71.9	12%
Briery Branch 2	13	151700	108.6	698.2	591.5	128.2	82%	277.6	273.2	61%	482.8	157.1	78%
Briery Branch 2	37	151600	832.9	91.0	953.6	79.5	13%	1014.0	74.8	18%	1014.0	74.8	18%
Briery Branch 2	38	133700	857.0	78.0	893.3	74.8	4%	1110.5	60.2	23%	1098.5	60.9	22%
Briery Branch 2	15	132400	772.5	85.7	700.1	94.6	10%	615.6	107.5	25%	615.6	107.5	25%
Briery Branch 2	19	131700	494.9	133.1	772.5	85.2	36%	953.6	69.1	48%	1038.1	63.4	52%
Briery Branch 2	28	122700	857.0	71.6	760.5	80.7	13%	832.9	73.7	3%	941.5	65.2	9%
Briery Branch 2	30	114400	953.6	60.0	748.4	76.4	27%	881.2	64.9	8%	893.3	64.0	7%
Briery Branch 2	14	100800	410.4	122.8	446.6	112.8	8%	386.3	130.5	6%	386.3	130.5	6%

Table 5.8: Predictions of overland flow length (in meters) by contour crenulation, flow accumulation, terrain curvature and ridge accumulation methods in 25 headwater sub-watersheds, with a minimum analysis unit size of 20 ha.

			Contour Crenulation Network		Flow Accumulation Network			Terrain Curvature Network			Ridge Accumulation Network		
Watershed	**ID**	**Area (m^2)**	**Stream Length**	**Flow Length**	**Stream Length**	**Flow Length**	**% Error**	**Stream Length**	**Flow Length**	**% Error**	**Stream Length**	**Flow Length**	**% Error**
Craigville 3	6	1001700	4756.0	105.3	6289.0	79.6	24%	6168.3	81.2	23%	6144.2	81.5	23%
Craigville 3	1	512900	4430.1	57.9	3645.5	70.3	22%	4514.6	56.8	2%	4140.4	61.9	7%
Craigville 3	3	505500	4152.4	60.9	3524.8	71.7	18%	4104.2	61.6	1%	3850.7	65.6	8%
Craigville 3	5	473700	3500.6	67.7	2993.6	79.1	17%	3573.0	66.3	2%	3198.8	74.0	9%
Craigville 3	2	466600	3862.7	60.4	3150.5	74.1	23%	3379.9	69.0	14%	3210.9	72.7	20%
Craigville 3	11	301400	1303.7	115.6	1629.6	92.5	20%	1291.6	116.7	1%	1677.9	89.8	22%
Craigville 4	1	440900	2800.5	78.7	2716.0	81.2	3%	2728.1	80.8	3%	2655.6	83.0	5%
Craigville 4	3	362500	2474.6	73.2	2390.1	75.8	4%	2341.8	77.4	6%	2402.1	75.5	3%
Craigville 4	2	324000	2233.1	72.5	2076.2	78.0	8%	2112.4	76.7	6%	2003.8	80.8	11%
Loiusa 5	1	409700	2643.6	77.5	2836.7	72.2	7%	2897.1	70.7	9%	2860.8	71.6	8%
Loiusa 5	2	274200	1750.3	78.3	1496.8	91.6	17%	1762.4	77.8	1%	1376.1	99.6	27%
Loiusa 5	3	272600	1279.5	106.5	1400.2	97.3	9%	1364.0	99.9	6%	1460.6	93.3	12%
Briery Branch 2	9	1314900	4659.4	141.1	5999.3	109.6	22%	4852.6	135.5	4%	4912.9	133.8	5%
Briery Branch 2	1	756700	4478.4	84.5	4381.8	86.3	2%	4043.8	93.6	11%	4092.1	92.5	9%
Briery Branch 2	21	730900	5721.7	63.9	4599.1	79.5	24%	5069.8	72.1	13%	5106.1	71.6	12%
Briery Branch 2	19	607200	3935.2	77.2	3790.3	80.1	4%	4176.6	72.7	6%	4236.9	71.7	7%
Briery Branch 2	7	603100	2812.6	107.2	3597.2	83.8	22%	3971.4	75.9	29%	3959.3	76.2	29%
Briery Branch 2	15	597200	3464.4	86.2	3247.1	92.0	7%	2196.9	135.9	58%	2607.4	114.5	33%
Briery Branch 2	3	531500	2619.4	101.5	2945.3	90.2	11%	2740.1	97.0	4%	2691.8	98.7	3%
Briery Branch 2	2	503400	2848.8	88.4	2800.5	89.9	2%	2872.9	87.6	1%	2909.1	86.5	2%
Briery Branch 2	18	444700	2981.6	74.6	2619.4	84.9	14%	2631.5	84.5	13%	2860.8	77.7	4%
Briery Branch 2	6	407300	2221.1	91.7	2003.8	101.6	11%	2040.0	99.8	9%	1931.4	105.4	15%
Briery Branch 2	23	253800	1677.9	75.6	1629.6	77.9	3%	1931.4	65.7	13%	1943.4	65.3	14%
Briery Branch 2	4	233700	1279.5	91.3	1303.7	89.6	2%	1412.3	82.7	9%	1364.0	85.7	6%
Briery Branch 2	16	223700	1364.0	82.0	1231.2	90.8	11%	1364.0	82.0	0%	1436.5	77.9	5%

6. Use of a Single, Regionally Calibrated Threshold Value

The usefulness of automatic drainage network identification hinges in part upon its ability to perform in an unsupervised fashion. The results of the previous section suggest that the flow accumulation, terrain curvature, and ridge accumulation methods are capable of representing a portion of the variation in average overland flow length exhibited by the contour crenulation method by employing a locally calibrated threshold value. However, the time necessary to consider this locally calibrated threshold value may limit the benefit of the process of automatic delineation. For the purpose of analyzing a large watershed area, the ideal ANIM would be able to produce an accurate network with a single threshold value. Therefore, this portion of the study will attempt to explore the ability of these methods to mimic the variation in overland flow length exhibited by the contour crenulation method with a single threshold value.

Once again, the means of choosing a threshold value are of primary importance. In the previous section, a "locally calibrated" threshold was employed, in which a threshold value was chosen for each method, such that it yielded an average overland flow length for a given watershed that was within 3.5% of that predicted by the contour crenulation method. The results in table 6.1 show range of threshold values used for the five watersheds analyzed in chapter 5. A wide range was seen, with the maximum threshold for the flow accumulation method being 159% greater than the minimum calibrated threshold value. The minimum and maximum thresholds for terrain curvature differed by 125%, and for ridge accumulation they differed by 54%. The same watersheds and sub-watersheds will be analyzed in this section, with the mean value of thresholds used in the previous section as an estimate of the "regionally calibrated" threshold value. For each method, the arithmetic mean threshold value was calculated from the five threshold values used in the larger watersheds to determine the drainage network for all watersheds. This choice of threshold value is still in some sense "calibrated", but more generalized, effectively reducing the degree to which the choice of threshold value is calibrated. It would be expected that this generalization would yield poorer results in the regression and ranking analyses, as well as in the more basic measures of variation such as the standard deviation of the predicted population.

Table 6.1: Range of regionally calibrated threshold values required to match average overland flow length.

Method	Minimum T	Maximum T	Mean T	% Difference max/min
Flow Accumulation	39	101	73	159
Terrain Curvature	4	9	6	125
Ridge Accumulation	13	20	17	54

6.1 Characteristics of ANIM Networks and Contour Crenulation Networks

Table 6.2 shows a comparison of the population characteristics of the observed and predicted networks for the headwater sub-watersheds, at a minimum analysis unit size of 10 ha. Comparing the standard deviation obtained with locally calibrated (from the previous section) and regionally calibrated threshold values, the flow accumulation method had the largest decrease in standard deviation, approximately 13.3%, followed by the terrain curvature method, 11.4%. The ridge accumulation method had the smallest decreases, with only 1.5% in standard deviation. Accordingly, the percent error for ANIM networks versus CC networks increased as compared to those for calibrated thresholds in section 5. As in the analysis with a locally calibrated threshold, the terrain curvature produced the closest match in standard deviation and range, followed by the ridge accumulation method, and then the flow accumulation method.

Table 6.2: Standard deviation and range statistics (in meters) for flow networks predicted for 53 headwater sub-watersheds in the Briery Branch, Craigville, Louisa, and Surry quads in Virginia determined with a 10 ha minimum analysis unit size. ANIM networks were generated using a regionally calibrated threshold value. Values in parentheses () are those that were obtained using a locally calibrated threshold value.

	Contour Crenulation	Flow Accumulation	% Error	Terrain Curvature	% Error	Ridge Accumulation	% Error
Mean	94.75	78.98	--	84.97	--	83.22	--
Standard Deviation	86.77	12.57 (14.51)	-86%	28.48 (32.16)	-67%	19.74 (20.05)	-77%
Range	650.60	70.21	-89%	180.95	-72%	101.48	-84%
Minimum	47.58	50.63	6%	51.78	9%	51.78	9%
Maximum	698.18	120.84	-83%	232.73	-67%	153.26	-78%

Table 6.3 shows the population characteristics determined using a 20 ha minimum analysis unit size. Once again, the standard deviations produced by the flow accumulation method were most sensitive to the use of a regionally calibrated threshold value, with a decrease of nearly 23%. The terrain curvature method saw its predicted standard deviation decreased by nearly 17%. Overall, the ridge curvature method was affected least, with a decrease of 7.5%.

In this instance also, the terrain curvature maintained its position as the method producing a standard deviation most similar to that of the contour crenulation (-14%). However, due to its lower overall sensitivity to a single threshold, the ridge accumulation method drew closer in terms of standard deviation (-22%), and actually had the most similar range, -19%.

Table 6.3: Standard deviation and range statistics (in meters) for flow networks predicted for 25 headwater sub-watersheds in the Briery Branch, Craigville, Louisa, and Surry quads in Virginia determined with a 20 ha minimum analysis unit size. ANIM networks were using a regionally calibrated threshold value. Values in parentheses () are those that were obtained using a locally calibrated threshold value.

	Contour Crenulation	**Flow Accumulation**	**% Error**	**Terrain Curvature**	**% Error**	**Ridge Accumulation**	**% Error**
Mean	84.8	78.5	--	81.6	--	83.3	--
Standard Deviation	19.6	7.5 (9.8)	-62%	16.9 (20.4)	-14%	15.4 (16.6)	-22%
Range	83.2	28.8	-65%	62.5	-25%	67.4	-19%
Minimum	57.9	66.6	15%	58.7	1%	63.0	9%
Maximum	141.1	95.4	-32%	121.2	-14%	130.3	-8%

6.2 Results of Rank Correlation / Regression Analysis

At an analysis unit size of 10 ha, the terrain curvature method had the highest R^2 with a value of 0.614 (table 6.5). However, this value was considerably lower than the R^2 of 0.747 obtained when employing a locally calibrated threshold. The ridge accumulation method had the next highest R^2, with a value of 0.349, and the accumulation method was again third, with a value of 0.308, although the difference in R^2 between these two methods was far smaller than their 95% confidence interval, suggesting this performance difference may not be statistically significant. Interestingly enough, the flow accumulation method performed slightly better with the constant value than with the varying threshold in terms of regression analysis. All methods show a considerable amount of scatter around the regression line (figures 6.1-3), and slopes that are far from the 1:1 line. This is expected, since the use of a regionally calibrated threshold produced a lower standard deviation for all methods. Once again, the terrain curvature had the most similar slope at this unit size, but had a few points that contained very large errors. In terms of Spearman ranking, results were mixed with the Ridge accumulation having the highest score (0.635), followed by the terrain curvature and then flow accumulation methods. Once again, these were in a very narrow range (0.04), and may not represent a significant difference between methods. However, it is interesting to note the while R_s values decreased for all methods, the ridge accumulation methods decrease was the smallest, and the flow accumulation method showed the largest decrease in R_s value. Since the ridge accumulation method had the smallest decrease in standard deviation with the use of a regionally calibrated threshold value (-1.5%), and the flow accumulation method had the greatest decrease (-13.3%), it might be reasonable to suspect that standard deviation may have a greater impact on a methods ability to rank as threshold calibration is less localized.

Table 6.4: Result of regression analysis with Contour Crenulation network as observed variable, and ANIM network as predicted variable for 53 headwater sub-watersheds in the Briery Branch, Craigville, Louisa, and Surry quads in Virginia. ANIM networks were generated using a regionally calibrated threshold value. P-value for all regressions was less than 0.01. Values in parentheses () are those that were obtained using a locally calibrated threshold value. 95% Confidence interval widths for R^2 estimate are also given.

	Flow Accumulation	**Terrain Curvature**	**Ridge Accumulation**
R^2	0.308 (0.306)	0.614 (0.747)	0.349 (0.384)
95% R^2 CI Width	0.37	0.22	0.37
Spearman	0.591 (0.691)	0.594 (0.686)	0.635 (0.661)

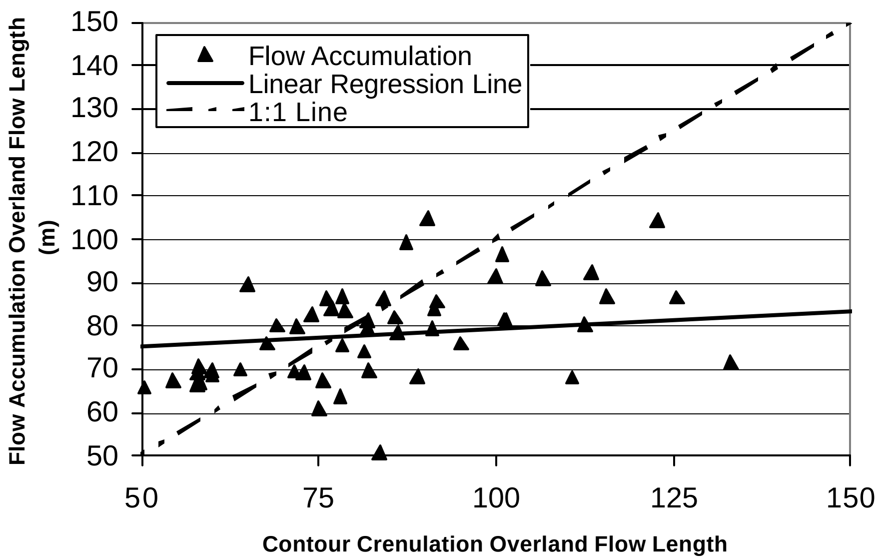

Figure 6.1: Plot of Contour Crenulation network versus Flow Accumulation values for 53 headwater sub-watersheds with a minimum size of 10 ha from the Briery Branch, Craigville, Louisa, and Surry quads in Virginia. ANIM networks were generated using a regionally calibrated threshold value.

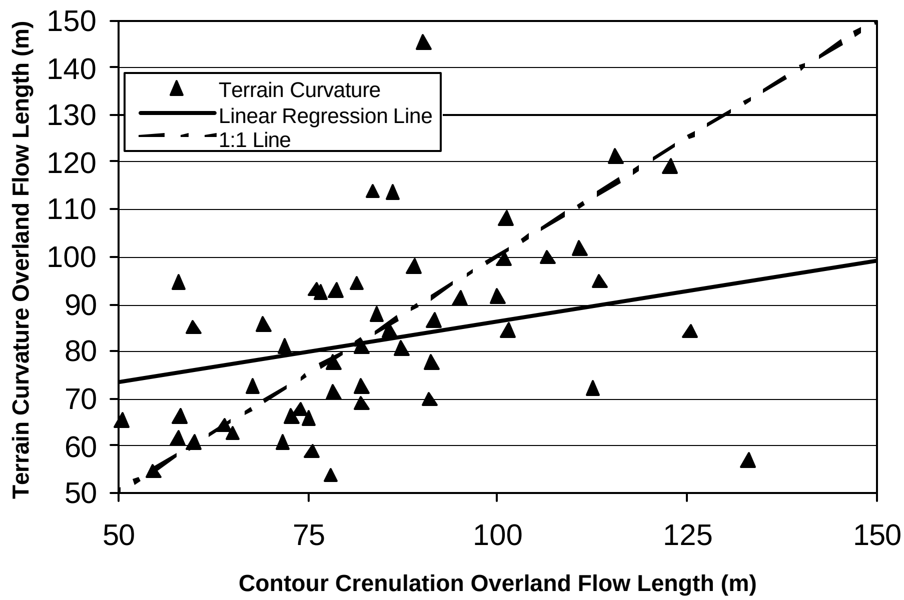

Figure 6.2 Plot of Contour Crenulation network versus Terrain Curvature values for 53 headwater sub-watersheds with a minimum size of 10 ha from the Briery Branch, Craigville, Louisa, and Surry quads in Virginia. ANIM networks were generated using a regionally calibrated threshold value.

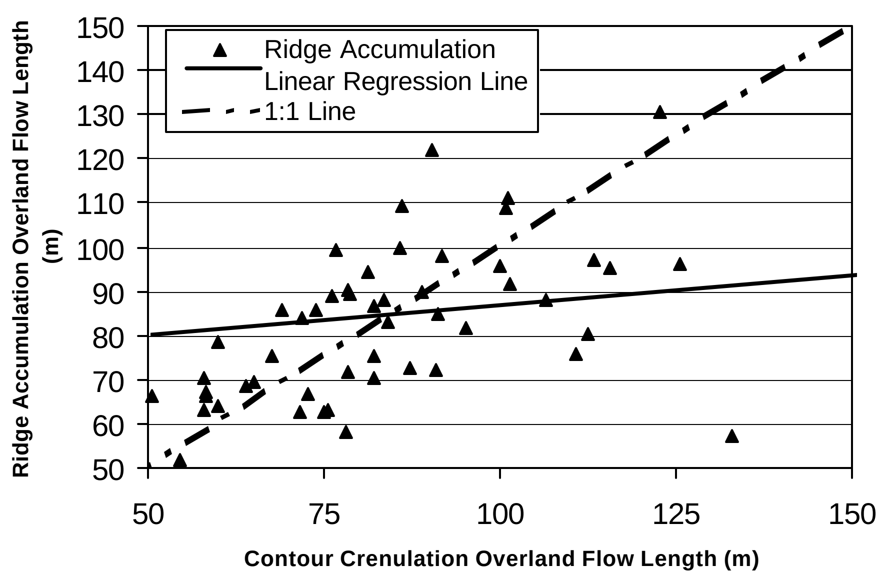

Figure 6.3 Plot of Contour Crenulation network versus Ridge Accumulation values for 53 headwater sub-watersheds with a minimum size of 10 ha from the Briery Branch, Craigville, Louisa, and Surry quads in Virginia. ANIM networks were generated using a regionally calibrated threshold value.

At an analysis unit size of 20 ha, the flow accumulation and ridge accumulation methods displayed higher R^2 values than in the 10 ha analysis unit size (see table 6.6). At this unit size, the terrain curvature method performs worst, with an R^2 of 0.469 using a regionally calibrated threshold value. This follows a similar trend to that of the analysis in section 5.4. The flow accumulation emerges as the best performer, with an R^2 of 0.551, and the ridge accumulation method was the second best performer, with an R^2 of 0.490 – however all methods were within a fairly narrow range (0.082). This difference in R^2 is considerably smaller than the confidence intervals calculated for each of the R^2 values, suggesting that the difference in R^2 may not be significant. Observing the regression lines and points in figures 6.4-6, it is clear that once again the flow accumulation methods produces a fairly tight cluster around the regression line, whereas the ridge accumulation and terrain curvature methods have a looser fit, but a more representative slope of data points. As might be expected, flow accumulation also yielded the highest Spearman ranking coefficient in the examination of headwaters, 0.722, followed by the terrain curvature (0.611) and then ridge accumulation (0.602). R_s values also decreased at this unit size as a result of using a single threshold value, however, the relative decreases between methods were not the same as at the 10 ha unit size. In this case, the terrain curvature and ridge accumulation methods experienced decreases in R_s value (-0.177 and –0.143 respectively) that were approximately twice the decrease experienced by the flow accumulation method (-0.075). This suggests that the sources of error impacting the terrain curvature and ridge accumulation method are more pronounced with a single threshold than those for the flow accumulation method.

Table 6.5: Result of regression analysis with Contour Crenulation network as observed variable, and ANIM network as predicted variable for 25 headwater sub-watersheds in the Briery Branch, Craigville, Louisa, and Surry quads in Virginia. ANIM networks were generated using a regionally calibrated threshold value. P-value for all regressions was less than 0.01. Values in parentheses () are those that were obtained using a locally calibrated threshold value. 95% Confidence interval widths for R^2 estimate are also given.

	Flow Accumulation	**Terrain Curvature**	**Ridge Accumulation**
R^2	0.551 (0.603)	0.469 (0.563)	0.490 (0.521)
95% R^2 CI Width	0.45	0.48	0.51
Spearman	0.722 (0.797)	0.611 (0.788)	0.602 (0.745)

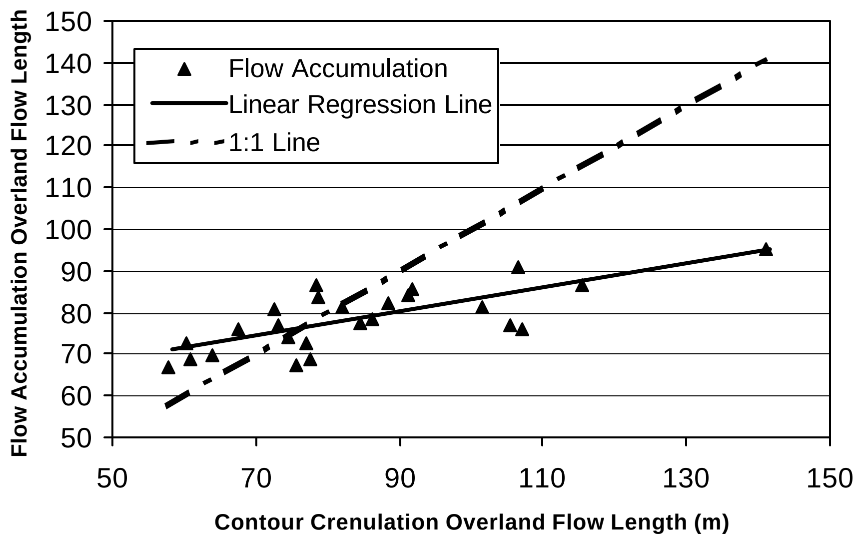

Figure 6.4: Plot of Contour Crenulation network versus Flow Accumulation network values for 25 headwater sub-watersheds with a minimum size of 20 ha from the Briery Branch, Craigville, Louisa, and Surry quads in Virginia. ANIM networks were generated using a regionally calibrated threshold value.

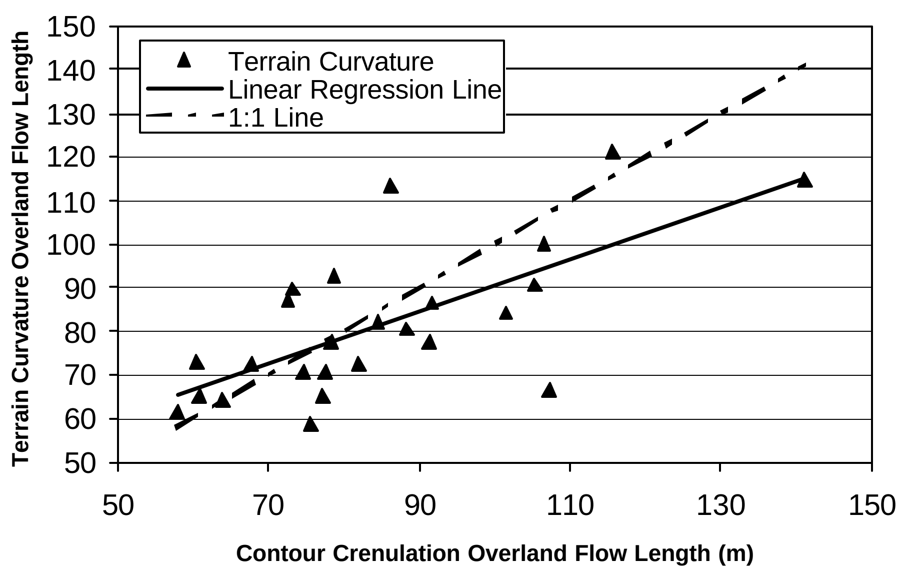

Figure 6.5: Plot of Contour Crenulation network versus Terrain Curvature network values for 25 headwater sub-watersheds with a minimum size of 20 ha from the Briery Branch, Craigville, Louisa, and Surry quads in Virginia. ANIM networks were generated using a regionally calibrated threshold value.

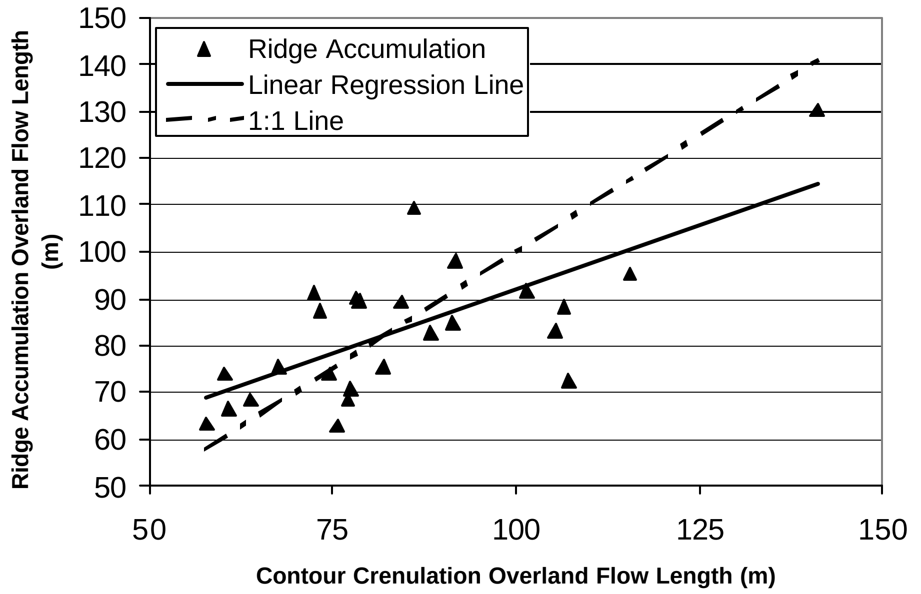

Figure 6.6: Plot of Contour Crenulation network versus Ridge Accumulation network values for 25 headwater sub-watersheds with a minimum size of 20 ha from the Briery Branch, Craigville, Louisa, and Surry quads in Virginia. ANIM networks were generated using a regionally calibrated threshold value.

The results of this analysis show that using a single regionally calibrated threshold value with the flow accumulation, terrain curvature, and ridge accumulation methods will produce less variation in overland flow than a locally calibrated threshold. This decrease in variation resulted in overall performance decreases in virtually all measures used herein. The ridge accumulation method seemed to be least impacted in this regard by the use of a regionally calibrated threshold value, while the flow accumulation method experienced the greatest decrease in standard deviation. Once again, the spread of points, and lack of representative ranges for all methods at 10 ha unit size, casts doubt on their usefulness for either prediction or ranking. Similarly, the results at 20 ha unit sizes were more promising. The flow accumulation method experienced the smallest decrease in Spearman ranking, from 0.797 (locally calibrated R_s) to 0.722 (regionally calibrated R_s), giving it the highest overall Spearman ranking at an analysis unit size of 20 ha. While no method displayed a strong linear relationship with the contour crenulation method, as predicted by the R^2 value, and the difference between the R^2 for the different methods was not statistically significant, the ridge accumulation and terrain curvature method still managed to produce reasonable ranges and standard deviations at the 20 ha analysis unit size (-14% to -22% errors), suggesting that they might be suitable for providing slope length predictions with a single threshold value. In order to confirm the usefulness of the terrain curvature and ridge accumulation methods, however, more investigation is needed into determining the sources of error that were shown to affect these methods in this investigation. While the flow accumulation method did not prove itself capable of producing realistic estimates of overland flow length in this analysis, it succeeded in representing overall trends, and managed to show the most promise for use as a tool to perform ranking by slope length.

Table 6.6: Predictions of overland flow length (in meters) by contour crenulation, flow accumulation, terrain curvature and ridge accumulation methods in 53 headwater sub-watersheds, with a minimum analysis unit size of 10 ha. ANIM networks were generated with a single threshold value.

			Contour Crenulation		Flow Accumulation			Terrain Curvature			Ridge Accumulation		
Watershed	Sub ID	Area (m^2)	Stream Length (m)	Flow Length (m)	Stream Length (m)	Flow Length (m)	% Error	Stream Length (m)	Flow Length (m)	% Error	Stream Length (m)	Flow Length (m)	% Error
Briery Branch 2	1	212700	1195.0	89.0	1557.2	68.3	-23%	1086.4	97.9	10%	1183.0	89.9	1%
Briery Branch 2	2	171900	1195.0	71.9	1074.3	80.0	11%	1062.3	80.9	13%	1026.0	83.8	16%
Briery Branch 2	3	311300	1557.2	100.0	1702.0	91.5	-9%	1702.0	91.5	-9%	1629.6	95.5	-4%
Briery Branch 2	5	233700	1279.5	91.3	1388.2	84.2	-8%	1508.9	77.4	-15%	1376.1	84.9	-7%
Briery Branch 2	6	174000	1195.0	72.8	1255.4	69.3	-5%	1315.7	66.1	-9%	1303.7	66.7	-8%
Briery Branch 2	7	531500	2619.4	101.5	3271.3	81.2	-20%	3150.5	84.4	-17%	2897.1	91.7	-10%
Briery Branch 2	10	399500	1774.4	112.6	2486.6	80.3	-29%	2776.3	71.9	-36%	2486.6	80.3	-29%
Briery Branch 2	11	407300	2221.1	91.7	2378.0	85.6	-7%	2353.9	86.5	-6%	2076.2	98.1	7%
Briery Branch 2	13	151700	108.6	698.2	627.7	120.8	-83%	325.9	232.7	-67%	494.9	153.3	-78%
Briery Branch 2	14	100800	410.4	122.8	482.8	104.4	-15%	422.5	119.3	-3%	386.3	130.5	6%
Briery Branch 2	15	132400	772.5	85.7	808.8	81.9	-4%	784.6	84.4	-2%	663.9	99.7	16%
Briery Branch 2	19	131700	494.9	133.1	917.4	71.8	-46%	1158.8	56.8	-57%	1146.8	57.4	-57%
Briery Branch 2	22	168300	1026.0	82.0	1207.1	69.7	-15%	1219.2	69.0	-16%	1195.0	70.4	-14%
Briery Branch 2	25	182100	1110.5	82.0	1146.8	79.4	-3%	1122.6	81.1	-1%	1050.2	86.7	6%
Briery Branch 2	28	122700	857.0	71.6	881.2	69.6	-3%	1014.0	60.5	-15%	977.8	62.7	-12%
Briery Branch 2	29	597200	3464.4	86.2	3814.5	78.3	-9%	2631.5	113.5	32%	2728.1	109.5	27%
Briery Branch 2	30	114400	953.6	60.0	832.9	68.7	14%	941.5	60.8	1%	893.3	64.0	7%
Briery Branch 2	31	223700	1364.0	82.0	1376.1	81.3	-1%	1545.1	72.4	-12%	1484.7	75.3	-8%
Briery Branch 2	35	438800	2800.5	78.3	2909.1	75.4	-4%	3078.1	71.3	-9%	3066.1	71.6	-9%
Briery Branch 2	37	151600	832.9	91.0	953.6	79.5	-13%	1086.4	69.8	-23%	1050.2	72.2	-21%
Briery Branch 2	38	133700	857.0	78.0	1050.2	63.7	-18%	1243.3	53.8	-31%	1146.8	58.3	-25%
Briery Branch 2	39	730900	5721.7	63.9	5226.8	69.9	9%	5685.5	64.3	1%	5335.4	68.5	7%
Briery Branch 2	43	253800	1677.9	75.6	1883.1	67.4	-11%	2160.7	58.7	-22%	2015.9	63.0	-17%
Craigville 3	1	166900	1653.7	50.5	1267.5	65.8	30%	1279.5	65.2	29%	1255.4	66.5	32%
Craigville 3	2	512900	4430.1	57.9	3850.7	66.6	15%	4164.5	61.6	6%	4055.9	63.2	9%
Craigville 3	3	139600	917.4	76.1	808.8	86.3	13%	748.4	93.3	23%	784.6	89.0	17%

Craigville 3	5	473700	3500.6	67.7	3114.3	76.1	12%	3271.3	72.4	7%	3138.5	75.5	12%
Craigville 3	6	102400	881.2	58.1	724.3	70.7	22%	772.5	66.3	14%	760.5	67.3	16%
Craigville 3	7	126500	1086.4	58.2	941.5	67.2	15%	953.6	66.3	14%	953.6	66.3	14%
Craigville 3	10	312700	1412.3	110.7	2293.5	68.2	-38%	1533.0	102.0	-8%	2064.2	75.7	-32%
Craigville 3	11	180800	796.7	113.5	977.8	92.5	-19%	953.6	94.8	-16%	929.5	97.3	-14%
Craigville 3	13	148400	591.5	125.4	857.0	86.6	-31%	881.2	84.2	-33%	772.5	96.0	-23%
Craigville 3	17	121000	724.3	83.5	1195.0	50.6	-39%	531.1	113.9	36%	688.1	87.9	5%
Craigville 3	19	150200	893.3	84.1	869.1	86.4	3%	857.0	87.6	4%	905.3	83.0	-1%
Craigville 3	22	301400	1303.7	115.6	1738.2	86.7	-25%	1243.3	121.2	5%	1581.3	95.3	-18%
Craigville 3	24	192900	953.6	101.1	1183.0	81.5	-19%	893.3	108.0	7%	869.1	111.0	10%
Craigville 4	1	440900	2800.5	78.7	2631.5	83.8	6%	2378.0	92.7	18%	2462.5	89.5	14%
Craigville 4	2	120100	869.1	69.1	748.4	80.2	16%	700.1	85.8	24%	700.1	85.8	24%
Craigville 4	3	165200	869.1	95.0	1086.4	76.0	-20%	905.3	91.2	-4%	1014.0	81.5	-14%
Craigville 4	5	194500	1267.5	76.7	1158.8	83.9	9%	1050.2	92.6	21%	977.8	99.5	30%
Craigville 4	8	126400	700.1	90.3	603.6	104.7	16%	434.6	145.4	61%	519.1	121.8	35%
Craigville 4	9	100200	615.6	81.4	676.0	74.1	-9%	531.1	94.3	16%	531.1	94.3	16%
Craigville 4	11	102600	857.0	59.9	736.3	69.7	16%	603.6	85.0	42%	651.8	78.7	31%
Louisa 5	1	190300	1267.5	75.1	1557.2	61.1	-19%	1448.5	65.7	-13%	1521.0	62.6	-17%
Louisa 5	2	153500	1038.1	73.9	929.5	82.6	12%	1134.7	67.6	-9%	893.3	85.9	16%
Louisa 5	4	274200	1750.3	78.3	1581.3	86.7	11%	1762.4	77.8	-1%	1521.0	90.1	15%
Louisa 5	5	272600	1279.5	106.5	1496.8	91.1	-15%	1364.0	99.9	-6%	1545.1	88.2	-17%
Louisa 5	8	168000	832.9	100.9	869.1	96.6	-4%	845.0	99.4	-1%	772.5	108.7	8%
Louisa 5	9	105000	905.3	58.0	760.5	69.0	19%	555.3	94.5	63%	748.4	70.1	21%
Louisa 5	12	105400	603.6	87.3	531.1	99.2	14%	651.8	80.8	-7%	724.3	72.8	-17%
Surry 3	1	127500	1339.9	47.6	1014.0	62.9	32%	1231.2	51.8	9%	1231.2	51.8	9%
Surry 3	4	218400	2003.8	54.5	1617.5	67.5	24%	2003.8	54.5	0%	2100.4	52.0	-5%
Surry 3	5	125600	965.7	65.0	700.1	89.7	38%	1001.9	62.7	-4%	905.3	69.4	7%

Table 6.7: Predictions of overland flow length by contour crenulation, flow accumulation, terrain curvature and ridge accumulation methods in 25 headwater sub-watersheds, with a minimum analysis unit size of 20 ha. ANIM networks were generated with a single threshold value.

		Contour Crenulation			Flow Accumulation			Terrain Curvature			Ridge Accumulation		
Watershed	Sub ID	Area (m2)	Stream Length (m)	Flow Length (m)	Stream Length (m)	Flow Length (m)	% Error	Stream Length (m)	Flow Length (m)	% Error	Stream Length (m)	Flow Length (m)	% Error
Briery Branch 2	1	756700	4478.4	84.5	4876.7	77.6	-8%	4599.1	82.3	-3%	4236.9	89.3	6%
Briery Branch 2	2	503400	2848.8	88.4	3066.1	82.1	-7%	3126.4	80.5	-9%	3041.9	82.7	-6%
Briery Branch 2	3	531500	2619.4	101.5	3271.3	81.2	-20%	3150.5	84.4	-17%	2897.1	91.7	-10%
Briery Branch 2	4	233700	1279.5	91.3	1388.2	84.2	-8%	1508.9	77.4	-15%	1376.1	84.9	-7%
Briery Branch 2	6	407300	2221.1	91.7	2378.0	85.6	-7%	2353.9	86.5	-6%	2076.2	98.1	7%
Briery Branch 2	7	603100	2812.6	107.2	3959.3	76.2	-29%	4538.7	66.4	-38%	4164.5	72.4	-32%
Briery Branch 2	9	1314900	4659.4	141.1	6892.6	95.4	-32%	5721.7	114.9	-19%	5045.7	130.3	-8%
Briery Branch 2	15	597200	3464.4	86.2	3814.5	78.3	-9%	2631.5	113.5	32%	2728.1	109.5	27%
Briery Branch 2	16	223700	1364.0	82.0	1376.1	81.3	-1%	1545.1	72.4	-12%	1484.7	75.3	-8%
Briery Branch 2	18	444700	2981.6	74.6	3005.7	74.0	-1%	3138.5	70.8	-5%	3005.7	74.0	-1%
Briery Branch 2	19	607200	3935.2	77.2	4176.6	72.7	-6%	4659.4	65.2	-16%	4430.1	68.5	-11%
Briery Branch 2	21	730900	5721.7	63.9	5226.8	69.9	9%	5685.5	64.3	1%	5335.4	68.5	7%
Briery Branch 2	23	253800	1677.9	75.6	1883.1	67.4	-11%	2160.7	58.7	-22%	2015.9	63.0	-17%
Craigville 3	1	512900	4430.1	57.9	3850.7	66.6	15%	4164.5	61.6	6%	4055.9	63.2	9%
Craigville 3	2	466600	3862.7	60.4	3223.0	72.4	20%	3198.8	72.9	21%	3150.5	74.1	23%
Craigville 3	3	505500	4152.4	60.9	3681.7	68.7	13%	3874.8	65.2	7%	3790.3	66.7	10%
Craigville 3	5	473700	3500.6	67.7	3114.3	76.1	12%	3271.3	72.4	7%	3138.5	75.5	12%
Craigville 3	6	1001700	4756.0	105.3	6506.3	77.0	-27%	5516.5	90.8	-14%	6023.5	83.1	-21%
Craigville 3	11	301400	1303.7	115.6	1738.2	86.7	-25%	1243.3	121.2	5%	1581.3	95.3	-18%
Craigville 4	1	440900	2800.5	78.7	2631.5	83.8	6%	2378.0	92.7	18%	2462.5	89.5	14%
Craigville 4	2	324000	2233.1	72.5	2003.8	80.8	11%	1858.9	87.1	20%	1774.4	91.3	26%
Craigville 4	3	362500	2474.6	73.2	2353.9	77.0	5%	2015.9	89.9	23%	2076.2	87.3	19%
Louisa 5	1	409700	2643.6	77.5	2969.5	69.0	-11%	2897.1	70.7	-9%	2897.1	70.7	-9%
Louisa 5	2	274200	1750.3	78.3	1581.3	86.7	11%	1762.4	77.8	-1%	1521.0	90.1	15%
Louisa 5	3	272600	1279.5	106.5	1496.8	91.1	-15%	1364.0	99.9	-6%	1545.1	88.2	-17%

7. Sensitivity of Predicted Overland flow length to Threshold and Stream Frequency in Actual DEMs

While the results of the analysis in sections 5 and 6 suggest that the networks generated by the flow accumulation, terrain curvature and ridge accumulation methods do not share a strong linear relationship with contour crenulation networks delineated in this study, the results of Spearman ranking are more encouraging. These analyses yielded Spearman rank correlations as high as 0.722 for the flow accumulation method at an analysis unit size of 20 ha, with a regionally calibrated threshold value, and 0.797 with a locally calibrated threshold value. This suggests that while these methods may show promise for use as a ranking tool, the calibration of the threshold value does have a measurable impact on performance. This section attempts to quantify the sensitivity to threshold value variation exhibited by the flow accumulation, terrain curvature and ridge accumulation methods in overland flow length rankings. That is, if the T value were to be changed by a small percentage, would this result in a significant change in rank? Since the results presented in the section 3 suggest that $\Delta L / \Delta T$ (change in overland flow distance as a function of change in threshold value) for ANIM generated networks may vary based on sub-watershed morphology, and that a relationship exists between stream frequency (F) and $\Delta L / \Delta T$, this section will also explore the use of stream frequency as a predictor of rank change.

This analysis used the Craigville Virginia digital orthoquad; a 10 m DEM that contains a variety of terrain forms, spanning 5 eco-regions. This quad was divided into sub-watersheds according to the methods outlined in section 2.5, using a minimum sub-watershed area of 20 ha, resulting in 138 sub-watersheds. In order to evaluate the potential for rank change given a varying threshold, four threshold values were chosen for each method, corresponding to networks whose average overland flow length were 75, 100, 125, and 150 meters. The sub-watersheds were then ranked according to the predicted overland flow length at each given threshold value, and a percent change in rank (number of ranks changed divided by the total number of samples) between thresholds was calculated. The average percent change in rank was then used to compare the performance of the various methods. Additionally, a sensitivity to stream frequency was computed for each method, by computing an R^2 value for F as a predictor of $\Delta L / \Delta T$.

Variation in $\Delta L / \Delta T$ between different sub-watersheds will be referred to as "rank change" as it may lead to inconsistency in relative ranking between different sub-watersheds as varying T are employed. Given a real world variation, it would be ideal to have a method for predicting $\Delta L / \Delta T$; therefore, the viability of stream frequency as a predictor will be explored. Since the value of F that is calculated from a DEM is dependent upon the T at which it is calculated, three values of F were considered as the predictor for $\Delta L / \Delta T$ over a range of two threshold values, the average value over the range (F_{avg}), F at T_{max} (F_{max}) and F at T_{min} (F_{min}). F_{min} gave slightly better performance than the others; therefore, in each of the analyses that follow, F_{min} has been used as the predictor of rank change. In order to evaluate the strength of the relationship between F and $\Delta L / \Delta T$, F was used as the independent variable and $\Delta L / \Delta T$ as the dependent variable in a least squares regression.

7.1 Results of Sensitivity Analysis

Table 7.1 shows the average percentage of rank change between adjacent flow length values, and the overall percentage rank change between thresholds which produced an average L = 75 m, and an average L = 150 m, for the flow accumulation, ridge accumulation and terrain curvature methods. These figures demonstrate a significant incidence of rank change for all 3 methods, however, the terrain curvature method shows consistently lower incidence of rank change (16.05%) with the ridge accumulation method second (16.73%), and the flow accumulation method showing the largest average rank change (25.18%) when the average overland flow length changes from 75 m to 150 m. Perhaps more illuminating is the percentage of rank change with smaller changes in overland flow length. The Ridge and Curvature methods perform similarly when the average overland flow length goes from 75 to 100 m, with an average rank change of just greater than 9%, however the flow accumulation method performs considerably worse, with a variation of nearly 15%. The results are similar when overland flow length goes from 100 to 125 m and from 125 to 150 m, although the terrain curvature method distinguishes itself at 125 to 150 m with a low figure of 5.81%, beating the ridge accumulation with an average rank change of 6.06%. In each case, the flow accumulation method displays an incidence of rank change that exceeds the rank change of the other two methods by nearly 50%.

Table 7.1: Average percent rank change with small changes in threshold value, for the terrain curvature, ridge accumulation and flow accumulation network identification methods. Threshold values are chosen to produce average overland flow lengths of 75, 100, 125 and 150 m.

Method	Threshold Values	Rank Change from L = 75m - 100m	Rank Change from L = 100-125	Rank Change from L = 125-150	Rank Change from L = 75-150
Curvature	4, 9, 18, 29	9.95%	7.70%	5.81%	16.05%
Ridge	14, 29, 51, 77	9.18%	7.81%	6.06%	16.73%
Flow Accumulation	81, 178, 320, 498	14.73%	10.73%	10.28%	25.18%

Table 7.2 shows the results of a regression analysis of ΔL as a function of F, using F evaluated at an average overland flow length of 75 m as a predictor of ΔL between 75m and 150 m. The flow accumulation method shows the strongest relationship, followed by the ridge accumulation method, then the terrain curvature method. However, all three methods show a significant relationship between ΔL and F, as can be seen in the graphs of F vs. ΔL in Figures 7.1 through 7.3.

Table 7.2: Results of a regression analysis with stream frequency (F) as a predictor of ΔL for 218 sub-watersheds in the Craigville quad.

	Terrain Curvature	Ridge Accumulation	Flow accumulation
R^2	0.171	0.352	0.505
# Observations	218	218	218
P-value	< 0.01	< 0.01	< 0.01

All three methods display a capacity for rank change, and a significant relationship between rank change and stream frequency. While the flow accumulation method shows a larger magnitude of rank change and greater sensitivity to stream frequency than the other two methods when overland flow length is doubled, from 75 m to 150 m, in narrow ranges (changes of 25 m), all methods have relatively low incidence of rank change. These narrower ranges correspond to a fairly large threshold value change for each method, indicating that small changes in threshold value may result in negligible incidence of rank change.

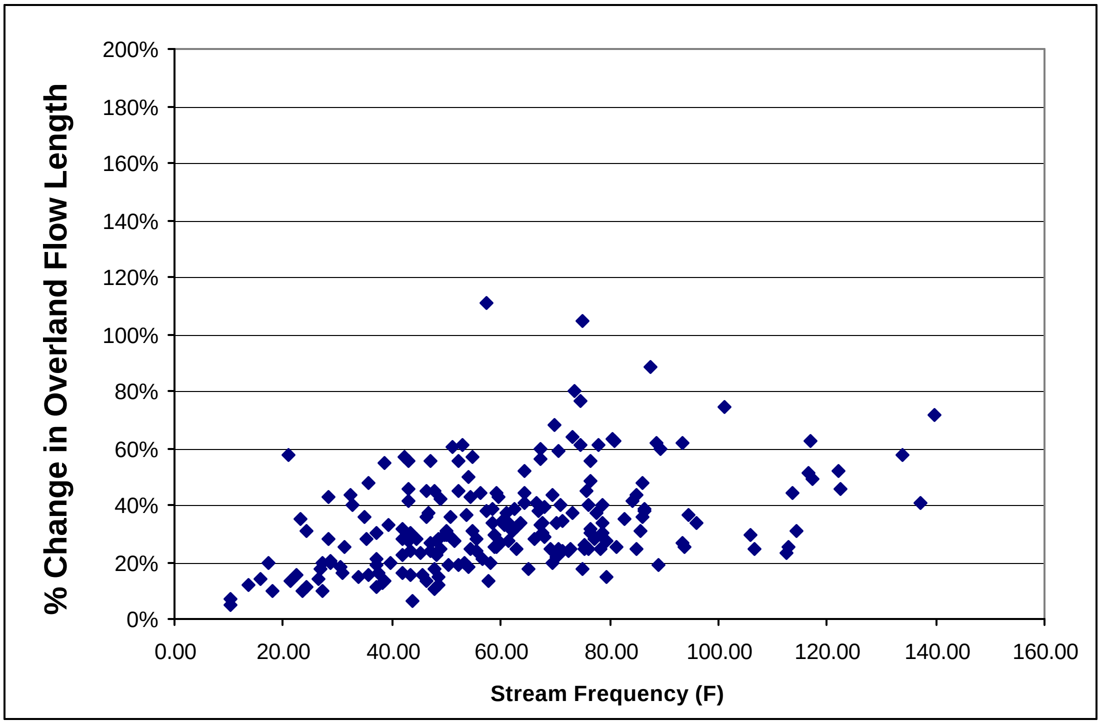

Figure 7.1: Change in overland flow length (?L) vs. stream frequency (F) for 218 sub-watersheds with area >= 20 ha, from an average overland flow length of 75 m to 150 m, for the terrain curvature method.

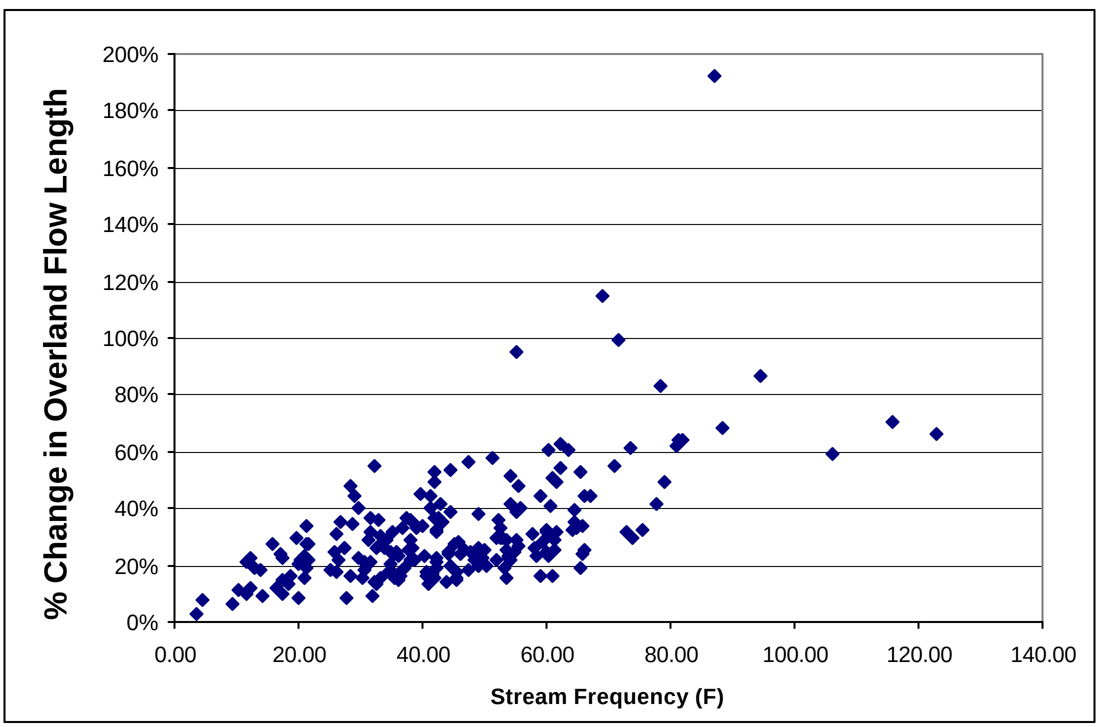

Figure 7.2: Change in overland flow length (?L) vs. stream frequency (F) for 218 sub-watersheds with area >= 20 ha, from an average overland flow length of 75 m to 150 m, for the ridge accumulation method.

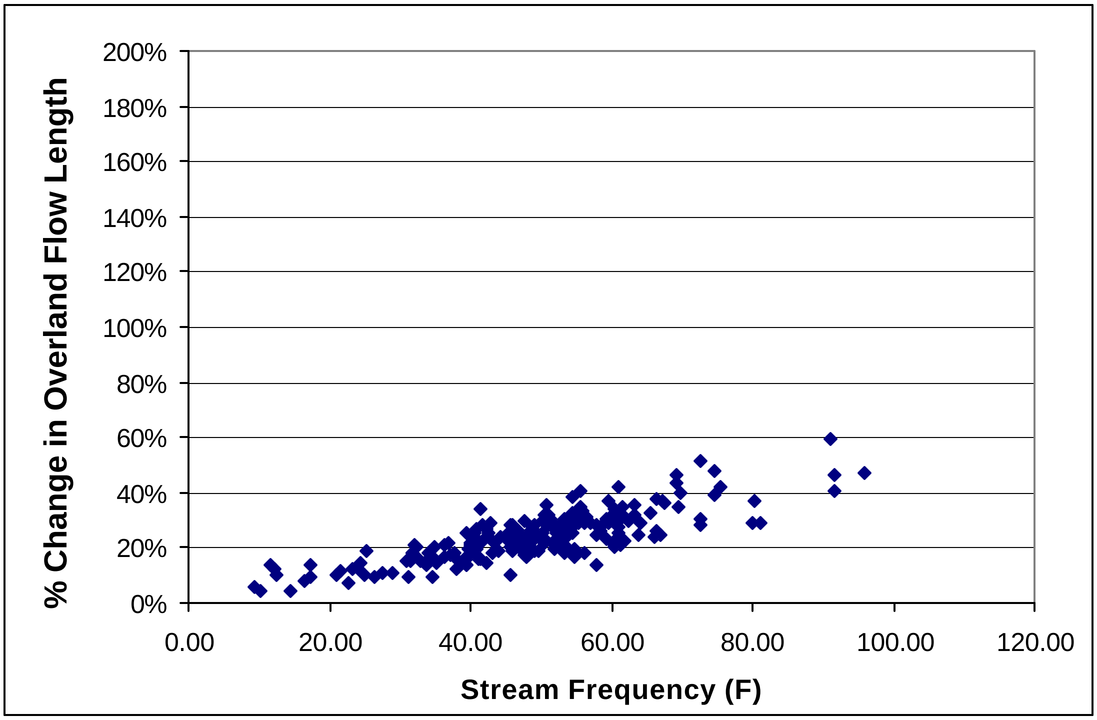

Figure 7.3: Percent change in overland flow length (?L) vs. stream frequency (F) for 218 sub-watersheds with area >= 20 ha, from an average overland flow length of 75 m to 150 m, for the flow accumulation method.

Conclusions

This study attempted to assess the feasibility of using accumulation-based network identification methods (ANIM) to derive flow length parameters for use in NPS pollution models by evaluating their ability to: produce channel networks with non-homogeneous overland flow lengths, match the distribution of overland flow lengths as suggested by the contour crenulations using regionally and locally calibrated threshold values, and to produce consistent ranking of different sub-watersheds given small variations in threshold value.

The underlying mechanism used by all ANIM, the interpretation of the convergent and divergent landforms present in the DEM, was shown to provide for the possibility of variation in overland flow length. The three ANIM in this study were shown to produce non-homogeneous overland flow lengths when applied to the terrain forms present in 10m DEMs, using a single threshold value. The terrain curvature method produced the widest standard deviation (16.9 m at 20 ha unit size), followed by ridge accumulation (15.4 m at 20 ha unit size) and then flow accumulation (7.5 m at 20 ha unit size).

While it was shown that it is technically incorrect to say that the flow accumulation method exhibits spatial homogeneity, its spatial variability was shown to be quite limited. This range was so limited in fact, that at neither of the unit sizes studied, 10 ha, or 20 ha, did it produce ranges within 50% of those indicated by manual contour delineation, regardless of threshold calibration. That said, none of the methods studied was capable of producing comparable ranges at a 10 ha unit size, although both terrain curvature and ridge accumulation produced comparable ranges at 20 ha. This suggests that for these methods, the 20 ha unit size might be a minimum unit size to expect realistic predictions given the current input data sets. Interestingly enough, while the flow accumulation method's range of predicted overland flow lengths was far narrower than any of the other methods, it was consistently the most successful in terms of producing sub-watershed ranks that were comparable to those produced by manual contour delineation. The terrain curvature and ridge accumulation methods, while producing much wider ranges of overland flow lengths, and matching overall trends well at the 20 ha unit size, appeared to be subject to considerable error in a sub-watershed by sub-watershed comparison to contour crenulation networks. Calibration of threshold value was shown to increase the ability of each method to match contour networks in producing comparable overland flow length ranges, and in ranking ability.

The importance of calibration was shown to be in part a result of the manner in which the basic ANIM mechanism interacts with networks of different terrain morphology, as evidenced by stream frequency. Watersheds with higher stream frequencies were shown to experience greater sensitivity to variations in threshold value than were watersheds with a lower stream frequency. This sensitivity was shown to result in inconsistency in producing relative rankings of sub-watersheds as threshold values were varied. This suggests that F may be used as *one* criterion for determining the feasibility of using a single threshold value over a given watershed area. In general, these results suggest that a single threshold value may be appropriate in areas where there is a relatively homogeneous distribution of stream frequencies, but that in areas with a wider distribution of F, a more local calibration of threshold value may be required. The flow accumulation method was shown to have a larger magnitude of change than were the terrain curvature and ridge accumulation methods.

In summary, all methods studied were shown to display spatial diversity in overland flow lengths without threshold calibration, when producing hill-slope scale networks. These results agree with a previous study conducted at the hill slope scale (Gandolfi and Bischetti, 1997). The failure of other studies (Tarboton, 2001; Helmlinger et al, 1993) to show variation was shown to be most likely due to the scale of networks studied, the analysis unit size, and/or the use of only qualitative methods of evaluation. By outlining a quantitative procedure for analyzing spatial diversity, this study confirmed previous claims (Tarboton, 2001) that the terrain curvature method produces networks that are far more spatially diverse than the flow accumulation method. This study also introduced a new method, the ridge accumulation method, which was shown to produce a considerably wider range of overland flow lengths than flow accumulation. The ridge accumulation networks were slightly less diverse than the terrain curvature networks, but were shown to be less sensitive to calibration than were the terrain curvature networks given the input data sets used in this study. Both terrain curvature and ridge accumulation methods showed potential for producing realistic estimates of overland flow length with single threshold values, although more study will be required to assess sources of error, and to determine if other flow weighting schemes are needed in order to produce useful estimates.

Suggestions for future research

Future research into the sources of error encountered in this study would be necessary to validate the use of terrain curvature and ridge accumulation in providing estimates of overland flow length for inputs to non-point source models. The acquisition of high-resolution ground level survey data would be optimal, and ultimately, the only means of truly evaluating the results of this study. While the areas used in this study were chosen to provide a diverse set of land-forms and potential overland flow lengths, the study areas were still selected from a fairly narrow geographical area, and quite likely do not represent the myriad of terrain forms that exist. Thus, the definitive study would include ground level surveys of a much wider geographic area as well.

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Appendix A: Additional Figures and Tables

Figure A.1: (a) Contour crenulation network, (b) ridge (T = 19), (c) terrain curvature (T = 9) and (d) flow accumulation (T = 101) networks for locally calibrated threshold values for Craigville 4 watershed.

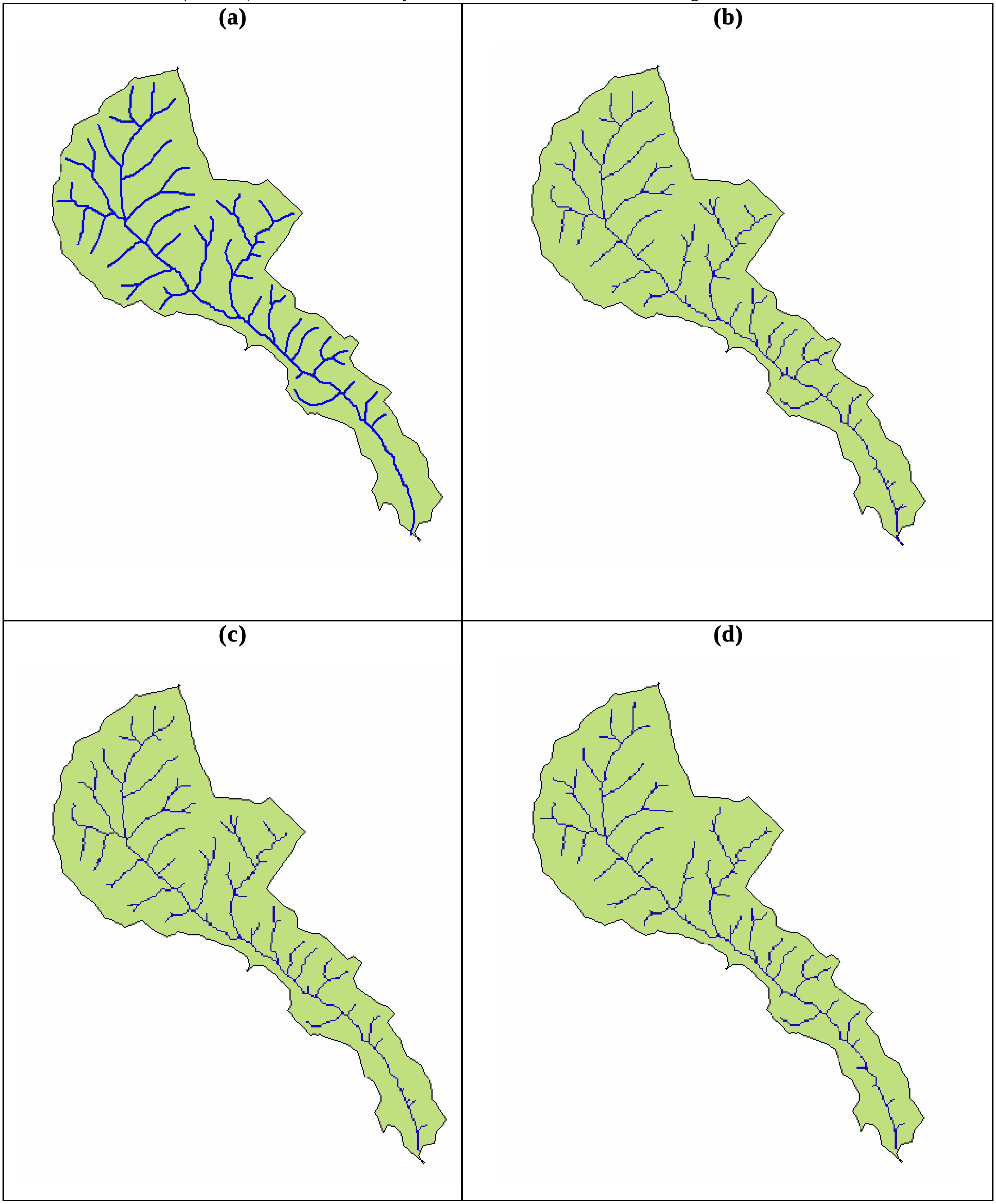

Figure A.2: (a) Contour crenulation network, (b) ridge (T = 19), (c) terrain curvature (T = 9) and (d) flow accumulation (T = 101) networks for locally calibrated threshold values for Briery Branch 2 watershed.

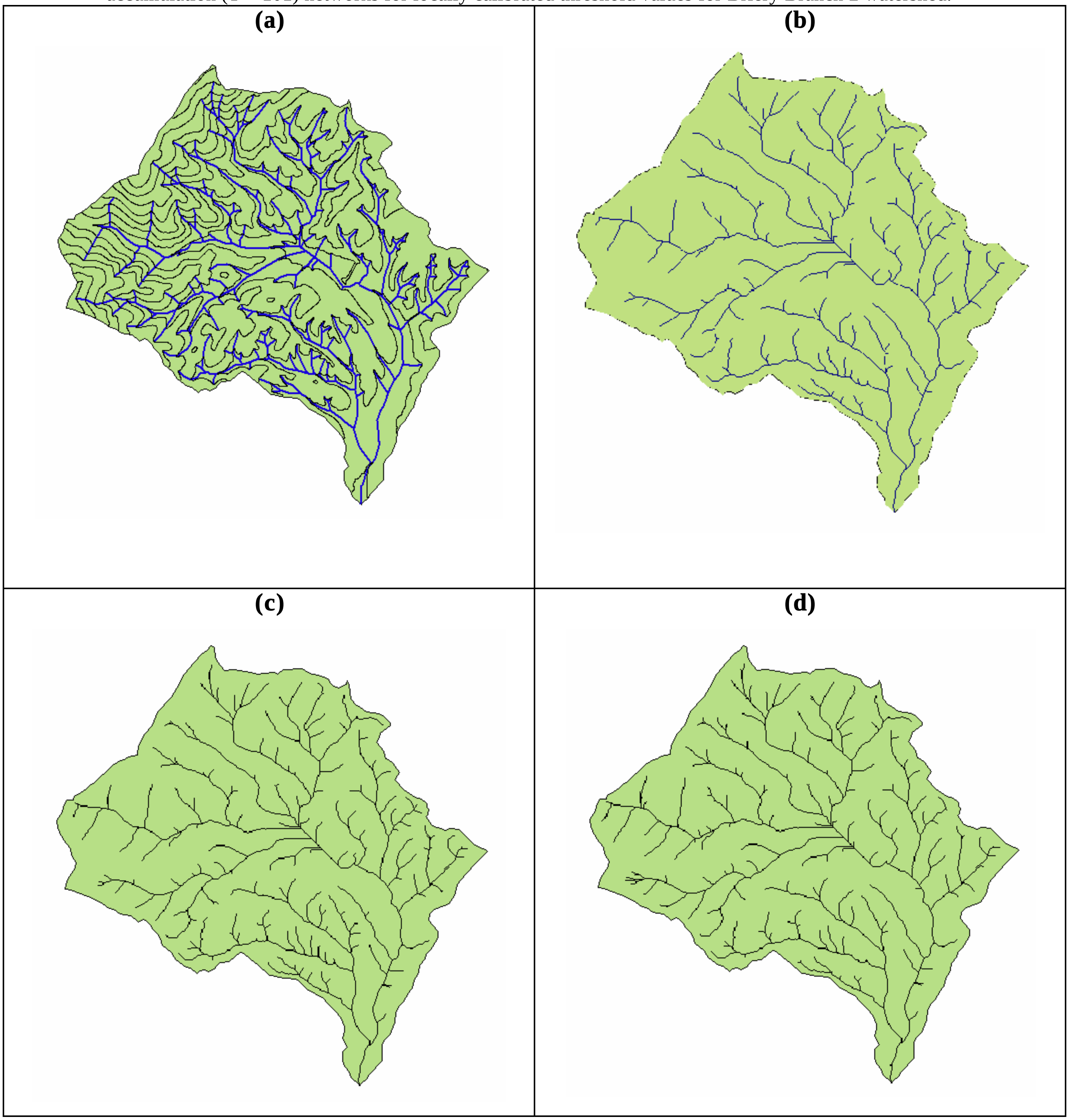

Figure A.3: (a) Contour Crenulation network, (b) ridge accumulation (T = 16), (c) terrain curvature (T = 5) and (d) flow accumulation (T = 81) networks for locally calibrated threshold values for Craigville 3 watershed.

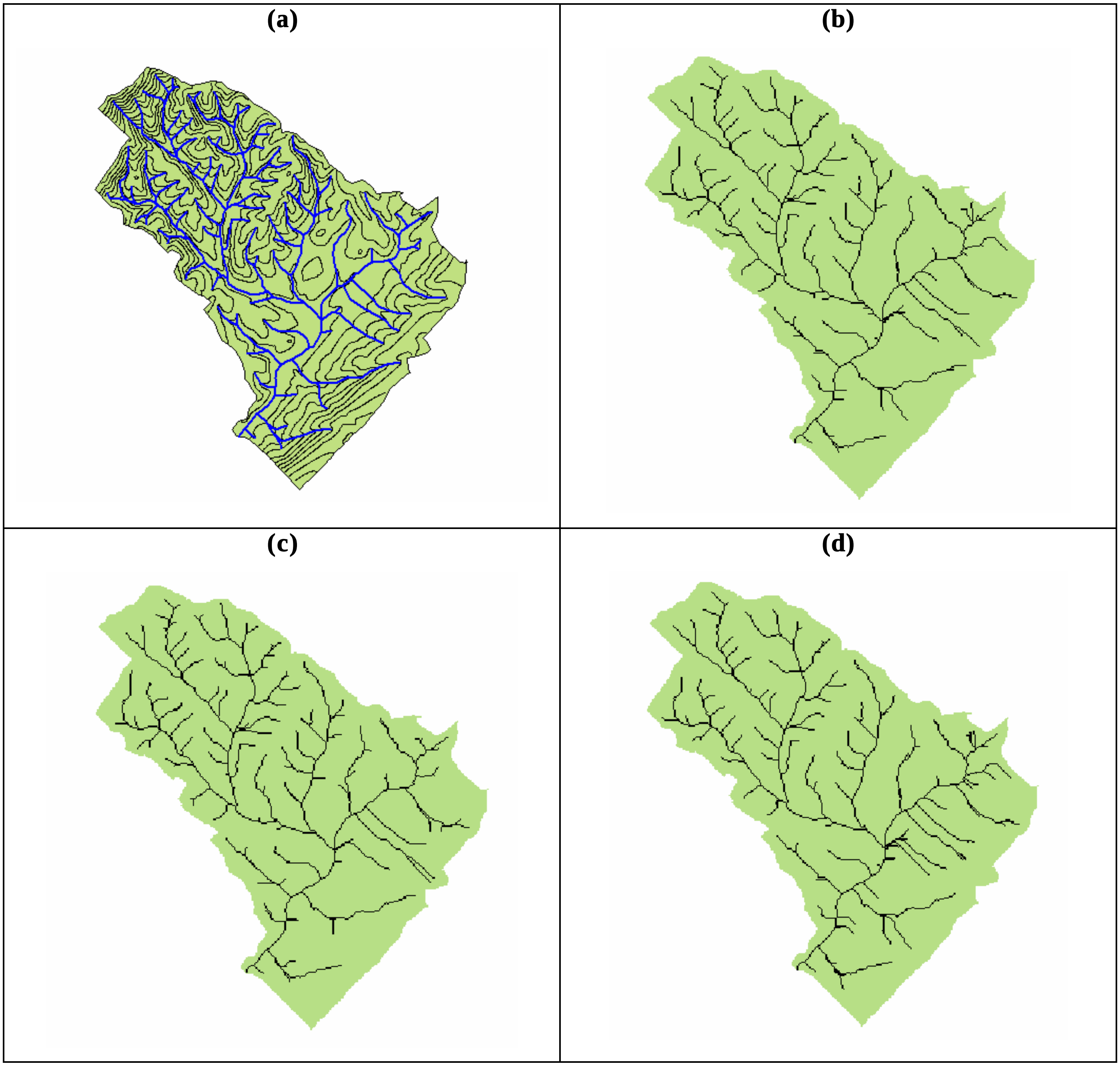

Figure A.4: (a) Contour Crenulation network, (b) ridge accumulation (T = 15), (c) terrain curvature (T = 6) and (d) flow accumulation (T = 39) networks for locally calibrated threshold values for Surry 3 watershed.

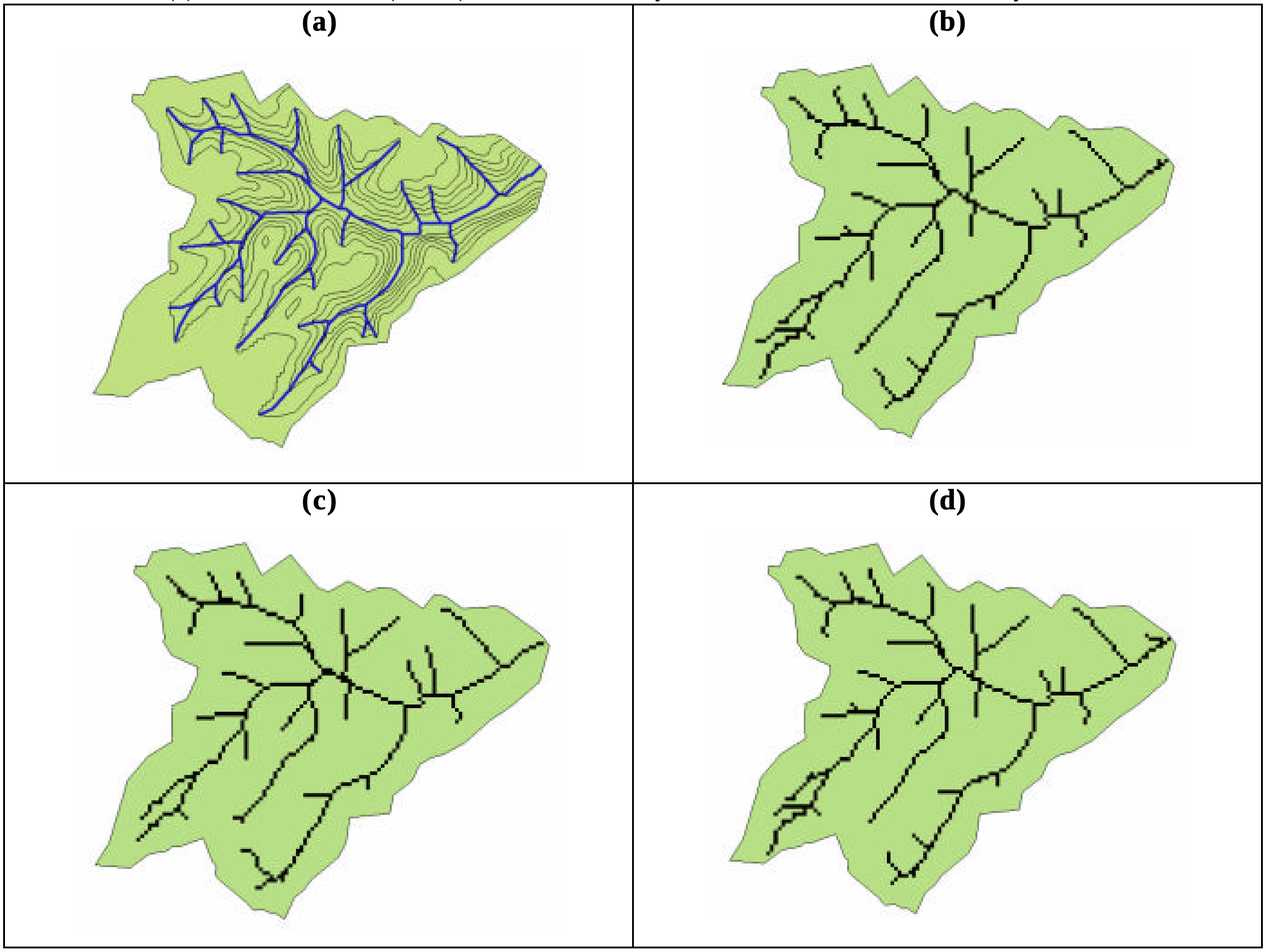

Figure A.5: (a) Contour Crenulation network, (b) ridge accumulation (T = 13), (c) terrain curvature (T = 6) and (d) flow accumulation (T = 80) networks for locally calibrated threshold values for Louisa 5 watershed.

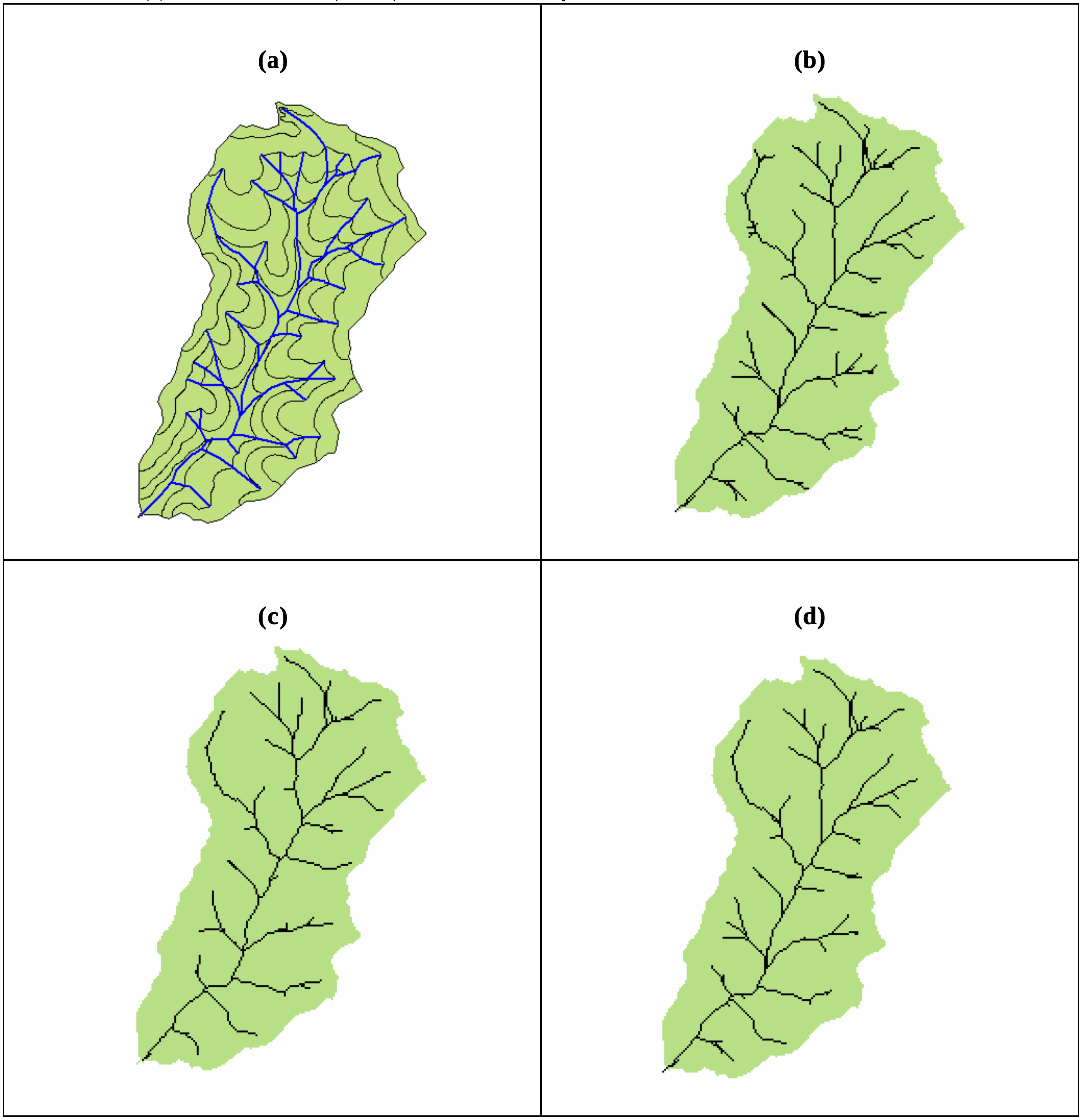

Table A.1: Results of rank change analysis for ridge accumulation method on 218 sub-watersheds of a minimum unit size of 20 ha in the Craigville quad.

															Avg. Flow Length = 150m			Avg. Flow Length = 125m			Avg. Flow Length = 100m			Avg. Flow Length = 75m			
Wshed ID	dR(150-125)	Rank @T =125	dR(125-100)	Rank @T =100	DR (100-75)	Rank @T =75	DR (75-125)	DR (75-150)	# streams @ L = 75m	F @ L = 75	dD (75 - 125)	dD (75 - 100)	dD (75 - 150)	total area (cells	stream cells	DD	Flow Len	stream cells	DD	Flow Len	stream cells	DD	Flow Len	stream cells	DD	Flow Len	% change
15	12	133	27	160	4	156	23	35	37	44.3	2.98	1.48	3.89	8345	243	3.64	137	304	4.55	110	404	6.05	82.6	503	7.53	66.4	0.25
18	5	194	50	144	57	87	107	112	3	9.28	0.58	0.35	0.89	3232	133	5.14	97.2	141	5.45	91.7	147	5.69	87.9	156	6.03	82.9	0.06
22	4	190	2	192	32	160	30	34	9	32.5	2.21	0.9	2.75	2771	107	4.83	104	119	5.37	93.1	148	6.68	74.9	168	7.58	66	0.14
24	4	8	5	3	1	2	6	10	9	20.1	0.98	0.56	1.26	4475	72	2.01	249	82	2.29	218	97	2.71	185	117	3.27	153	0.21
30	6	59	7	66	19	85	26	20	28	41.3	2.6	1.71	3.17	6782	154	2.84	176	185	3.41	147	233	4.29	116	326	6.01	83.2	0.4
36	0	29	7	22	16	6	23	23	3	10.4	0.95	0.39	1.51	2895	54	2.33	214	67	2.89	173	80	3.45	145	89	3.84	130	0.11
37	44	43	16	59	42	101	58	14	17	61.5	3.12	2.08	3.12	2765	70	3.16	158	70	3.16	158	93	4.2	119	139	6.28	79.6	0.49
41	17	27	18	45	1	44	17	34	21	35	2.46	1.27	3.29	5995	95	1.98	252	135	2.81	178	192	4	125	253	5.28	94.8	0.32
43	2	208	0	208	4	204	4	2	13	60.3	3.3	1.91	4.29	2156	100	5.8	86.2	117	6.78	73.7	141	8.17	61.2	174	10.1	49.6	0.23
44	17	68	24	44	13	31	37	20	7	29.8	1.38	0.91	2.24	2348	50	2.66	188	66	3.51	142	75	3.99	125	92	4.9	102	0.23
45	72	188	3	185	26	159	29	43	32	59.1	2.22	1.06	3.97	5411	156	3.6	139	232	5.36	93.3	282	6.51	76.8	328	7.58	66	0.16
46	1	4	3	7	1	8	4	3	7	26.8	1.82	1.05	2.15	2613	39	1.87	268	46	2.2	227	62	2.97	169	84	4.02	124	0.35
49	2	183	11	172	46	126	57	59	3	12.4	1.6	0.72	2.37	2424	88	4.54	110	103	5.31	94.1	120	6.19	80.8	134	6.91	72.4	0.12
50	8	159	18	141	20	121	38	46	7	26.3	1.93	1.22	2.54	2661	91	4.27	117	104	4.89	102	119	5.59	89.4	145	6.81	73.4	0.22
51	18	49	13	36	1	37	12	30	9	21.4	1.78	1.28	2.17	4213	97	2.88	174	110	3.26	153	127	3.77	133	170	5.04	99.1	0.34
52	1	10	15	25	7	18	8	9	7	32.9	2.06	0.94	2.53	2127	33	1.94	258	41	2.41	208	60	3.53	142	76	4.47	112	0.27
54	33	97	8	89	5	84	13	46	25	46.7	2.03	1.22	2.27	5348	160	3.74	134	170	3.97	126	205	4.79	104	257	6.01	83.2	0.25
55	9	86	4	82	13	69	17	8	15	46.2	1.96	1.12	2.77	3247	78	3	167	99	3.81	131	121	4.66	107	150	5.77	86.6	0.24
58	8	91	6	85	33	52	39	31	7	17.4	1.52	0.68	2.33	4032	99	3.07	163	125	3.88	129	152	4.71	106	174	5.39	92.7	0.14
59	18	21	5	26	22	48	27	45	15	42	2.62	1.75	3.57	3573	50	1.75	286	77	2.69	186	102	3.57	140	152	5.32	94	0.49
60	7	24	15	39	8	47	23	16	53	43.2	2.55	1.38	2.95	###	231	2.35	213	270	2.75	182	385	3.92	128	521	5.3	94.3	0.35
61	15	20	2	18	6	12	8	23	7	33.3	1.67	1.01	1.97	2099	40	2.38	210	45	2.68	187	56	3.33	150	73	4.35	115	0.3
63	12	106	28	78	5	73	33	45	13	21.8	1.65	1.26	2.18	5973	173	3.62	138	198	4.14	121	217	4.54	110	277	5.8	86.3	0.28
64	16	149	48	101	60	41	108	124	1	3.4	0.43	0.13	0.89	2941	100	4.25	118	111	4.72	106	118	5.02	99.7	121	5.14	97.2	0.03
65	23	31	2	29	18	11	20	3	3	12.9	1.45	0.7	2.41	2331	36	1.93	259	54	2.9	173	68	3.65	137	81	4.34	115	0.19

67	1	197	6	191	33	158	39	40	9	43.8	1.95	0.91	2.5	2053	83	5.05	98.9	92	5.6	89.3	109	6.64	75.3	124	7.55	66.2	0.14
68	5	83	3	86	0	86	3	2	63	45.2	2.23	1.3	2.79	###	360	3.23	155	422	3.78	132	526	4.72	106	671	6.02	83.1	0.28
71	28	12	38	50	1	51	39	11	7	31.7	2.89	1.3	2.89	2207	44	2.49	201	44	2.49	201	72	4.08	123	95	5.38	92.9	0.32
72	27	54	53	107	4	103	49	76	84	25.8	3.04	1.25	4.08	###	596	2.29	218	867	3.33	150	1333	5.12	97.6	1658	6.37	78.5	0.24
73	4	39	6	33	9	24	15	19	23	37.8	1.6	0.94	2.15	6092	124	2.54	197	151	3.1	161	183	3.75	133	229	4.7	106	0.25
74	3	206	2	204	4	200	6	3	11	53	2.95	2.17	3.91	2077	93	5.6	89.3	109	6.56	76.2	122	7.34	68.1	158	9.51	52.6	0.3
75	0	207	1	206	4	202	5	5	19	73	3.07	2.35	3.94	2604	122	5.86	85.4	140	6.72	74.4	155	7.44	67.2	204	9.79	51.1	0.32
77	13	57	18	75	14	61	4	17	8	32.7	2.3	1.18	3.12	2446	50	2.56	196	66	3.37	148	88	4.5	111	111	5.67	88.1	0.26
79	14	186	30	156	47	109	77	63	7	19.9	1.14	0.5	2.14	3511	122	4.34	115	150	5.34	93.6	168	5.98	83.6	182	6.48	77.2	0.08
80	130	180	27	207	2	209	29	159	26	123	7.39	5.02	9.99	2115	45	2.66	188	89	5.26	95.1	129	7.62	65.6	214	12.6	39.5	0.66
81	3	78	13	65	26	39	39	42	19	31.1	1.39	0.84	2.09	6110	148	3.03	165	182	3.72	134	209	4.28	117	250	5.11	97.8	0.2
86	4	121	21	100	38	62	59	63	7	18.2	1.33	0.68	2.02	3840	113	3.68	136	134	4.36	115	154	5.01	99.7	175	5.7	87.8	0.14
88	1	17	12	5	4	1	16	17	1	4.53	0.45	0.23	0.91	2208	38	2.15	232	46	2.6	192	50	2.83	177	54	3.06	164	0.08
91	17	82	29	53	17	36	46	63	7	17.4	1.27	0.93	1.62	4024	110	3.42	146	121	3.76	133	132	4.1	122	162	5.03	99.4	0.23
93	9	15	7	8	4	4	11	20	11	36.3	1.15	0.7	1.48	3034	54	2.22	225	62	2.55	196	73	3.01	166	90	3.71	135	0.23
95	30	140	17	123	49	74	66	96	5	17.5	1.18	0.52	1.48	2862	99	4.32	116	106	4.63	108	121	5.28	94.6	133	5.81	86.1	0.1
97	0	209	0	209	10	199	10	10	9	32.3	2.33	1.17	3.19	2785	138	6.19	80.7	157	7.05	71	183	8.21	60.9	209	9.38	53.3	0.14
103	5	157	11	146	28	118	39	44	24	41.5	1.88	0.97	2.57	5778	193	4.18	120	225	4.87	103	267	5.78	86.6	312	6.75	74.1	0.17
104	1	204	4	200	16	184	20	21	3	14	2.1	1.28	2.68	2143	97	5.66	88.4	107	6.24	80.1	121	7.06	70.8	143	8.34	59.9	0.18
105	0	110	8	118	23	95	15	15	7	21.3	2.01	0.99	2.66	3292	94	3.57	140	111	4.21	119	138	5.24	95.4	164	6.23	80.3	0.19
106	25	64	26	90	79	169	105	80	19	81	4.32	2.99	4.53	2345	61	3.25	154	65	3.46	144	90	4.8	104	146	7.78	64.2	0.62
107	24	79	4	83	19	102	23	1	11	42.7	2.62	1.7	2.91	2575	71	3.45	145	77	3.74	134	96	4.66	107	131	6.36	78.6	0.36
108	7	101	44	57	19	38	63	70	3	12.3	1.02	0.92	1.54	2441	69	3.53	142	79	4.05	124	81	4.15	121	99	5.07	98.6	0.22
109	15	109	38	71	22	49	60	75	3	11.8	1.18	0.93	1.66	2553	75	3.67	136	85	4.16	120	90	4.41	113	109	5.34	93.7	0.21
110	14	38	8	30	13	17	21	35	9	31.5	1.4	0.79	1.79	2859	61	2.67	187	70	3.06	163	84	3.67	136	102	4.46	112	0.21
111	25	47	7	54	9	63	16	9	24	44.7	2.47	1.6	2.74	5375	128	2.98	168	140	3.26	154	177	4.12	121	246	5.72	87.4	0.39
116	21	92	19	111	74	185	93	72	25	62.3	4.51	3.24	4.83	4015	115	3.58	140	125	3.89	128	166	5.17	96.7	270	8.41	59.5	0.63
119	3	52	12	40	5	45	7	10	9	28.8	2	1.36	2.6	3122	67	2.68	186	82	3.28	152	98	3.92	127	132	5.29	94.6	0.35
120	16	37	10	27	43	70	33	49	17	60.5	2.76	2.18	3.6	2811	49	2.18	229	68	3.02	165	81	3.6	139	130	5.78	86.5	0.6
121	32	116	32	84	27	57	59	91	8	30.6	1.24	0.86	1.53	2615	84	4.02	125	90	4.3	116	98	4.68	107	116	5.54	90.2	0.18
122	11	50	12	62	6	56	6	5	7	19.7	2.25	1.27	2.71	3557	80	2.81	178	93	3.27	153	121	4.25	118	157	5.52	90.6	0.3
123	3	205	16	189	25	164	41	44	11	26.3	1.34	1.13	1.79	4186	197	5.88	85	212	6.33	79	219	6.54	76.5	257	7.67	65.2	0.17

127	1	154	32	122	32	90	64	63	11	36.3	1.32	0.87	2.06	3028	99	4.09	122	117	4.83	104	128	5.28	94.6	149	6.15	81.3	0.16
129	1	181	9	190	4	186	5	4	15	61.3	3.17	1.89	3.94	2445	88	4.5	111	103	5.27	95	128	6.54	76.4	165	8.44	59.3	0.29
131	22	120	25	145	13	132	12	10	17	51.8	2.67	1.26	3.05	3279	104	3.96	126	114	4.35	115	151	5.76	86.9	184	7.01	71.3	0.22
132	17	45	4	41	7	34	11	28	5	15.9	1.74	1.07	2.18	3152	71	2.82	178	82	3.25	154	99	3.93	127	126	5	100	0.27
134	12	129	28	157	34	191	62	50	25	54.1	4.03	2.49	4.55	4619	146	3.95	127	165	4.47	112	222	6.01	83.2	314	8.5	58.8	0.41
135	3	42	38	80	2	78	36	39	26	34.1	2.79	1.33	3.51	7624	149	2.44	205	193	3.16	158	282	4.62	108	363	5.95	84	0.29
136	61	166	10	176	2	174	8	69	29	58.2	2.86	1.63	4.41	4985	139	3.49	143	201	5.04	99.2	250	6.27	79.8	315	7.9	63.3	0.26
137	17	40	6	34	6	40	0	17	15	37.6	2	1.38	2.41	3992	87	2.72	184	100	3.13	160	120	3.76	133	164	5.14	97.4	0.37
138	14	119	25	94	18	76	43	57	14	42.2	1.54	1.02	2.07	3319	101	3.8	131	115	4.33	115	129	4.86	103	156	5.88	85.1	0.21
140	3	192	44	148	13	135	57	60	8	38.2	1.61	1.25	2.15	2093	82	4.9	102	91	5.43	92	97	5.79	86.3	118	7.05	70.9	0.22
141	3	187	38	149	38	111	76	79	5	16.3	1.14	0.69	1.88	3061	113	4.61	108	131	5.35	93.5	142	5.8	86.2	159	6.49	77	0.12
142	2	172	1	173	29	144	28	30	44	47.5	2.23	1.15	2.98	9259	323	4.36	115	379	5.12	97.7	459	6.2	80.7	544	7.34	68.1	0.19
143	5	32	13	19	11	30	2	7	15	39.7	1.98	1.52	2.48	3783	73	2.41	207	88	2.91	172	102	3.37	148	148	4.89	102	0.45
145	26	163	21	142	0	142	21	47	55	59.4	2.23	1.58	2.6	9266	341	4.6	109	369	4.98	100	417	5.63	88.9	534	7.2	69.4	0.28
146	18	152	40	112	70	182	30	48	16	63.7	3.53	3.13	4.48	2513	77	3.83	131	96	4.78	105	104	5.17	96.7	167	8.31	60.2	0.61
147	7	23	6	17	3	14	9	2	23	42.4	1.64	1.06	2.26	5428	91	2.1	239	118	2.72	184	143	3.29	152	189	4.35	115	0.32
148	15	124	14	110	20	130	6	21	15	64.6	2.58	1.83	3.44	2323	66	3.55	141	82	4.41	113	96	5.17	96.8	130	7	71.5	0.35
149	52	143	50	193	0	193	50	102	21	57.7	4.12	2.09	5.46	3641	97	3.33	150	136	4.67	107	195	6.69	74.7	256	8.79	56.9	0.31
153	2	67	26	93	4	89	22	20	15	34	2.58	1.25	3.17	4413	103	2.92	171	124	3.51	142	171	4.84	103	215	6.09	82.1	0.26
154	6	131	26	105	8	97	34	40	9	21	1.78	1.17	2.34	4277	134	3.92	128	153	4.47	112	174	5.09	98.3	214	6.25	79.9	0.23
155	5	90	23	67	45	112	22	27	15	60.9	2.64	2.18	3.35	2463	62	3.15	159	76	3.86	130	85	4.31	116	128	6.5	77	0.51
156	14	150	31	119	25	94	56	70	9	25	1.5	0.97	2.02	3594	121	4.21	119	136	4.73	106	151	5.25	95.2	179	6.23	80.3	0.19
159	7	203	0	203	15	188	15	8	15	45.4	2.31	1.14	3.48	3302	131	4.96	101	162	6.13	81.5	193	7.31	68.4	223	8.44	59.2	0.16
160	6	174	0	174	24	150	24	30	29	49.1	2.31	1.23	3.03	5907	209	4.42	113	243	5.14	97.2	294	6.22	80.4	352	7.45	67.1	0.2
161	11	130	15	115	12	127	3	8	27	36.7	2.45	1.72	3.28	7361	214	3.63	138	263	4.47	112	306	5.2	96.2	407	6.91	72.3	0.33
162	11	118	16	134	41	175	57	46	25	66	3.6	2.44	4.19	3788	113	3.73	134	131	4.32	116	166	5.48	91.3	240	7.92	63.1	0.45
163	8	168	2	170	11	181	13	21	58	65.8	3.19	2.1	4.11	8821	293	4.15	120	358	5.07	98.6	435	6.16	81.1	583	8.26	60.5	0.34
164	15	41	10	31	23	54	13	2	15	28.3	2.29	1.77	2.76	5296	114	2.69	186	134	3.16	158	156	3.68	136	231	5.45	91.7	0.48
166	22	132	1	131	9	140	8	14	21	61.5	2.63	1.72	3.07	3416	112	4.1	122	124	4.54	110	149	5.45	91.7	196	7.17	69.7	0.32
167	3	66	2	64	28	92	26	29	29	59	2.67	1.91	3.36	4914	111	2.82	177	138	3.51	142	168	4.27	117	243	6.18	80.9	0.45
168	18	141	3	138	9	147	6	12	47	52.6	2.74	1.85	3.25	8927	296	4.14	121	332	4.65	108	396	5.54	90.2	528	7.39	67.6	0.33
169	27	74	3	77	11	88	14	41	13	40	2.42	1.54	3.5	3249	67	2.58	194	95	3.65	137	118	4.54	110	158	6.08	82.3	0.34

172	40	196	1	197	5	192	4	36	34	65.9	2.98	1.67	4.45	5163	170	4.12	121	231	5.59	89.4	285	6.9	72.5	354	8.57	58.3	0.24
173	4	98	52	150	4	146	48	44	26	55.3	3.35	1.57	3.94	4698	129	3.43	146	151	4.02	124	218	5.8	86.2	277	7.37	67.8	0.27
175	17	115	16	99	20	119	4	13	19	52.3	2.51	1.79	3	3631	110	3.79	132	124	4.27	117	145	4.99	100	197	6.78	73.7	0.36
176	91	195	4	199	12	187	8	83	7	34.8	2.92	1.43	4.97	2014	56	3.48	144	89	5.52	90.5	113	7.01	71.3	136	8.44	59.2	0.2
177	19	144	30	114	56	58	86	105	9	27.6	0.92	0.42	1.42	3258	109	4.18	120	122	4.68	107	135	5.18	96.5	146	5.6	89.3	0.08
178	45	162	40	202	1	201	39	84	17	75.6	4.62	2.34	5.95	2248	65	3.61	138	89	4.95	101	130	7.23	69.2	172	9.56	52.3	0.32
179	1	3	3	6	94	100	97	98	18	69	4.22	3.36	4.7	2608	33	1.58	316	43	2.06	243	61	2.92	171	131	6.28	79.6	1.15
183	50	146	42	188	8	180	34	84	31	61.1	3.53	1.68	4.83	5070	137	3.38	148	190	4.68	107	265	6.53	76.5	333	8.21	60.9	0.26
184	61	103	62	165	41	206	103	164	41	94.4	7.28	5.27	8.84	4342	88	2.53	197	142	4.09	122	212	6.1	81.9	395	11.4	44	0.86
186	11	135	18	153	8	145	10	1	23	48.6	2.8	1.48	3.38	4737	151	3.98	125	173	4.57	110	223	5.88	85	279	7.36	67.9	0.25
187	6	99	8	91	0	91	8	2	35	45.8	2.16	1.36	2.83	7650	205	3.35	149	246	4.02	124	295	4.82	104	378	6.18	81	0.28
188	7	142	14	128	5	133	9	2	43	52.5	2.36	1.6	3.16	8195	253	3.86	130	305	4.65	107	355	5.41	92.3	460	7.02	71.3	0.3
189	2	198	19	179	55	124	74	76	7	14.3	1.17	0.56	1.73	4905	203	5.17	96.7	225	5.73	87.2	249	6.35	78.8	271	6.91	72.4	0.09
191	10	76	5	81	10	71	5	5	46	34.8	2.08	1.15	2.93	###	301	2.85	176	391	3.7	135	489	4.63	108	611	5.78	86.5	0.25
192	3	104	8	96	27	123	19	16	56	55.9	2.79	1.98	3.36	###	283	3.53	142	328	4.09	122	393	4.9	102	552	6.89	72.6	0.4
193	17	62	20	42	37	79	17	0	11	54.1	2.52	2.03	2.95	2034	49	3.01	166	56	3.44	145	64	3.93	127	97	5.96	83.9	0.52
197	13	9	4	13	85	98	89	76	23	55.1	3.96	3.06	4.08	4171	73	2.19	229	77	2.31	217	107	3.21	156	209	6.26	79.8	0.95
199	7	184	37	147	30	117	67	74	7	21	1.35	0.9	1.99	3329	125	4.69	107	142	5.33	93.8	154	5.78	86.5	178	6.68	74.8	0.16
202	10	105	62	167	11	178	73	83	34	64.8	4.05	2.03	4.81	5245	141	3.36	149	173	4.12	121	258	6.15	81.3	343	8.17	61.2	0.33
203	21	147	4	143	33	176	29	50	34	77.7	3.32	2.34	4.29	4373	130	3.72	135	164	4.69	107	198	5.66	88.3	280	8	62.5	0.41
204	0	202	15	187	19	168	34	34	9	42.3	1.65	1.23	2.17	2127	95	5.58	89.6	104	6.11	81.8	111	6.52	76.6	132	7.76	64.5	0.19
205	1	179	3	182	30	152	27	26	14	35.1	2.25	1.06	3.07	3992	141	4.42	113	167	5.23	95.6	205	6.42	77.9	239	7.48	66.8	0.17
209	17	75	1	74	57	131	56	39	11	47.4	3.34	2.53	3.66	2321	62	3.34	150	68	3.66	137	83	4.47	112	130	7	71.4	0.57
210	14	125	5	120	15	105	20	34	16	38.7	2	1.15	2.48	4135	130	3.93	127	146	4.41	113	174	5.26	95.1	212	6.41	78	0.22
211	24	22	15	37	43	80	58	34	16	44.4	3.26	2.08	3.4	3604	74	2.57	195	78	2.71	185	112	3.88	129	172	5.97	83.8	0.54
213	13	88	15	73	26	99	11	24	18	60.6	2.44	1.81	3.28	2969	71	2.99	167	91	3.83	131	106	4.46	112	149	6.27	79.7	0.41
214	9	134	7	127	2	129	5	14	32	53.5	2.38	1.57	2.97	5983	190	3.97	126	218	4.55	110	257	5.37	93.1	332	6.94	72.1	0.29
215	14	100	32	68	42	26	74	88	7	31.9	0.68	0.4	1.14	2197	63	3.58	139	71	4.04	124	76	4.32	116	83	4.72	106	0.09
217	2	19	4	23	2	21	2	4	20	39.1	1.96	1.15	2.52	5109	86	2.1	238	109	2.67	187	142	3.47	144	189	4.62	108	0.33
218	23	48	10	58	10	68	20	3	30	48.9	2.51	1.59	2.83	6136	144	2.93	170	160	3.26	153	205	4.18	120	283	5.77	86.7	0.38
219	31	53	3	56	16	72	19	12	9	29.8	2.48	1.65	2.69	3023	75	3.1	161	80	3.31	151	100	4.13	121	140	5.79	86.4	0.4
224	6	117	38	155	40	195	78	72	25	79	4.58	2.92	5.21	3166	93	3.67	136	109	4.3	116	151	5.96	83.9	225	8.88	56.3	0.49

225	2	175	21	154	17	171	4	2	20	60	2.66	1.91	3.49	3334	116	4.35	115	138	5.17	96.6	158	5.92	84.4	209	7.84	63.8	0.32
226	8	155	18	137	12	125	30	22	17	47.7	2.07	1.37	2.91	3564	114	4	125	138	4.84	103	158	5.54	90.2	197	6.91	72.4	0.25
227	32	156	13	169	30	139	17	49	9	40.7	2.31	1.02	2.6	2214	81	4.57	109	86	4.86	103	109	6.15	81.2	127	7.17	69.7	0.17
230	12	113	48	161	11	172	59	71	15	60.5	3.63	1.82	4.44	2478	68	3.43	146	84	4.24	118	120	6.05	82.6	156	7.87	63.5	0.3
231	9	102	14	116	6	110	8	1	14	35.4	2.44	1.27	2.91	3952	113	3.57	140	128	4.05	124	165	5.22	95.8	205	6.48	77.1	0.24
232	0	136	0	136	8	128	8	8	25	66.3	2.35	1.39	3.05	3772	117	3.88	129	138	4.57	109	167	5.53	90.3	209	6.93	72.2	0.25
233	7	7	17	24	40	64	57	50	17	82	3.44	2.23	3.68	2074	34	2.05	244	38	2.29	218	58	3.5	143	95	5.73	87.3	0.64
236	20	151	30	121	6	115	36	56	19	38.3	1.91	1.38	2.32	4964	172	4.33	115	188	4.73	106	209	5.26	95	264	6.65	75.2	0.26
238	11	65	39	104	37	67	2	13	13	40.9	2.24	0.67	3.06	3182	68	2.67	187	89	3.5	143	129	5.07	98.7	146	5.74	87.2	0.13
240	0	201	6	195	30	165	36	36	13	45.5	1.66	1.01	2.36	2856	122	5.34	93.6	138	6.04	82.8	153	6.7	74.7	176	7.7	64.9	0.15
242	5	85	10	95	19	114	29	34	103	38.9	2.75	1.66	3.52	###	640	3.02	166	804	3.79	132	1036	4.89	102	1387	6.54	76.4	0.34
246	7	127	74	201	7	208	81	88	31	116	7.65	4.99	8.45	2679	78	3.64	137	95	4.43	113	152	7.09	70.5	259	12.1	41.4	0.7
247	10	160	2	158	7	151	9	1	33	44.1	2.59	1.45	3.46	7483	241	4.03	124	293	4.89	102	361	6.03	82.9	448	7.48	66.8	0.24
248	54	123	25	98	21	77	46	100	9	36.9	1.49	0.92	1.49	2441	86	4.4	114	86	4.4	114	97	4.97	101	115	5.89	84.9	0.19
249	23	145	39	184	29	155	10	13	25	53.5	2.84	1.02	3.24	4673	160	4.28	117	175	4.68	107	243	6.5	76.9	281	7.52	66.5	0.16
250	40	44	12	32	7	25	19	21	7	27.4	1.47	0.98	2.89	2551	37	1.81	276	66	3.23	155	76	3.72	134	96	4.7	106	0.26
254	0	60	5	55	61	116	56	56	29	73.5	3.23	2.53	3.9	3947	87	2.76	181	108	3.42	146	130	4.12	121	210	6.65	75.2	0.62
255	40	46	5	51	23	28	18	58	7	18.6	1.49	0.66	1.59	3766	95	3.15	159	98	3.25	154	123	4.08	122	143	4.75	105	0.16
256	9	77	31	108	0	108	31	40	28	49.9	2.74	1.31	3.54	5613	131	2.92	171	167	3.72	134	231	5.14	97.2	290	6.46	77.4	0.26
258	28	25	13	38	169	207	182	154	22	87.1	8.66	7.52	8.76	2527	54	2.67	187	56	2.77	181	79	3.91	128	231	11.4	43.8	1.92
259	18	55	17	72	3	75	20	2	43	42.1	2.5	1.41	2.85	###	244	2.99	167	273	3.34	150	362	4.43	113	477	5.84	85.7	0.32
261	4	30	2	28	5	33	3	1	51	41.9	2.06	1.32	2.58	12181	232	2.38	210	282	2.89	173	354	3.63	138	483	4.96	101	0.36
262	62	69	56	125	58	183	114	176	37	71.1	4.78	2.95	6.41	5205	79	1.9	264	147	3.53	142	223	5.36	93.4	346	8.31	60.2	0.55
263	26	126	13	113	20	93	33	7	14	44.6	1.79	1.03	2.79	3141	86	3.42	146	111	4.42	113	130	5.17	96.6	156	6.21	80.5	0.2
264	2	191	14	177	4	173	18	20	30	53.7	2.46	1.59	3.09	5588	214	4.79	104	242	5.41	92.4	281	6.29	79.5	352	7.87	63.5	0.25
265	8	5	11	16	26	42	37	29	25	51.3	2.98	1.9	3.16	4869	79	2.03	247	86	2.21	226	128	3.29	152	202	5.19	96.4	0.58
266	6	169	3	166	23	143	26	32	21	35.1	2.13	1.09	2.86	5986	209	4.36	115	244	5.1	98.1	294	6.14	81.4	346	7.23	69.2	0.18
267	2	35	26	9	10	19	16	14	14	41.4	1.59	1.4	2.18	3384	64	2.36	212	80	2.96	169	85	3.14	159	123	4.54	110	0.45
276	0	94	3	97	25	122	28	28	84	55.3	2.94	1.92	3.51	15199	408	3.36	149	477	3.92	127	602	4.95	101	835	6.87	72.8	0.39
280	35	80	4	76	16	60	20	55	13	54.9	1.9	1.11	2.06	2370	68	3.59	139	71	3.74	134	86	4.54	110	107	5.64	88.6	0.24
281	2	171	9	180	26	154	17	15	33	40.7	2.41	1.14	3.22	8101	278	4.29	117	331	5.11	97.9	413	6.37	78.5	487	7.51	66.5	0.18
282	5	14	2	12	5	7	7	12	7	27.4	1.47	0.83	1.86	2551	44	2.16	232	52	2.55	196	65	3.19	157	82	4.02	124	0.26

284	2	18	4	14	1	15	3	5	31	32.8	1.83	1.18	2.26	9452	164	2.17	231	197	2.61	192	246	3.25	154	335	4.43	113	0.36
285	22	139	0	139	19	120	19	41	13	42.2	2.19	1.26	2.63	3084	103	4.17	120	114	4.62	108	137	5.55	90	168	6.81	73.4	0.23
288	2	185	14	171	10	161	24	22	15	40.2	2.28	1.44	3.09	3727	135	4.53	110	159	5.33	93.8	184	6.17	81	227	7.61	65.7	0.23
290	13	63	6	69	16	53	10	23	19	35.8	1.98	1.08	2.45	5309	127	2.99	167	147	3.46	144	185	4.36	115	231	5.44	91.9	0.25
292	0	1	0	1	4	5	4	4	13	55.6	2.46	1.23	3.37	2338	8	0.43	1169	25	1.34	374	48	2.57	195	71	3.8	132	0.48
293	10	177	6	183	20	163	14	24	25	34.4	2.43	1.15	3.07	7257	265	4.56	110	302	5.2	96.1	376	6.48	77.2	443	7.63	65.5	0.18
297	1	16	5	11	9	20	4	5	60	28.9	2	1.41	2.52	###	343	2.07	242	430	2.59	193	527	3.18	157	761	4.59	109	0.44
298	14	11	36	47	4	43	32	18	9	31.3	2.78	1.17	2.96	2874	52	2.26	221	56	2.44	205	93	4.04	124	120	5.22	95.8	0.29
299	3	178	16	194	15	179	1	2	39	48.2	2.97	1.48	3.71	8083	289	4.47	112	337	5.21	95.9	433	6.7	74.7	529	8.18	61.1	0.22
300	21	173	10	163	29	134	39	18	19	35.5	1.89	0.96	2.97	5350	174	4.07	123	220	5.14	97.3	260	6.07	82.3	301	7.03	71.1	0.16
302	64	96	36	132	26	106	10	74	13	45.4	2.44	0.96	4.06	2865	54	2.36	212	91	3.97	126	125	5.45	91.7	147	6.41	78	0.18
303	46	84	56	140	57	197	113	159	75	81.3	5.34	3.56	6.69	9228	180	2.44	205	280	3.79	132	411	5.57	89.8	674	9.13	54.8	0.64
304	71	199	1	198	2	196	3	68	23	73.7	3.25	2.04	5.29	3119	93	3.73	134	144	5.77	86.6	174	6.97	71.7	225	9.02	55.4	0.29
307	1	193	12	181	33	148	45	44	51	41.9	1.97	1.01	2.66	###	463	4.76	105	530	5.45	91.8	624	6.41	78	722	7.42	67.4	0.16
308	9	122	29	151	15	166	44	35	32	64.3	3.31	1.88	3.97	4979	149	3.74	134	175	4.39	114	232	5.82	85.8	307	7.71	64.9	0.32
314	17	58	3	61	11	50	8	9	19	48.9	1.96	1.09	2.83	3887	78	2.51	199	105	3.38	148	132	4.24	118	166	5.34	93.7	0.26
316	17	167	5	162	13	149	18	35	53	54	2.41	1.39	2.92	9819	356	4.53	110	396	5.04	99.2	476	6.06	82.5	585	7.45	67.1	0.23
318	21	61	13	48	26	22	39	60	15	36	1.23	0.6	1.59	4164	102	3.06	163	114	3.42	146	135	4.05	123	155	4.65	107	0.15
320	4	2	0	2	7	9	7	3	11	32.3	2.16	1.47	2.27	3409	51	1.87	267	54	1.98	253	73	2.68	187	113	4.14	121	0.55
321	65	93	24	117	10	107	14	79	14	49.7	2.53	1.2	4.13	2815	52	2.31	217	88	3.91	128	118	5.24	95.4	145	6.44	77.7	0.23
322	0	36	1	35	30	65	29	29	17	65.5	2.75	1.98	3.32	2594	50	2.41	208	62	2.99	167	78	3.76	133	119	5.73	87.2	0.53
324	24	164	11	175	5	170	6	30	46	59.9	2.8	1.53	3.86	7683	242	3.94	127	307	4.99	100	385	6.26	79.8	479	7.79	64.2	0.24
325	19	26	37	63	17	46	20	1	9	17.1	2.51	1.02	2.73	5271	108	2.56	195	117	2.77	180	180	4.27	117	223	5.29	94.5	0.24
326	25	87	44	43	30	13	74	99	3	11.6	0.53	0.39	0.77	2586	74	3.58	140	79	3.82	131	82	3.96	126	90	4.35	115	0.1
327	19	51	1	52	25	27	24	43	7	28.2	1.46	0.66	1.81	2480	58	2.92	171	65	3.28	153	81	4.08	122	94	4.74	106	0.16
328	4	200	5	205	11	194	6	10	15	53.2	2.84	1.42	3.19	2820	127	5.63	88.8	135	5.98	83.6	167	7.4	67.5	199	8.82	56.7	0.19
332	5	6	2	4	1	3	3	8	18	21.4	1.28	0.76	1.5	8402	134	1.99	251	149	2.22	226	184	2.74	183	235	3.5	143	0.28
333	3	176	2	178	11	167	9	12	73	53.8	2.55	1.42	3.33	13557	479	4.42	113	563	5.19	96.3	686	6.33	79	840	7.75	64.6	0.22
335	17	107	19	126	10	136	29	46	48	59.9	2.93	1.72	3.78	8013	212	3.31	151	266	4.15	120	344	5.37	93.2	454	7.08	70.6	0.32
336	11	138	29	109	28	81	57	68	9	30.5	1.35	0.8	1.95	2953	95	4.02	124	109	4.61	108	122	5.16	96.8	141	5.97	83.8	0.16
337	2	28	18	10	0	10	18	20	16	38.1	1.46	1.13	1.93	4202	79	2.35	213	95	2.83	177	106	3.15	159	144	4.28	117	0.36
340	10	128	26	102	20	82	46	56	18	37.2	1.55	0.95	2.06	4844	152	3.92	127	172	4.44	113	195	5.03	99.4	232	5.99	83.5	0.19

341	45	71	1	70	11	59	12	33	21	55.2	2.04	1.25	3.35	3806	69	2.27	221	109	3.58	140	133	4.37	114	171	5.62	89	0.29
342	18	158	25	133	20	113	45	63	13	50.2	1.64	1.06	2.13	2588	91	4.4	114	101	4.88	102	113	5.46	91.6	135	6.52	76.7	0.19
343	46	81	32	49	17	32	49	95	9	21.5	1.19	0.89	1.22	4193	125	3.73	134	126	3.76	133	136	4.05	123	166	4.95	101	0.22
344	10	13	2	15	20	35	22	12	17	42.1	2.51	1.73	2.82	4040	71	2.2	228	81	2.51	200	106	3.28	152	162	5.01	99.8	0.53
347	21	165	31	196	19	177	12	33	42	54.1	3.14	1.47	4.19	7764	247	3.98	126	312	5.02	99.5	416	6.7	74.7	507	8.16	61.3	0.22
348	8	72	7	79	110	189	117	125	45	78.4	4.85	3.83	5.62	5743	130	2.83	177	165	3.59	139	212	4.61	108	388	8.45	59.2	0.83
350	31	114	26	88	33	55	59	90	13	33.4	1.22	0.74	1.51	3897	124	3.98	126	133	4.27	117	148	4.75	105	171	5.48	91.2	0.16
351	3	189	30	159	18	141	48	45	27	65.5	1.82	1.15	2.64	4124	150	4.55	110	177	5.36	93.2	199	6.03	82.9	237	7.18	69.6	0.19
352	9	148	16	164	11	153	5	4	14	58.4	2.82	1.41	3.39	2397	79	4.12	121	90	4.69	107	117	6.1	81.9	144	7.51	66.6	0.23
353	25	73	30	103	100	203	130	155	43	71.6	6.43	5.01	7.45	6007	125	2.6	192	174	3.62	138	242	5.04	99.3	483	10.1	49.7	1
354	21	95	8	87	21	66	29	8	21	30.8	1.8	1.01	2.75	6822	163	2.99	167	215	3.94	127	258	4.73	106	313	5.74	87.2	0.21
355	3	56	10	46	17	29	27	30	5	20.3	1.53	0.86	2.14	2459	54	2.75	182	66	3.36	149	79	4.02	125	96	4.88	102	0.22
356	17	89	29	60	23	83	6	23	25	42.8	2.14	1.76	2.48	5838	164	3.51	142	180	3.85	130	198	4.24	118	280	6	83.4	0.41
357	24	182	4	186	19	205	23	47	33	106	5.11	3.86	6.23	3108	103	4.14	121	131	5.27	94.9	162	6.52	76.7	258	10.4	48.2	0.59
358	14	108	27	135	55	190	82	68	24	62.3	4.31	2.98	4.8	3855	113	3.66	136	128	4.15	120	169	5.48	91.2	261	8.46	59.1	0.54
360	16	33	13	20	4	16	17	33	9	26.3	1.53	1.06	1.82	3426	72	2.63	190	80	2.92	171	93	3.39	147	122	4.45	112	0.31
362	5	161	32	129	25	104	57	62	12	45.4	1.47	0.95	2.13	2643	90	4.26	117	104	4.92	102	115	5.44	91.9	135	6.38	78.3	0.17
364	8	70	22	92	4	96	26	18	11	51.8	2.71	1.41	3.24	2123	51	3	167	60	3.53	142	82	4.83	104	106	6.24	80.1	0.29
365	24	34	13	21	2	23	11	35	19	31.5	1.72	1.24	1.93	6029	132	2.74	183	142	2.94	170	165	3.42	146	225	4.66	107	0.36
366	39	112	12	124	38	162	50	11	19	67	3.39	2.34	3.57	2837	92	4.05	123	96	4.23	118	120	5.29	94.6	173	7.62	65.6	0.44
367	27	170	18	152	5	157	13	40	19	38.2	2.44	1.68	2.54	4975	199	5	100	203	5.1	98	233	5.85	85.4	300	7.54	66.3	0.29
370	2	153	15	168	30	138	15	17	13	60.9	2.34	1	3.05	2133	70	4.1	122	82	4.81	104	105	6.15	81.3	122	7.15	69.9	0.16
377	13	111	5	106	31	137	26	39	21	64.4	2.88	1.99	3.68	3259	89	3.41	146	110	4.22	119	133	5.1	98	185	7.1	70.5	0.39
380	40	137	7	130	68	198	61	101	62	88.3	4.61	3.74	5.79	7021	191	3.4	147	257	4.58	109	306	5.45	91.8	516	9.19	54.4	0.69

Table A.2: Results of rank change analysis for flow accumulation method on 218 sub-watersheds of a minimum unit size of 20 ha in the Craigville quad.

																Avg. Flow Length = 150m			Avg. Flow Length = 125m			Avg. Flow Length = 100m			Avg. Flow Length = 75m			
Wshed ID	R @ 150	dR(150-125)	R @ 125	dR(125-100)	R @ 100	dR(100-75)	R @ 75	dR(75-125)	dR(75-150)	# streams @ L = 75m	F @ L = 75	dD (75 -> 125)	dD (75 -> 100)	dD (75 -> 150)	total area (cells	stream cells	DD	Flow Len	stream cells	DD	Flow Len	stream cells	DD	Flow Len	stream cells	DD	Flow Len	% change
15	113	23	136	4	140	11	151	15	38	39	46.7	2.9	1.9	3.7	8345	226.0	3.4	147.7	284.0	4.3	117.5	352.0	5.3	94.8	476.0	7.1	70.1	26.05%
18	201	3	198	31	167	103	64	134	137	3	9.3	0.5	0.3	0.9	3232	133.0	5.1	97.2	142.0	5.5	91.0	146.0	5.6	88.5	155.0	6.0	83.4	5.81%
22	199	22	177	0	177	15	162	15	37	9	32.5	2.5	1.5	2.5	2771	107.0	4.8	103.6	107.0	4.8	103.6	129.0	5.8	85.9	162.0	7.3	68.4	20.37%
24	13	7	6	4	2	1	1	5	12	18	40.2	1.2	0.8	1.7	4475	79.0	2.2	226.6	95.0	2.7	188.4	112.0	3.1	159.8	139.0	3.9	128.8	19.42%
30	56	21	35	57	92	26	118	83	62	35	51.6	3.4	1.8	3.8	6782	157.0	2.9	172.8	178.0	3.3	152.4	264.0	4.9	102.8	363.0	6.7	74.7	27.27%
36	76	22	54	30	24	20	4	50	72	11	38.0	0.9	0.6	1.4	2895	70.0	3.0	165.4	81.0	3.5	143.0	90.0	3.9	128.7	103.0	4.4	112.4	12.62%
37	84	41	43	86	129	30	159	116	75	15	54.2	3.8	2.1	4.1	2765	70.0	3.2	158.0	75.0	3.4	147.5	114.0	5.2	97.0	160.0	7.2	69.1	28.75%
41	14	39	53	8	45	15	60	7	46	29	48.4	2.4	1.6	3.6	5995	109.0	2.3	220.0	167.0	3.5	143.6	209.0	4.4	114.7	284.0	5.9	84.4	26.41%
43	151	43	194	7	201	4	205	11	54	13	60.3	3.5	1.9	5.1	2156	66.0	3.8	130.7	93.0	5.4	92.7	122.0	7.1	70.7	154.0	8.9	56.0	20.78%
44	168	58	110	33	143	56	87	23	81	9	38.3	2.3	1.0	2.3	2348	75.0	4.0	125.2	75.0	4.0	125.2	100.0	5.3	93.9	118.0	6.3	79.6	15.25%
45	129	57	186	8	194	24	170	16	41	26	48.1	2.3	1.2	3.8	5411	155.0	3.6	139.6	221.0	5.1	97.9	266.0	6.1	81.4	319.0	7.4	67.8	16.61%
46	41	20	21	13	34	27	61	40	20	19	72.7	2.9	1.8	3.2	2613	57.0	2.7	183.4	63.0	3.0	165.9	86.0	4.1	121.5	124.0	5.9	84.3	30.65%
49	184	11	195	8	187	67	120	75	64	3	12.4	1.3	0.7	2.4	2424	84.0	4.3	115.4	105.0	5.4	92.3	117.0	6.0	82.9	130.0	6.7	74.6	10.00%
50	198	5	193	20	173	58	115	78	83	9	33.8	1.3	0.9	1.9	2661	102.0	4.8	104.4	114.0	5.4	93.4	122.0	5.7	87.2	142.0	6.7	75.0	14.08%
51	123	45	78	8	70	43	27	51	96	13	30.9	1.8	0.8	2.0	4213	117.0	3.5	144.0	125.0	3.7	134.8	157.0	4.7	107.3	185.0	5.5	91.1	15.14%
52	21	6	27	18	9	4	13	14	8	17	79.9	2.0	1.5	2.7	2127	41.0	2.4	207.5	53.0	3.1	160.5	62.0	3.6	137.2	87.0	5.1	97.8	28.74%
54	155	47	108	8	116	20	96	12	59	27	50.5	2.5	1.4	2.5	5348	166.0	3.9	128.9	169.0	4.0	126.6	216.0	5.0	99.0	275.0	6.4	77.8	21.45%
55	71	19	52	10	62	14	48	4	23	13	40.0	2.3	1.2	2.8	3247	78.0	3.0	166.5	90.0	3.5	144.3	119.0	4.6	109.1	150.0	5.8	86.6	20.67%
58	126	18	144	35	109	80	29	115	97	7	17.4	1.2	0.5	2.0	4032	114.0	3.5	141.5	140.0	4.3	115.2	161.0	5.0	100.2	178.0	5.5	90.6	9.55%
59	5	13	18	2	16	6	22	4	17	17	47.6	2.4	1.6	3.3	3573	59.0	2.1	242.2	84.0	2.9	170.1	108.0	3.8	132.3	154.0	5.4	92.8	29.87%
60	30	11	19	8	27	7	20	1	10	59	48.0	2.4	1.3	2.8	12280	251.0	2.6	195.7	293.0	3.0	167.6	394.0	4.0	124.7	524.0	5.3	93.7	24.81%
61	65	26	91	22	69	3	66	25	1	13	61.9	2.2	1.4	3.0	2099	50.0	3.0	167.9	64.0	3.8	131.2	78.0	4.6	107.6	101.0	6.0	83.1	22.77%
63	144	14	130	54	76	27	49	81	95	15	25.1	1.6	1.1	2.0	5973	180.0	3.8	132.7	201.0	4.2	118.9	225.0	4.7	106.2	277.0	5.8	86.3	18.77%
64	185	18	167	61	106	90	16	151	169	3	10.2	0.5	0.2	0.9	2941	102.0	4.3	115.3	111.0	4.7	106.0	117.0	5.0	100.5	122.0	5.2	96.4	4.10%
65	78	37	41	23	18	9	9	32	69	11	47.2	1.6	1.2	1.9	2331	57.0	3.1	163.6	63.0	3.4	148.0	71.0	3.8	131.3	93.0	5.0	100.3	23.66%

67	181	3	184	11	195	17	178	6	3	9	43.8	2.6	1.5	3.3	2053	70.0	4.3	117.3	82.0	5.0	100.1	101.0	6.1	81.3	125.0	7.6	65.7	19.20%
68	89	16	73	6	67	5	62	11	27	64	45.9	2.3	1.3	2.7	13939	360.0	3.2	154.9	412.0	3.7	135.3	516.0	4.6	108.1	663.0	5.9	84.1	22.17%
71	24	0	24	29	53	25	28	4	4	9	40.8	2.4	1.1	3.0	2207	44.0	2.5	200.6	54.0	3.1	163.5	78.0	4.4	113.2	97.0	5.5	91.0	19.59%
72	109	71	180	11	191	9	182	2	73	168	51.6	2.9	1.7	4.4	32531	873.0	3.4	149.1	1267.0	4.9	102.7	1579.0	6.1	82.4	####	7.8	64.4	21.79%
73	64	14	50	22	28	9	19	31	45	27	44.3	1.8	1.3	2.3	6092	145.0	3.0	168.1	168.0	3.4	145.0	197.0	4.0	123.7	258.0	5.3	94.4	23.64%
74	206	1	205	3	208	13	195	10	11	5	24.1	1.9	1.0	2.6	2077	96.0	5.8	86.5	109.0	6.6	76.2	123.0	7.4	67.5	140.0	8.4	59.3	12.14%
75	204	2	206	1	207	20	187	19	17	9	34.6	1.6	0.8	2.7	2604	113.0	5.4	92.2	137.0	6.6	76.0	154.0	7.4	67.6	170.0	8.2	61.3	9.41%
77	31	16	15	33	48	19	67	52	36	10	40.9	3.1	1.6	3.5	2446	50.0	2.6	195.7	57.0	2.9	171.6	86.0	4.4	113.8	118.0	6.0	82.9	27.12%
79	195	6	201	5	196	61	135	66	60	11	31.3	1.2	0.6	2.1	3511	134.0	4.8	104.8	160.0	5.7	87.8	175.0	6.2	80.3	193.0	6.9	72.8	9.33%
80	8	182	190	15	205	1	206	16	198	14	66.2	4.4	2.3	7.4	2115	36.0	2.1	235.0	88.0	5.2	96.1	123.0	7.3	68.8	162.0	9.6	52.2	24.07%
81	81	5	76	38	38	21	17	59	64	21	34.4	1.5	1.0	2.1	6110	152.0	3.1	160.8	181.0	3.7	135.0	207.0	4.2	118.1	254.0	5.2	96.2	18.50%
86	183	15	168	31	137	53	84	84	99	15	39.1	1.5	1.0	1.9	3840	133.0	4.3	115.5	145.0	4.7	105.9	161.0	5.2	95.4	192.0	6.3	80.0	16.15%
88	50	30	20	16	4	2	2	18	48	7	31.7	1.1	0.7	1.2	2208	50.0	2.8	176.6	53.0	3.0	166.6	59.0	3.3	149.7	72.0	4.1	122.7	18.06%
91	135	28	107	64	43	31	12	95	123	7	17.4	1.1	0.7	1.4	4024	117.0	3.6	137.6	127.0	3.9	126.7	140.0	4.3	115.0	163.0	5.1	98.7	14.11%
93	17	1	16	3	13	8	5	11	12	17	56.0	1.6	0.8	2.2	3034	57.0	2.3	212.9	71.0	2.9	170.9	90.0	3.7	134.8	110.0	4.5	110.3	18.18%
95	188	23	165	53	112	57	55	110	133	7	24.5	1.2	0.8	1.4	2862	103.0	4.5	111.1	107.0	4.7	107.0	115.0	5.0	99.5	134.0	5.9	85.4	14.18%
97	208	1	209	0	209	2	207	2	1	11	39.5	2.2	1.3	3.3	2785	142.0	6.4	78.5	166.0	7.5	67.1	186.0	8.3	59.9	215.0	9.6	51.8	13.49%
103	147	4	151	6	157	48	109	42	38	24	41.5	2.2	1.1	2.8	5778	175.0	3.8	132.1	205.0	4.4	112.7	256.0	5.5	90.3	305.0	6.6	75.8	16.07%
104	209	1	208	5	203	15	188	20	21	5	23.3	1.5	1.0	1.7	2143	110.0	6.4	77.9	114.0	6.6	75.2	123.0	7.2	69.7	140.0	8.2	61.2	12.14%
105	197	2	199	15	184	70	114	85	83	15	45.6	1.1	0.7	1.9	3292	126.0	4.8	104.5	145.0	5.5	90.8	157.0	6.0	83.9	175.0	6.6	75.2	10.29%
106	25	9	34	5	39	165	204	170	179	17	72.5	5.6	4.6	6.3	2345	47.0	2.5	199.6	61.0	3.3	153.8	80.0	4.3	117.3	166.0	8.8	56.5	51.81%
107	114	43	71	34	37	44	81	10	33	13	50.5	2.5	2.0	2.8	2575	70.0	3.4	147.1	76.0	3.7	135.5	87.0	4.2	118.4	128.0	6.2	80.5	32.03%
108	161	44	117	68	49	39	10	107	151	3	12.3	1.0	0.6	1.1	2441	77.0	3.9	126.8	79.0	4.0	123.6	86.0	4.4	113.5	98.0	5.0	99.6	12.24%
109	165	25	140	66	74	50	24	116	141	3	11.8	1.1	0.7	1.5	2553	81.0	4.0	126.1	88.0	4.3	116.0	96.0	4.7	106.4	111.0	5.4	92.0	13.51%
110	37	15	22	7	15	7	8	14	29	13	45.5	2.0	1.3	2.3	2859	61.0	2.7	187.5	69.0	3.0	165.7	85.0	3.7	134.5	114.0	5.0	100.3	25.44%
111	77	40	37	2	35	18	53	16	24	32	59.5	2.5	1.7	2.8	5375	130.0	3.0	165.4	142.0	3.3	151.4	178.0	4.1	120.8	251.0	5.8	85.7	29.08%
116	118	17	135	0	135	65	200	65	82	28	69.7	4.5	3.5	5.3	4015	110.0	3.4	146.0	136.0	4.2	118.1	168.0	5.2	95.6	279.0	8.7	57.6	39.78%
119	59	34	25	2	23	24	47	22	12	17	54.5	2.7	1.9	2.8	3122	73.0	2.9	171.1	77.0	3.1	162.2	97.0	3.9	128.7	144.0	5.8	86.7	32.64%
120	40	4	36	16	20	32	52	16	12	17	60.5	2.5	2.0	3.1	2811	61.0	2.7	184.3	74.0	3.3	151.9	86.0	3.8	130.7	131.0	5.8	85.8	34.35%
121	177	16	161	68	93	15	108	53	69	14	53.5	2.0	1.7	2.4	2615	88.0	4.2	118.9	97.0	4.6	107.8	102.0	4.9	102.5	138.0	6.6	75.8	26.09%
122	96	31	127	15	142	64	78	49	18	15	42.2	2.0	0.9	2.9	3557	93.0	3.3	153.0	119.0	4.2	119.6	151.0	5.3	94.2	176.0	6.2	80.8	14.20%
123	207	3	204	5	199	24	175	29	32	9	21.5	1.3	0.9	1.7	4186	195.0	5.8	85.9	207.0	6.2	80.9	223.0	6.7	75.1	252.0	7.5	66.4	11.51%

127	159	19	178	37	141	52	89	89	70	11	36.3	1.5	1.0	2.4	3028	95.0	3.9	127.5	117.0	4.8	103.5	128.0	5.3	94.6	153.0	6.3	79.2	16.34%
129	112	50	162	1	161	13	148	14	36	13	53.2	2.5	1.5	3.7	2445	66.0	3.4	148.2	91.0	4.7	107.5	109.0	5.6	89.7	139.0	7.1	70.4	21.58%
131	170	42	128	56	72	35	107	21	63	17	51.8	2.4	1.9	2.6	3279	105.0	4.0	124.9	110.0	4.2	119.2	123.0	4.7	106.6	173.0	6.6	75.8	28.90%
132	63	34	97	18	79	43	36	61	27	13	41.2	1.7	0.9	2.7	3152	75.0	3.0	168.1	98.0	3.9	128.7	119.0	4.7	105.9	142.0	5.6	88.8	16.20%
134	176	16	160	32	192	3	189	29	13	27	58.5	3.6	2.1	4.1	4619	152.0	4.1	121.6	171.0	4.6	108.0	225.0	6.1	82.1	303.0	8.2	61.0	25.74%
135	67	10	77	42	119	3	122	45	55	36	47.2	3.0	1.7	3.7	7624	182.0	3.0	167.6	226.0	3.7	134.9	309.0	5.1	98.7	410.0	6.7	74.4	24.63%
136	55	37	92	84	176	11	165	73	110	23	46.1	3.5	1.5	4.4	4985	115.0	2.9	173.4	152.0	3.8	131.2	232.0	5.8	85.9	292.0	7.3	68.3	20.55%
137	58	9	49	16	33	7	26	23	32	17	42.6	2.0	1.4	2.6	3992	93.0	2.9	171.7	110.0	3.4	145.2	131.0	4.1	121.9	175.0	5.5	91.2	25.14%
138	122	15	137	9	128	46	82	55	40	16	48.2	2.0	1.1	2.7	3319	92.0	3.5	144.3	113.0	4.3	117.5	136.0	5.1	97.6	165.0	6.2	80.5	17.58%
140	196	8	188	19	169	110	59	129	137	3	14.3	0.8	0.2	1.1	2093	80.0	4.8	104.7	86.0	5.1	97.3	95.0	5.7	88.1	99.0	5.9	84.6	4.04%
141	194	3	197	16	181	87	94	103	100	5	16.3	0.9	0.5	1.7	3061	116.0	4.7	105.6	134.0	5.5	91.4	145.0	5.9	84.4	157.0	6.4	78.0	7.64%
142	128	26	154	0	154	10	144	10	16	44	47.5	2.6	1.6	3.5	9259	263.0	3.6	140.8	330.0	4.5	112.2	406.0	5.5	91.2	521.0	7.0	71.1	22.07%
143	33	4	29	21	8	6	14	15	19	19	50.2	2.0	1.5	2.6	3783	78.0	2.6	194.0	95.0	3.1	159.3	110.0	3.6	137.6	156.0	5.2	97.0	29.49%
145	160	3	157	26	131	34	97	60	63	48	51.8	1.9	1.3	2.5	9266	292.0	3.9	126.9	337.0	4.5	110.0	385.0	5.2	96.3	479.0	6.5	77.4	19.62%
146	142	38	104	5	99	78	177	73	35	14	55.7	3.6	2.6	3.8	2513	75.0	3.7	134.0	79.0	3.9	127.2	99.0	4.9	101.5	152.0	7.6	66.1	34.87%
147	11	1	10	5	5	2	7	3	4	25	46.1	1.9	1.4	2.6	5428	95.0	2.2	228.5	124.0	2.9	175.1	148.0	3.4	146.7	207.0	4.8	104.9	28.50%
148	90	12	102	24	126	25	101	1	11	11	47.4	2.6	1.4	3.3	2323	60.0	3.2	154.9	73.0	3.9	127.3	95.0	5.1	97.8	121.0	6.5	76.8	21.49%
149	115	53	62	106	168	34	202	140	87	23	63.2	5.1	3.1	5.4	3641	99.0	3.4	147.1	105.0	3.6	138.7	165.0	5.7	88.3	255.0	8.8	57.1	35.29%
153	52	14	66	24	90	18	72	6	20	16	36.3	2.5	1.3	3.3	4413	101.0	2.9	174.8	128.0	3.6	137.9	171.0	4.8	103.2	216.0	6.1	81.7	20.83%
154	167	5	172	1	171	52	119	53	48	15	35.1	2.0	1.0	2.7	4277	136.0	4.0	125.8	162.0	4.7	105.6	195.0	5.7	87.7	229.0	6.7	74.7	14.85%
155	116	4	112	41	71	14	57	55	59	13	52.8	1.9	1.2	2.5	2463	67.0	3.4	147.0	79.0	4.0	124.7	92.0	4.7	107.1	116.0	5.9	84.9	20.69%
156	169	6	163	3	160	81	79	84	90	9	25.0	1.5	0.6	2.2	3594	115.0	4.0	125.0	134.0	4.7	107.3	160.0	5.6	89.9	178.0	6.2	80.8	10.11%
159	203	1	202	4	206	7	199	3	4	13	39.4	2.8	1.2	3.1	3302	143.0	5.4	92.4	152.0	5.8	86.9	195.0	7.4	67.7	226.0	8.6	58.4	13.72%
160	182	16	166	23	189	15	174	8	8	29	49.1	2.8	1.4	3.2	5907	204.0	4.3	115.8	222.0	4.7	106.4	286.0	6.1	82.6	353.0	7.5	66.9	18.98%
161	172	3	169	23	146	9	155	14	17	29	39.4	2.5	1.9	3.2	7361	237.0	4.0	124.2	278.0	4.7	105.9	315.0	5.3	93.5	424.0	7.2	69.4	25.71%
162	130	21	109	8	117	23	140	31	10	22	58.1	3.0	1.9	3.4	3788	109.0	3.6	139.0	120.0	4.0	126.3	153.0	5.0	99.0	212.0	7.0	71.5	27.83%
163	146	13	159	0	159	12	171	12	25	51	57.8	2.8	1.8	3.6	8821	267.0	3.8	132.1	323.0	4.6	109.2	392.0	5.6	90.0	521.0	7.4	67.7	24.76%
164	86	0	86	13	73	10	63	23	23	17	32.1	2.2	1.3	2.8	5296	135.0	3.2	156.9	160.0	3.8	132.4	199.0	4.7	106.5	253.0	6.0	83.7	21.34%
166	158	16	142	10	132	39	93	49	65	17	49.8	2.1	1.2	2.5	3416	107.0	3.9	127.7	118.0	4.3	115.8	142.0	5.2	96.2	175.0	6.4	78.1	18.86%
167	43	26	69	18	87	16	71	2	28	26	52.9	2.4	1.3	3.4	4914	108.0	2.7	182.0	144.0	3.7	136.5	189.0	4.8	104.0	240.0	6.1	81.9	21.25%
168	134	35	99	2	97	37	134	35	0	49	54.9	3.0	1.9	3.2	8927	259.0	3.6	137.9	279.0	3.9	128.0	351.0	4.9	101.7	490.0	6.9	72.9	28.37%
169	19	66	85	19	66	14	80	5	61	17	52.3	2.4	1.6	3.8	3249	62.0	2.4	209.6	98.0	3.8	132.6	120.0	4.6	108.3	161.0	6.2	80.7	25.47%

172	48	75	123	41	164	1	163	40	115	26	50.4	3.2	1.7	4.5	5163	116.0	2.8	178.0	171.0	4.1	120.8	231.0	5.6	89.4	302.0	7.3	68.4	23.51%
173	101	11	90	8	82	59	141	51	40	24	51.1	3.2	2.2	3.7	4698	124.0	3.3	151.5	143.0	3.8	131.4	179.0	4.8	105.0	263.0	7.0	71.5	31.94%
175	132	11	121	7	114	14	100	21	32	17	46.8	2.4	1.5	2.9	3631	105.0	3.6	138.3	119.0	4.1	122.1	146.0	5.0	99.5	189.0	6.5	76.8	22.75%
176	85	97	182	20	202	4	198	16	113	7	34.8	3.5	1.4	5.3	2014	51.0	3.2	158.0	80.0	5.0	100.7	115.0	7.1	70.1	137.0	8.5	58.8	16.06%
177	178	5	173	48	125	84	41	132	137	9	27.6	1.0	0.6	1.5	3258	110.0	4.2	118.5	124.0	4.8	105.1	133.0	5.1	98.0	149.0	5.7	87.5	10.74%
178	120	22	98	52	150	23	173	75	53	11	48.9	3.6	2.1	4.0	2248	62.0	3.4	145.0	70.0	3.9	128.5	97.0	5.4	92.7	134.0	7.5	67.1	27.61%
179	3	4	7	15	22	145	167	160	164	25	95.9	4.6	3.5	5.3	2608	42.0	2.0	248.4	56.0	2.7	186.3	81.0	3.9	128.8	153.0	7.3	68.2	47.06%
183	62	7	55	56	111	43	154	99	92	27	53.3	3.7	2.2	4.2	5070	120.0	3.0	169.0	143.0	3.5	141.8	203.0	5.0	99.9	292.0	7.2	69.5	30.48%
184	7	7	14	44	58	132	190	176	183	30	69.1	5.4	3.9	6.2	4342	73.0	2.1	237.9	101.0	2.9	172.0	156.0	4.5	111.3	290.0	8.3	59.9	46.21%
186	66	47	113	13	100	5	105	8	39	23	48.6	2.5	1.6	3.6	4737	113.0	3.0	167.7	152.0	4.0	124.7	187.0	4.9	101.3	248.0	6.5	76.4	24.60%
187	107	11	118	24	94	21	73	45	34	35	45.8	2.1	1.2	2.8	7650	204.0	3.3	150.0	248.0	4.1	123.4	299.0	4.9	102.3	375.0	6.1	81.6	20.27%
188	97	25	72	24	96	4	92	20	5	41	50.0	2.7	1.5	3.1	8195	215.0	3.3	152.5	242.0	3.7	135.5	322.0	4.9	101.8	419.0	6.4	78.2	23.15%
189	202	1	203	6	197	50	147	56	55	13	26.5	1.1	0.7	1.8	4905	208.0	5.3	94.3	233.0	5.9	84.2	252.0	6.4	77.9	278.0	7.1	70.6	9.35%
191	51	36	87	7	80	26	54	33	3	54	40.9	2.1	1.1	3.0	13208	301.0	2.8	175.5	400.0	3.8	132.1	499.0	4.7	105.9	618.0	5.8	85.5	19.26%
192	117	22	95	27	68	31	99	4	18	57	56.9	2.6	1.9	3.1	10018	274.0	3.4	146.2	309.0	3.9	129.7	371.0	4.6	108.0	521.0	6.5	76.9	28.79%
193	75	8	67	26	41	1	40	27	35	13	63.9	2.1	1.4	2.7	2034	49.0	3.0	166.0	59.0	3.6	137.9	70.0	4.3	116.2	93.0	5.7	87.5	24.73%
197	15	3	12	2	14	44	58	46	43	28	67.1	3.0	2.2	3.6	4171	77.0	2.3	216.7	96.0	2.9	173.8	124.0	3.7	134.5	197.0	5.9	84.7	37.06%
199	192	4	196	10	186	69	117	79	75	7	21.0	1.2	0.7	2.1	3329	123.0	4.6	108.3	145.0	5.4	91.8	160.0	6.0	83.2	178.0	6.7	74.8	10.11%
202	73	20	93	77	170	14	184	91	111	29	55.3	4.2	2.3	5.0	5245	126.0	3.0	166.5	160.0	3.8	131.1	239.0	5.7	87.8	336.0	8.0	62.4	28.87%
203	100	32	68	18	86	40	126	58	26	28	64.0	3.1	2.0	3.5	4373	115.0	3.3	152.1	128.0	3.7	136.7	168.0	4.8	104.1	237.0	6.8	73.8	29.11%
204	200	9	191	1	190	37	153	38	47	7	32.9	1.9	1.1	2.2	2127	85.0	5.0	100.1	90.0	5.3	94.5	103.0	6.1	82.6	122.0	7.2	69.7	15.57%
205	175	1	174	4	178	26	152	22	23	16	40.1	2.4	1.3	3.0	3992	131.0	4.1	121.9	152.0	4.8	105.1	187.0	5.9	85.4	228.0	7.1	70.0	17.98%
209	98	40	58	26	32	44	76	18	22	13	56.0	2.6	2.0	2.9	2321	61.0	3.3	152.2	66.0	3.6	140.7	76.0	4.1	122.2	114.0	6.1	81.4	33.33%
210	141	34	175	23	152	31	121	54	20	22	53.2	1.9	1.2	3.0	4135	123.0	3.7	134.5	158.0	4.8	104.7	181.0	5.5	91.4	222.0	6.7	74.5	18.47%
211	6	32	38	7	31	114	145	107	139	22	61.0	3.7	2.9	5.0	3604	60.0	2.1	240.3	96.0	3.3	150.2	118.0	4.1	122.2	203.0	7.0	71.0	41.87%
213	68	35	33	21	54	29	83	50	15	18	60.6	3.0	1.8	3.2	2969	71.0	3.0	167.3	77.0	3.2	154.2	105.0	4.4	113.1	148.0	6.2	80.2	29.05%
214	153	14	139	48	91	5	86	53	67	25	41.8	2.0	1.4	2.4	5983	185.0	3.9	129.4	204.0	4.3	117.3	232.0	4.8	103.2	300.0	6.3	79.8	22.67%
215	154	22	132	90	42	36	6	126	148	5	22.8	0.5	0.3	0.8	2197	68.0	3.9	129.2	74.0	4.2	118.8	76.0	4.3	115.6	82.0	4.7	107.2	7.32%
217	23	6	17	7	10	25	35	18	12	26	50.9	2.7	2.0	3.2	5109	101.0	2.5	202.3	120.0	2.9	170.3	149.0	3.6	137.2	230.0	5.6	88.9	35.22%
218	53	9	44	8	36	20	56	12	3	36	58.7	2.5	1.7	3.0	6136	141.0	2.9	174.1	167.0	3.4	147.0	206.0	4.2	119.1	288.0	5.9	85.2	28.47%
219	46	24	70	7	63	31	32	38	14	13	43.0	1.9	1.0	2.8	3023	67.0	2.8	180.5	89.0	3.7	135.9	111.0	4.6	108.9	135.0	5.6	89.6	17.78%
224	44	13	57	128	185	8	193	136	149	23	72.6	4.8	2.4	5.6	3166	70.0	2.8	180.9	90.0	3.6	140.7	152.0	6.0	83.3	212.0	8.4	59.7	28.30%

225	95	46	141	10	151	20	131	10	36	16	48.0	2.5	1.4	3.6	3334	87.0	3.3	153.3	115.0	4.3	116.0	145.0	5.4	92.0	182.0	6.8	73.3	20.33%
226	127	12	115	12	127	50	77	38	50	17	47.7	2.1	1.1	2.6	3564	101.0	3.5	141.1	115.0	4.0	124.0	146.0	5.1	97.6	176.0	6.2	81.0	17.05%
227	191	12	179	16	163	5	168	11	23	9	40.7	2.5	1.8	2.8	2214	81.0	4.6	109.3	86.0	4.9	103.0	99.0	5.6	89.5	130.0	7.3	68.1	23.85%
230	49	11	60	41	101	63	164	104	115	15	60.5	3.7	2.4	4.5	2478	56.0	2.8	177.0	71.0	3.6	139.6	98.0	4.9	101.1	145.0	7.3	68.4	32.41%
231	152	21	131	1	130	5	125	6	27	18	45.5	2.6	1.6	2.9	3952	122.0	3.9	129.6	133.0	4.2	118.9	164.0	5.2	96.4	214.0	6.8	73.9	23.36%
232	124	23	101	17	84	22	106	5	18	23	61.0	2.7	1.8	3.1	3772	105.0	3.5	143.7	118.0	3.9	127.9	144.0	4.8	104.8	199.0	6.6	75.8	27.64%
233	4	3	1	16	17	133	150	149	146	19	91.6	5.0	3.3	5.1	2074	34.0	2.0	244.0	35.0	2.1	237.0	63.0	3.8	131.7	118.0	7.1	70.3	46.61%
236	163	8	171	48	123	4	127	44	36	27	54.4	2.1	1.7	2.8	4964	157.0	4.0	126.5	188.0	4.7	105.6	202.0	5.1	98.3	270.0	6.8	73.5	25.19%
238	88	23	111	47	158	19	139	28	51	17	53.4	3.0	1.5	3.8	3182	82.0	3.2	155.2	102.0	4.0	124.8	141.0	5.5	90.3	178.0	7.0	71.5	20.79%
240	189	11	200	2	198	18	180	20	9	9	31.5	2.0	1.2	3.2	2856	103.0	4.5	110.9	130.0	5.7	87.9	148.0	6.5	77.2	176.0	7.7	64.9	15.91%
242	57	22	79	10	89	34	123	44	66	121	45.7	3.0	1.9	3.9	####	615.0	2.9	172.3	789.0	3.7	134.3	####	4.8	103.6	####	6.8	74.0	28.56%
246	16	127	143	21	122	72	194	51	178	20	74.7	4.1	3.3	6.1	2679	50.0	2.3	214.3	93.0	4.3	115.2	109.0	5.1	98.3	180.0	8.4	59.5	39.44%
247	103	52	155	20	175	6	169	14	66	31	41.4	2.8	1.6	4.0	7483	198.0	3.3	151.2	270.0	4.5	110.9	345.0	5.8	86.8	440.0	7.3	68.0	21.59%
248	187	38	149	90	59	15	44	105	143	9	36.9	1.3	1.2	1.3	2441	86.0	4.4	113.5	86.0	4.4	113.5	88.0	4.5	111.0	112.0	5.7	87.2	21.43%
249	111	23	134	19	115	9	124	10	13	19	40.7	2.5	1.7	3.4	4673	126.0	3.4	148.3	158.0	4.2	118.3	188.0	5.0	99.4	253.0	6.8	73.9	25.69%
250	133	39	94	43	51	145	196	102	63	19	74.5	4.6	4.0	4.8	2551	74.0	3.6	137.9	78.0	3.8	130.8	90.0	4.4	113.4	172.0	8.4	59.3	47.67%
254	54	12	42	36	78	58	136	94	82	25	63.3	3.5	2.2	4.0	3947	91.0	2.9	173.5	107.0	3.4	147.6	149.0	4.7	106.0	218.0	6.9	72.4	31.65%
255	105	41	64	7	57	13	70	6	35	25	66.4	2.5	1.6	2.8	3766	100.0	3.3	150.6	109.0	3.6	138.2	135.0	4.5	111.6	183.0	6.1	82.3	26.23%
256	34	47	81	43	124	13	111	30	77	30	53.4	2.9	1.5	4.0	5613	118.0	2.6	190.3	168.0	3.7	133.6	229.0	5.1	98.0	297.0	6.6	75.6	22.90%
258	45	36	9	55	64	145	209	200	164	23	91.0	8.6	6.8	8.6	2527	56.0	2.8	180.5	56.0	2.8	180.5	93.0	4.6	108.7	230.0	11.4	43.9	59.57%
259	119	35	84	14	98	48	146	62	27	57	55.8	3.3	2.2	3.6	10214	280.0	3.4	145.9	308.0	3.8	132.6	402.0	4.9	101.6	578.0	7.1	70.7	30.45%
261	60	36	96	44	52	33	85	11	25	73	59.9	2.4	1.8	3.3	12181	287.0	2.9	169.8	376.0	3.9	129.6	430.0	4.4	113.3	610.0	6.3	79.9	29.51%
262	20	99	119	54	65	121	186	67	166	36	69.2	4.1	3.5	5.7	5205	100.0	2.4	208.2	169.0	4.1	123.2	192.0	4.6	108.4	339.0	8.1	61.4	43.36%
263	102	41	61	83	144	70	74	13	28	12	38.2	2.5	0.8	2.8	3141	83.0	3.3	151.4	90.0	3.6	139.6	134.0	5.3	93.8	154.0	6.1	81.6	12.99%
264	171	12	183	4	179	36	143	40	28	22	39.4	2.1	1.1	3.0	5588	179.0	4.0	124.9	222.0	5.0	100.7	263.0	5.9	85.0	314.0	7.0	71.2	16.24%
265	10	7	3	4	7	18	25	22	15	30	61.6	3.1	1.9	3.3	4869	84.0	2.2	231.9	91.0	2.3	214.0	139.0	3.6	140.1	213.0	5.5	91.4	34.74%
266	166	28	138	24	162	30	132	6	34	19	31.7	2.6	1.3	2.9	5986	190.0	4.0	126.0	204.0	4.3	117.4	267.0	5.6	89.7	327.0	6.8	73.2	18.35%
267	80	15	65	25	40	28	68	3	12	19	56.1	2.4	1.8	3.0	3384	84.0	3.1	161.1	98.0	3.6	138.1	116.0	4.3	116.7	164.0	6.1	82.5	29.27%
276	61	13	74	3	77	51	128	54	67	86	56.6	3.1	2.1	3.9	15199	359.0	3.0	169.3	450.0	3.7	135.1	573.0	4.7	106.1	828.0	6.8	73.4	30.80%
280	164	38	126	41	85	40	45	81	119	13	54.9	1.6	0.9	1.8	2370	75.0	4.0	126.4	79.0	4.2	120.0	91.0	4.8	104.2	109.0	5.7	87.0	16.51%
281	162	4	158	16	174	14	160	2	2	33	40.7	2.7	1.5	3.3	8101	256.0	4.0	126.6	295.0	4.6	109.8	372.0	5.7	87.1	469.0	7.2	69.1	20.68%
282	38	6	32	13	19	2	21	11	17	13	51.0	2.1	1.5	2.6	2551	55.0	2.7	185.5	66.0	3.2	154.6	78.0	3.8	130.8	109.0	5.3	93.6	28.44%

284	35	5	30	19	11	7	18	12	17	56	59.2	2.1	1.6	2.7	9452	199.0	2.6	190.0	240.0	3.2	157.5	279.0	3.7	135.5	400.0	5.3	94.5	30.25%
285	137	4	133	13	120	22	98	35	39	15	48.6	2.3	1.4	2.8	3084	90.0	3.6	137.1	104.0	4.2	118.6	125.0	5.1	98.7	160.0	6.5	77.1	21.88%
288	179	6	185	13	172	23	149	36	30	15	40.2	2.1	1.4	2.9	3727	126.0	4.2	118.3	149.0	5.0	100.1	170.0	5.7	87.7	212.0	7.1	70.3	19.81%
290	39	9	48	19	29	36	65	17	26	29	54.6	2.6	1.9	3.3	5309	115.0	2.7	184.7	146.0	3.4	145.5	173.0	4.1	122.8	255.0	6.0	83.3	32.16%
292	12	4	8	97	105	37	142	134	130	19	81.3	4.3	2.0	4.8	2338	41.0	2.2	228.1	51.0	2.7	183.4	93.0	5.0	100.6	131.0	7.0	71.4	29.01%
293	156	8	164	24	188	7	181	17	25	29	40.0	3.0	1.7	3.8	7257	226.0	3.9	128.4	271.0	4.7	107.1	351.0	6.0	82.7	448.0	7.7	64.8	21.65%
297	32	6	26	1	25	66	91	65	59	113	54.5	3.2	2.4	3.8	20734	425.0	2.6	195.1	516.0	3.1	160.7	647.0	3.9	128.2	1053.0	6.3	78.8	38.56%
298	2	3	5	7	12	26	38	33	36	20	69.6	3.0	2.0	3.7	2874	46.0	2.0	249.9	60.0	2.6	191.6	85.0	3.7	135.2	130.0	5.7	88.4	34.62%
299	140	41	181	2	183	0	183	2	43	37	45.8	3.0	1.9	4.1	8083	240.0	3.7	134.7	315.0	4.9	102.6	385.0	6.0	84.0	508.0	7.9	63.6	24.21%
300	69	60	129	37	166	36	130	1	61	17	31.8	2.6	1.2	3.8	5350	128.0	3.0	167.2	180.0	4.2	118.9	240.0	5.6	89.2	292.0	6.8	73.3	17.81%
302	83	6	89	6	95	5	90	1	7	13	45.4	2.5	1.4	3.2	2865	72.0	3.1	159.2	87.0	3.8	131.7	112.0	4.9	102.3	145.0	6.3	79.0	22.76%
303	27	32	59	88	147	50	197	138	170	74	80.2	4.9	3.1	5.9	9228	187.0	2.5	197.4	263.0	3.6	140.3	395.0	5.4	93.4	623.0	8.4	59.2	36.60%
304	106	23	83	110	193	8	185	102	79	19	60.9	4.4	2.0	4.8	3119	83.0	3.3	150.3	94.0	3.8	132.7	152.0	6.1	82.1	203.0	8.1	61.5	25.12%
307	186	3	189	9	180	24	156	33	30	46	37.8	2.1	1.3	2.8	12163	426.0	4.4	114.2	500.0	5.1	97.3	575.0	5.9	84.6	701.0	7.2	69.4	17.97%
308	93	13	80	30	110	6	116	36	23	25	50.2	2.9	1.7	3.4	4979	129.0	3.2	154.4	149.0	3.7	133.7	199.0	5.0	100.1	266.0	6.7	74.9	25.19%
314	26	15	11	39	50	4	46	35	20	23	59.2	2.9	1.4	3.2	3887	78.0	2.5	199.3	89.0	2.9	174.7	137.0	4.4	113.5	179.0	5.8	86.9	23.46%
316	143	13	156	22	134	30	104	52	39	46	46.8	2.0	1.3	2.8	9819	294.0	3.7	133.6	355.0	4.5	110.6	409.0	5.2	96.0	514.0	6.5	76.4	20.43%
318	87	36	51	25	26	8	34	17	53	26	62.4	2.2	1.7	2.4	4164	107.0	3.2	155.7	115.0	3.5	144.8	132.0	4.0	126.2	187.0	5.6	89.1	29.41%
320	1	3	4	2	6	37	43	39	42	19	55.7	3.4	2.3	3.7	3409	54.0	2.0	252.5	64.0	2.3	213.1	93.0	3.4	146.6	156.0	5.7	87.4	40.38%
321	99	43	56	1	55	4	51	5	48	12	42.6	2.3	1.4	2.5	2815	74.0	3.3	152.2	80.0	3.6	140.8	100.0	4.4	112.6	131.0	5.8	86.0	23.66%
322	29	34	63	39	102	35	137	74	108	15	57.8	3.3	2.0	4.4	2594	53.0	2.6	195.8	75.0	3.6	138.3	103.0	5.0	100.7	144.0	6.9	72.1	28.47%
324	110	22	88	45	133	5	138	50	28	38	49.5	3.2	1.8	3.6	7683	207.0	3.4	148.5	233.0	3.8	131.9	320.0	5.2	96.0	428.0	7.0	71.8	25.23%
325	121	15	106	23	83	96	179	73	58	35	66.4	3.7	2.9	4.2	5271	146.0	3.5	144.4	166.0	3.9	127.0	201.0	4.8	104.9	324.0	7.7	65.1	37.96%
326	157	37	120	64	56	26	30	90	127	9	34.8	1.5	1.1	1.6	2586	81.0	3.9	127.7	84.0	4.1	123.1	92.0	4.4	112.4	115.0	5.6	89.9	20.00%
327	82	35	47	0	47	10	37	10	45	15	60.5	2.2	1.3	2.5	2480	62.0	3.1	160.0	68.0	3.4	145.9	87.0	4.4	114.0	112.0	5.6	88.6	22.32%
328	205	2	207	3	204	3	201	6	4	9	31.9	2.0	1.5	3.1	2820	127.0	5.6	88.8	150.0	6.6	75.2	162.0	7.2	69.6	196.0	8.7	57.6	17.35%
332	9	7	2	1	1	2	3	1	6	36	42.8	1.8	1.2	2.0	8402	144.0	2.1	233.4	152.0	2.3	221.1	196.0	2.9	171.5	276.0	4.1	121.8	28.99%
333	136	9	145	3	148	15	133	12	3	59	43.5	2.5	1.5	3.2	13557	395.0	3.6	137.3	471.0	4.3	115.1	581.0	5.4	93.3	741.0	6.8	73.2	21.59%
335	91	25	116	37	153	4	157	41	66	40	49.9	3.2	1.7	4.0	8013	207.0	3.2	154.8	259.0	4.0	123.8	351.0	5.5	91.3	462.0	7.2	69.4	24.03%
336	79	73	152	31	121	46	75	77	4	11	37.3	1.7	1.1	3.0	2953	73.0	3.1	161.8	105.0	4.4	112.5	120.0	5.1	98.4	145.0	6.1	81.5	17.24%
337	18	5	23	2	21	12	33	10	15	26	61.9	2.6	1.8	3.2	4202	79.0	2.4	212.8	102.0	3.0	164.8	129.0	3.8	130.3	188.0	5.6	89.4	31.38%
340	145	2	147	39	108	77	31	116	114	14	28.9	1.2	0.6	1.8	4844	146.0	3.8	132.7	169.0	4.4	114.7	193.0	5.0	100.4	216.0	5.6	89.7	10.65%

341	36	64	100	13	113	25	88	12	52	23	60.4	2.4	1.3	3.6	3806	81.0	2.7	188.0	119.0	3.9	127.9	153.0	5.0	99.5	192.0	6.3	79.3	20.31%
342	190	3	187	22	165	62	103	84	87	15	58.0	1.4	0.9	2.0	2588	94.0	4.5	110.1	106.0	5.1	97.7	116.0	5.6	89.2	135.0	6.5	76.7	14.07%
343	131	26	105	45	60	21	39	66	92	23	54.9	1.8	1.1	2.1	4193	121.0	3.6	138.6	132.0	3.9	127.1	153.0	4.6	109.6	191.0	5.7	87.8	19.90%
344	28	3	31	44	75	6	69	38	41	21	52.0	2.9	1.4	3.5	4040	82.0	2.5	197.1	103.0	3.2	156.9	152.0	4.7	106.3	196.0	6.1	82.4	22.45%
347	92	11	103	33	136	25	161	58	69	38	48.9	3.3	2.0	4.0	7764	201.0	3.2	154.5	244.0	3.9	127.3	325.0	5.2	95.6	452.0	7.3	68.7	28.10%
348	22	17	39	49	88	41	129	90	107	35	60.9	3.5	2.0	4.4	5743	112.0	2.4	205.1	153.0	3.3	150.1	221.0	4.8	103.9	313.0	6.8	73.4	29.39%
350	149	1	148	44	104	54	50	98	99	13	33.4	1.4	0.8	2.0	3897	119.0	3.8	131.0	136.0	4.4	114.6	155.0	5.0	100.6	181.0	5.8	86.1	14.36%
351	173	3	176	20	156	54	102	74	71	13	31.5	1.7	1.0	2.5	4124	133.0	4.0	124.0	159.0	4.8	103.7	182.0	5.5	90.6	215.0	6.5	76.7	15.35%
352	108	14	122	41	81	31	112	10	4	10	41.7	2.5	1.9	3.3	2397	64.0	3.3	149.8	79.0	4.1	121.4	91.0	4.7	105.4	127.0	6.6	75.5	28.35%
353	104	66	170	30	200	8	208	38	104	55	91.6	6.6	4.6	8.0	6007	159.0	3.3	151.1	227.0	4.7	105.9	323.0	6.7	74.4	545.0	11.3	44.1	40.73%
354	74	1	75	14	61	19	42	33	32	27	39.6	2.0	1.1	2.7	6822	164.0	3.0	166.4	202.0	3.7	135.1	250.0	4.6	109.2	312.0	5.7	87.5	19.87%
355	42	2	40	6	46	23	23	17	19	10	40.7	2.0	1.0	2.6	2459	54.0	2.7	182.1	66.0	3.4	149.0	86.0	4.4	114.4	106.0	5.4	92.8	18.87%
356	148	34	114	4	118	85	203	89	55	44	75.4	4.7	3.7	5.0	5838	177.0	3.8	131.9	188.0	4.0	124.2	236.0	5.1	98.9	409.0	8.8	57.1	42.30%
357	150	4	146	1	145	46	191	45	41	21	67.6	4.0	3.0	4.5	3108	95.0	3.8	130.9	108.0	4.3	115.1	133.0	5.3	93.5	208.0	8.4	59.8	36.06%
358	138	14	124	15	139	53	192	68	54	23	59.7	4.2	3.1	4.7	3855	113.0	3.7	136.5	128.0	4.2	120.5	162.0	5.3	95.2	258.0	8.4	59.8	37.21%
360	70	42	28	2	30	15	15	13	55	21	61.3	2.0	1.1	2.2	3426	82.0	3.0	167.1	86.0	3.1	159.3	112.0	4.1	122.4	142.0	5.2	96.5	21.13%
362	180	27	153	15	138	28	166	13	14	14	53.0	2.9	2.1	3.1	2643	90.0	4.3	117.5	94.0	4.4	112.5	111.0	5.2	95.2	155.0	7.3	68.2	28.39%
364	72	27	45	1	44	51	95	50	23	13	61.2	3.0	2.1	3.4	2123	51.0	3.0	166.5	58.0	3.4	146.4	74.0	4.4	114.8	109.0	6.4	77.9	32.11%
365	47	34	13	10	3	8	11	2	36	25	41.5	2.2	1.7	2.3	6029	134.0	2.8	180.0	139.0	2.9	173.5	160.0	3.3	150.7	243.0	5.0	99.2	34.16%
366	174	24	150	43	107	3	110	40	64	19	67.0	2.2	1.6	2.5	2837	93.0	4.1	122.0	100.0	4.4	113.5	113.0	5.0	100.4	150.0	6.6	75.7	24.67%
367	193	1	192	10	182	24	158	34	35	17	34.2	1.9	1.3	2.5	4975	188.0	4.7	105.9	211.0	5.3	94.3	236.0	5.9	84.3	287.0	7.2	69.3	17.77%
370	139	14	125	30	155	21	176	51	37	9	42.2	3.4	2.1	3.9	2133	63.0	3.7	135.4	71.0	4.2	120.2	94.0	5.5	90.8	129.0	7.6	66.1	27.13%
377	125	43	82	67	149	36	113	31	12	15	46.0	2.9	1.3	3.1	3259	91.0	3.5	143.3	98.0	3.8	133.0	140.0	5.4	93.1	173.0	6.6	75.4	19.08%
380	94	48	46	57	103	69	172	126	78	46	65.5	4.0	2.4	4.1	7021	182.0	3.2	154.3	192.0	3.4	146.3	279.0	5.0	100.7	415.0	7.4	67.7	32.77%

Table A.3: Results of rank change analysis for terrain curvature method on 218 sub-watersheds of a minimum unit size of 20 ha in the Craigville quad.

																Avg. Flow Length = 150m			Avg. Flow Length = 125m			Avg. Flow Length = 100m			Avg. Flow Length = 75m			
Wshed ID	R @ 150	dR(150-125)	R @ 125	dR(125-100)	R @ 100	dR(100-75)	R @ 75	dR(75-125)	dR(75-150)	# streams @ L = 75m	F @ L = 75	dD (75 -> 125)	dD (75 -> 100)	dD (75 -> 150)	total area (cells	stream cells	DD	Flow Len	stream cells	DD	Flow Len	stream cells	DD	Flow Len	stream cells	DD	Flow Len	% change
15	129	8	137	11	148	5	153	16	24	52	62.3	3.3	1.9	4.0	8345	261	3.9	127.9	309.0	4.6	108.0	402.0	6.0	83.0	526.0	7.9	63.5	30.8%
18	201	12	189	43	146	47	99	90	102	15	46.4	1.1	0.8	1.3	3232	143	5.5	90.4	147.0	5.7	87.9	155.0	6.0	83.4	176.0	6.8	73.5	13.5%
22	194	8	202	4	206	11	195	7	1	15	54.1	2.4	1.4	3.7	2771	113	5.1	98.1	142.0	6.4	78.1	166.0	7.5	66.8	196.0	8.8	56.6	18.1%
24	17	11	6	4	2	1	1	5	16	7	15.6	0.6	0.3	0.7	4475	72	2.0	248.6	74.0	2.1	241.9	84.0	2.3	213.1	96.0	2.7	186.5	14.3%
30	62	5	67	13	80	17	97	30	35	37	54.6	3.3	2.0	3.9	6782	153	2.8	177.3	187.0	3.4	145.1	257.0	4.7	105.6	367.0	6.8	73.9	42.8%
36	25	0	25	9	16	12	4	21	21	7	24.2	0.7	0.3	1.3	2895	50	2.2	231.6	62.0	2.7	186.8	71.0	3.1	163.1	79.0	3.4	146.6	11.3%
37	74	28	46	41	87	27	60	14	14	13	47.0	2.9	1.2	3.0	2765	68	3.1	162.6	70.0	3.2	158.0	108.0	4.9	102.4	134.0	6.1	82.5	24.1%
41	35	41	76	1	77	16	61	15	26	30	50.0	2.4	1.4	3.6	5995	116	2.4	206.7	176.0	3.7	136.3	225.0	4.7	106.6	291.0	6.1	82.4	29.3%
43	208	1	209	0	209	0	209	0	1	23	106.7	3.9	2.1	4.8	2156	104	6.0	82.9	120.0	7.0	71.9	150.0	8.7	57.5	187.0	10.8	46.1	24.7%
44	9	30	39	14	25	14	11	28	2	5	21.3	1.1	0.5	2.2	2348	35	1.9	268.3	56.0	3.0	167.7	68.0	3.6	138.1	77.0	4.1	122.0	13.2%
45	117	57	174	6	168	13	155	19	38	30	55.4	2.5	1.5	4.2	5411	162	3.7	133.6	235.0	5.4	92.1	279.0	6.4	77.6	345.0	8.0	62.7	23.7%
46	24	13	11	4	7	2	5	6	19	11	42.1	1.4	0.8	1.5	2613	45	2.2	232.3	48.0	2.3	217.8	60.0	2.9	174.2	77.0	3.7	135.7	28.3%
49	197	0	197	18	179	50	129	68	68	9	37.1	1.4	0.8	2.2	2424	102	5.3	95.1	117.0	6.0	82.9	130.0	6.7	74.6	145.0	7.5	66.9	11.5%
50	128	14	142	9	133	52	81	61	47	7	26.3	1.7	0.8	2.5	2661	83	3.9	128.2	100.0	4.7	106.4	120.0	5.6	88.7	137.0	6.4	77.7	14.2%
51	88	5	83	35	48	10	38	45	50	21	49.8	1.7	1.3	2.2	4213	109	3.2	154.6	127.0	3.8	132.7	140.0	4.2	120.4	183.0	5.4	92.1	30.7%
52	4	1	5	2	3	4	7	2	3	7	32.9	1.6	1.1	2.4	2127	22	1.3	386.7	35.0	2.1	243.1	45.0	2.6	189.1	63.0	3.7	135.0	40.0%
54	101	1	102	23	79	4	75	27	26	36	67.3	2.2	1.5	2.9	5348	146	3.4	146.5	174.0	4.1	122.9	202.0	4.7	105.9	268.0	6.3	79.8	32.7%
55	92	13	105	13	118	3	115	10	23	28	86.2	3.0	1.9	3.9	3247	85	3.3	152.8	107.0	4.1	121.4	137.0	5.3	94.8	186.0	7.2	69.8	35.8%
58	125	3	128	20	108	44	64	64	61	15	37.2	1.6	1.0	2.2	4032	125	3.9	129.0	146.0	4.5	110.5	166.0	5.1	97.2	197.0	6.1	81.9	18.7%
59	31	3	34	6	28	10	18	16	13	15	42.0	1.7	0.8	2.2	3573	66	2.3	216.5	82.0	2.9	174.3	106.0	3.7	134.8	130.0	4.5	109.9	22.6%
60	41	9	50	18	68	0	68	18	27	66	53.7	2.9	1.6	3.7	12280	243	2.5	202.1	319.0	3.2	154.0	442.0	4.5	111.1	604.0	6.1	81.3	36.7%
61	54	28	26	9	35	7	28	2	26	9	42.9	2.3	1.1	2.3	2099	45	2.7	186.6	45.0	2.7	186.6	65.0	3.9	129.2	83.0	4.9	101.2	27.7%
63	131	11	120	31	89	13	76	44	55	21	35.2	1.9	1.4	2.3	5973	188	3.9	127.1	210.0	4.4	113.8	234.0	4.9	102.1	300.0	6.3	79.6	28.2%
64	166	17	149	37	112	71	41	108	125	3	10.2	0.6	0.3	1.1	2941	104	4.4	113.1	115.0	4.9	102.3	123.0	5.2	95.6	129.0	5.5	91.2	4.9%
65	5	11	16	4	20	14	6	10	1	9	38.6	1.3	0.4	2.1	2331	29	1.6	321.5	45.0	2.4	207.2	61.0	3.3	152.9	69.0	3.7	135.1	13.1%
67	200	5	195	2	197	67	130	65	70	9	43.8	1.6	0.4	2.1	2053	89	5.4	92.3	96.0	5.8	85.5	116.0	7.1	70.8	123.0	7.5	66.8	6.0%

68	95	18	113	17	130	30	100	13	5	67	48.1	2.6	1.2	3.5	13939	369	3.3	151.1	472.0	4.2	118.1	623.0	5.6	89.5	761.0	6.8	73.3	22.2%
71	43	49	92	17	109	18	91	1	48	13	58.9	2.8	1.5	4.2	2207	44	2.5	200.6	69.0	3.9	127.9	91.0	5.2	97.0	118.0	6.7	74.8	29.7%
72	7	11	18	14	32	7	39	21	32	105	32.3	2.9	1.7	3.7	32531	456	1.8	285.4	658.0	2.5	197.8	989.0	3.8	131.6	1420.0	5.5	91.6	43.6%
73	57	1	58	16	42	5	47	11	10	38	62.4	2.3	1.6	2.9	6092	133	2.7	183.2	164.0	3.4	148.6	198.0	4.1	123.1	274.0	5.6	88.9	38.4%
74	199	1	200	7	193	5	198	2	1	9	43.3	2.8	2.1	3.7	2077	90	5.4	92.3	105.0	6.3	79.1	116.0	7.0	71.6	151.0	9.1	55.0	30.2%
75	206	2	208	3	205	25	180	28	26	15	57.6	1.7	1.0	2.6	2604	122	5.9	85.4	141.0	6.8	73.9	155.0	7.4	67.2	176.0	8.4	59.2	13.5%
77	52	46	98	31	129	1	128	30	76	15	61.3	3.5	1.9	4.8	2446	52	2.7	188.2	78.0	4.0	125.4	109.0	5.6	89.8	146.0	7.5	67.0	33.9%
79	191	11	180	17	163	25	138	42	53	13	37.0	2.1	1.3	2.6	3511	139	4.9	101.0	155.0	5.5	90.6	176.0	6.3	79.8	213.0	7.6	65.9	21.0%
80	22	14	8	44	52	32	20	12	2	5	23.6	2.5	0.4	2.5	2115	36	2.1	235.0	36.0	2.1	235.0	71.0	4.2	119.2	78.0	4.6	108.5	9.9%
81	70	11	81	12	93	14	107	26	37	30	49.1	3.3	2.1	3.9	6110	149	3.0	164.0	183.0	3.7	133.6	241.0	4.9	101.4	342.0	7.0	71.5	41.9%
86	140	5	135	30	105	42	63	72	77	11	28.6	1.5	1.0	2.1	3840	123	4.0	124.9	141.0	4.6	108.9	156.0	5.1	98.5	187.0	6.1	82.1	19.9%
88	37	6	31	21	10	8	2	29	35	3	13.6	0.5	0.3	0.8	2208	43	2.4	205.4	49.0	2.8	180.2	51.0	2.9	173.2	57.0	3.2	154.9	11.8%
91	108	9	99	36	63	29	34	65	74	7	17.4	1.2	0.9	1.8	4024	112	3.5	143.7	129.0	4.0	124.8	141.0	4.4	114.2	169.0	5.2	95.2	19.9%
93	26	2	28	10	18	5	13	15	13	7	23.1	1.6	1.1	2.1	3034	53	2.2	229.0	66.0	2.7	183.9	77.0	3.2	157.6	104.0	4.3	116.7	35.1%
95	126	17	109	21	88	56	32	77	94	3	10.5	1.1	0.3	1.4	2862	89	3.9	128.6	95.0	4.1	120.5	112.0	4.9	102.2	120.0	5.2	95.4	7.1%
97	195	12	207	3	204	37	167	40	28	5	18.0	1.4	0.7	2.9	2785	116	5.2	96.0	150.0	6.7	74.3	165.0	7.4	67.5	181.0	8.1	61.5	9.7%
103	167	4	163	6	157	13	144	19	23	44	76.2	2.4	1.5	3.2	5778	206	4.5	112.2	241.0	5.2	95.9	284.0	6.1	81.4	353.0	7.6	65.5	24.3%
104	209	4	205	7	198	1	197	8	12	11	51.3	2.4	1.9	2.9	2143	105	6.1	81.6	113.0	6.6	75.9	122.0	7.1	70.3	155.0	9.0	55.3	27.0%
105	149	5	154	18	136	3	139	15	10	13	39.5	2.6	1.9	3.5	3292	108	4.1	121.9	131.0	5.0	100.5	150.0	5.7	87.8	200.0	7.6	65.8	33.3%
106	99	24	75	41	34	32	66	9	33	21	89.6	2.5	2.3	2.8	2345	63	3.4	148.9	68.0	3.6	137.9	72.0	3.8	130.3	115.0	6.1	81.6	59.7%
107	119	12	107	47	154	35	119	12	0	13	50.5	3.1	1.2	3.4	2575	78	3.8	132.1	85.0	4.1	121.2	125.0	6.1	82.4	149.0	7.2	69.1	19.2%
108	145	44	101	35	66	30	36	65	109	7	28.7	1.3	0.9	1.3	2441	79	4.0	123.6	79.0	4.0	123.6	87.0	4.5	112.2	105.0	5.4	93.0	20.7%
109	156	20	136	17	119	32	87	49	69	8	31.3	2.0	1.3	2.4	2553	86	4.2	118.7	94.0	4.6	108.6	108.0	5.3	94.6	135.0	6.6	75.6	25.0%
110	53	10	43	12	55	104	159	116	106	25	87.4	4.9	3.8	5.3	2859	61	2.7	187.5	71.0	3.1	161.1	97.0	4.2	117.9	183.0	8.0	62.5	88.7%
111	76	21	55	44	99	17	82	27	6	26	48.4	3.2	1.4	3.4	5375	133	3.1	161.7	142.0	3.3	151.4	217.0	5.0	99.1	278.0	6.5	77.3	28.1%
116	47	17	30	28	58	58	116	86	69	28	69.7	4.4	2.9	4.6	4015	81	2.5	198.3	89.0	2.8	180.4	137.0	4.3	117.2	230.0	7.2	69.8	67.9%
119	48	1	49	4	45	12	33	16	15	15	48.0	2.0	1.1	2.7	3122	63	2.5	198.2	81.0	3.2	154.2	103.0	4.1	121.2	131.0	5.2	95.3	27.2%
120	39	1	38	13	51	8	59	21	20	13	46.2	3.1	1.9	3.6	2811	55	2.4	204.4	66.0	2.9	170.4	94.0	4.2	119.6	136.0	6.0	82.7	44.7%
121	124	9	115	43	72	35	37	78	87	7	26.8	1.1	0.8	1.5	2615	81	3.9	129.1	90.0	4.3	116.2	96.0	4.6	109.0	113.0	5.4	92.6	17.7%
122	84	25	59	16	43	20	23	36	61	11	30.9	1.4	0.7	1.5	3557	91	3.2	156.4	96.0	3.4	148.2	116.0	4.1	122.7	135.0	4.7	105.4	16.4%
123	205	4	201	14	187	27	160	41	45	20	47.8	1.7	1.2	2.2	4186	196	5.9	85.4	212.0	6.3	79.0	228.0	6.8	73.4	268.0	8.0	62.5	17.5%
127	168	12	156	13	143	5	148	8	20	26	85.9	2.7	1.8	3.3	3028	108	4.5	112.1	121.0	5.0	100.1	143.0	5.9	84.7	187.0	7.7	64.8	30.8%

129	184	3	181	19	200	9	191	10	7	17	69.5	3.2	1.4	4.0	2445	92	4.7	106.3	108.0	5.5	90.6	143.0	7.3	68.4	171.0	8.7	57.2	19.6%
131	136	10	146	3	149	24	173	27	37	31	94.5	3.4	2.2	4.3	3279	104	4.0	126.1	126.0	4.8	104.1	158.0	6.0	83.0	216.0	8.2	60.7	36.7%
132	90	5	85	29	56	4	52	33	38	11	34.9	1.9	1.5	2.5	3152	82	3.3	153.8	96.0	3.8	131.3	107.0	4.2	117.8	145.0	5.8	87.0	35.5%
134	133	17	116	10	126	9	135	19	2	27	58.5	3.2	2.1	3.6	4619	146	4.0	126.5	160.0	4.3	115.5	201.0	5.4	91.9	279.0	7.6	66.2	38.8%
135	42	9	33	36	69	9	78	45	36	58	76.1	3.5	1.8	3.9	7624	151	2.5	202.0	173.0	2.8	176.3	276.0	4.5	110.5	387.0	6.3	78.8	40.2%
136	120	46	166	17	183	15	168	2	48	29	58.2	2.8	1.4	4.3	4985	152	3.8	131.2	211.0	5.3	94.5	270.0	6.8	73.9	324.0	8.1	61.5	20.0%
137	38	4	42	15	57	14	43	1	5	27	67.6	2.4	1.3	3.1	3992	78	2.4	204.7	99.0	3.1	161.3	136.0	4.3	117.4	177.0	5.5	90.2	30.1%
138	141	0	141	9	132	22	154	13	13	28	84.4	3.3	2.3	3.9	3319	107	4.0	124.1	124.0	4.7	107.1	149.0	5.6	89.1	211.0	7.9	62.9	41.6%
140	202	6	196	41	155	61	94	102	108	10	47.8	0.8	0.7	1.2	2093	93	5.6	90.0	99.0	5.9	84.6	102.0	6.1	82.1	113.0	6.7	74.1	10.8%
141	188	13	175	34	141	21	120	55	68	15	49.0	1.9	1.4	2.5	3061	118	4.8	103.8	133.0	5.4	92.1	144.0	5.9	85.0	179.0	7.3	68.4	24.3%
142	170	6	176	2	174	2	172	4	2	67	72.4	2.8	1.6	3.7	9259	337	4.5	109.9	404.0	5.5	91.7	492.0	6.6	75.3	609.0	8.2	60.8	23.8%
143	34	13	47	15	62	14	48	1	14	19	50.2	2.5	1.3	3.3	3783	71	2.3	213.1	96.0	3.2	157.6	132.0	4.4	114.6	171.0	5.7	88.5	29.5%
145	176	5	171	24	147	5	152	19	24	71	76.6	2.5	1.8	3.2	9266	342	4.6	108.4	395.0	5.3	93.8	446.0	6.0	83.1	582.0	7.9	63.7	30.5%
146	82	5	77	23	54	11	65	12	17	12	47.8	2.4	1.9	2.9	2513	64	3.2	157.1	74.0	3.7	135.8	85.0	4.2	118.3	123.0	6.1	81.7	44.7%
147	49	8	41	3	44	30	74	33	25	35	64.5	3.2	2.1	3.7	5428	110	2.5	197.4	134.0	3.1	162.0	179.0	4.1	121.3	272.0	6.3	79.8	52.0%
148	121	22	143	1	144	25	169	26	48	17	73.2	3.4	2.2	4.3	2323	71	3.8	130.9	88.0	4.7	105.6	110.0	5.9	84.5	151.0	8.1	61.5	37.3%
149	100	20	80	1	81	8	89	9	11	50	137.3	2.9	1.9	3.3	3641	99	3.4	147.1	109.0	3.7	133.6	138.0	4.7	105.5	194.0	6.7	75.1	40.6%
153	65	22	87	5	92	6	86	1	21	31	70.2	2.8	1.7	3.7	4413	101	2.9	174.8	135.0	3.8	130.8	174.0	4.9	101.4	233.0	6.6	75.8	33.9%
154	113	2	111	16	95	19	114	3	1	24	56.1	3.0	2.2	3.5	4277	124	3.6	138.0	144.0	4.2	118.8	170.0	5.0	100.6	245.0	7.2	69.8	44.1%
155	83	1	82	9	91	20	111	29	28	28	113.7	3.3	2.2	3.9	2463	63	3.2	156.4	74.0	3.8	133.1	97.0	4.9	101.6	140.0	7.1	70.4	44.3%
156	163	13	150	8	158	23	181	31	18	22	61.2	3.5	2.3	4.1	3594	126	4.4	114.1	141.0	4.9	102.0	177.0	6.2	81.2	243.0	8.5	59.2	37.3%
159	196	24	172	13	159	54	105	67	91	16	48.5	1.6	0.8	1.7	3302	138	5.2	95.7	142.0	5.4	93.0	163.0	6.2	81.0	183.0	6.9	72.2	12.3%
160	189	4	185	1	186	0	186	1	3	48	81.3	2.9	1.7	3.6	5907	231	4.9	102.3	265.0	5.6	89.2	321.0	6.8	73.6	403.0	8.5	58.6	25.5%
161	135	4	139	8	131	9	122	17	13	31	42.1	2.7	1.8	3.4	7361	233	4.0	126.4	273.0	4.6	107.9	329.0	5.6	89.5	434.0	7.4	67.8	31.9%
162	122	16	106	6	100	31	131	25	9	29	76.6	3.4	2.4	3.7	3788	116	3.8	130.6	125.0	4.1	121.2	153.0	5.0	99.0	227.0	7.5	66.7	48.4%
163	154	28	126	30	156	22	134	8	20	63	71.4	3.0	1.4	3.3	8821	297	4.2	118.8	318.0	4.5	111.0	430.0	6.1	82.1	532.0	7.5	66.3	23.7%
164	58	4	54	5	59	44	103	49	45	27	51.0	3.6	2.6	4.2	5296	116	2.7	182.6	139.0	3.3	152.4	182.0	4.3	116.4	292.0	6.9	72.5	60.4%
166	138	21	117	42	75	65	140	23	2	40	117.1	3.3	2.9	3.6	3416	109	4.0	125.4	119.0	4.4	114.8	128.0	4.7	106.8	208.0	7.6	65.7	62.5%
167	63	1	62	1	61	32	93	31	30	33	67.2	3.4	2.4	3.9	4914	111	2.8	177.1	133.0	3.4	147.8	170.0	4.3	115.6	265.0	6.7	74.2	55.9%
168	158	6	152	12	164	3	161	9	3	69	77.3	3.1	1.8	3.8	8927	306	4.3	116.7	353.0	4.9	101.2	450.0	6.3	79.4	575.0	8.1	62.1	27.8%
169	44	0	44	62	106	8	98	54	54	19	58.5	3.7	1.7	4.3	3249	65	2.5	199.9	81.0	3.1	160.4	132.0	5.1	98.5	176.0	6.8	73.8	33.3%
172	173	21	194	13	207	1	208	14	35	59	114.3	4.2	2.3	5.4	5163	189	4.6	109.3	241.0	5.8	85.7	317.0	7.7	65.1	414.0	10.0	49.9	30.6%

173	116	7	123	30	153	5	158	35	42	36	76.6	3.6	1.9	4.3	4698	140	3.7	134.2	166.0	4.4	113.2	228.0	6.1	82.4	300.0	8.0	62.6	31.6%
175	139	15	124	7	117	11	106	18	33	22	60.6	2.5	1.7	3.0	3631	116	4.0	125.2	130.0	4.5	111.7	153.0	5.3	94.9	203.0	7.0	71.5	32.7%
176	179	25	204	1	203	1	202	2	23	11	54.6	2.7	1.8	4.5	2014	75	4.7	107.4	104.0	6.5	77.5	119.0	7.4	67.7	148.0	9.2	54.4	24.4%
177	165	5	160	33	127	55	72	88	93	11	33.8	1.1	0.8	1.8	3258	115	4.4	113.3	135.0	5.2	96.5	142.0	5.4	91.8	163.0	6.3	80.0	14.8%
178	109	44	153	37	190	24	166	13	57	20	89.0	3.2	1.3	4.6	2248	63	3.5	142.7	89.0	4.9	101.0	123.0	6.8	73.1	146.0	8.1	61.6	18.7%
179	3	0	3	5	8	8	16	13	13	11	42.2	2.8	1.6	3.4	2608	24	1.2	434.7	36.0	1.7	289.8	60.0	2.9	173.9	94.0	4.5	111.0	56.7%
183	144	43	187	14	201	1	200	13	56	43	84.8	3.5	1.8	5.1	5070	164	4.0	123.7	229.0	5.6	88.6	297.0	7.3	68.3	369.0	9.1	55.0	24.2%
184	130	22	108	94	202	1	203	95	73	49	112.9	5.1	1.8	5.3	4342	136	3.9	127.7	144.0	4.1	120.6	256.0	7.4	67.8	320.0	9.2	54.3	25.0%
186	142	15	127	38	165	27	192	65	50	41	86.6	4.2	2.5	4.7	4737	153	4.0	123.8	171.0	4.5	110.8	239.0	6.3	79.3	332.0	8.8	57.1	38.9%
187	115	4	119	12	107	27	80	39	35	45	58.8	2.0	1.3	2.7	7650	224	3.7	136.6	267.0	4.4	114.6	313.0	5.1	97.8	391.0	6.4	78.3	24.9%
188	143	15	158	18	140	23	163	5	20	55	67.1	3.1	2.2	4.0	8195	265	4.0	123.7	329.0	5.0	99.6	383.0	5.8	85.6	529.0	8.1	62.0	38.1%
189	198	0	198	28	170	21	149	49	49	15	30.6	1.7	1.2	2.4	4905	211	5.4	93.0	237.0	6.0	82.8	257.0	6.5	76.3	304.0	7.7	64.5	18.3%
191	81	22	103	18	121	12	109	6	28	83	62.8	3.0	1.7	3.9	13208	336	3.2	157.2	430.0	4.1	122.9	565.0	5.3	93.5	746.0	7.1	70.8	32.0%
192	91	19	110	12	98	10	108	2	17	71	70.9	2.9	2.0	3.8	10018	261	3.3	153.5	333.0	4.2	120.3	403.0	5.0	99.4	565.0	7.0	70.9	40.2%
193	59	14	73	23	50	46	96	23	37	19	93.4	3.2	2.6	4.0	2034	45	2.8	180.8	58.0	3.6	140.3	68.0	4.2	119.6	110.0	6.8	74.0	61.8%
197	13	0	13	8	5	44	49	36	36	24	57.5	3.4	3.0	3.7	4171	65	1.9	256.7	77.0	2.3	216.7	90.0	2.7	185.4	190.0	5.7	87.8	111.1%
199	193	16	177	38	139	60	79	98	114	9	27.0	0.9	0.6	1.4	3329	134	5.0	99.4	146.0	5.5	91.2	155.0	5.8	85.9	170.0	6.4	78.3	9.7%
202	110	15	125	53	178	4	182	57	72	49	93.4	4.0	1.8	4.9	5245	148	3.5	141.8	188.0	4.5	111.6	281.0	6.7	74.7	355.0	8.5	59.1	26.3%
203	137	8	145	30	175	21	196	51	59	42	96.0	4.1	2.3	4.9	4373	139	4.0	125.8	168.0	4.8	104.1	233.0	6.7	75.1	312.0	8.9	56.1	33.9%
204	203	4	199	26	173	4	177	22	26	16	75.2	2.2	1.7	2.8	2127	95	5.6	89.6	104.0	6.1	81.8	113.0	6.6	75.3	142.0	8.3	59.9	25.7%
205	174	17	191	1	192	21	171	20	3	26	65.1	2.4	1.2	3.5	3992	147	4.6	108.6	184.0	5.8	86.8	221.0	6.9	72.3	260.0	8.1	61.4	17.6%
209	87	8	79	26	53	51	104	25	17	17	73.2	3.2	2.7	3.7	2321	60	3.2	154.7	69.0	3.7	134.6	78.0	4.2	119.0	128.0	6.9	72.5	64.1%
210	111	11	122	1	123	52	71	51	40	18	43.5	1.8	0.8	2.7	4135	118	3.6	140.2	146.0	4.4	113.3	178.0	5.4	92.9	206.0	6.2	80.3	15.7%
211	33	3	36	2	38	29	67	31	34	17	47.2	3.3	2.2	3.8	3604	67	2.3	215.2	83.0	2.9	173.7	114.0	4.0	126.5	177.0	6.1	81.4	55.3%
213	86	2	88	6	94	32	126	38	40	16	53.9	3.6	2.5	4.3	2969	76	3.2	156.3	91.0	3.8	130.5	118.0	5.0	100.6	177.0	7.5	67.1	50.0%
214	159	25	134	21	113	28	85	49	74	26	43.5	1.9	1.3	2.2	5983	206	4.3	116.2	219.0	4.6	109.3	251.0	5.2	95.3	311.0	6.5	77.0	23.9%
215	123	9	114	41	73	15	88	26	35	13	59.2	2.4	2.0	2.8	2197	68	3.9	129.2	75.0	4.3	117.2	81.0	4.6	108.5	117.0	6.7	75.1	44.4%
217	23	3	20	14	6	2	8	12	15	34	66.5	1.3	1.1	1.8	5109	87	2.1	234.9	105.0	2.6	194.6	113.0	2.8	180.8	159.0	3.9	128.5	40.7%
218	68	8	60	0	60	32	92	32	24	47	76.6	3.3	2.4	3.8	6136	143	2.9	171.6	166.0	3.4	147.9	212.0	4.3	115.8	329.0	6.7	74.6	55.2%
219	69	6	63	22	41	36	77	14	8	13	43.0	2.9	2.2	3.3	3023	72	3.0	167.9	82.0	3.4	147.5	98.0	4.1	123.4	152.0	6.3	79.6	55.1%
224	151	11	140	26	114	29	143	3	8	24	75.8	3.0	2.4	3.5	3166	104	4.1	121.8	118.0	4.7	107.3	133.0	5.3	95.2	193.0	7.6	65.6	45.1%
225	186	7	179	6	185	2	183	4	3	21	63.0	3.0	1.7	3.7	3334	126	4.7	105.8	147.0	5.5	90.7	181.0	6.8	73.7	226.0	8.5	59.0	24.9%

226	146	15	161	0	161	37	124	37	22	19	53.3	2.2	1.2	3.4	3564	116	4.1	122.9	148.0	5.2	96.3	177.0	6.2	80.5	212.0	7.4	67.2	19.8%
227	172	39	133	49	84	39	45	88	127	5	22.6	1.0	0.7	1.0	2214	81	4.6	109.3	81.0	4.6	109.3	86.0	4.9	103.0	99.0	5.6	89.5	15.1%
230	97	32	129	37	166	45	121	8	24	12	48.4	2.8	1.0	4.0	2478	66	3.3	150.2	90.0	4.5	110.1	126.0	6.4	78.7	145.0	7.3	68.4	15.1%
231	104	20	84	2	86	13	73	11	31	20	50.6	2.5	1.4	2.8	3952	109	3.4	145.0	120.0	3.8	131.7	154.0	4.9	102.6	198.0	6.3	79.8	28.6%
232	148	4	144	6	150	3	147	3	1	30	79.5	2.9	1.7	3.6	3772	123	4.1	122.7	144.0	4.8	104.8	182.0	6.0	82.9	232.0	7.7	65.0	27.5%
233	2	0	2	9	11	19	30	28	28	29	139.8	3.5	2.1	4.6	2074	7	0.4	1185.1	26.0	1.6	319.1	49.0	3.0	169.3	84.0	5.1	98.8	71.4%
236	180	32	148	3	145	17	162	14	18	30	60.4	3.2	2.1	3.4	4964	185	4.7	107.3	194.0	4.9	102.4	238.0	6.0	83.4	320.0	8.1	62.1	34.5%
238	56	9	65	9	74	4	70	5	14	25	78.6	2.8	1.6	3.5	3182	69	2.7	184.5	87.0	3.4	146.3	118.0	4.6	107.9	158.0	6.2	80.6	33.9%
240	204	1	203	9	194	24	170	33	34	12	42.0	1.7	1.1	2.5	2856	130	5.7	87.9	147.0	6.4	77.7	160.0	7.0	71.4	186.0	8.1	61.4	16.3%
242	96	6	90	11	101	1	102	12	6	123	46.4	3.0	1.8	3.5	26496	705	3.3	150.3	823.0	3.9	128.8	1071.0	5.1	99.0	1455.0	6.9	72.8	35.9%
246	29	14	15	15	30	60	90	75	61	20	74.7	4.3	2.9	4.4	2679	49	2.3	218.7	50.0	2.3	214.3	81.0	3.8	132.3	143.0	6.7	74.9	76.5%
247	155	10	165	2	167	25	142	23	13	39	52.1	2.4	1.2	3.4	7483	252	4.2	118.8	315.0	5.3	95.0	383.0	6.4	78.2	456.0	7.6	65.6	19.1%
248	164	43	121	36	85	32	117	4	47	21	86.0	2.8	2.3	2.8	2441	86	4.4	113.5	86.0	4.4	113.5	95.0	4.9	102.8	140.0	7.2	69.7	47.4%
249	160	4	164	27	191	26	165	1	5	35	74.9	2.9	1.2	3.8	4673	161	4.3	116.1	196.0	5.2	95.4	258.0	6.9	72.4	303.0	8.1	61.7	17.4%
250	8	14	22	2	24	5	19	3	11	14	54.9	2.0	1.1	2.7	2551	38	1.9	268.5	53.0	2.6	192.5	72.0	3.5	141.7	94.0	4.6	108.6	30.6%
254	45	7	52	12	64	49	113	61	68	32	81.1	3.9	2.8	4.7	3947	79	2.5	199.8	103.0	3.3	153.3	139.0	4.4	113.6	226.0	7.2	69.9	62.6%
255	79	28	51	14	65	30	35	16	44	15	39.8	2.0	0.9	2.1	3766	95	3.2	158.6	98.0	3.3	153.7	133.0	4.4	113.3	159.0	5.3	94.7	19.5%
256	89	49	138	1	137	9	146	8	57	38	67.7	3.0	1.9	4.4	5613	146	3.3	153.8	208.0	4.6	107.9	257.0	5.7	87.4	344.0	7.7	65.3	33.9%
258	61	26	35	116	151	55	206	171	145	17	67.3	6.8	3.6	6.8	2527	57	2.8	177.3	58.0	2.9	174.3	122.0	6.0	82.9	195.0	9.6	51.8	59.8%
259	67	19	48	11	37	13	50	2	17	44	43.1	2.5	1.8	2.9	10214	234	2.9	174.6	265.0	3.2	154.2	320.0	3.9	127.7	467.0	5.7	87.5	45.9%
261	40	8	32	6	26	3	29	3	11	57	46.8	2.2	1.4	2.5	12181	241	2.5	202.2	271.0	2.8	179.8	355.0	3.6	137.3	487.0	5.0	100.0	37.2%
262	6	13	19	10	9	8	17	2	11	11	21.1	2.0	1.7	3.0	5205	65	1.6	320.3	106.0	2.5	196.4	120.0	2.9	173.5	189.0	4.5	110.2	57.5%
263	102	6	96	20	116	61	55	41	47	12	38.2	2.0	0.7	2.5	3141	86	3.4	146.1	100.0	4.0	125.6	132.0	5.3	95.2	149.0	5.9	84.3	12.9%
264	187	1	186	5	181	7	188	2	1	38	68.0	3.1	1.9	3.9	5588	214	4.8	104.4	251.0	5.6	89.1	301.0	6.7	74.3	388.0	8.7	57.6	28.9%
265	21	6	27	22	49	2	51	24	30	28	57.5	3.0	1.6	3.6	4869	81	2.1	240.4	105.0	2.7	185.5	162.0	4.2	120.2	223.0	5.7	87.3	37.7%
266	171	13	184	13	171	14	157	27	14	34	56.8	2.4	1.4	3.4	5986	218	4.6	109.8	267.0	5.6	89.7	316.0	6.6	75.8	382.0	8.0	62.7	20.9%
267	30	7	37	15	22	7	15	22	15	15	44.3	1.5	1.0	2.1	3384	62	2.3	218.3	79.0	2.9	171.3	93.0	3.4	145.5	119.0	4.4	113.7	28.0%
276	85	4	89	22	111	1	112	23	27	118	77.6	3.3	1.9	4.0	15199	389	3.2	156.3	470.0	3.9	129.4	634.0	5.2	95.9	870.0	7.2	69.9	37.2%
280	77	5	72	5	67	84	151	79	74	24	101.3	4.3	3.3	4.7	2370	59	3.1	160.7	67.0	3.5	141.5	85.0	4.5	111.5	148.0	7.8	64.1	74.1%
281	182	10	192	3	189	5	184	8	2	59	72.8	2.7	1.7	3.8	8101	302	4.7	107.3	375.0	5.8	86.4	443.0	6.8	73.1	551.0	8.5	58.8	24.4%
282	11	11	22	1	23	19	42	20	31	18	70.6	2.9	2.1	3.6	2551	39	1.9	261.6	53.0	2.6	192.5	71.0	3.5	143.7	113.0	5.5	90.3	59.2%
284	18	8	10	5	15	5	10	0	8	23	24.3	1.8	0.9	2.0	9452	154	2.0	245.5	168.0	2.2	225.0	231.0	3.1	163.7	302.0	4.0	125.2	30.7%

285	162	11	151	23	128	1	127	24	35	22	71.3	2.6	1.9	3.1	3084	107	4.3	115.3	121.0	4.9	102.0	137.0	5.6	90.0	184.0	7.5	67.0	34.3%
288	178	16	162	10	172	31	141	21	37	17	45.6	2.4	1.0	3.0	3727	138	4.6	108.0	155.0	5.2	96.2	197.0	6.6	75.7	227.0	7.6	65.7	15.2%
290	64	5	69	2	71	18	53	16	11	25	47.1	2.3	1.2	2.9	5309	121	2.8	175.5	147.0	3.5	144.5	193.0	4.5	110.0	245.0	5.8	86.7	26.9%
292	1	0	1	0	1	2	3	2	2	9	38.5	2.4	1.2	3.0	2338	6	0.3	1558.7	18.0	1.0	519.6	40.0	2.1	233.8	62.0	3.3	150.8	55.0%
293	185	2	183	5	188	1	187	4	2	43	59.3	3.0	1.7	3.8	7257	274	4.7	105.9	323.0	5.6	89.9	396.0	6.8	73.3	496.0	8.5	58.5	25.3%
297	16	4	12	9	21	0	21	9	5	89	42.9	2.4	1.4	2.7	20734	333	2.0	249.1	381.0	2.3	217.7	547.0	3.3	151.6	775.0	4.7	107.0	41.7%
298	14	3	17	14	31	9	40	23	26	15	52.2	3.0	1.7	3.5	2874	46	2.0	249.9	56.0	2.4	205.3	87.0	3.8	132.1	126.0	5.5	91.2	44.8%
299	175	6	169	13	182	3	179	10	4	57	70.5	3.1	1.7	3.8	8083	298	4.6	108.5	344.0	5.3	94.0	437.0	6.8	74.0	545.0	8.4	59.3	24.7%
300	152	21	173	4	169	37	132	41	20	20	37.4	2.1	1.1	3.4	5350	178	4.2	120.2	231.0	5.4	92.6	277.0	6.5	77.3	322.0	7.5	66.5	16.2%
302	60	35	95	2	97	28	69	26	9	13	45.4	2.2	1.2	3.4	2865	64	2.8	179.1	91.0	4.0	125.9	115.0	5.0	99.7	142.0	6.2	80.7	23.5%
303	15	51	66	69	135	64	199	133	184	72	78.0	5.6	3.4	7.1	9228	148	2.0	249.4	254.0	3.4	145.3	417.0	5.6	88.5	671.0	9.1	55.0	60.9%
304	127	66	193	15	208	1	207	14	80	33	105.8	4.1	2.2	6.1	3119	97	3.9	128.6	145.0	5.8	86.0	192.0	7.7	65.0	248.0	9.9	50.3	29.2%
307	192	4	188	8	180	4	176	12	16	84	69.1	2.7	1.6	3.3	12163	488	5.0	99.7	551.0	5.7	88.3	653.0	6.7	74.5	812.0	8.3	59.9	24.3%
308	112	19	131	11	142	6	136	5	24	33	66.3	3.0	1.7	3.9	4979	144	3.6	138.3	182.0	4.6	109.4	235.0	5.9	84.7	301.0	7.6	66.2	28.1%
314	66	2	64	18	82	63	145	81	79	29	74.6	4.2	2.9	4.8	3887	89	2.9	174.7	106.0	3.4	146.7	148.0	4.8	105.1	238.0	7.7	65.3	60.8%
316	181	11	170	7	177	3	174	4	7	74	75.4	3.0	1.6	3.6	9819	366	4.7	107.3	418.0	5.3	94.0	524.0	6.7	75.0	652.0	8.3	60.2	24.4%
318	75	1	74	4	78	6	84	10	9	36	86.5	2.9	1.8	3.4	4164	103	3.1	161.7	120.0	3.6	138.8	157.0	4.7	106.1	216.0	6.5	77.1	37.6%
320	12	8	4	8	12	13	25	21	13	18	52.8	2.9	1.8	2.9	3409	53	1.9	257.3	54.0	2.0	252.5	82.0	3.0	166.3	132.0	4.8	103.3	61.0%
321	28	42	70	33	103	49	54	16	26	10	35.5	2.4	0.8	3.6	2815	51	2.3	220.8	78.0	3.5	144.4	114.0	5.1	98.8	132.0	5.9	85.3	15.8%
322	46	6	40	11	29	33	62	22	16	23	88.7	3.0	2.3	3.6	2594	52	2.5	199.5	64.0	3.1	162.1	78.0	3.8	133.0	126.0	6.1	82.3	61.5%
324	134	25	159	17	176	2	178	19	44	72	93.7	3.3	1.7	4.4	7683	243	4.0	126.5	309.0	5.0	99.5	410.0	6.7	75.0	513.0	8.3	59.9	25.1%
325	36	15	21	7	14	0	14	7	22	15	28.5	1.8	1.3	1.9	5271	102	2.4	206.7	109.0	2.6	193.4	128.0	3.0	164.7	183.0	4.3	115.2	43.0%
326	93	7	86	50	36	14	22	64	71	7	27.1	0.9	0.8	1.4	2586	68	3.3	152.1	79.0	3.8	130.9	81.0	3.9	127.7	97.0	4.7	106.6	19.8%
327	80	27	53	7	46	11	57	4	23	16	64.5	2.7	1.8	2.8	2480	63	3.2	157.5	65.0	3.3	152.6	82.0	4.1	121.0	118.0	5.9	84.1	43.9%
328	207	1	206	7	199	5	204	2	3	14	49.6	2.7	2.1	3.4	2820	135	6.0	83.6	150.0	6.6	75.2	163.0	7.2	69.2	211.0	9.4	53.5	29.4%
332	10	3	7	3	4	5	9	2	1	30	35.7	1.8	1.3	2.1	8402	126	1.9	266.7	142.0	2.1	236.7	179.0	2.7	187.8	264.0	3.9	127.3	47.5%
333	177	5	182	13	195	6	189	7	12	106	78.2	3.2	1.7	4.1	13557	501	4.6	108.2	602.0	5.6	90.1	760.0	7.0	71.4	946.0	8.7	57.3	24.5%
335	103	1	104	2	102	7	95	9	8	51	63.6	2.6	1.7	3.3	8013	221	3.4	145.0	264.0	4.1	121.4	324.0	5.1	98.9	433.0	6.8	74.0	33.6%
336	94	38	132	12	120	2	118	14	24	15	50.8	2.6	1.9	3.9	2953	78	3.3	151.4	108.0	4.6	109.4	125.0	5.3	94.5	170.0	7.2	69.5	36.0%
337	32	18	14	3	17	10	27	13	5	22	52.4	2.6	1.8	2.6	4202	78	2.3	215.5	78.0	2.3	215.5	106.0	3.2	158.6	165.0	4.9	101.9	55.7%
340	132	2	130	5	125	24	101	29	31	29	59.9	2.3	1.4	2.9	4844	153	3.9	126.6	177.0	4.6	109.5	210.0	5.4	92.3	266.0	6.9	72.8	26.7%
341	27	34	61	22	39	7	46	15	19	30	78.8	2.2	1.6	3.4	3806	67	2.2	227.2	103.0	3.4	147.8	122.0	4.0	124.8	171.0	5.6	89.0	40.2%

342	150	3	147	23	124	26	150	3	0	22	85.0	2.9	2.4	3.7	2588	85	4.1	121.8	101.0	4.9	102.5	112.0	5.4	92.4	161.0	7.8	64.3	43.8%
343	118	27	91	21	70	13	83	8	35	25	59.6	2.6	1.9	2.7	4193	126	3.8	133.1	131.0	3.9	128.0	152.0	4.5	110.3	217.0	6.5	77.3	42.8%
344	20	11	9	10	19	7	12	3	8	15	37.1	2.0	1.0	2.1	4040	66	2.0	244.8	69.0	2.1	234.2	103.0	3.2	156.9	134.0	4.1	120.6	30.1%
347	169	9	178	18	196	5	201	23	32	61	78.6	3.7	2.1	4.7	7764	279	4.5	111.3	341.0	5.5	91.1	438.0	7.1	70.9	570.0	9.2	54.5	30.1%
348	51	5	56	9	47	9	56	0	5	40	69.7	2.6	1.8	3.4	5743	118	2.6	194.7	154.0	3.4	149.2	190.0	4.1	120.9	273.0	5.9	84.1	43.7%
350	147	29	118	35	83	39	44	74	103	31	79.5	1.2	0.7	1.5	3897	127	4.1	122.7	136.0	4.4	114.6	151.0	4.8	103.2	173.0	5.5	90.1	14.6%
351	161	7	168	16	152	29	123	45	38	29	70.3	2.1	1.3	3.1	4124	143	4.3	115.4	175.0	5.3	94.3	200.0	6.1	82.5	244.0	7.4	67.6	22.0%
352	183	7	190	6	184	9	175	15	8	27	112.6	2.6	1.6	3.7	2397	90	4.7	106.5	110.0	5.7	87.2	130.0	6.8	73.8	160.0	8.3	59.9	23.1%
353	19	5	24	3	27	110	137	113	118	45	74.9	5.0	3.9	5.5	6007	98	2.0	245.2	126.0	2.6	190.7	178.0	3.7	135.0	364.0	7.6	66.0	104.5%
354	72	22	94	18	76	18	58	36	14	42	61.6	2.0	1.3	2.9	6822	167	3.1	163.4	216.0	4.0	126.3	256.0	4.7	106.6	326.0	6.0	83.7	27.3%
355	71	14	57	24	33	7	26	31	45	7	28.5	1.5	1.1	1.8	2459	60	3.1	163.9	66.0	3.4	149.0	75.0	3.8	131.1	96.0	4.9	102.5	28.0%
356	107	10	97	7	90	104	194	97	87	43	73.7	4.8	3.9	5.4	5838	162	3.5	144.1	186.0	4.0	125.5	229.0	4.9	102.0	412.0	8.8	56.7	79.9%
357	153	2	155	5	160	45	205	50	52	38	122.3	4.4	3.2	5.2	3108	104	4.2	119.5	124.0	5.0	100.3	154.0	6.2	80.7	234.0	9.4	53.1	51.9%
358	114	21	93	29	122	68	190	97	76	31	80.4	4.8	3.4	5.1	3855	112	3.6	137.7	121.0	3.9	127.4	165.0	5.4	93.5	269.0	8.7	57.3	63.0%
360	55	10	45	5	40	9	31	14	24	19	55.5	2.0	1.1	2.4	3426	74	2.7	185.2	86.0	3.1	159.3	110.0	4.0	124.6	141.0	5.1	97.2	28.2%
362	157	0	157	19	138	26	164	7	7	18	68.1	3.1	2.3	3.8	2643	90	4.3	117.5	106.0	5.0	99.7	123.0	5.8	86.0	171.0	8.1	61.8	39.0%
364	73	5	78	32	110	23	133	55	60	26	122.5	3.8	2.4	4.5	2123	52	3.1	163.3	63.0	3.7	134.8	88.0	5.2	96.5	128.0	7.5	66.3	45.5%
365	50	21	29	16	13	11	24	5	26	33	54.7	2.0	1.7	2.2	6029	123	2.6	196.1	132.0	2.7	182.7	146.0	3.0	165.2	229.0	4.7	105.3	56.8%
366	98	14	112	8	104	52	156	44	58	38	133.9	3.7	2.9	4.6	2837	76	3.3	149.3	96.0	4.2	118.2	115.0	5.1	98.7	181.0	8.0	62.7	57.4%
367	190	23	167	5	162	31	193	26	3	32	64.3	3.5	2.5	3.9	4975	195	4.9	102.1	211.0	5.3	94.3	249.0	6.3	79.9	350.0	8.8	56.9	40.6%
370	106	6	100	4	96	29	125	25	19	25	117.2	3.4	2.5	4.0	2133	59	3.5	144.6	69.0	4.0	123.7	85.0	5.0	100.4	127.0	7.4	67.2	49.4%
377	105	34	71	63	134	51	185	114	80	38	116.6	5.0	2.9	5.1	3259	90	3.5	144.8	91.0	3.5	143.3	147.0	5.6	88.7	222.0	8.5	58.7	51.0%
380	78	10	68	47	115	5	110	42	32	58	82.6	3.6	1.8	4.0	7021	176	3.1	159.6	194.0	3.5	144.8	295.0	5.3	95.2	398.0	7.1	70.6	34.9%

Appendix B: Map calculator commands, software used, and scripts.

Map Calculator Commands:

1. Isolating the flow accumulation data for a given sub-watershed:

([wshed20000] = 20).con([Facc], (0.asgrid / 0.asgrid)).Int

(0.asgrid / 0.asgrid) returns a [No Data] section for the remainder of the watershed. The "Int" command returns an integer grid which is essential for displaying the value / count grid attribute table.

2. Breaking a larger watershed area into smaller sub-watershed units for analysis:
create coarse flow net: ([flow accumulation] > 999).con(1.asgrid,0.asgrid)
create stream links: ([coarsenet]).streamlink([flow direction])
create sub-watersheds: [flow direction].Watershed([streamLinkGrid])

3. Analyzing Stream Frequency at a given threshold value:
Create flow net at desired threshold: ([flow accumulation] > 81).con(1.asgrid,0.asgrid)
Create streamlinks: ([flownet81]).streamlink([flow direction])
Summarize zones with sub-watershed as zonal theme, the result "Variety" contains the number of streams links in each subshed, # / Area gives stream frequency.

4. Calculating Flow Length, avoiding problems with parallel flow paths creating artificially high. Set the stream network to null in the flow direction grid, thus, all measurements are only to stream length, not downstream measurements.

5. Obtaining a grid from the vector Contour Crenulation network appropriate for overland flow length calculations and comparison with ANIM raster grids.
First, thin the CCNEt: ([Ccnet]).thin(FALSE, FALSE, TRUE, 1)
Calculate Flowdir_nilchannel: ([ccnet_thin]).setnull([Bb2_dir])
Obtain overland flow length: ([Flowdir_nilchannel]).flowlength(Nil, FALSE)

6. Producing the ridge accumulation weighting grid and use this grid as a weighting grid input into the flow accumulation routine:

```
Isolate ridgecells=grid:([Flow Accumulation] == 0)
Perform accumulation:
FlowDir.FlowAccumulation(ridgecellgrid)
```

Software Installation and use:

Install the MapWindow extension for ArcGIS available at:
http://hydrology.neng.usu.edu/taudem/
Must un-select the option to “Check for Edge Contamination”.

Identifying Outlet Point: outlet = con([facc] = *max of flow acc.*, 1)

B.1: Avenue Script for automating the division of watersheds into sub-watershed units based on a minimum threshold for stream links, the identification of headwater sub-watersheds, and the calculation of flow lengths for each sub-watershed and ANIM.

```
' do a subshed theme based on streamlinks and given threshold
' takes as input a minimum threshold for determining sub-watershed
' analysis units, a prefix for output dbase files, a flow direction
' grid theme, and a flow accumulation theme.
' The ANIM networks to be analyzed should be selected at the time
' of script execution.

theView = av.GetActiveDoc

workdir = "C:\working\thesis\analysis\regional_T\nw10ha\"
tempDir = "C:\working\thesis\analysis\temp\"

' get minimum size
status = TRUE
while (status)
  minSize = MsgBox.Input("Enter the minimum number of"+NL+
                         "cells for a Stream Network:", "Stream
Network", "5000")

if (minSize = NIL) then return NIL end
  if (minSize.IsNumber and (minSize.AsNumber > 0)) then
    status = FALSE
  else
    status = TRUE
    MsgBox.Error("The minimum Stream Network size must be a number
greater than 0","Watershed")
  end
end

' get file prefix
prefix = MsgBox.Input("Enter prefix for the output files:", "Prefix",
"pre_")

'Prompt for flow direction theme.  zye 10/4
TheThms=av.run("hydro.GetThms",{TheView,false,GTheme})
TheFdirThm=msgbox.ChoiceAsString(TheThms,"Select the Flow Direction
grid theme",Script.The.GetName)
if(TheFdirThm=nil)then
   exit
end
FlowDir=TheFdirThm.GetGrid


'Prompt for flow Accum theme.  zye 10/4
TheThms=av.run("hydro.GetThms",{TheView,false,GTheme})
TheFaccThm=msgbox.ChoiceAsString(TheThms,"Select the Flow Accumulation
grid theme",Script.The.GetName)
if(TheFaccThm=nil)then
   exit
end
Faccum=TheFaccThm.GetGrid
```

```
'Faccum = FlowDir.FlowAccumulation(1.asGrid)

StreamNet = (Faccum < minSize.AsNumber.AsGrid).SetNull(1.AsGrid)
LinkNet=StreamNet.streamLink(FlowDir)
SubShedTheme=FlowDir.watershed(LinkNet)

' create a theme to add SubShed theme to view
gthm = GTheme.Make(SubShedTheme)

' set name of theme
gthm.SetName("SubShed " + minSize)
' add theme to the view
theView.AddTheme(gthm)
' get zone theme
zoneTargets = theView.GetActiveThemes

zoneObj = SubShedTheme.GetVTab
'get zone Field from zoneObj
zoneField = zoneObj.FindField("Value")
' get value theme

  for each zTarg in zoneTargets
    valueTheme = zTarg
    ' obtain grid from value theme and create VTab
    theGrid = valueTheme.GetGrid
    aPrj = theView.GetProjection
    bName = valueTheme.GetName
    aFN = (workdir + prefix + "_" + bName + "_" + minSize +
".dbf").AsFileName
    theVTab =
theGrid.ZonalStatsTable(SubShedTheme,aPrj,zoneField,FALSE,aFN)

    ' attempt to join a summary of the flow accum table
    ' to the summary of the stream network table
    ' in order to evaluate if it is a headwater subshed
    ' a headwater subshed will have its (max accum value + 1) equal to
its
    ' number of cells
    accumFileName = (tempDir + prefix + "_" + bName + "_acc_" + minSize
+ ".dbf").AsFileName
    theAccumTab =
Faccum.ZonalStatsTable(SubShedTheme,aPrj,zoneField,FALSE,accumFileName)
    ' now locate the Value fields
    theBitmap=theVTab.GetSelection
    theAccumTab.Query( "[Count] = ([Max] + 1)",
theBitmap,#vtab_seltype_new)
    NetVField=theVTab.FindField("Value")
    AccumVField=theAccumTab.FindField("Value")
    theVTab.Join(NetVField,theAccumTab,AccumVField)


    ' check for error during operation
    if (theVTab.HasError) then
       return NIL
    end
    zoneTable = Table.Make(theVTab)
    'zoneTable.GetWin.Activate
```

```
  'accTable = Table.Make(theAccumTab)
  'accTable.GetWin.Activate

  theVTab.SetEditable(TRUE)

  ' add field indicating headwater, and set selected to be true
  Apn = field.make("Headwater",#field_char,10,0)
  'zFtab = zoneTable.GetFTab
  theVTab.addfields({apn})
  HWRecords = theVTab.GetSelection

  hwfield = theVTab.FindField("Headwater")

  for each rec in HWRecords
     theVTab.SetValue(hwfield, rec, "true")
  end
  theVTab.SetEditable(FALSE)

end
```