FLUVIAL GEOMORPHOLOGY ON A GLACIAL TILL PLAIN

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By

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SCOPE AND CONTENTS:

Fluvial channel adjustment on a glaciated till plain in Southern Ontario is investigated. Mallot River, a component of the Grand River system is used as an example. Concepts of equilibrium and underfitness are discussed. Field studies include over thirty miles of longitudinal and transverse valley profiles. Laboratory investigation produced a detailed map from air photographs. It contains more than 15,000 First Order segments. Morphometric analyses were conducted using this base. A hierarchy of drainage density is suggested. A comparison with drainage on non-glaciated material concludes the study.

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CHAPTER ONE

INTRODUCTION AND LITERATURE REVIEW

The purpose of this paper is to investigate certain fluvial morphometric parameters on a glacial till plain. The emphasis is toward descriptive and analytical river basin morphology relating to the role of equilibrium. A stream basin in Ontario is studied as an example of conditions common to many glacial till plains. The basin contains a Wisconsin glacial spillway. The modern stream in the basin can be expected to be of underfit type with morphometric parameters altered by the fossil valley. Stream basin morphometry will be investigated to clarify anomalies discovered by the analysis.

Three conceptual methods are used. First, Hortonian analysis is a well known tool which is readily and cheaply available to measure basin properties. Second, Dury has led exhaustive research concerning underfit streams. Results of these published reports have application to fluvial morphology in Ontario. Third, the concept of equilibrium acts as a convenient device to distinguish regimes of fluvial adjustment. The interrelationships of underfit streams and equilibrium characteristics can be examined to help explain post-glacial landscape evolution. Definition and clarification must be given to the above topics before the techniques of analysis can be developed.

HORTONIAN ANALYSIS

Hortonian analysis involves the employment of a series of tests investigating aspects of river basin numeric, metric and areal parameters with respect to their "order". Strahler (1957) adjusted Horton's (1945) method so that any unbranched tributary, defined as a First Order stream, will produce a Second Order when combining with another First Order segment. A large number of Second Order streams will be developed by this method. Similarly, a stream of one order combines with another stream of the same order to produce a channel one order greater. A hierarchy of orders results. Measurements taken within each order are analysed. Strahler and Morisawa, among others, have shown that there is an excellent exponential relationship between stream order and the following: number of stream segments, length of segments and area and relief of basins. These properties are commonly displayed as straight line functions on semi-logarithmic scales.

The reason for excellent correlation between order and the logarithm of a parameter has been questioned. Horton indicated that the function was due to natural fluvial processes. Research by Shreve has proven that random factors alone can account for the observed correlation. A random walk model produces Hortonian results. Shreve (1966, 1967, 1969), Smart (1968, 1969), and James and Krumbein (1969) show that most areas free of geologic controls have natural water channel networks which are close to being topologically random (Abrahams, 1972: 627). As a corollary, one would expect that for most cases variations away from random conditions will indicate the effect of geological controls. Since a surface of random topography will provide excellent Hortonian correlations, irregularities appearing in the analysis will represent deviations from randomness. The geologic controls of an area can be seen as departures from topological randomness. In Hortonian analysis a straight line represents a topologically random situation; deviations from it represent a form of disequilibrium.

It is suggested that a stream segment on a till plain and its basin are topologically random if either can be shown to be in equilibrium or quasi-equilibrium with its climatic environment. In this graded situation only random variations control the network of channels, and therefore, their basins. Disequilibrium conditions are indicative of non-random adjustment. The underfit stream is the most striking departure from randomness upon a till plain dissected by a spillway. This method, therefore, can filter valuable information concerning the glacial tills in the test basin. The Horton-Strahler ordering technique allows standardized analysis, producing values easily comparable with other environments. Allometric basin scaling can be effectively equated to isometry or Strahler's (1958) homotheticity for areas larger than model size.

The exact definition of a First Order stream has been a point of controversy in the literature. This unit is the prime building block in the analysis. Horton (1945) proposed the use of the blue line on topographic maps; Morisawa (1957) strongly questioned this method. Her alternative, contour crenulations, provides an indication of channel position. Neither method resolves the problems of scale where many orders may be missing on a small scale map. Seasonal variations are problematic if the definition of a water-bearing channel is used. The unbranched channel is the most logical definition, but in reality there are ephemeral passages, fractions of inches in length, that transmit water. No exact method is available to distinguish what constitutes a channel. In this study, an unbranched segment of the river network on whatever map is used, best describes a First Order segment. The methods of map preparation are ignored at this stage.

UNDERFIT RIVERS AND STREAMS

The existence of a glacial spillway containing a small stream suggests the study of underfit streams. There has been little research concerned with the role of misfit streams in Ontario. The term misfit river is a more general term effectively equivalent to underfit in usage.

An early description of underfit streams is given by Davis (1913: 1). There is a relation "...between the small-curved meanders of a river and the larger-curved meanders of its valley...." Further, he states that

> ...the best cases...are found in well-defined incised meandering valleys, the floors of which have a breadth sufficient to allow the river to wander in a more irregular path than that of the curved valley.

The widespread occurrence of meandering rivers in meandering valleys indicates that there has been a general reduction in dominant discharge (Dury, 1958: 116; 1953: 197). While high discharge is not necessarily always caused by glacial or near-glacial conditions of climate, this concept seems sound when considering Southern

Ontario drainage. The manifestly underfit stream described above is the most common form of the underfit.

Davis' definition of an underfit presupposes that the paleo-channel must have been in a meandering regime or stage. There is no reason to require a meandering paleo-stream and, therefore, valley in order to produce an underfit. The underfit is caused by a simple reduction of flow. A straight valley could contain a meandering underfit stream. Dury (1964a) describes in detail the possible arrangements of rivers and their valleys. It is not even necessary for the existing stream to meander. As Dury (1966) states:

> It is entirely possible for a stream to occupy valley meanders and to be underfit, without developing stream meanders on its present channel. A leading instance of this is the Osage River...where underfitness is proved by spacing of pool and riffle.

In Ontario, straight valleys and reasonably straight rivers are associated to produce underfit environments.

While Davis did not intend to imply that there is an appropriate valley size for a given stream, it can be said there is an appropriate grade or equilibrium condition for the valley and stream related to the local climate after an interval of time (Dury, 1954: 194).

EQUILIBRIUM

Melton (1955: 21) recognizes that mature drainage systems are adjusted to the regional climatic and geologic environment. Gilbert and Davis both used concepts of equilibrium in fluvial geomorphology long before it was populariezed by Hack (1957) and as quasi-equilibrium by Langbein and Leopold (1964). Howard (1965: 303-305), citing Hall and Fagen (1956), describes equilibrium as a complete adjustment of the internal variables to external conditions. If the external variables remain constant, the system will remain in equilibrium; a change in an external variable will cause an adjustment in the system parameters.

Hack (1960: 89) entitles a section "Examples of Erosionally Graded or Equilibrium Topography", indicating he considers his dynamic equilibrium and Mackin's (1948) concept of grade to be virtually synonymous. Mackin's (1948: 471) definition of a graded stream is:

> ...one in which over a period of years, slope is delicately adjusted to provide, with available discharge and with prevailing channel characteristics, just the velocity required for the transportation of the load supplied from the drainage basin. The graded stream is a system in equilibrium; its diagnostic characteristic is that any change in any of the controlling factors will cause a displacement of the equilibrium in

> a direction that will tend to absorb the effect of the change.

The term "shifting equilibrium" (Mackin, 1948) or "quasi-equilibrium" (Langbein & Leopold, 1964) is best used to describe natural conditions. Scouring and filling with daily and seasonal weather variations will alter characteristics of the stream but change in altitude or declivity will not occur (Mackin, 1948: 475-476). Howard (1965: 305) feels that even if a river system never achieves exact equilibrium, " it will within a finite period reach any desired approximation to equilibrium".

Geomorphic systems exchange mass and energy with their surroundings and so operate as open systems subject to Le Chatelier's Principle. If

> ...given sufficient time and a reasonably constant environment, the graded stream tends to the steady state, wherein the slope is adjusted to provide sufficient velocity to transport out of any segment an amount of debris load equivalent to that which is introduced from the upstream segment.
>
> (Culling, 1957: 261)

In a closed system the initial conditions are enough to predict the ultimate equilibrium position. There is no ultimate position in an open system, only a position of equilibrium adjusted to the long-term prevailing conditions

(Langbein & Leopold, 1964: 793). Geologic controls, therefore, are not determining factors in profile and basin shape, but are one input amongst a number of external variables. Closed systems have a geologic memory; open systems do not.

The role of eroded material is further refined by Ahnert (1966). He defines equilibrium as the condition where waste removal is equal to the rate of waste arrival from upstream plus the local rate of waste production. This is a denudational equilibrium. Where local weathering is zero, a transport equilibrium is established. A negative disequilibrium exists if potential removal is greater than the total of the waste arriving and that locally produced. Ahnert similarly defines a positive disequilibrium, then contrasts the terms with degradation and aggradation. An "external equilibrium" (Young, 1970, quoting Ahnert, 1966) can be clarified with an example: a slope is adjusted by both surface processes acting on it and the external rate of river erosion at its base.

A definition relating the passage of material through a system to equilibrium is basically Davisian in origin. This form of equilibrium is reached almost immediately (Hack, 1960: 86). Hack's equilibrium is between the processes of erosion and the resistance of the rocks as they are uplifted or tilted. Davis' concept is not stage related, while Hack's attempts are. The implied tool, producing equilibrium, is energy.

Chorley (1956: 423) referring to Strahler (1952) states that the landscape is a

> ...series of open physical systems... tending toward equilibrium with respect to the import and export of energy considered over a period of time.

Langbein and Leopold (1964: 305) believe equilibrium is a condition of balance between tendencies toward equal areal distribution of energy expenditure and minimum total work expended. There would be an efficiency of erosion in an equilibrium state. Overland flow of runoff produces equal areal distribution of energy while channel flow produces the economies of scale for efficient erosion (Jackson, 1971, quoting Woldenberg, 1968). A combination of the two factors, sheetflow and channel flow, are displayed in the areal distribution of the flow network. It can be expected that areally measurable parameters will be able to define equilibrium.

The shape of the longitudinal profile has been used as the most diagnostic tool for determining equilibrium in a river basin. Culling (1957: 261) has argued that "the history of the graded stream segment as a self-regulatory entity commences at the regularization of the profile". The term "regularization" is deliberately left vague since many complex inter-related factors are involved. Discharge, velocity, sediment load, channel shape, channel roughness, lithology, relief and climate all adjust a stream's long profile (Miller, 1958 and Brush, 1961). Hack (1960: 84) describes the profile of equilibrium only as "the uniform or regular concave-upward longitudinal profile that is characteristic of many streams". At no time does he propose a quantitative differentiation between equilibrium and non-equilibrium profiles of streams. The cause of equilibrium is simply described as a regular downstream change in some of the many variables mentioned above. Increasing discharge downstream, a function of area, is most important.

In glacial drift areas the processes initiated by spillways must be studied in light of underfit morphology.

> If a particular valley had been carved during the Pleistocene by a relatively large river, and through change in climate or other physiographic factors the valley at present carries only a minor streamlet, it is likely that the small stream would not be able to recarve the valley bed to such an extent that the valley slope is materially altered. In such a circumstance the minor stream, initially at least, would have to accommodate itself to the slope of the valley in which it flows.
>
> (Leopold & Miller, 1956)

The river is not in grade nor in a dynamic equilibrium with the existing climatic conditions. In Mackin's shifting equilibrium a slow lowering of grade maintains equilibrium. A rapid lowering, typical of glacially-caused underfits, creates features such as waterfalls and rapids which aim to re-establish a graded profile. The stream is "clearly ungraded or not in equilibrium during the transitional periods" (Mackin, 1948: 477).

Culling (1957: 262) describes a river's adjustment to a new external environment as:

> ...a continual source of disturbance to the open system to which it responds as a complex unit. Any disturbance will ultimately affect the regularity of the profile and, by way of changes in the bed slope will be propogated throughout the segment.

The transmission of disturbance is the prime cause of the variations away from a topographically random areal drainage pattern. The time of adjustment to the new environment would involve changes in slope profile, drainage pattern and basin shape (Howard, 1965 and Langbein & Leopold, 1964). It is implied in Davis' work that

> ...some parts of a drainage system would be in equilibrium whereas at the same time other parts would not, and that the condition of equilibrium is in time gradually extending from the downstream position to the entire drainage system.
>
> (Hack, 1960: 86)

Davis' concept of regrading is consistent with the three stages of Surrell (1870) where a stream is first characterized by regularity, solidarity and persistence, then regrades due to external conditions, and then finally achieves stability and balance of steady state (Culling, 1957). Erosion does progress upstream at a knickpoint, but the progression to equilibrium is more complex.

A river basin, it may be argued, is the primary unit of fluvial equilibrium. The basin catchment develops the discharge which produces the overland, groundwater and channelized flow. To be in equilibrium with the existing climatic environment, a stream must be in equilibrium with its basin. The change toward equilibrium upstream from the mouth in an underfit river system appears to be in conflict with the observations of basin response. Small basins, irregardless of location, come to equilibrium before larger ones. When hierarchies of basins are considered, stochastic changes by order can be conceived.

As an example, a moderately large underfit system of Order Seven can be seen to be in disequilibrium, since it was not created by existing climatic conditions. Insufficient erosion has occurred to produce a graded environment. It is a fossil landform. The variables in the river basin may similarly be considered not to be in equilibrium nor in a random arrangement. Within the same Seventh Order basin a small river segment of First Order may have come to equilibrium.

The amount of erosion, since the climatic change, was sufficient to allow the low relief segment to recarve its basin to conditions in keeping with its new environment. The variables within the First Order basin and its similarly adjusted neighbours will be randomly expressed. This is in keeping with the findings of Shreve (1966). Over a finite period of time, internal adjustments toward equilibrium will progress hierarchically and stochastically from the First Order toward the higher order basins. Despite complex successive regrading in the headward direction, relative to order, equilibrium is progressing in the downstream direction. Given this reasoning, a stochastic point of discontinuity must exist between the higher order segments and the lower order portions. This threshold would separate two rather different stream economies (Langbein & Leopold, 1964). Rephrased, the upper portion of Horton's mesh length would have achieved grade through erosion. Successively higher Horton orders would obtain equilibrium until the entire underfit system, through erosion and deposition, achieves grade.

Locating such points of discontinuity could contribute toward a general theory dating underfit stream adjustment and a theory of erosional knickpoint behaviour. The relevance to this study is as an aid to the understanding of fluvial processes in an underfit glacial drift environment.

TECHNIQUE

The analysis in this paper is biased toward a planimetric investigation stemming from a desire to utilize remote sensing capabilities. Much of the data used in CHAPTER THREE is based on a map compiled from low altitude panchromatic aerial photography. Techniques used to produce the map are described in APPENDIX ONE. Field study was used for ground truth and the construction of longitudinal and transverse profiles. Profiling could have been accomplished with the photography, but ground control was lacking. As great an accuracy as possible was desired. Although the drainage pattern was easily observed using standard coverage, it has been proven that other altitudes, films and imaging techniques can produce equivalent or superior results with less time input (Bruce & Jackson, in preparation).

Parry and Turner (1971) detail evidence that infrared film is superior to panchromatic in the delineation of small water courses. I.-R. photography has the capability of showing depositional forms, shallow water inundations and saturated ground water conditions. First Order delineation was better, and Second and Third Order detection was far superior, using I.-R. in basin analysis (Parry & Turner, 1971).

K-Band radar imagery is a growing field producing accurate and inexpensive reconnaissance surveys (McCoy, 1969). A visual, essentially planimetric, representation of a drainage network at 1:200,000 is roughly equivalent to a topographic map at 1:62,500 for drainage display. Stream numbers, lengths, areas and ratios are all well represented. The tool is important for humid (cloudy) and arctic (unmapped) zones. McCoy's (1971) edge enhancement method has been coupled with an automatic measuring system to give direct river basin analysis. The W.A.T.E.R.[1] system, parts of which are shown in CHAPTER THREE, is a straightforward tool analyzing planimetric aspects in great detail. Tedious repetitive measures are rapidly accomplished using the program. Remote sensing capabilities coupled with computerized analysis will allow innumerable comparisons of fluvial environments. This study, areal in nature, allows comparison with a potentially large library of fluvial environments.

A strong correlation between many measured variables permits the substitution of areally calculated values for parameters of different dimensions. The most common example is that of the ability to substitute basin drainage area

---

[1] W.A.T.E.R., Computer Programs for Watershed Analysis developed by the University of Toronto and Purdue University and adapted to C.D.C. by Wm. Bruce.

for basin runoff. The two values are well correlated (Leopold, 1953: 611; Hack, 1957: 54; Morisawa, 1962:1038; and Howard, 1965: 304). Cherkawer (1972: 353) equated not only runoff but sediment load to area. The correlation of flow and load was previously shown by Hack (1960: 84).

Leopold and Miller (1956) and Gregory (1966) working with ephemeral desert networks were forced to obtain equivalent parameters representing hydrologic data. Planimetric methods of analysis were used. A "spin-off" of the research was the potential application of the method to other environments. The equivalent parameters can be easily and cheaply obtained using remote sensing sources. The developed techniques have been shown to be closely connected to channel network topology by Shreve (1969), Abrahams (1972) and Cherkawer (1972).

Melton (1957, 1958), Gregory and Walling (1968) and Orsborn (1970) have correlated density to water yield, sediment yield, the precipitation-effectiveness index, the runoff-intensity frequency and the percent of bare area. Channel width varies with discharge downstream and thus may be calculated from area (Leopold & Miller, 1956: 13). Dury (1954) and Nixon (1959) have related bedwidth to the square root of runoff. Morisawa (1962: 1038) associates basin outline to the unit hydrograph and basin circularity to runoff. It is becoming clear that it is no longer necessary to do tedious field analysis when simple equivalents are available. Efficiency increased, expensive field time can be put to more effective use accomplishing analyses as yet impossible from afar.

CHAPTER TWO

STUDY AREA

In order to study fluvial development upon surfaces of glacial deposition, a sample area was chosen in west-central Southern Ontario. Topographic and thematic maps were used to select a locality which satisfied predetermined requirements. The basin had to be of a size suitable for study in one summer season. It had to be upon a glacial till plain devoid of major irregularities. The setting had to approximate as closely as possible the requirement of low-relief topological randomness. A glacial spillway was required to bisect the basin, as this is typical of a glaciated area.

The Mallot River, a segment of the Conestogo, which is a major tributary of the Grand River, filled the basic requirements and thus was chosen for study. The basin is shown in FIGURES 2-1 and 2-2.

Having a basin approximately 30.9 square miles in area, the river originates in the north, just south of an esker, at an altitude of 1525 feet, then falls 350 feet to its mouth at about 1275 feet. The water

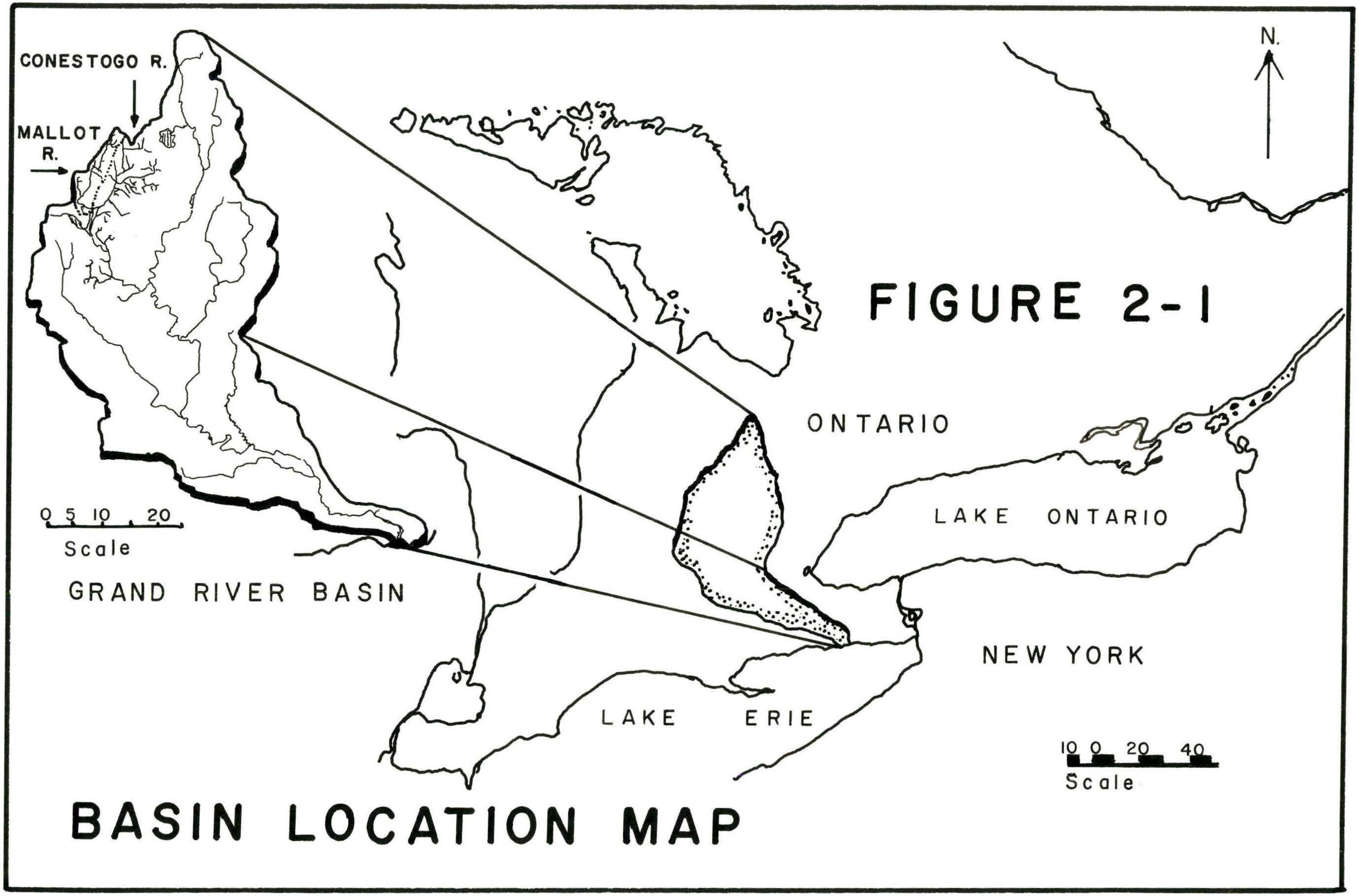
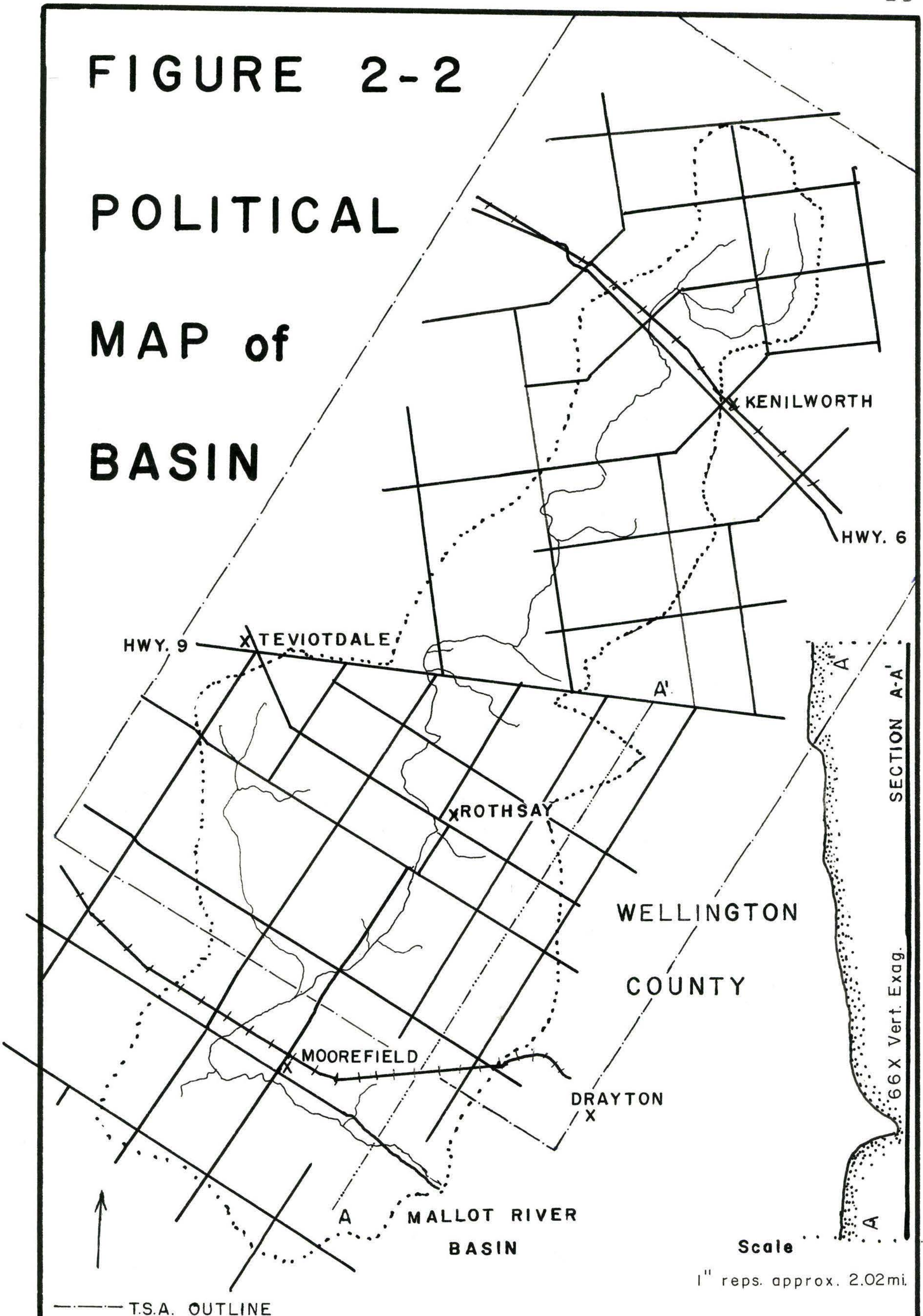


FIGURE 2-1

BASIN LOCATION MAP

FIGURE 2-2 POLITICAL MAP of BASIN



flows into the Conestogo River south of Drayton, in a reach which at high water comprises part of the back-water curve from the Conestogo Dam. A cross-section A to A' on FIGURE 2-2 shows the nature of the till plain and the river valley.

The economy of the area is basically one of field crops, dairy cattle and hogs. Rural non-farm housing is recent, but growing. A feed processing plant and poultry co-operative complete the rural land use. The local centres of Moorefield, Rothsay and Kenilworth service the agri-cultural, building and low order urban needs.

TABLE 2-1 gives basic rainfall and temperature data for the recent past. FIGURE 2-3 shows a plot of the data which typifies the weather of central Southern Ontario.

Bankfull discharge has a recurrence interval of between 1.58 and 2.54 years according to some authors (Leopold & Wolman, 1957; Dury, 1958). The river channel is scaled to the bankfull stage. Spring thaws probably increase the frequency of the dominant local discharge to once each year in Ontario. Yearly bankfull stages in un-consolidated material quicken the rate of adjustment to equilibrium.

There has been no systematic measurement of the discharge of the Mallot River, but data is available for

TABLE 2-1

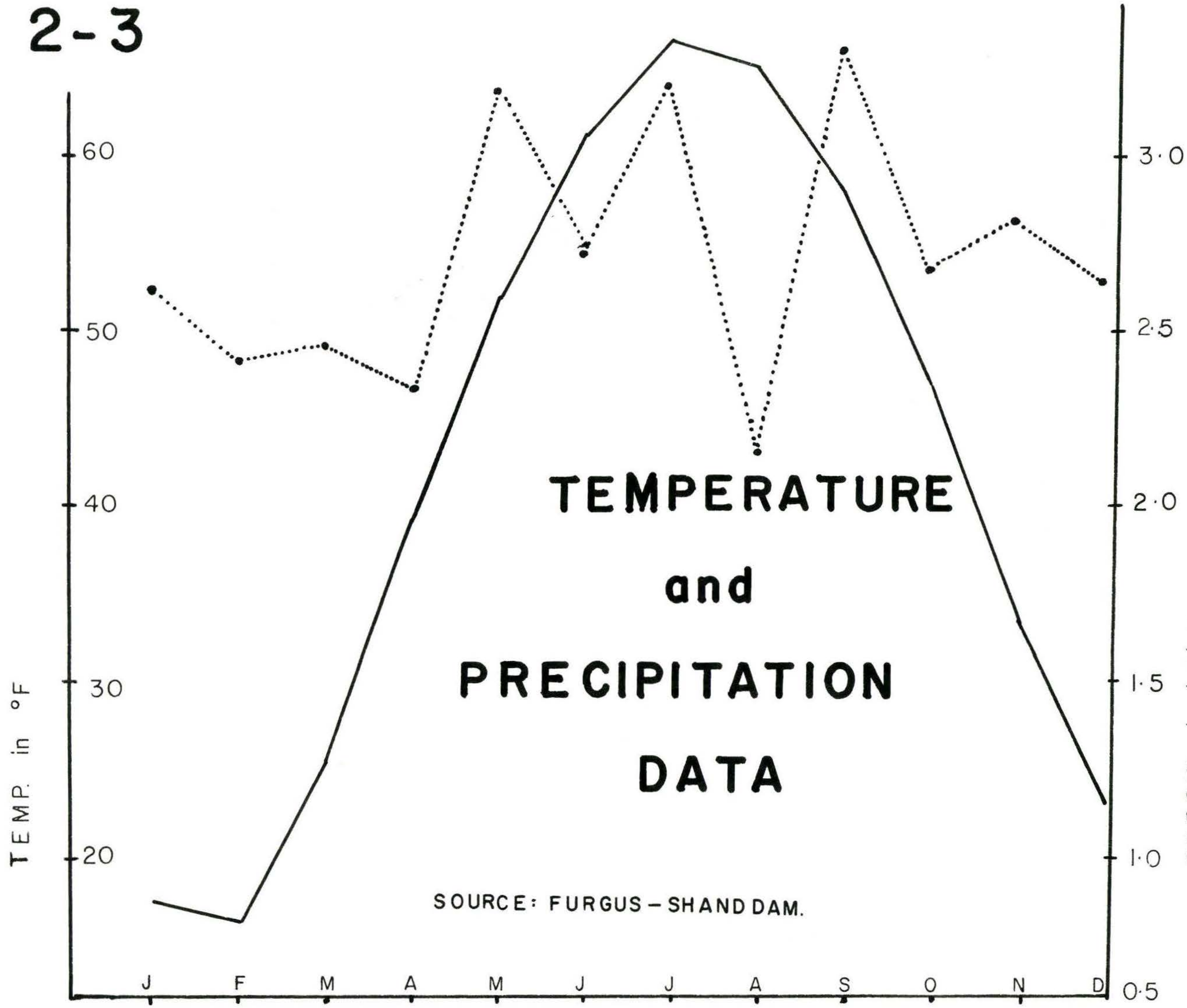
MEAN MONTHLY TEMPERATURE AND PRECIPITATION

	J	F	M	A	M	J	J	A	S	O	N	D
Mean Daily Temperature for the Month in Degrees Farenheit	17.6	16.4	25.5	39.1	51.9	61.2	66.6	65.1	58.0	46.9	33.4	23.1
$\bar{x}$ = 42.1												
Total Monthly Precipitation in inches	2.62	2.41	2.46	2.33	3.19	2.72	3.20	2.15	3.30	2.67	2.81	2.64
Total = 32.5												
$\bar{x}$ = 2.7												

Data from Fergus-Shand Dam, 15 miles to the E.S.E. from Mallot River.

Data gives 'normal' values as calculated for 1958 conditions.

FIGURE 2-3



TEMPERATURE
and
PRECIPITATION
DATA
SOURCE: FURGUS – SHAND DAM.
TEMP. in °F
60
50
40
30
20
PRECIP. in inches
3·0
2·5
2·0
1·5
1·0
0·5
J F M A M J J A S O N D

the neighbouring basin, the Upper Conestogo at Drayton. Values were generated for the Mallot Basin using Conestogo data scaled to the appropriate drainage basin area (TABLE 2-2). This transformation is used only to provide an indication of yearly flow levels.

The bedrock of the region has been described in detail by Sanford (1961) and Sanford and Quillian (1959). Silurian sandstone, limestone and shale of the Medina formation underlies grey and buff dolomites of the Lockport and Guelph formations. Grey calcareous shales and brown platy dolomite of the Salina formation cap the bedrock (Hoffman, et al, 1963).

Hough (1958: 76-86) briefly summarized the pre-Pleistocene geologic history. The paths of pre-glacial streams have been determined from well logs of bedrock height (Subins, 1964). The paleo-rivers that existed on bedrock can be argued to have achieved equilibrium with their environment. Bedrock is not exposed in the Mallot Basin. The importance of the bedrock is not in its exact composition but in its existence and slope orientation at specific depths.

The till overburden combines with the bedrock to jointly produce the topographic surface. The drift is of two slightly different groups, loam and clay loam tills. In the northern half of the basin loam tills are characterized by yellowish brown colour and brown dolomitic

TABLE 2-2

MEAN DAILY DISCHARGE BY MONTH IN C.F.S.

Time	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sept.
1958-59	0.9	3.9	3.7	2.4	1.9	52.4	264.5	46.5	2.3	2.1	16.8	17.6
1959-60	29.9	79.8	31.9	17.1	24.5	18.0	257.1	91.0	14.1	0.9	0.3	0.2
1960-61	0.6	3.2	1.3	1.2	33.9	72.4	49.2	25.0	8.6	1.3	1.0	1.2
1961-62	0.7	4.0	15.8	2.6	2.5	95.4	75.6	3.8	1.2	0.5	0.6	0.6
1962-63	2.5	5.0	5.5	5.8	2.9	32.9	8.9	6.7	1.2	1.1	0.9	1.1
1963-64	0.5	1.6	1.2	19.3	12.0	90.5	71.2	6.5	1.6	0.4	12.6	1.2

Data Source: Drayton Ontario Readings of Conestogo River (Stn. #2GA17) adjusted to Mallot River area.
Average Discharge over 10 years is 33.4 c.f.s.
Extreme flows: maximum - 1370 c.f.s. (April, 1956)
minimum - 0 c.f.s. (occasional summer periods).

origin. The till is highly calcareous (Hoffman, et al, 1963). The clay loam tills in the southern basin have a small variation of silt and clay content within the overburden. There are few stones within the material. Thin silt deposits cover the till.

The three elements, bedrock depth, till thickness, and topological surface height, can be studied for possible inter-relationships. Trend surface analyses were made of these elements in an area which comprises most of the basin. FIGURE 2-2 shows the outline of the area investigated. The analyses were biased toward the upper and central reaches to remove the influence of the radical shift in river direction south of Moorefield. The bedrock trend was used to indicate possible pre-glacial factors that might correlate with surface patterns. The thickness of till was similarly investigated to study glacial and post-glacial effects.

Data was randomly obtained by interpolation from the 1:50,000 topographic maps, 40P15 East and West, and Preliminary Map Number P166, the Palmerston sheet of the bedrock topography series. Of the two hundred and thirty-nene control points, only surface bench marks and well loggings give accurate point data. All of these available values were used.

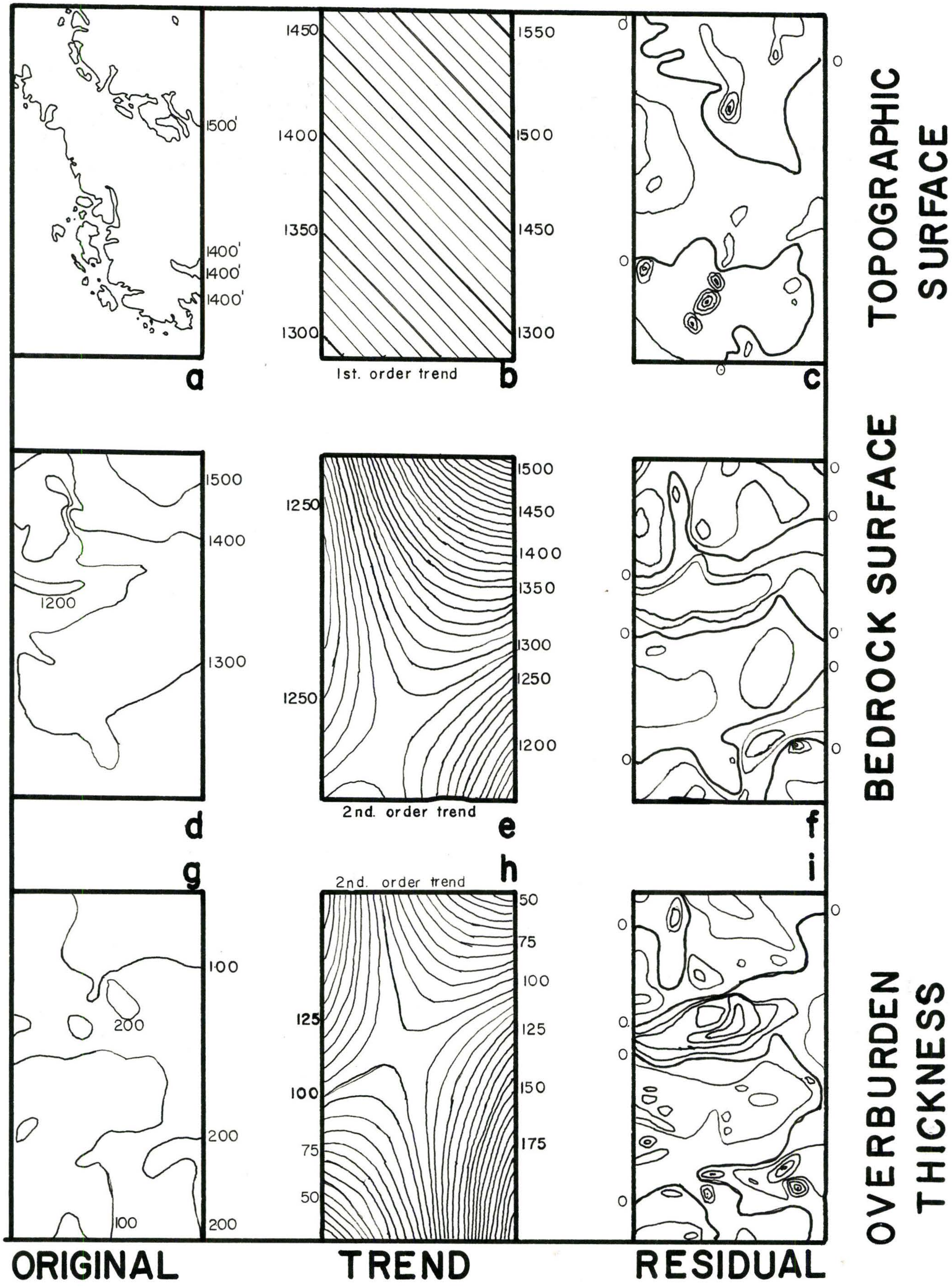
The method, according to Dillon (1967: 1194), is

"...useful to delineate regional or generalized trends in a set of data" or as a means of "...subtracting out these regional effects and leaving behind a 'residual' that represents variations caused by local anomalies". Details of methods used are supplied in APPENDIX TWO. The regional trend is of a limited area, only tens of square miles in area, the micro-topographic features on the scale of the river are important. The simplification of the three surfaces allows an ease of comparison not available from normal maps. Correlations, for example, are made with more facility.

The surface landscape is shown in FIGURE 2-4a with contours from the topographic maps. The first order trend, with a correlation of 84 percent, is obvious from the original map. The dip slope of 7.3 degrees is oriented -47 degrees to the page. The residuals of the surface show the effect of the river along its route. Despite the regional surface trend, the residuals indicate that there is a weak saddle with higher points in the upper and lower quadrants and the lower points across the centre. The role of the area as a drainage divide between the Grand and Thames systems is emphasized by this saddle. The topographic surface is straightforward in its first order simplification.

Regionally, the general orientation of the bedrock, "...a plain sloping gently to the south west at

FIGURE 2-4 TOPOGRAPHIC T.S.A.



about 12 or 15 feet per mile," (Karrow: 6) controls the ground surface slope. A quadratic trend of random numbers generates a correlation of 12.0 percent. The bedrock correlation of 71.0 percent indicates a significant value. The resultant pattern is indicative of a saddle that was probably a feature of the pre-glacial drainage. The location of the basin in the figure, and the low central 1200 foot contour line "V" in the west tends to indicate the direction of paleo-flow. Fluvial discharge can be expected to have caused the low point. Random variations in till overburden, stream piracy and the effects of the spillway would influence the final drainage direction. No distinctive features stand out in the residuals. The pattern of the fluvially eroded bedrock is emphasized in the left centre of the figure. The topographic and bedrock surfaces are definitely comparable. Slopes, saddles and orientations are similar upon them. As a result, we are concerned with a rather uniform veneer of till deposited over the original rock surface.

The overburden creates what Sanford (1961: 16) described as a "...very flat surface topography" with depths ranging from a few to six hundred feet. The blanket of till does, in fact, damp the effect of bedrock on the surface features as Sanford proposes, but the similarity of FIGURES 2-4b and 2-4e remains. The second order trend, FIGURE 2-4h, has a pattern the mirror image of that of the bedrock. High bedrock areas are thinly covered; low bedrock areas thickly covered. The quadratic trends of bedrock and till are strikingly similar (FIGURES 2-4e and 2-4h). The relative heights in the similarly oriented saddles are opposites. A high point in one corresponds to a low point on the other. The central points of the saddles are slightly offset. This shift could be investigated further as an indicator of the process of glacial deposition, but that is not the purpose of this paper. Residual values, influenced greatly by local fluctuations, are again opposite in value to those of the bedrock residuals.

Buffered from the bedrock, influenced only by the gentle surface tilt, surface stream channel patterns develop randomly. The existence of the glacial spillway has acted as an interruption, delaying the river's adjustment toward equilibrium.

If there was indeed a glacial spillway through the Mallot River Basin, its existence could be verified by a series of transverse valley profiles. Schumm (1956: 634) has sketched a theoretical progression of fluvial valley profiles across a basin. The series, shown in FIGURE 2-5a, ranges from a flattened V-shaped valley

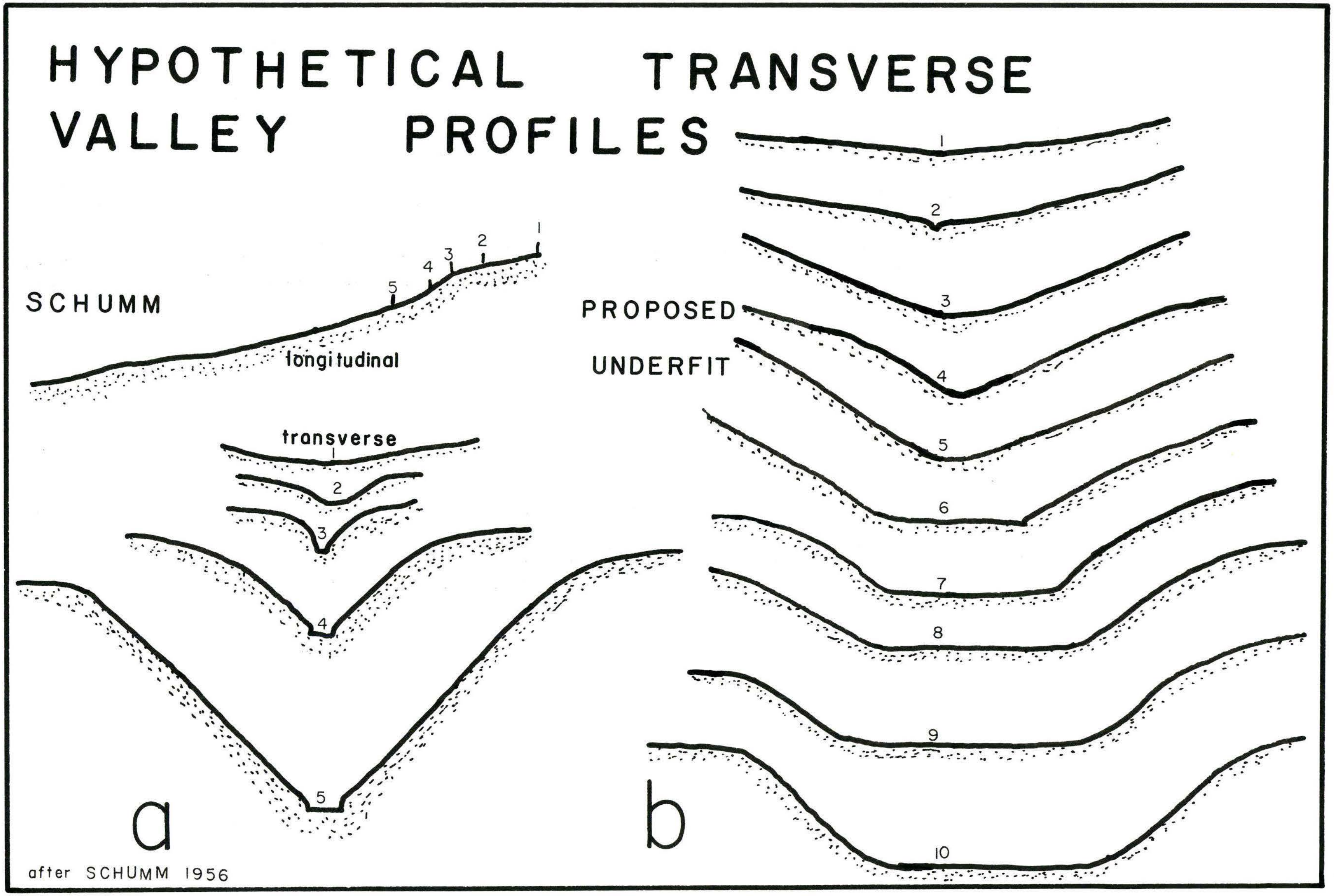

HYPOTHETICAL TRANSVERSE VALLEY PROFILES
SCHUMM
1
2
3
4
5
longitudinal
transverse
1
2
3
4
5
a
after SCHUMM 1956
PROPOSED UNDERFIT
1
2
3
4
5
6
7
8
9
10
b

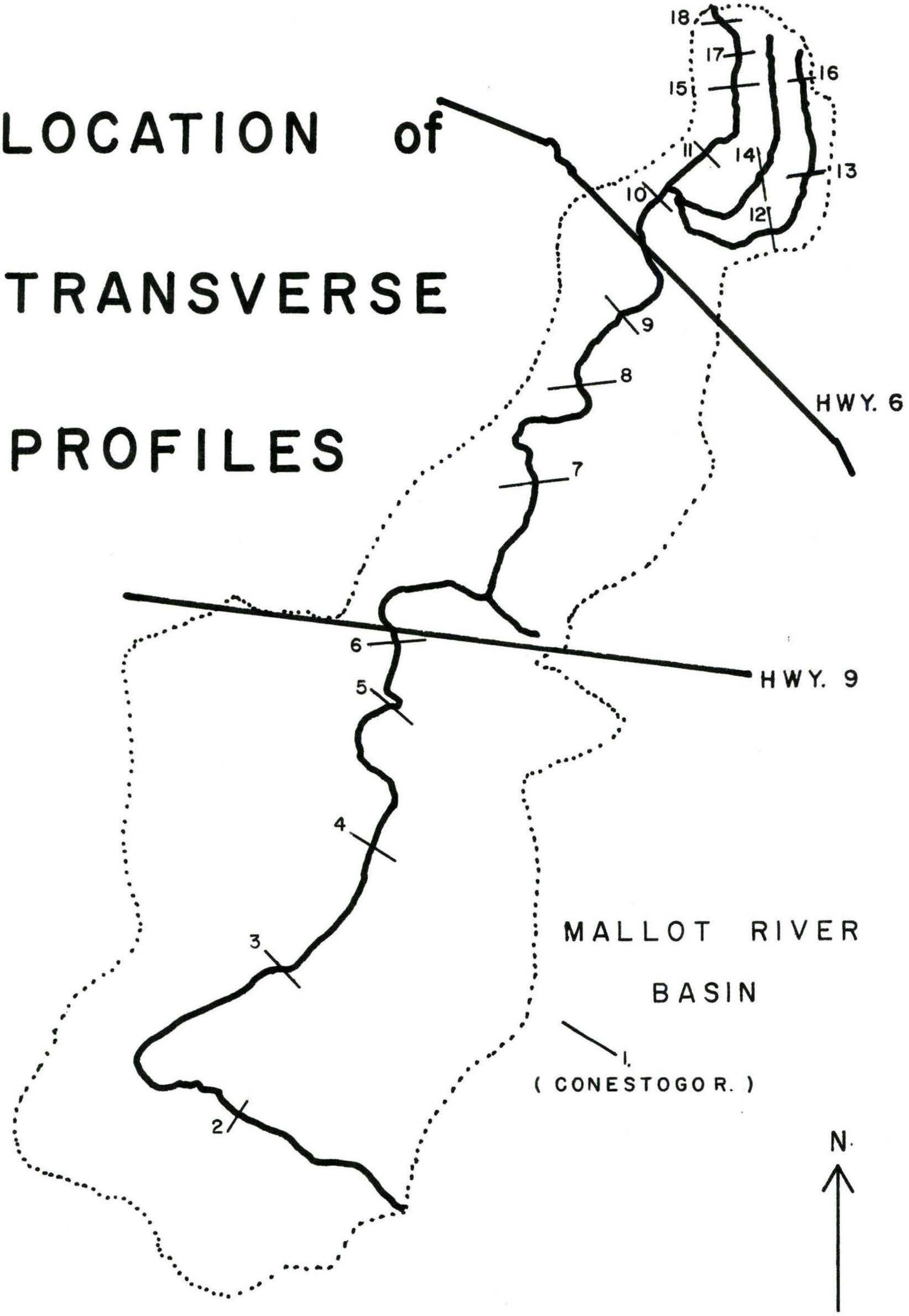
FIGURE 2-5

to a larger, deeper, but similarly shaped section in the lower reaches. A similar progression can be projected for an underfit river in a glacial spillway, FIGURE 2-5b, assuming symmetry of valley slopes. The lower basin would have a flat-bottomed, U-shaped valley, the underfit occupying a portion of the floor. There would be a similar valley floor in equivalent profiles extending up the basin until the main river channel ceased to have been glacially caused. Headwaters would have the characteristic V-shaped valley, which flattens progressively toward the basin top.

Eighteen topographic profiles were surveyed by levelling across the Mallot valley to investigate the spillway location and the character of the valley slopes. Approximately half of the profiles were across the three upper-most tributaries. Profile locations are given in FIGURE 2-6 and the results in FIGURE 2-7. There is a 10X vertical exaggeration to emphasize irregularities. The profiles are viewed as if looking upstream. The arrows intersect the profile at the position of the river and indicate the direction of valley sinuosity at that point. Although efforts were made to use only straight valley reaches to avoid valley widening due to meanders, in some cases this was impossible. The resultant deviation is relevant to the valley assymmetry discussed below.

FIGURE 2-6

LOCATION of TRANSVERSE PROFILES



PROFILES for FIGURE 2-7 are NUMBERED.

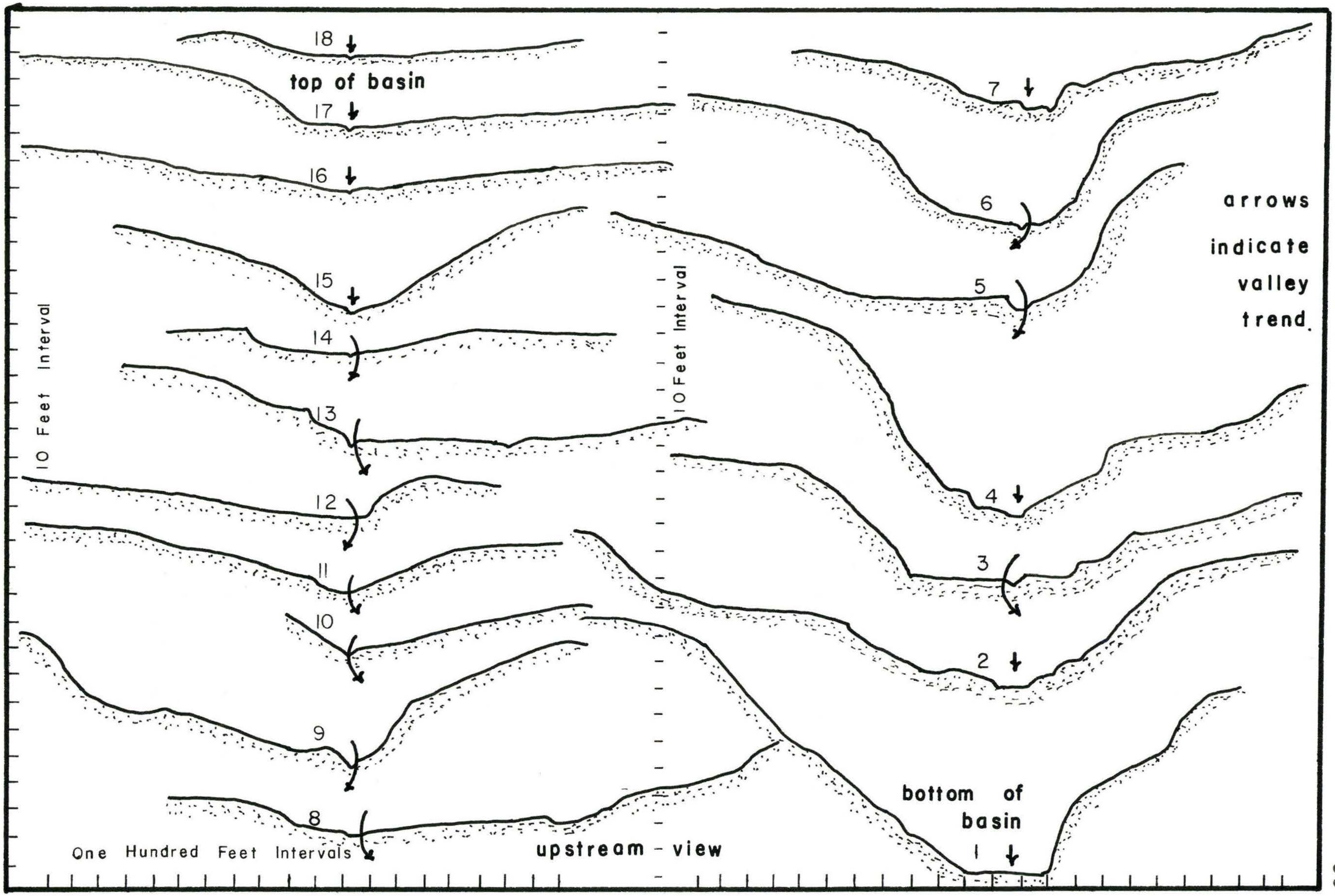


FIGURE 2-7 TRANSVERSE PROFILES

Reading the figure top to bottom, left to right, the progression downstream is not dissimilar to that which was expected, except for the assymmetry of the valley shape. Upper reaches, profiles 10-18 (FIGURE 2-7), have the V-shaped valley common for slopes which are adjusted to the river. The lower river valley, exemplified by profile 3, has a greater relief and a flat-bottomed valley. Irregularities seem to exist in the progression of profiles.

Profiles of the lower basin seem to fit into two different categories. Cross sections 1 to 6 have well defined valley walls and, at least, a small floodplain a couple of hundred feet wide. Profiles 7 to 9 have more irregular topography with less relief. The existence of an underfit system is evident in the latter not from the profiles but from the pattern of a meandering river in a meandering valley. The wide low relief plain is undoubtedly a result of the movement of the paleochannel. Meander cut-offs in the central portion of the basin indicate that the irregularities are fluvially caused. If Davis' definition of underfit streams is employed, the Mallot River is an underfit in its central reaches. If the central basin is underfit, then by the classic definition the lower basin can be expected to be the same.

The first six profiles correspond to the model proposed in FIGURE 2-5. The valleys are generally over 2000 feet across; the valley floor wider than a few hundred feet; the river is rarely wider than 30 feet. Contemporary discharges are insufficient to produce valley widths as large as those indicated.

The spillway must have extended through the Mallot Basin from a point below profile 10 (FIGURE 2-7). Profile 10 is too narrow to have held a spillway. An inspection of onsite conditions and topographic maps verifies the route. The basin divide West of the river and above Highway 6 consists of a swamp, unlike most of the perimeter. This was the entrance of the spillway into the basin.

The location of the glacio-fluvial channel is shown in FIGURE 2-8. In the north-west the water entered from what is now the Saugeen River system, meandering near profile 9, undercutting the east bank. The paleo-channel is of a moderate size, smaller than a master channel to the east, in what is now the Conestogo valley. Regionally, a braided fluvial environment may be pictured. A similar, although smaller, runoff channel meanders into the basin near Wagram. A swamp on the basin divide again indicates the entrance.

Below Highway 9 and the confluence of the two

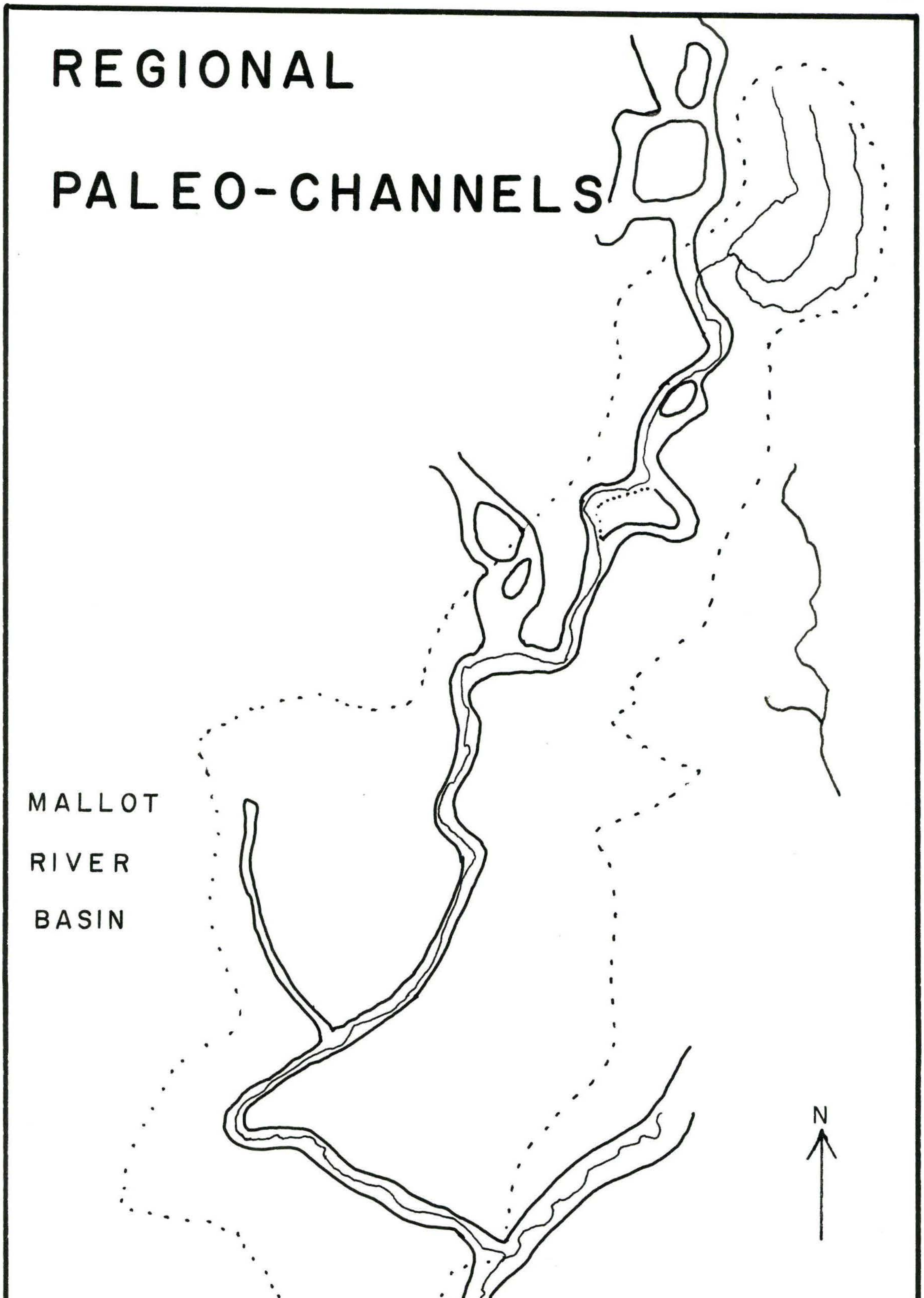

REGIONAL
PALEO-CHANNELS
MALLOT
RIVER
BASIN
N
1" reps. approx. 2.02 mi.

FIGURE 2-8

channels mentioned above, the increased discharge was of sufficient strength to produce erosion downwards. The greater entrenchment can be seen by comparing the relief of profiles 6 and 7. Profile 6 has 50 feet of relief, while profile 7 has 33 feet. The valley gradient does not change significantly below the confluence, but the quantity of flow and, therefore, available river power has.

In order to more clearly evaluate the problem of regime change in the Mallot Basin, the cross-sectional area of the paleo-channel, as indicated by the transverse levelling, was compared for the spillway both above and below the confluence of the two channels. Existing slopes roughly indicate the paleo-bankfull waterlevel. Profile 8 yields a cross-sectional area of 3.3 square units for the spillway. Profiles 2, 3 and 4 have areas of 3.9, 3.3, and 3.5 square units. It would appear from this weak evidence that the cross-sectional areas of the spillway are approximately similar both above and below the confluence. If this is indeed true, then an increase in channel velocity must compensate for the increased discharge. It is this increased velocity which accounts for the straightening and deepening of the valley.

The mechanism which may cause the regime change at this location may also be related to the change in till classification. The meandering paleo-channel was on loam tills while the straighter valley is through clay-loam tills. No data is available on the relative shear strengths of the two tills. It may be argued that a slightly higher clay content in southern basin tills caused a change in spillway regime so that entrenchment was produced. The erosion was amplified by an increased water velocity.

Although the paleo-channel is quite straight, neither a uniform bed nor a straight thalweg may be assumed (Leopold & Wolman, 1957: 55). Thalwegs have been noticed to meander in straight channels. The underfit would tend to follow the thalweg of the paleo-channel. Constrained by the entrenchment of the thalweg, a river of the Osage type, typified by pool and riffle, would result until through deposition the bed was raised sufficiently to allow meandering on the floodplain. The reduced flow would warrant a regime change in the discharge. A manifestly underfit river should be created, but the pre-existing constraint prevents stream meandering from developing. The river then creates pools and riffles to compensate. The relatively weak channel is unable to significantly modify the thalweg by erosion. Deposition from erosion upstream may result from the very low channel slope. A floodplain would only exist after the paleo-thalweg had been filled in; the constriction reduced. Until the process of deposition had occurred there would be no stream meanders. Observations of the lower Mallot River tend to support these points.

The portion of the river immediately below Rothsay and extending downstream three concessions has marked pool and riffle. The portion of the river from south of Moorefield to the mouth has pronounced meandering. The longitudinal profile of the two areas indicates no irregularity in the slight slope. It is possible to argue that deposition downstream from Moorefield has removed the constraint of the thalweg and allowed meandering to commence.

Braiding of glacial meltwater channels is common below existing alpine glaciers. A change in scale allows an analogy to be extended to the meltwaters of the continental glaciers. The fluvial source extended across a far wider frontage. Not one braided stream, but an interconnected lattice, would result. Cogley (1973) has created a model which indicates the tremendous water discharge from a melting icecap. Chapman and Putnam (1966), on their map, clearly display the braiding of spillway channels in Southern Ontario.

The complex pattern of spillway channels is related to a regime change in flow. Leopold and Miller (1956: 63) proposed that decreased discharge would change a braided reach to a meandering one. The existing meanders and relatively low discharge in Southern Ontario contrast with paleo-conditions of braided spillways and greater flow. This helps prove that Leopold and Miller's interpretation is correct. There has been a regime change since the deglacial period. An equivalent interpretation of the regime change has been made by Troll (1954) and Kremer (1954) in Europe according to Dury (1964).

The valley profiles shown in FIGURE 2-7 are presumed, by reason of valley meander tendencies, to be of fluvial origin. The paleo-stream can be seen to have undercut its bank predictably at valley bends. While the fluvial influence seems to explain assymmetry in valley slopes, this is not the only possible factor. Assymmetrical valleys commonly have a climatic origin.

An inspection was made of east-west trending and north-south trending transverse profiles in order that comparisons could be made to examples of climatically caused valley assymmetry. Melton (1960) uses basal corrosion in east-west trending valleys to show that north facing slopes become steeper. The river at profiles 2, 12, and 14 trend east-west. The steepest slope is towards the north in one, towards the south in another, and is about equal in the third. Melton's climatically caused assymmetry fails to explain differences of slope angle in this Southern Ontario river.

In an area of greater relief Hack and Goodlett (1960) found slopes facing the eastern quadrants to be steeper. This observation is true in a third of the remaining profiles (3, 4, 10, 13, and 17), but untrue in another third (1,5,6,9, and 11), and unclear in the remainder of the profiles (7, 8, 15, 16, and 18). This suggests strongly that climate again cannot account for the slope angle orientation.

Packer (1964) investigated slope angles and orientation in topography very similar to that of the Mallot River. He found no correlation. The present study adds further evidence to indicate that there is a lack of climatic influence on slope angles. The poor explanations derived from theories of differential weathering contrast with excellent results if a fluvial origin is believed. A fluvial rather than glacial or slope process oriented explanation of valley origin is upheld for the Mallot Basin.

Dury (1964c) has evaluated individual factors most likely to have operated in the past to produce higher discharges. In Southern Ontario it is recognized that a melting ice front put out the enormous quantities of water which produce spillways (Chapman and Putnam, 1966; Cogley, 1973). More and larger rainfalls appear to be the most likely causative factors in underfit valleys which are not spillways (Dury, 1964c). It appears probable that there was increased precipitation on the spillway interfluves in Ontario. Both large and small channels would be influenced by the greater frequency and intensity of rainfall.

Packer (1964) studied slope form in relation to fluvial erosion in parts of Southern Ontario which are quite similar to the Mallot River environment. He concluded that there are five types of slope, the "slip-off", "active", "transitional", "stability", and "oversteepened". An oversteepened reach becomes active as it is undercut by a stream. A stability slope is unchanging in angle, ending usually at a floodplain rather than a stream, and is generally steeper than the slip-off slope which is common inside a meander. This slope exists during stages of active downcutting. An active slope is basally sapped. The transitional slope has decreasing slope as the stability situation is approached.

Packer's explanation of the origin of these slopes is as follows: a river in a "v"-shaped valley produces an active and slip-off slope. The slip-off will regress to become a stability slope producing a small floodplain. As the stream changes sides and undercuts the slope an oversteepened reach will be produced. The floodplain will gradually widen as the stream basally saps the valley slope. Successive meandering effectively widens the valley floor producing the characteristic profile which is evident in FIGURE 2-7, profiles 1 to 6. An explanation is given for the origin of valleys which does not include mention of underfit valleys.

The findings in the Mallot River basin cast serious doubt upon these conclusions of Packer. The transverse profiles 10 through 18 indicate support for aspects of the classification if the vertical exaggeration of the minor relief is accepted. Profile 1, akin to relief studied by Packer, displays bank erosion, but the process did not produce the wide Conestogo River valley. Chapman and Putnam (1966: map insert) clearly indicate that it is a spillway route. It is believed that the figure of fifty meters of river erosion cut through drift discussed by Packer needs further investigation. If the valley erosion and related basal sapping he describes was virtually completed by the spillway, as is most likely, the most recent ten thousand years will have produced changes in the slope to proceed toward an equilibrium with existing climate. This appears to negate the existence of the active slope and the growing slip-off slope of Packer. Landforms would be reduced in relief by denudation and deposition. Packer supposes that considerable erosion of the valley has been caused by the existing streams and neglects either the existence of, or the erosive power of, the spillway. His system of valley genesis fails, because what he saw were underfits undergoing adjustment. The floodplain is altered by ongoing processes but was not caused by existing processes. The situation has been summarized by Peltier (1950: 230): considering the regimes of different climatic cycles

> ...there may occur transition phases and areas of the invasion of first one and then another climatic regime as the climatic zones have shifted or changed their properties. Whenever these changes are so recent that the effects of the previous geographic cycle have not been erased, polygenetic topographics result. Those topographics are the result of two or more superimposed morphogenetic regimes.

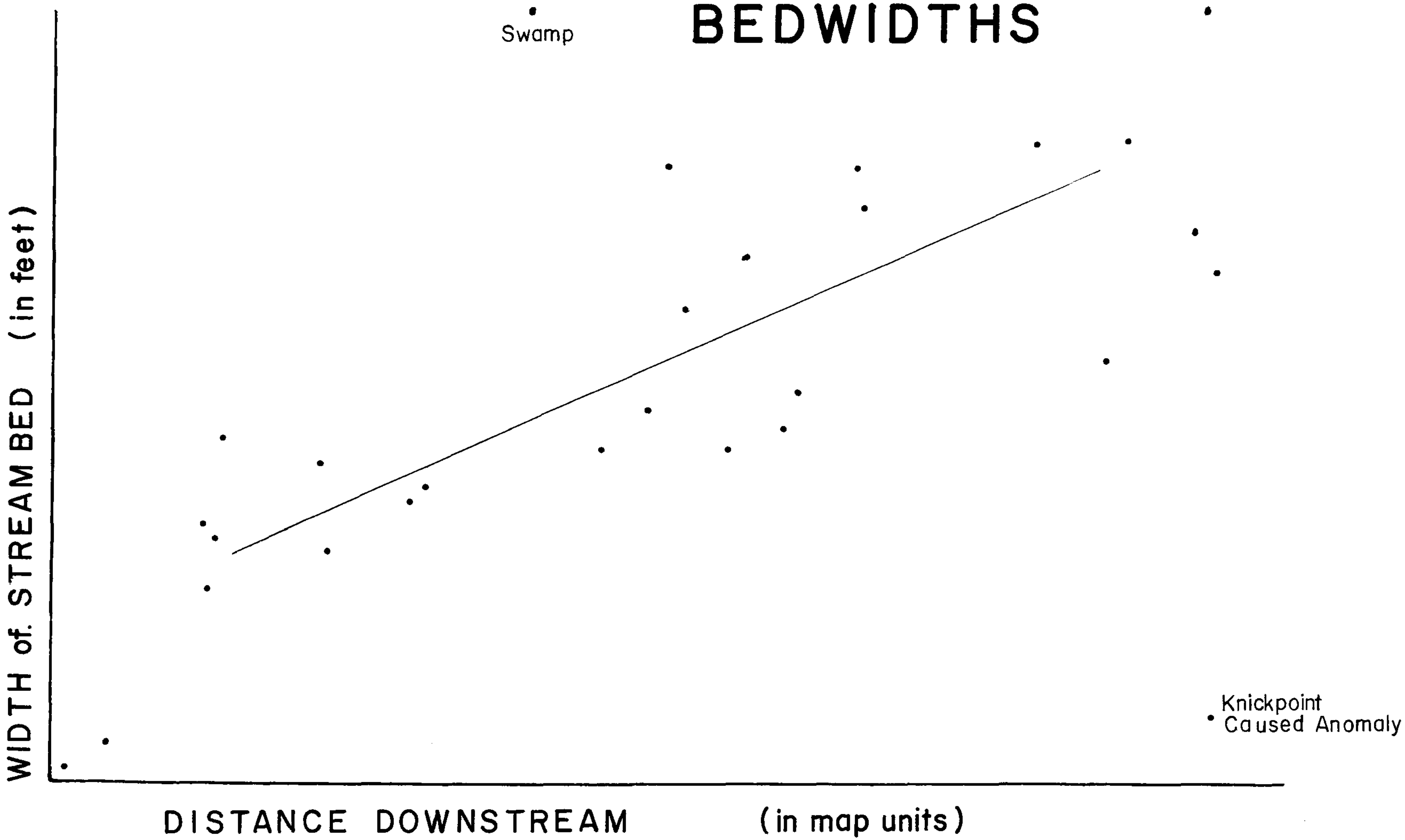
An anomaly exists in the measurements of the Mallot channel. FIGURE 2-10 shows the downstream changes in river bedwidth. The last measure, of five feet, is not in keeping with the expected increase of channel width with drainage area. The longitudinal profile shows an

FIGURE 2-9
PLATES of BEDWIDTH ANOMALY

VIEW UPSTREAM

VIEW DOWNSTREAM

FIGURE 2-10 MALLOT RIVER BEDWIDTHS



increase in gradient at this point. FIGURE 2-9 shows the reach which fulfills Brush and Wolman's (1960) definition of a knickpoint. There is an abrupt change in the stream's longitudinal profile with an oversteepened reach immediately downstream.

The obvious explanation relates to the Conestogo dam further downstream. During high water periods the lake is backed up into the lower reaches of the Mallot River. The raised base level flattens the upstream declivity of the water surface, and deposition results due to the reduced velocity (Mackin, 1948: 496). Lower water levels during most of the year cause the river to erode the deltaic materials, entrenching itself and reducing the width. Longitudinal profiling was not extended below this point and the small area of the basin involved will be ignored for the balance of the report, save that tributary streams within it are considered.

CHAPTER THREE

BASIN MORPHOMETRY

The role of equilibrium is vital to the proper interpretation of fluvial action in a post-glacial environment. Streams change with their climate. The change, a continuum of stages, involves the processes of sediment transport, erosion and deposition. Comprehension of the processes requires a knowledge of change over time.

Adjustment to equilibrium may imply knickpoint changes. A point may successively undergo deposition, erosion, then deposition before a transport or degradation (quasi-) equilibrium is established. A multicyclic environment entails a disruptive series of knickpoints until the interadjusted elements of the landscape evolve. Brush (1961: 155) has found that in such rivers "...the relation among number of streams, length, drainage area, and order possess very little point scatter...." This suggests that "...these elements of the basin are in equilibrium with their environment". Point scatter at a specific order or group of orders will indicate a disequilibrium characteristic. Howard (1965: 304) has summarized many elements of the interaction:

> Stream discharge, sediment load, slope, width, depth, et cetera are clearly interrelated (Leopold and Maddock, 1953); the gradient, width and length of streams, drainage area, discharge and drainage basin shape and relief observe consistent relationships among themselves and with stream order within the same drainage complex. (Leopold and Miller, 1956; Morisawa, 1962; Lubowe, 1964)

The map accompanying this thesis (FIGURE 3-1) was used to produce values for the analysis of the Mallot Basin contained in this chapter. Map production techniques are discussed in APPENDIX ONE. The resulting detailed picture represents the network that would occur during or immediately following a rainfall. Horton-Strahler First and Second Order channels shown here are definitely ephemeral; i.e., they carry water only during storms (Leopold & Miller, 1956: 1). Fifth Order and larger channels of the Basin are perennial, although the flow varies. The intervening orders, as defined by the map, change condition with the weather.

Numerical values, lengths, areas and ratios were derived from the original map and recorded in a series of figures given below. The chapter is organized to systematically investigate most measures of basin morphometry. Numerical, linear, areal and ratiometric categories divide the chapter.

NUMERICAL PROPERTIES OF ORDERING

The Horton-Strahler method of river ordering will be used here. Methods derived by others (Shreve, Scheidegger, Woldenberg, etc.) have not been widely adopted due to some unresolved complexity. Horton's (1945) law of stream numbers states that there should be an inverse linear relation between order and the logarithm of the number of streams in an order. The law has been attacked by Smart (1967) who feels that it is internally inconsistent. Milton (1966: 95) argued that it is the application of only an abstract mathematical relationship. Shreve (1969) complained that the method works primarily because deviations have been averaged out. He showed that the numerical values originate from a statistical relationship resulting not from orderly evolution as was assumed, but from random development (Shreve, 1963: 44). However, whether or not the cause of linearity is orderly or random evolution, significant variances from the expected must have interpretable meaning.

The Mallot Basin is of Seventh Order. TABLE 3-1 lists the total number of Strahler segments in it. FIGURE 3-2 displays the data in semi-logarithmic order-number plots. The 7th Order graph approximates the expected straight line relationship. More 5th and 4th

TABLE 3-1

MALLOT RIVER STRAHLER SEGMENTS

Seventh Order Basin Segments

1	2	3	4	5	6	7
15,753	4,249	1,004	218	46	6	1

Sixth Order Basin Segments

Basin No./Order	1	2	3	4	5	6
1	318	82	19	6	2	1
2	1,595	400	110	26	5	1
3	470	123	27	8	3	1
4	2,225	606	146	25	6	1
5	956	252	59	18	5	1
6	6,692	1,836	424	92	17	1

Fifth Order Basin Segments

Basin No./Order	1	2	3	4	5
1	342	93	26	6	1
2	384	108	27	5	1
3	359	108	23	4	1
4	153	46	11	2	1
5	252	75	17	3	1
6	156	47	15	5	1
7	360	96	21	6	1
8	220	70	14	5	1
9	132	41	6	2	1

TABLE 3-1

MALLOT RIVER STRAHLER SEGMENTS
(Continued)

Fifth Order Basin Segments

Basin No./Order	1	2	3	4	5
10	265	72	20	4	1
11	81	29	8	2	1
12	675	185	44	8	1
13	282	75	15	4	1
14	102	30	8	2	1
15	177	28	6	2	1
16	72	15	4	2	1
17	527	150	34	6	1
18	60	18	6	2	1
19	65	21	5	2	1
20	148	36	11	4	1
21	265	77	18	5	1
22	179	44	6	2	1
23	339	98	26	3	1
24	201	52	11	4	1
25	259	72	17	4	1
26	567	154	31	4	1
27	95	26	6	2	1
28	113	29	10	2	1
29	382	104	28	4	1
30	308	81	22	5	1
31	102	31	8	2	1
32	117	33	7	2	1
33	122	42	13	2	1
34	40	11	4	2	1
35	146	39	9	3	1
36	222	59	10	2	1
37	88	25	7	2	1
38	319	99	24	7	1
39	383	101	25	5	1
40	169	45	14	4	1
41	124	38	10	3	1
42	611	173	47	10	1
43	140	34	11	3	1
44	92	23	7	2	1
45	100	49	11	2	1
46	87	24	7	3	1

TABLE 3-1

MALLOT RIVER STRAHLER SEGMENTS
(Continued)

Selected Fourth Order Segments

Basin No./Order	1	2	3	4
a	132	38	7	1
b	68	24	4	1
c	127	35	10	1
d	24	7	2	1
e	42	13	2	1
f	43	10	2	1
g	44	11	2	1
h	45	12	3	1
i	86	19	5	1
j	42	10	4	1
k	14	4	2	1
l	31	8	2	1
m	26	7	3	1
n	35	8	3	1
o	54	12	2	1
p	43	11	2	1
q	69	18	3	1
r	34	10	3	1
s	55	15	3	1
t	69	15	4	1
u	33	10	3	1
v	60	14	4	1
w	60	18	4	1
x	108	32	8	1

FIGURE 3-2a

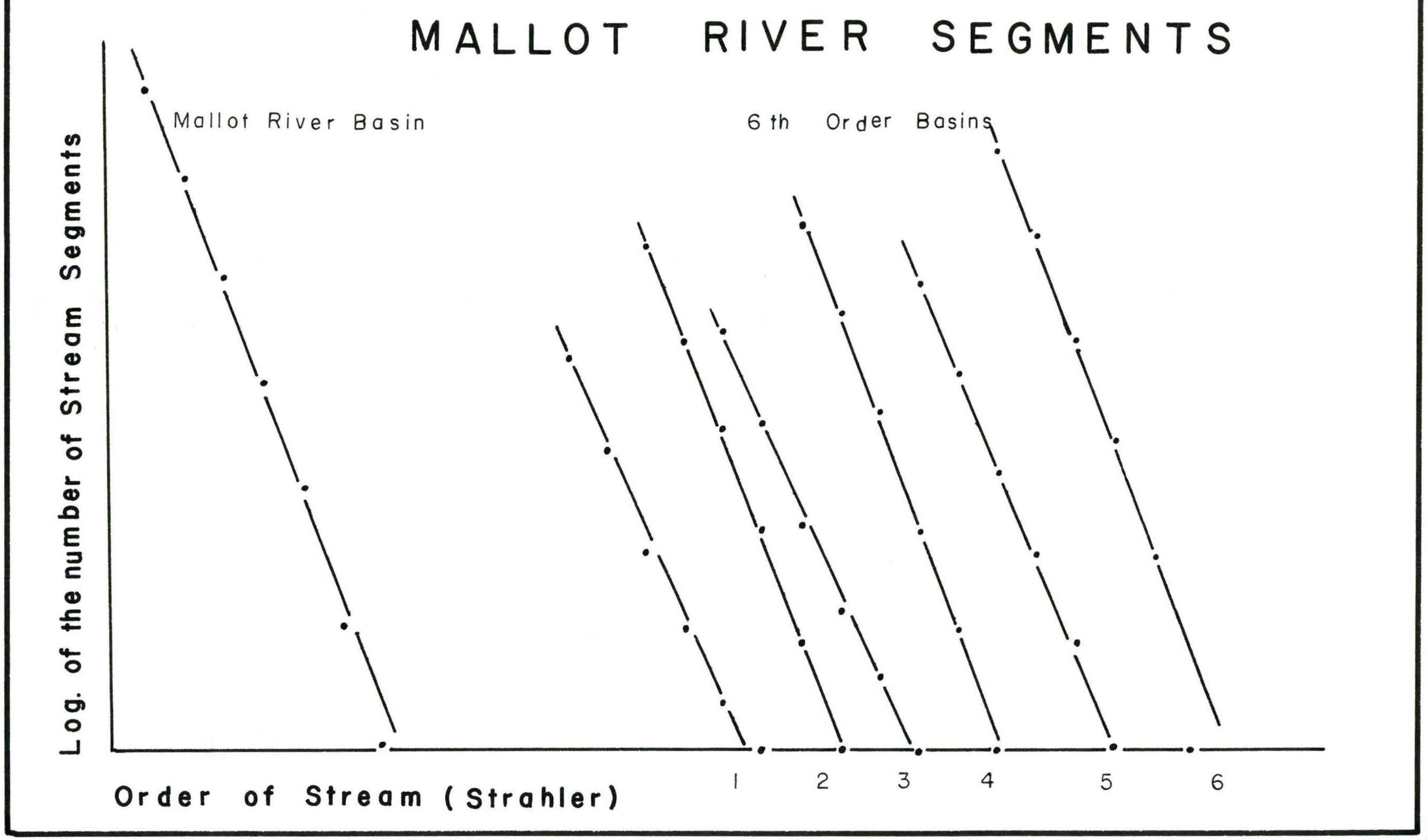
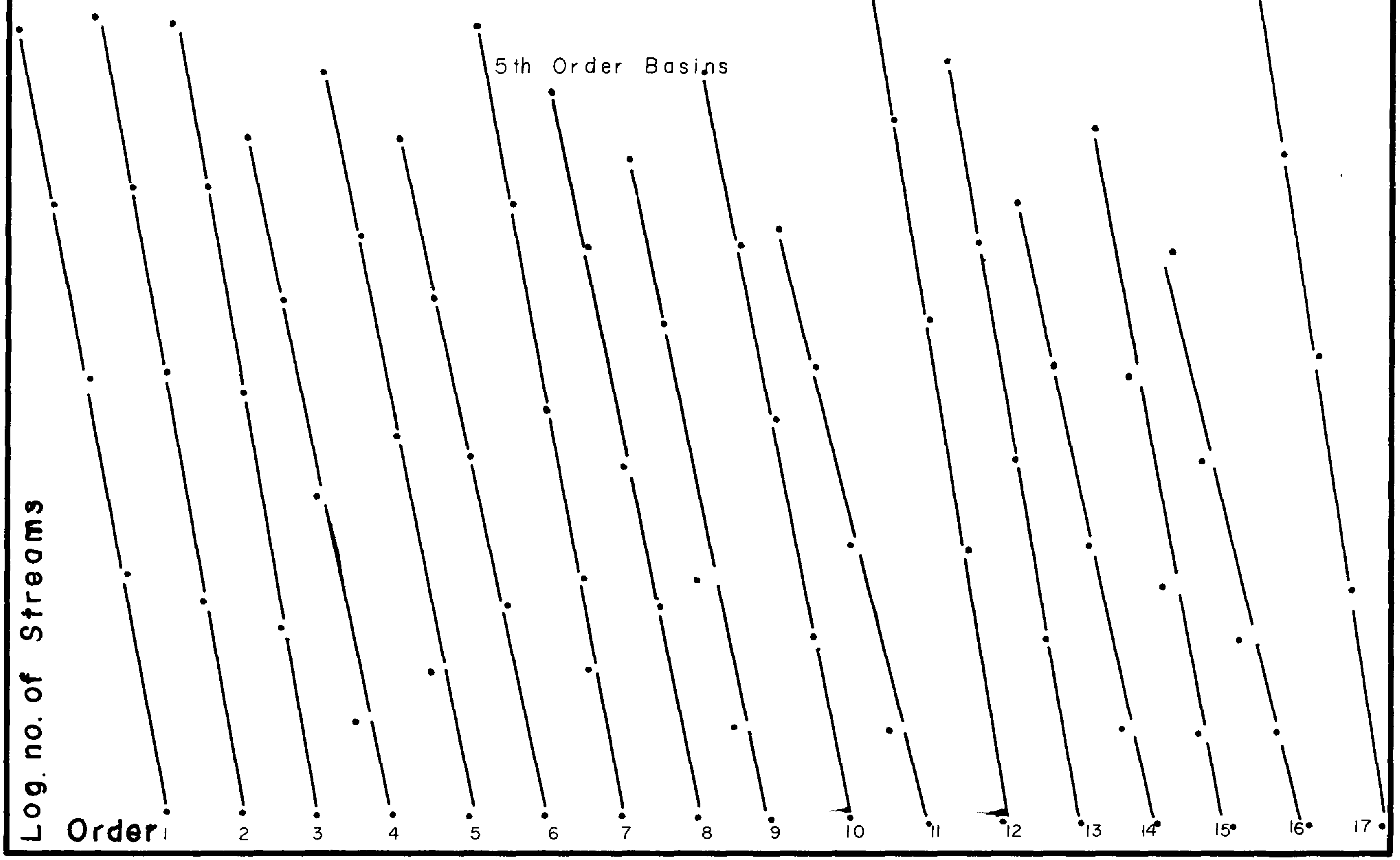

MALLOT RIVER SEGMENTS
Mallot River Basin
6 th Order Basins
Log. of the number of Stream Segments
Order of Stream (Strahler)
1
2
3
4
5
6

FIGURE 3-2b


5th Order Basins
Log. no. of Streams
Order
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

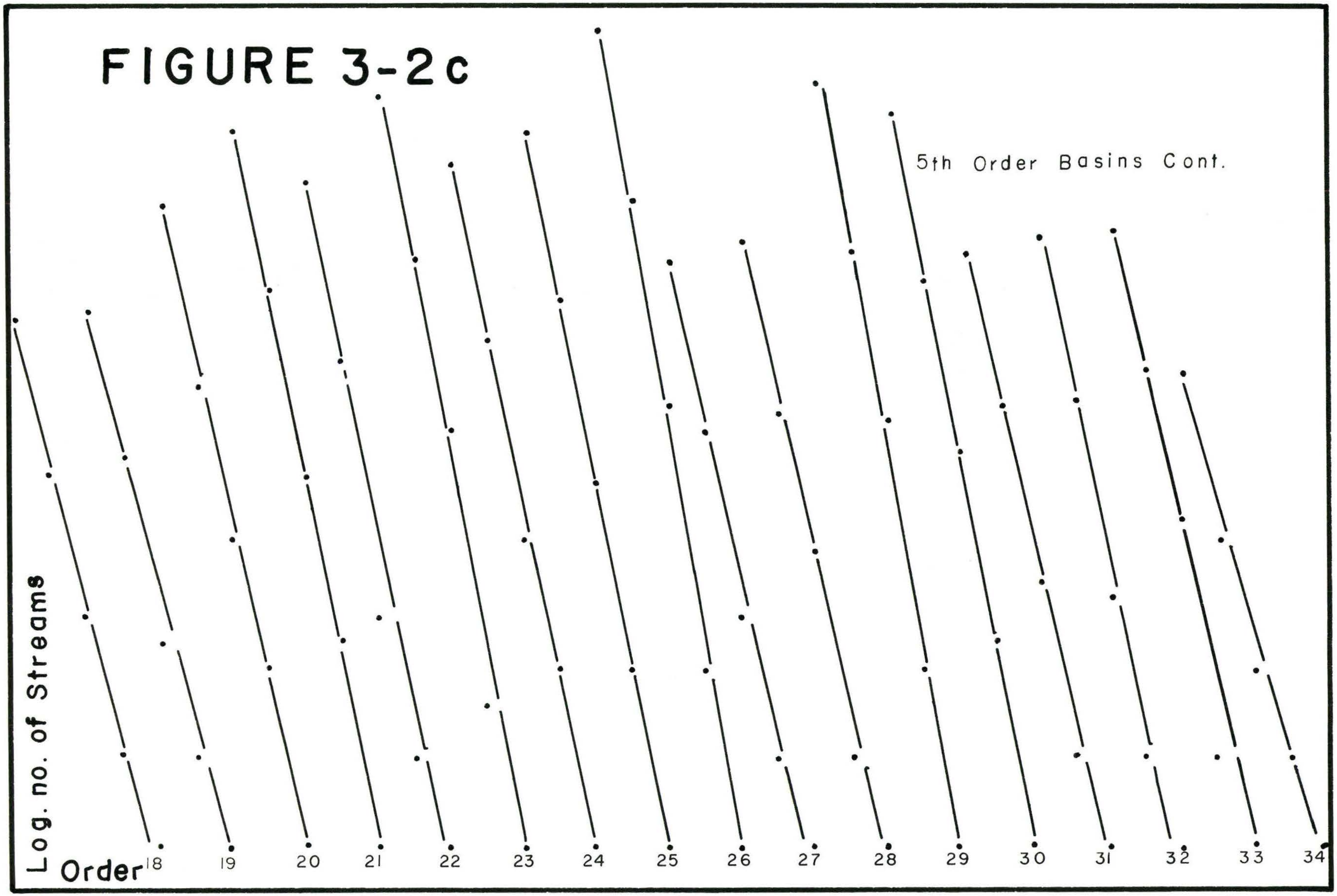

5th Order Basins Cont.
Log. no. of Streams
Order
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34

FIGURE 3-2c

FIGURE 3-2d

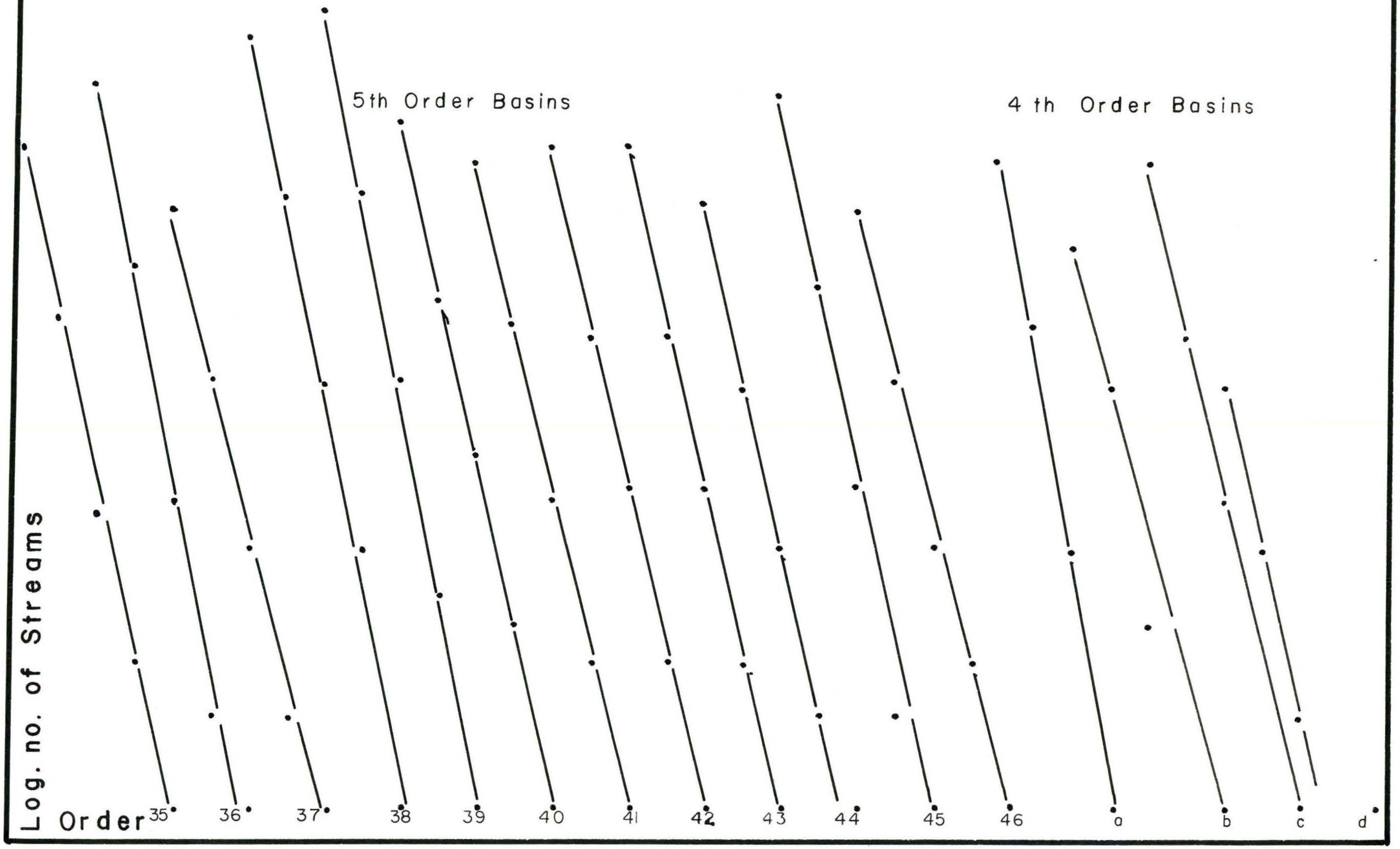
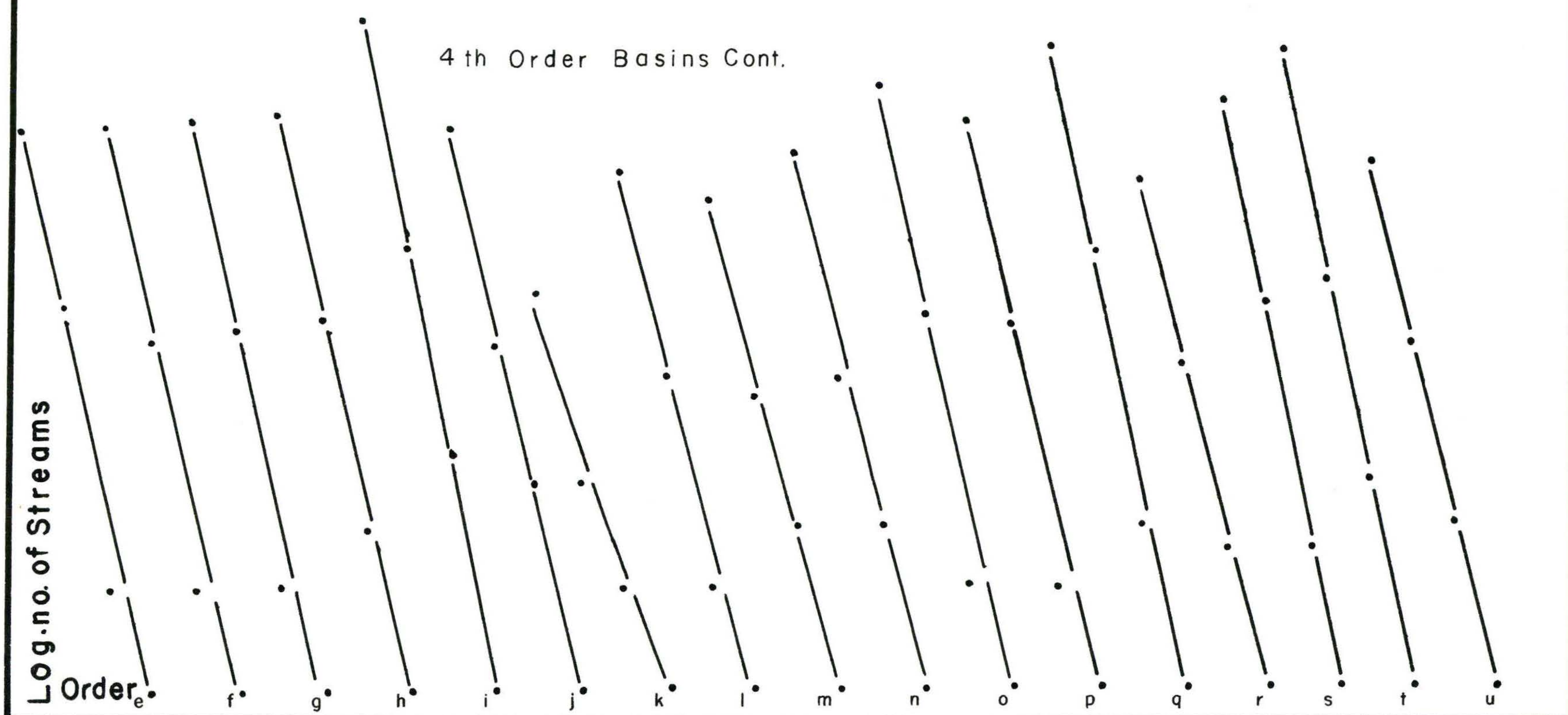

5th Order Basins
4 th Order Basins
Log. no. of Streams
Order
35
36
37
38
39
40
41
42
43
44
45
46
a
b
c
d

FIGURE 3-2e


4 th Order Basins Cont.
Log.no. of Streams
Order
e
f
g
h
i
j
k
l
m
n
o
p
q
r
s
t
u

Orders exist than are expected, while there are fewer 1st and 2nd Order segments.

The graph of 6th Order basins indicates no variations from the Horton model. One unusually long 6th Order stream, number 6, does influence the placement of the main segment value. The variation in the plot indicates only that for the size of the basin, it should have developed into a 7th Order. The 46 Fifth Order basins are similarly uniform. Optically, there appear only random deviations from the expected. No order is consistently shifted in one direction from the line of best fit. Selected 4th Order basins are also well behaved.

There is more variation of values within a basin than there is between basins. The plotted values do not appear to differentiate equilibrium and probable non-equilibrium conditions by showing a consistent shift in numerical values at one level of orders.

Components of the Mallot River react numerically very similarly to the totals for the complete basin. The 4th, 5th, 6th, and 7th Order graphs all produce comparable semi-logarithmic functions. The smaller basins may, as a result of local conditions, show more internal homogeneity than larger basins. On a glaciated till surface it is suggested that there is a greater variation in the number of segments per order than occurs on unglaciated plains. The Hortonian pattern is not significantly altered by this variation.

The Mallot River within the Grand River System

The Mallot River is a segment of the Grand drainage system. It is interesting to compare them because it is possible to extrapolate results derived from the Mallot Basin to the larger unit. The resolution of drainage patterns changes with map scale. This form of analysis was first performed by Leopold and Miller (1956: 16-17). Although numeric values can be transformed, Yang and Stall (1971: 709) have shown ratios, which are independent of scale, to be the best values comparable between scales.

> We have also shown that all the constants in the Horton-Strahler equations obtained from a map system of one scale can be transferred to a map system of another scale provided that the stream order difference between the two systems is given.
>
> (Yang & Stall, 1971: 712)

From 1:50,000 topographic maps the complete Grand River was ordered using Horton's blue line method. The Grand River is located upon two distinct geological units. South of Horner Creek, the lower Grand crosses a clay plain where there is high drainage density. The northern portion of the basin is on a surface of till and comparatively coarse pro-glacial material. The Grand is of the Sixth Order and composed of four major Fifth Order basins in the upper reaches, the Nith, the Speed, the Conestogo, and upper Grand. The Mallot River is depicted as a Third Order element in the Conestogo Basin.

The Grand may be reordered to a Tenth Order stream as is shown in TABLE 3-2. Comparable bifurcation ratios of 6.0 and 6.7 between our Mallot 6th and 7th Orders, and the 1:50,000 2nd and 3rd Orders, indicate that a factor of 103 best shows basin equivalence; i.e., for every single Third Order on the official maps, detailed photo analysis indicates there should really be 103. Comparisons at the other possible overlapping order (2nd) are not practical due to the widely divergent bifurcation values of 7.7 and 2.4. Subjective decisions made by the topographic mapmaker do not represent detailed ground conditions. The First and Second Order presentation of streams on the Ontario topographic maps is unreliable.

FIGURE 3-3 shows the equation that best fits the Grand River, 1:50,000 scale,data. A plot very close to that of a straight line results. A shift does seem to exist between Fifth and Sixth Orders. The large basins have fewer than the expected number of segments. The small basins have more than that expected.

TABLE 3-2

GRAND RIVER BASIN SEGMENTS AND Rb RATIOS

Order / River	1	2	3	4	5	6	7	8	9	10
Grand River (1:50,000)	1687	690	103	16	5	1				
$\overline{Rb}$ = 4.74		2.4	6.7	6.4	3.2	5.0				
Grand River Readjusted to Mallot Basin Data	1622559	437647	103412	22454	4738	618	103	16	5	1
$\overline{Rb}$ = 5.30		3.7	4.2	4.6	4.7	7.7	6.0	6.4	3.2	5.0
North & Central Grand River (Till Plain) Readjusted to Mallot Basin Data	834904	225197	53212	11554	2438	318	53	11	4	1
Rb		3.7	4.2	4.6	4.7	7.7	6.0	4.8	2.8	4.0

Grand River Tributaries (1:50,000)	1	2	3	4	5	$\overline{Rb}$
Conestogo	205	47	11	2	1	
		4.36	4.27	5.50	2.00	4.03
Nith	226	62	12	2	1	
		3.60	5.20	6.00	2.00	4.20
Upper Grand	218	54	12	3	1	
		4.00	4.50	4.00	3.00	3.88
Speed	108	28	7	2	1	
		3.90	4.00	3.50	2.00	3.34

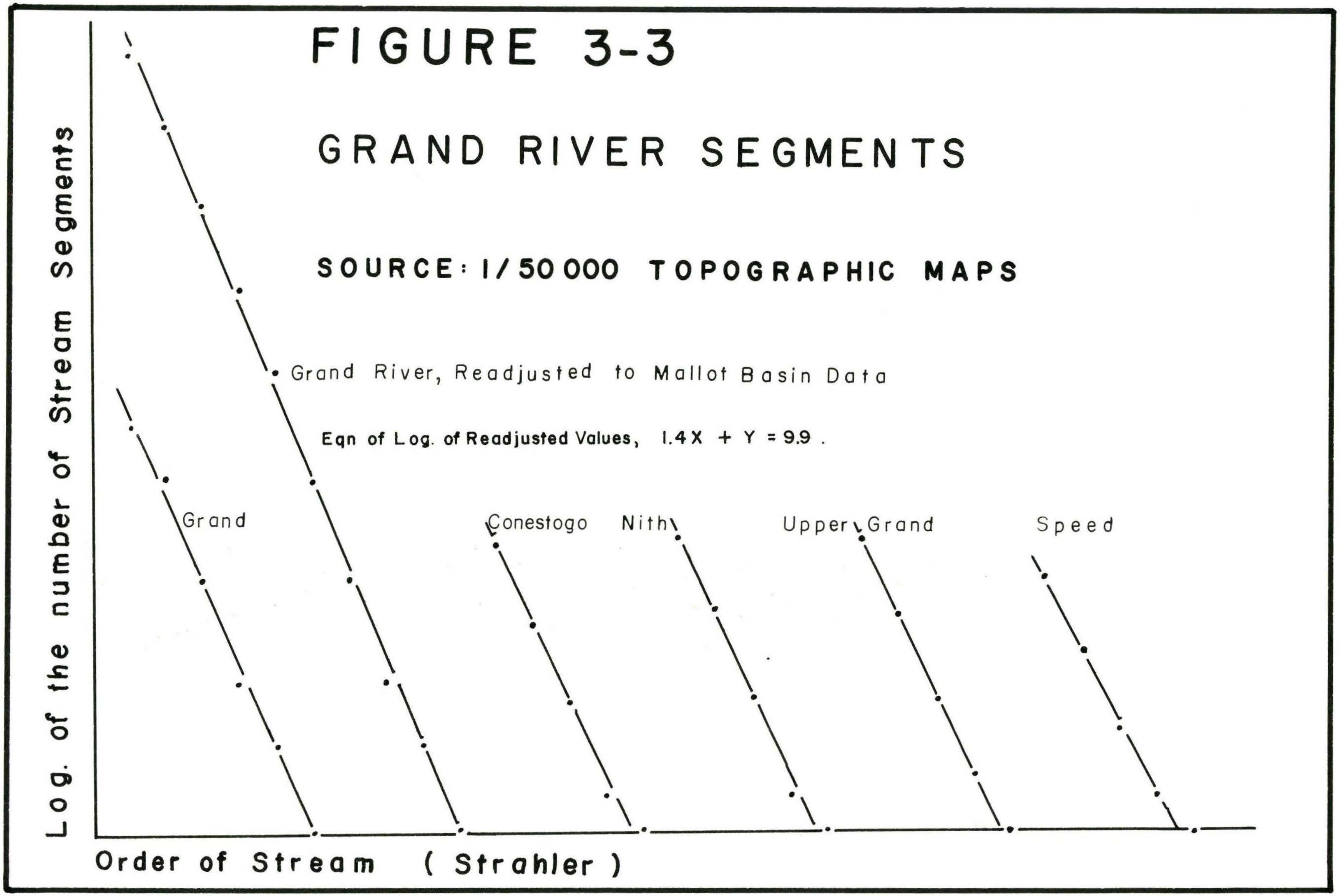


FIGURE 3-3
GRAND RIVER SEGMENTS
SOURCE: 1/50 000 TOPOGRAPHIC MAPS
Grand River, Readjusted to Mallot Basin Data
Eqn of Log. of Readjusted Values, 1.4X + Y = 9.9 .
Grand
Conestogo
Nith
Upper Grand
Speed
Log. of the number of Stream Segments
Order of Stream (Strahler)

The four Fifth Order components of the upper Grand Basin all exhibit similar characteristics. The estimated best fit equations are similar. Fewer Fourth Order basins than expected are indicated in all four cases. A surplus of Second Orders on the topographic maps corresponds to the shift mentioned previously.

The variation between 5th and 6th Orders of the adjusted Grand and the 2nd Order 1:50,000 scale value may be interrelated. Doubt has already been cast upon the accuracy of stream delineation at this level. This deviation, the only one of significance, may only be due to cartographic error. Hortonian channel expansion is supported in the investigation. Since the Hortonian system is produced from a topographically random surface, the observation of Hortonian values indicates no differentiation between zones in the basin. A point of discontinuity is not clearly depicted.

LINEAR PROPERTIES OF ORDERING

The original base map of the river network was used to measure the lengths of successive orders. An approximation is made to channel form in the lower orders. The First and Second Orders in some localities may not necessarily have a visible channel, although a measure of length has been taken from the seepage pattern on the air photographs.

Various terms have been used to distinguish measurable valley lengths. The "mesh length" is the total stream length from the mouth, up the channel to the uppermost stream divide (Horton, 1945: 291). The "channel length" of the basin is the total, or per order total, of the length of all stream segments in the basin. The "mean stream length" of an order is the arithmetic average of stream segment length. The "cumulative stream length" is a running total, and is self-explanatory. Horton's (1945: 291) Law of Stream Length states that the average lengths of streams of successive orders closely approximates a direct geometric series in which the first term is the average length of streams of the First Order.

The Strahler method of reordering streams adversely affects this law, causing unacceptable deviation from the geometric series. Bowden and Wallis' (1964: 770) method uses a cumulative mean length which modifies the Strahler ordering. This makes it comparable to Horton's law. FIGURE 3-4 gives both the semi-logarithmic plot of the cumulative mean values and the mean values for the Mallot River. Only the former will be discussed; mean values are presented as a comparison. Seventh, Sixth and Fifth Orders were measured in their entirety. An adequate sampling was made to obtain other values.

FIGURE 3-4

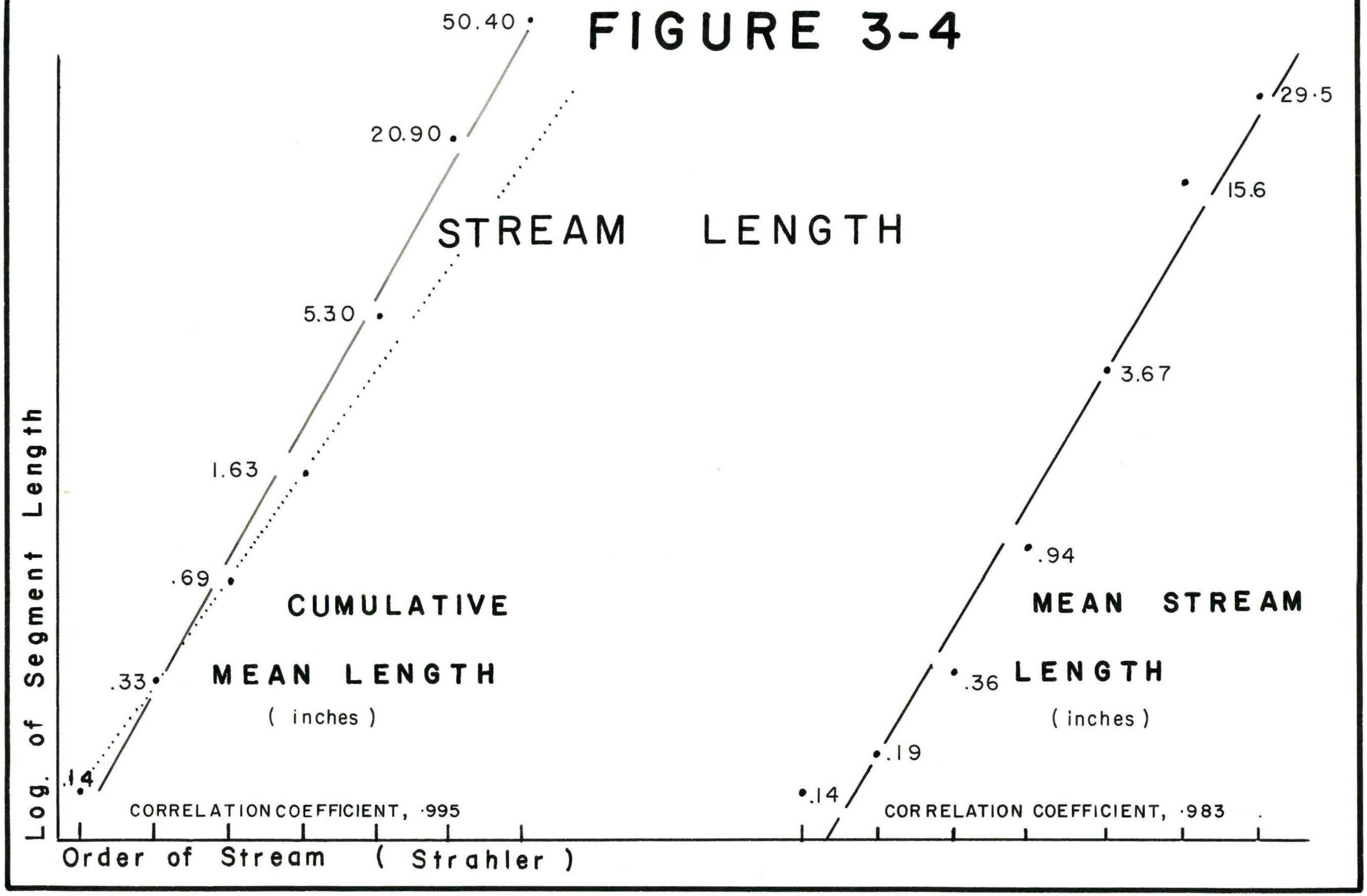

STREAM LENGTH
50.40
20.90
5.30
1.63
.69
.33
.14
CUMULATIVE
MEAN LENGTH
(inches)
CORRELATION COEFFICIENT, ·995
29·5
15.6
3.67
.94
.36
.19
.14
MEAN STREAM
LENGTH
(inches)
CORRELATION COEFFICIENT, ·983
Log. of Segment Length
Order of Stream (Strahler)

FIGURE 3-4, cumulative, could have a number of interpretations, depending on how the "best fit" line is drawn. The dashed line represents an "eye-balled" interpretation of the regression equation. The dotted line is an extrapolation of the excellent lineation of the first four orders. It is possible to interpret deviations from both lines.

The dotted line may best represent the Mallot River's geomorphology. An expected progression of stream lengths extends through the first four orders. Fifth and Sixth Order streams are progressively longer than expected. The rate of elongation is decreased with the Seventh Order.

The extended length is notable at the Fifth Order, but is more pronounced at Order Six because the channels are now large enough to be influenced by the glacial spillways. The Seventh Order segment is also elongated by a paleo-channel.

Glacial fluting also has an effect on stream length. Many streams of First and Second Order are oriented down flute valleys. The central streams are delayed from integrating into a network until they are of sufficient size to alter the topography or empty into a master stream. Channels normal to the flute direction are necessarily short. Stream length and thus basin shape are slightly modified on the glaciated plain.

The dashed line of FIGURE 3-4 can produce alternative interpretations of stream length. Orders One and Six appear too long, while Three, Four, and Five appear too short. No simple causal explanation can explain the deviations. The dotted line seems the best indicator of variations in the Mallot River stream length.

Mallot River Longitudinal Profile

Young (1970: 590) quotes Baulig (1950), stating that the profile of equilibrium is a slope on which the position of each point of the profile is dependent at any moment on the position of all the other points. Thirty miles of the Mallot channel were surveyed. Three lateral and two headwater sample tributaries were measured along their thalweg. The main river channel was surveyed at the water surface. The results were plotted at a horizontal scale of 1:12,000 with a vertical exaggeration of 50X. These plots, FIGURES 3-5, 3-6, and 3-7, were studied in detail and correlated with river features, utilizing field notes and air photography.

Smooth profiles would be expected of channels in equilibrium. If external variables remain constant through time, then the parameters of a system should

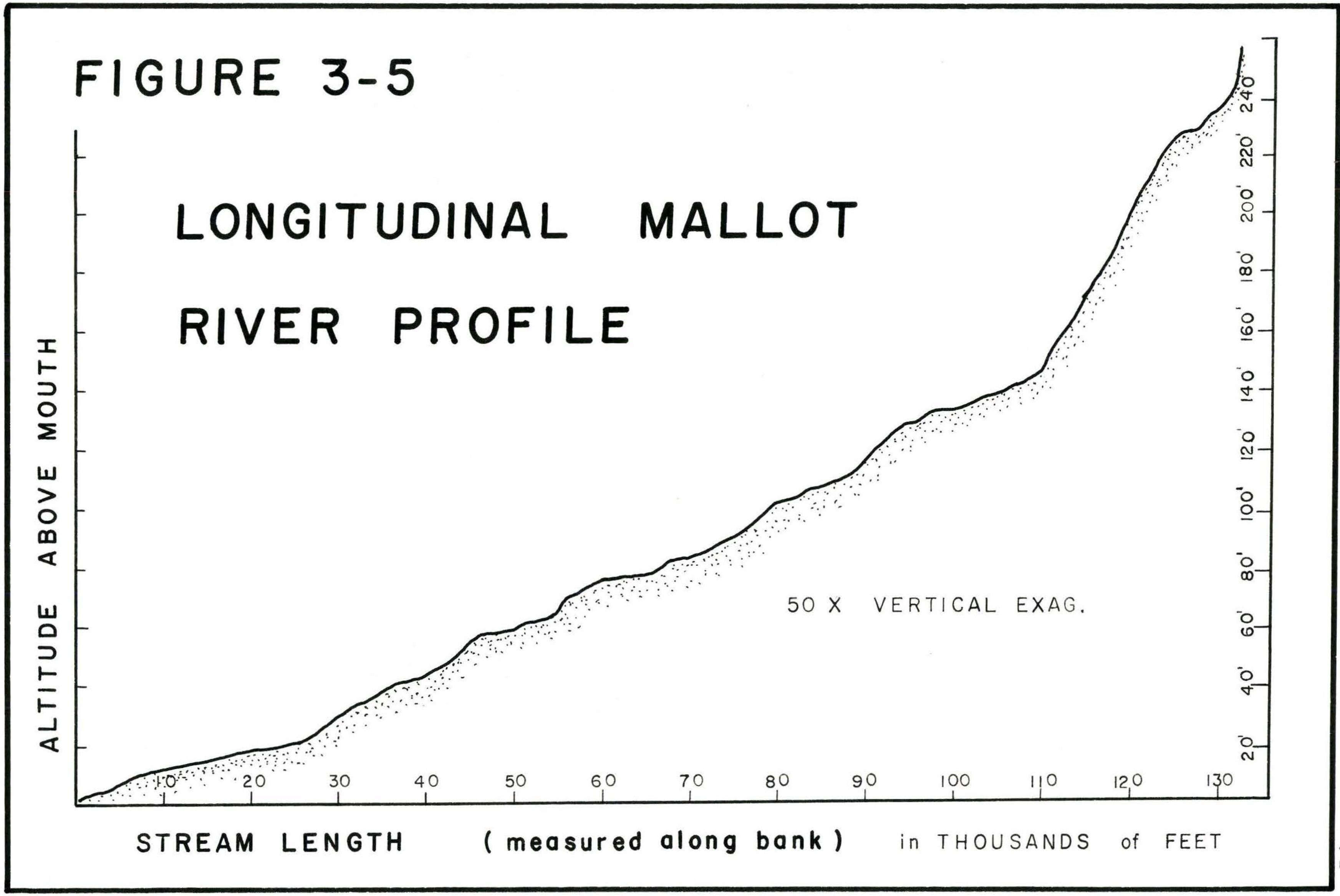


FIGURE 3-5
LONGITUDINAL MALLOT
RIVER PROFILE
ALTITUDE ABOVE MOUTH
50 X VERTICAL EXAG.
20' 40' 60' 80' 100' 120' 140' 160' 180' 200' 220' 240'
10 20 30 40 50 60 70 80 90 100 110 120 130
STREAM LENGTH (measured along bank) in THOUSANDS of FEET

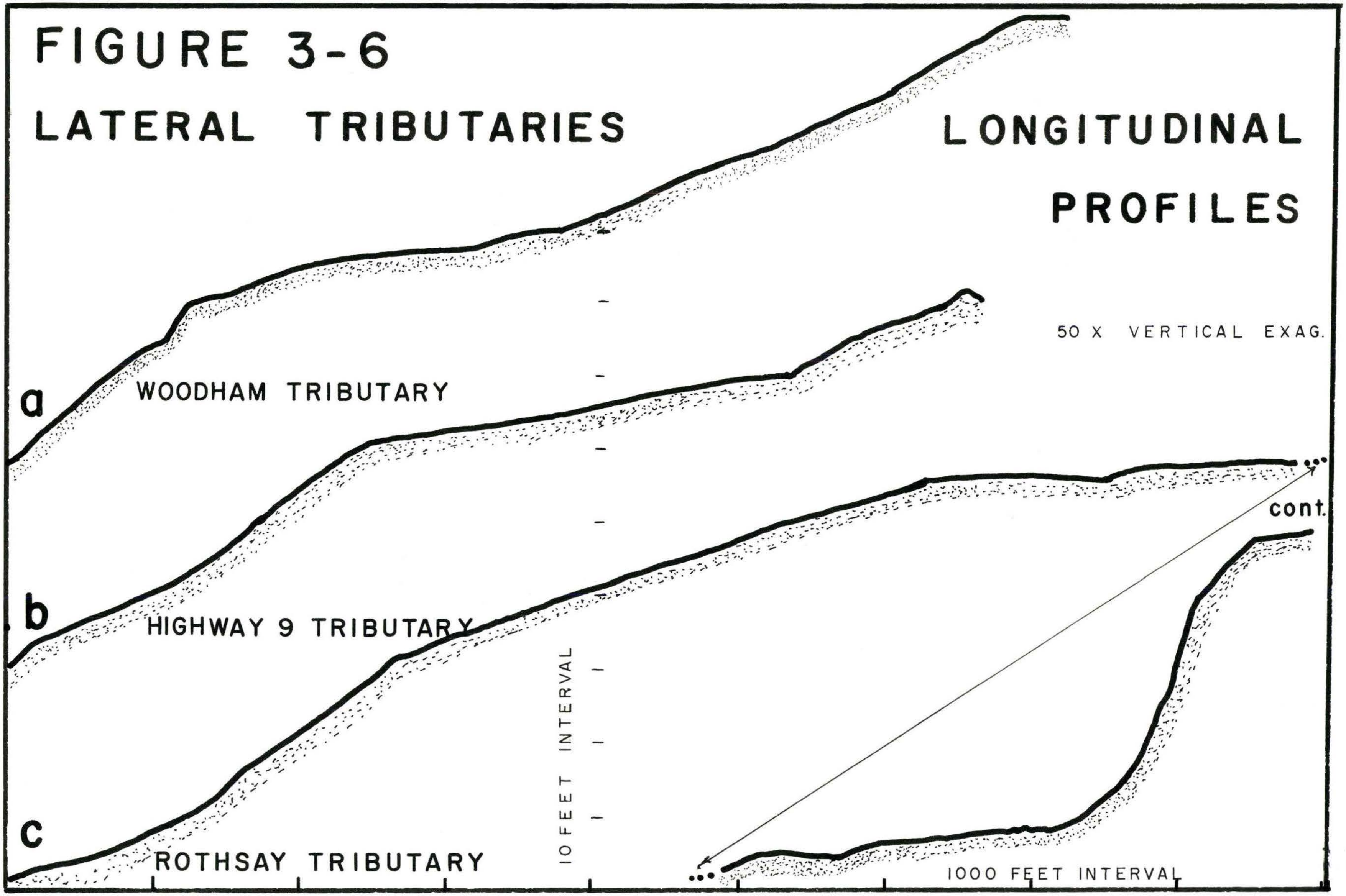
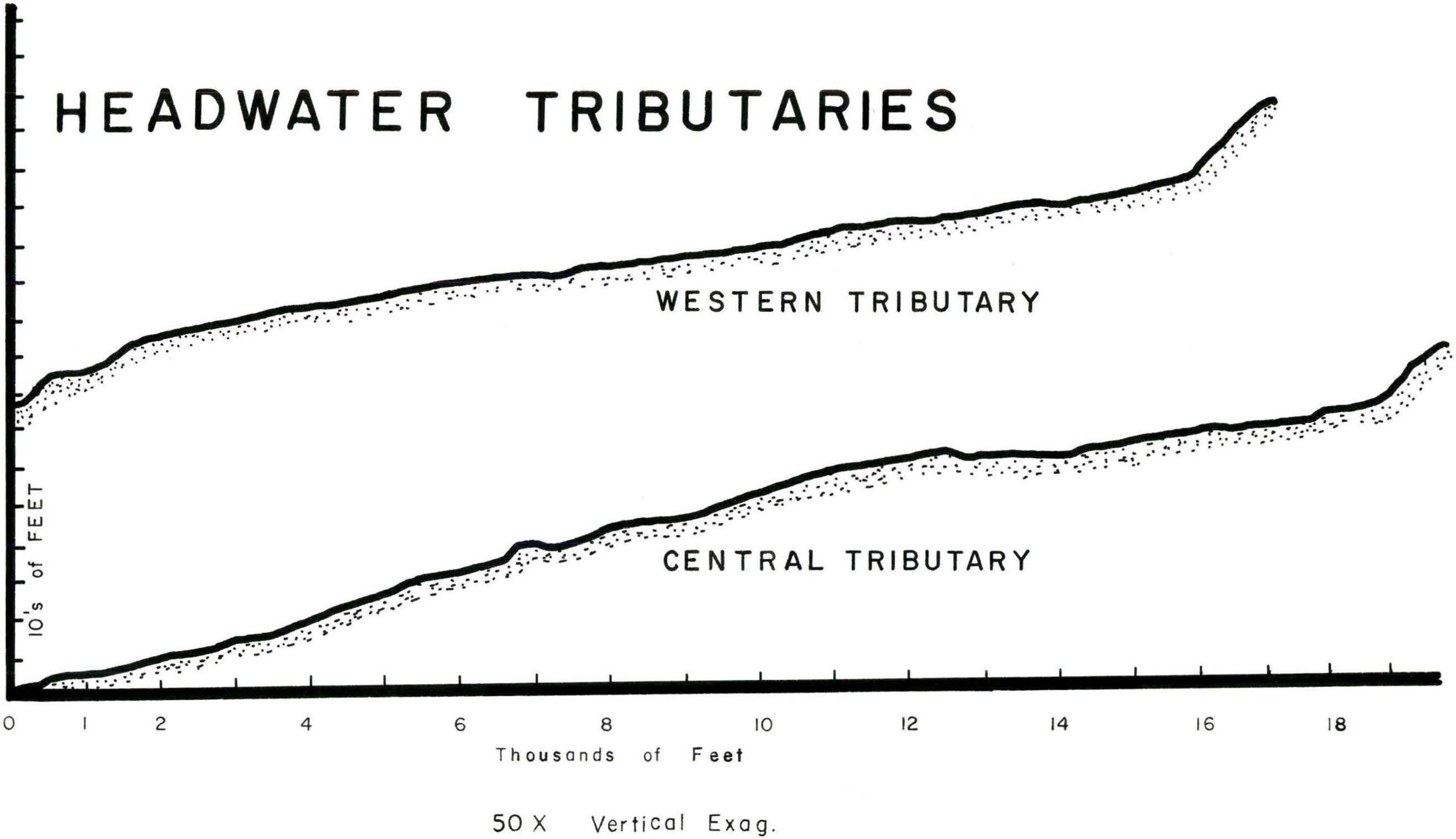


FIGURE 3-6
LATERAL TRIBUTARIES LONGITUDINAL PROFILES

FIGURE 3-7


HEADWATER TRIBUTARIES
WESTERN TRIBUTARY
CENTRAL TRIBUTARY
10's of FEET
0
1
2
4
6
8
10
12
14
16
18
Thousands of Feet
50 X Vertical Exag.

also remain constant (Howard, 1965: 305). Isolated irregularities seem to indicate a disequilibrium.

Upstream of the effects of the Conestogo Dam backwater curve, the River profile is monotonously flat. The slope south-east of Moorefield is 4.2 feet per mile. The east-flowing lower section of the river has its flow interrupted by numerous riffles. The figure indicates that there is no significant deviation from a straight line despite the riffles (FIGURE 3-5). Where a farmer has widened the riffle by adding fill to provide a more extensive ford, an oversteepened reach develops to attempt to offset the enlarged pool. In general, the overall smoothness of the reach profile is not compromised.

The large number of riffles and their location indicates the existence of a natural phenomena. The river resembles an underfit stream of the Osage type. Pairs of pool and riffle sequences represent a single wavelength.

A similar situation of pool and riffle with a nearly flat water surface profile extends around the river bend west of Moorefield and northwards past the community of Rothsay. Throughout its length, the Seventh Order segment contains pool and riffle sequences, but relatively few meanders.

The profile of the main channel is regular until a point north of Rothsay, where an oversteepened reach is encountered. A shallow rapids has a swamp above, and the meandering channel below. A meandering pattern is re-established North of the swamp near Highway 9. The smooth profile extends upstream to the vicinity of transverse profile 8, FIGURE 2-7. A set of short rapids, each with a swamp upstream is found on either side of this profile. Were it not for these irregularities, the longitudinal profile would be smooth north of Highway 6, where the glacial spillway ends and stream meanders cease.

Brush and Wolman (1960: 73) predicted narrow, deep channels upstream of knickpoints, and wider, more shallow channels downstream. With swamps upstream and eroding channels downstream from knicks, the Mallot appears to be behaving in direct contradiction to their proposals.

An explanation of the three anomalies could be related to the underfit nature of the river. The spillway at this location was widely meandering on a plain of only slight slope. The oversteepened reach and oxbow was created shortly before the major decrease in discharge. The modern stream encounters the flat reach upstream from the rapids and deposits its sediment load. The swamp is created by quite recent deposition. Below the rapids, the velocity and turbidity imparted by the oversteepened slope is sufficient to allow minor erosion. There is greater erosion in reaches associated with the oxbow since fine materials from the meander are more easily eroded. The situation of deposition upstream and erosion downstream would only occur in an underfit river as described. This series of fluvial landforms are unique to underfits. The set does not necessarily have to be on a drift surface.

Summarizing, the thalweg in the spillway is very smooth, with but three irregularities. The two exceptions between Highways 6 and 9 are in an environment where paleo-meanders made mile-wide loops. Meander cut-offs would be sufficient to cause the swamp-rapids complex. When the oxbow was created, the paleo-channel tended to again lengthen its course to eradicate the oversteepened reach by meandering (Brush & Wolman, 1960: 70). With a change in climate and reduced flow, the oversteepened reach has remained. A fossil knick remains at these two locations. Recent fluvial erosion has modified the knicks slightly and they have moved upstream, draining the oxbow.

The third and more substantial knickpoint north of Rothsay is indicative of a different effect. These rapids differentiate two distinct channel and valley pattern types. Downstream is a relatively straight valley containing some meanders, but with pool and riffle dominant. Upstream, the valley is less pronounced but meandering widely. The channel within it similarly meanders. The change in regime corresponds to a change in the type of glacial till. The river proceeds from an environment of loam till to one of clay loam till. It is contended here that the regime change is directly due to the change of till composition.

Headwater (Fifth Order) tributaries have their mouths upstream of the spillway portion of the basin. The two examples shown in FIGURE 3-7 display no grossly irregular pattern in their profiles. They increase unevenly in slope to the basin head. The effect of the spillway is not evident in them because the descent to the spillway floor is a half mile downstream of their termini. Fifth Order and smaller basins, therefore, are unaffected as yet by underfit-caused knicks. An equilibrium state is being approached in an interim period, before the knick adjusts the Fifth Order system to the slope of the higher order segment.

A profile was made of a lateral tributary entering the River a mile north of Moorefield. "Woodham" tributary extends east of the main channel across a short meadow, up the underfit valley side, under a road, and then progresses over nearly flat grain fields. The profile, FIGURE 3-6a, gives a detailed picture of a channel in disequilibrium due to the underfit. According to Strahler (1950: 687), all slope profiles should be in equilibrium with the channel profiles to which the slopes contribute their debris. This does not seem to be the case in the Woodham tributary.

Above the fossil valley and the effects of the bridge, the profile indicates a sloping plain rising smoothly to a peak. It is suggested that it is an equilibrium form. The knickpoint, originating in the fossil valley has not yet penetrated far upstream.

A second stream, "Highway 9" tributary, enters the main channel laterally at a location where paleomeanders widened the valley. This stream has 2,400 feet of its profile altered by the underfit, while the Woodham tributary is influenced only half as much. Only man-made features disrupt the "regular" stream profile above the spillway valley. Mackin (1945: 506) indicates that the profile of aggradation should be more strongly concave upwards than the graded profile. Despite Hack's (1960: 84) contention that Mackin's streams are special cases, this is observed in both lateral profiles. A classic knickpoint develops between the two segments of different concavity.

The "Rothsay" tributary (FIGURE 3-6c) has the steep initial section in the underfit, and a flat central reach. An unusually pronounced hill on the basin boundary causes the steep termination of the segment.

Thus, in all cases the lateral tributaries have the pattern of a normal stream rising to its head, but with a severely truncated lower reach. An oversteepened reach, the side of the underfit valley, is clearly visible.

Complexity is introduced by the large valley. Normally a decrease in discharge, such as that following the immediate post-Pleistocene, would affect the rate of river-load transport. Deposition of sediment would locally steepen slopes until the increase of velocity is able to transport load (Mackin, 1945: 495). A small stream on low relief would have much lower erosive power than the paleo-stream. What erosion takes place in headwater areas would produce deposition in the more level reaches of the spillway portion of the channel. The greatest erosion is at the oversteepened reach in the lateral tributaries where the stream cascades into the underfit valley.

No adequate studies have been made of the sediment output of streams in an underfit system. Sediment output can be expected to fluctuate even upon a homogeneous random surface of till. In the underfit case, the location of the knickpoint or family of knickpoints is of paramount importance.

Materials of different sizes will be eroded at the knickpoints. In the early stages of degradation, where a single large knick progresses up the tributary channel, fine and coarse material will be eroded. Armouring, the process where large rocks cover and protect smaller material from erosion, will rapidly take place. The output of sediment will be sharply curtailed. Stream power which is focused at this location is not sufficient to significantly change the bed in this reach, but is great enough to transport material input into the reach from upstream.

The knickpoint will proceed up the channel, eroding material and leaving an armoured reach in its wake. Knickpoints multiply as the stream bifurcates. Available power is diffused with shrinking drainage area. Power is reduced as the stream progresses upstream by a factor equal to the bifurcation ratio. The result of this pattern is to effect eroded grain size. Fine materials will be eroded until armouring sets in. It may be argued that with a uniform climate, a hierarchy of armouring will occur as the system progresses. Downstream, all eroded materials will be transported out of the armoured reaches. Proceeding upstream, the bed will be armoured first with large material and then with progressively smaller materials. The smaller grained armouring will occur over a time period not dissimilar to that required by the lower reaches. The smaller amount of material required to produce armouring will speed the process, but the decreased water quantity will slow the process.

The results of the process would be a graded deposition of material on the low relief underfit valley floor. The size of material eroded, transported, then deposited becomes smaller as the knick moves upstream. A graded bedding of materials in the depositional zone should result with unaltered fines at the top. Not all the debris load would be deposited, much material would enter the main channel. The mode of the sediment size distribution in the main channel would be strongly weighted toward the size of sediment introduced to the system by the lateral tributaries. A change in the major grain size component in the main channel bedload is caused by the progression of knickpoints up lateral basins.

A more complex ramification is possible. Size and occurrence of stream sediment has been correlated with secondary currents and, therefore, meanders (Leliavsky, 1955; Vanoni & Nomicos, 1959; and Tanner, 1960). It may be possible to extrapolate changes in meander tendency of the main channel to the position of knickpoints in the basin.

Attempts have been made to express the longitudinal profile of a river in equilibrium by use of equations. Were this possible, it would be a simple matter to compare the ideal profile to that observed at the Mallot River. Although Lewis (1945: 257) talks of the equation of a profile, originating at the mouth, most recent works start the equation at the divide (Strahler, 1952; Brush, 1961).

Strahler (1952: 936) hypothesized that the reduction of relief and valley wall slope steepness would cause a steady reduction of load and a diminishing supply of potential energy. This will cause regrading of the master stream to become increasingly slow. The rate of profile reduction is, therefore, proportional to the slope at that point. A graded stream would be of the form:

$$y = Ae^{-k_1 x},$$

where y = the elevation,

A, k_1 = constants,

and $(0, y)$ = the uppermost point of the basin mesh length.

Brush (1961: 148) showed that similar simple equations can approximate the long profile:

$$F = kL^{p},$$

where k,p = constants,

F = fall in feet taken positively,

and L = stream length in feet taken positively downstream.

Plots were made of the Mallot profiles using Brush's equation. The fall of the river in feet is plotted against the dependent logarithm of the length from the divide. Although Brush obtained, or simplified to, straight lines from his work, FIGURE 3-8 shows the conflicting variations that are obtainable at a larger scale.

If the mathematical analysis of the stream is to be valid, the model must entirely describe the profile. Brush's method fails in a transitory zone at the top of the basin. A straight line is not present. The curve toward the summit is sufficiently large to indicate the break-down of the simple equation. the curvature is too great to be randomly generated. It is possible that the irregular Mallot system could skew the results away from a straight line. The smooth curvature of the "best fit" line indicates the probable regularity of the profile change in the Mallot system.

A second graph by Brush uses the logarithm of the length of stream from the divide plotted against the logarithm of fall from the basin summit, taken positively. His result is a straight line relationship.

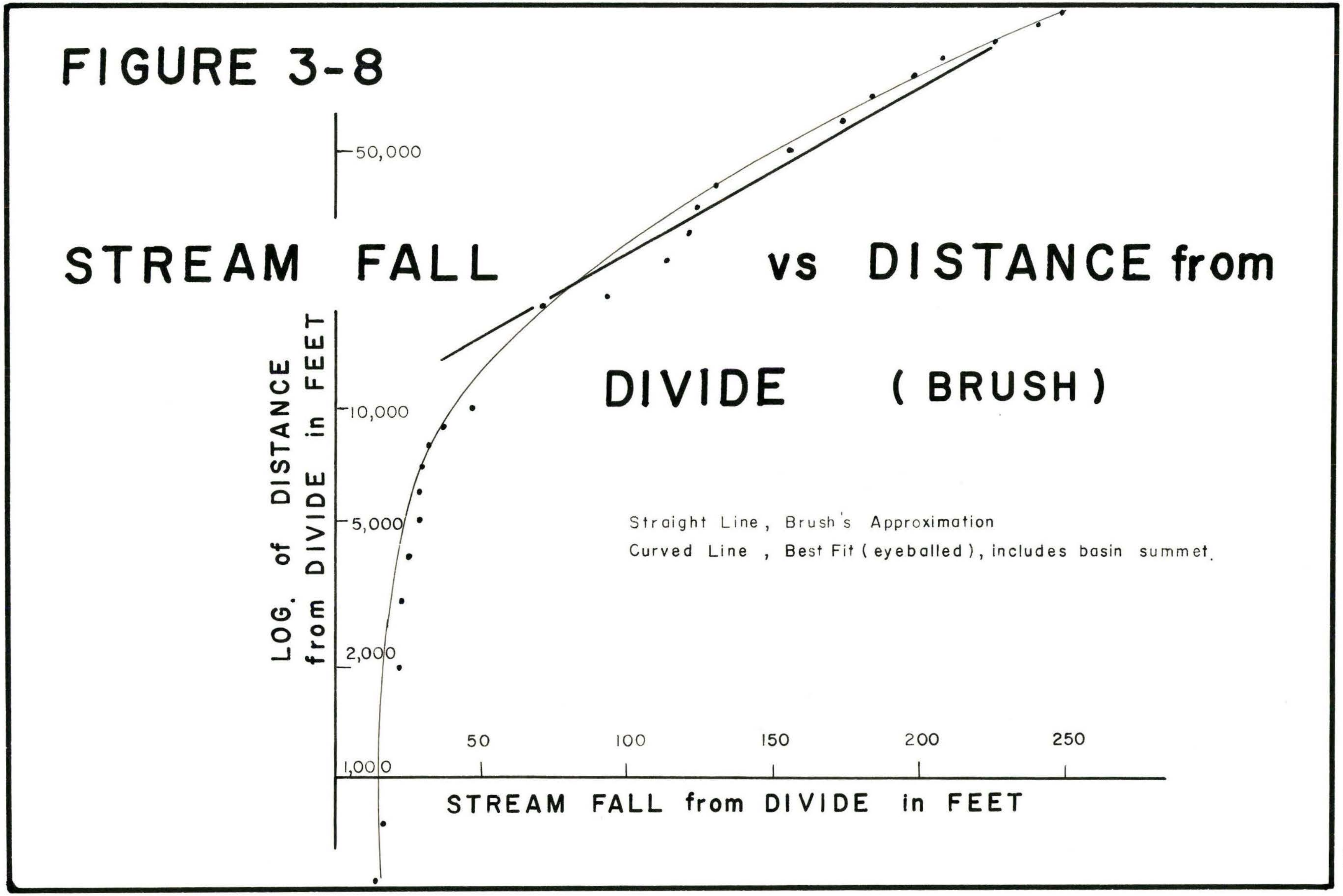


FIGURE 3-8

STREAM FALL vs DISTANCE from DIVIDE (BRUSH)

The Mallot River data gives an approximation to a straight line (FIGURE 3-9), but irregularities in the reaches do not allow more than a gross approximation to be made by the simple function.

It may be concluded that mathematical relationships may be of some assistance in the elucidation of profiles. However, the state of the art today has not progressed far from 1948 when Mackin stated that the graded profile cannot be a simple mathematical curve in anything more than a loose or superficial sense (Chorley, 1958: 370). No mathematical model is yet ready to define equilibrium.

Knickpoints have been shown to be active along the Mallot River. Regularized and integrated channel segments have not replaced the initial underfit conditions. Therefore, as shown by its long profile, the system is not in equilibrium.

In the words of Howard (1965: 308):

> Even if it is demonstrated that a system or system parameter is not in equilibrium with an external parameter, the existence of a theoretical equilibrium state retains its significance as it defines the direction of system response.

The direction of response is indeed beginning to be more clearly understood. The existing situation of the Mallot River as represented by many parameters has been stated. The most probable situation of the sys-

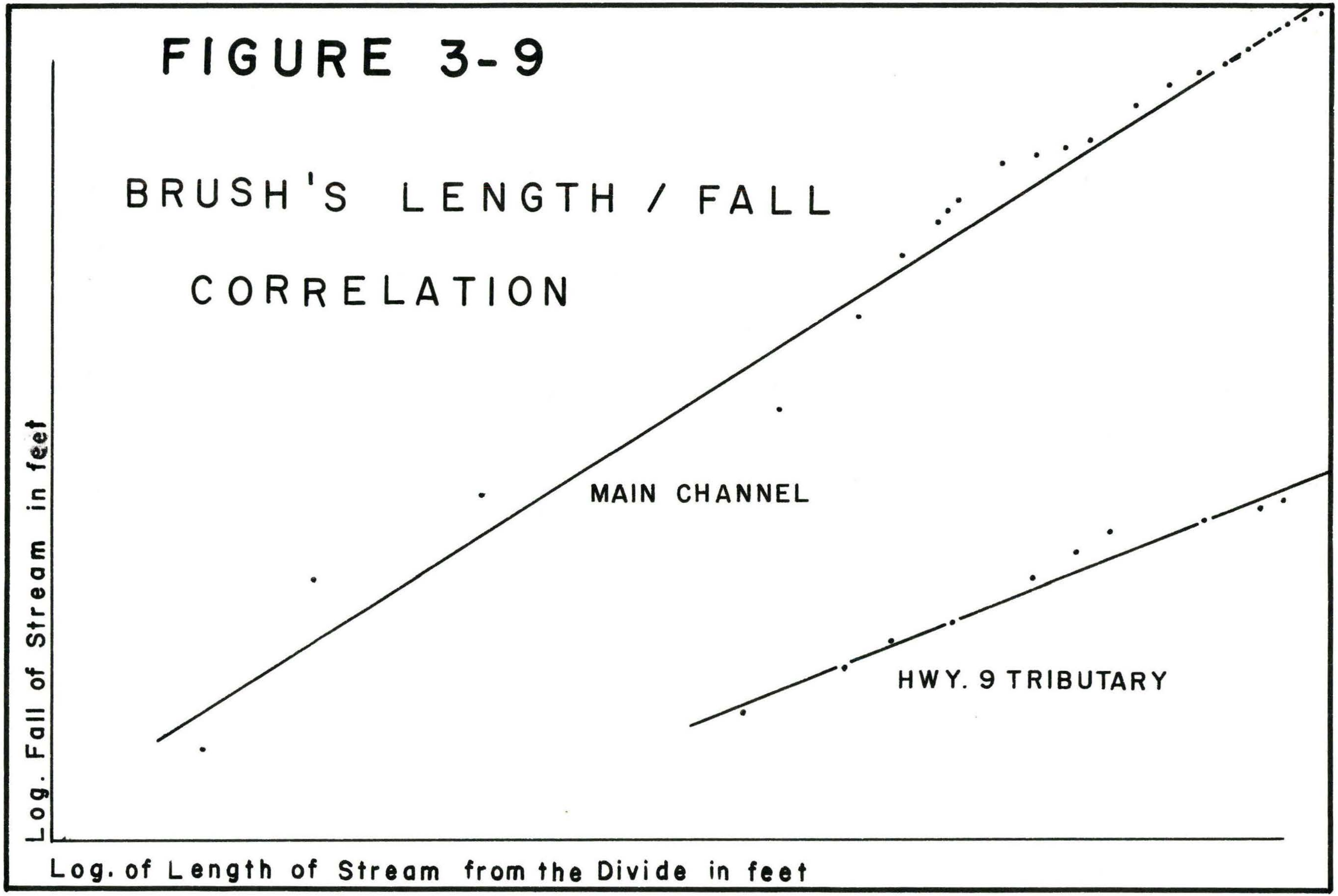


FIGURE 3-9

BRUSH'S LENGTH / FALL CORRELATION

tem in equilibrium has similarly been presented. Major variance from normally expected erosion rates will occur where an underfit river valley is consumed by erosion. The Mallot River's lateral tributaries are eroding the underfit valley sides upstream, reducing the slope. Deposition on the valley floor also reduces relief. The greatest change occurs at knickpoints where relief focuses available energy. Upstream progression of knicks will lower the basin relief and smooth profiles to a position compatible with the existing climate. Small headwater basins, as yet unaffected by the advancing knicks, will in the interim, proceed to come to equilibrium. The small amount of material needed to be eroded in the low relief allows the progression. Basin equilibrium proceeds downstream by order as stated above until disrupted by an advancing knick. The progression to equilibrium is directed by erosion and deposition at predictable locations.

AREAL PROPERTIES

A third Hortonian relation is that of the "Law of Stream Areas". Areas of successively increasing orders of stream correspond to a geometric series. This relationship was investigated using Mallot River data.

Basin outlines were interpolated from the detailed network pattern. The Seventh, Sixth and Fifth

Order basins were measured in their entirety. Fourth Order and lower basins were not measured. Areas were measured on a polar planimeter. Calculation errors could range upwards of 50 percent for the First and Second Orders, so no attempt to evaluate them was made. Small Third and Fourth Order basins would similarly introduce error. An indication of area by order using an extrapolation sufficiently describes the environment.

FIGURE 3-10 shows basin area plotted against order. A close approximation to a straight line is seen despite the few points used. The one large Sixth Order stream raises the average area at the Sixth Order level. There is no indication of a shift or point of discontinuity such as was noticeable in FIGURE 3-4. Such a shift may exist, having been lost in the difficulty of determining exact basin outlines in areas of low relief.

Hortonian analysis of area has been only semi-successful in studying the Mallot Basin. A description is presented, but the analysis is weak due to imprecision.

COMPLICATION OF THE LINEAR AND AREAL PROPERTIES

FIGURE 3-11 is a reproduction of an aerial photograph taken over the southern portion of the Mallot

FIGURE 3-10

BASIN AREAS

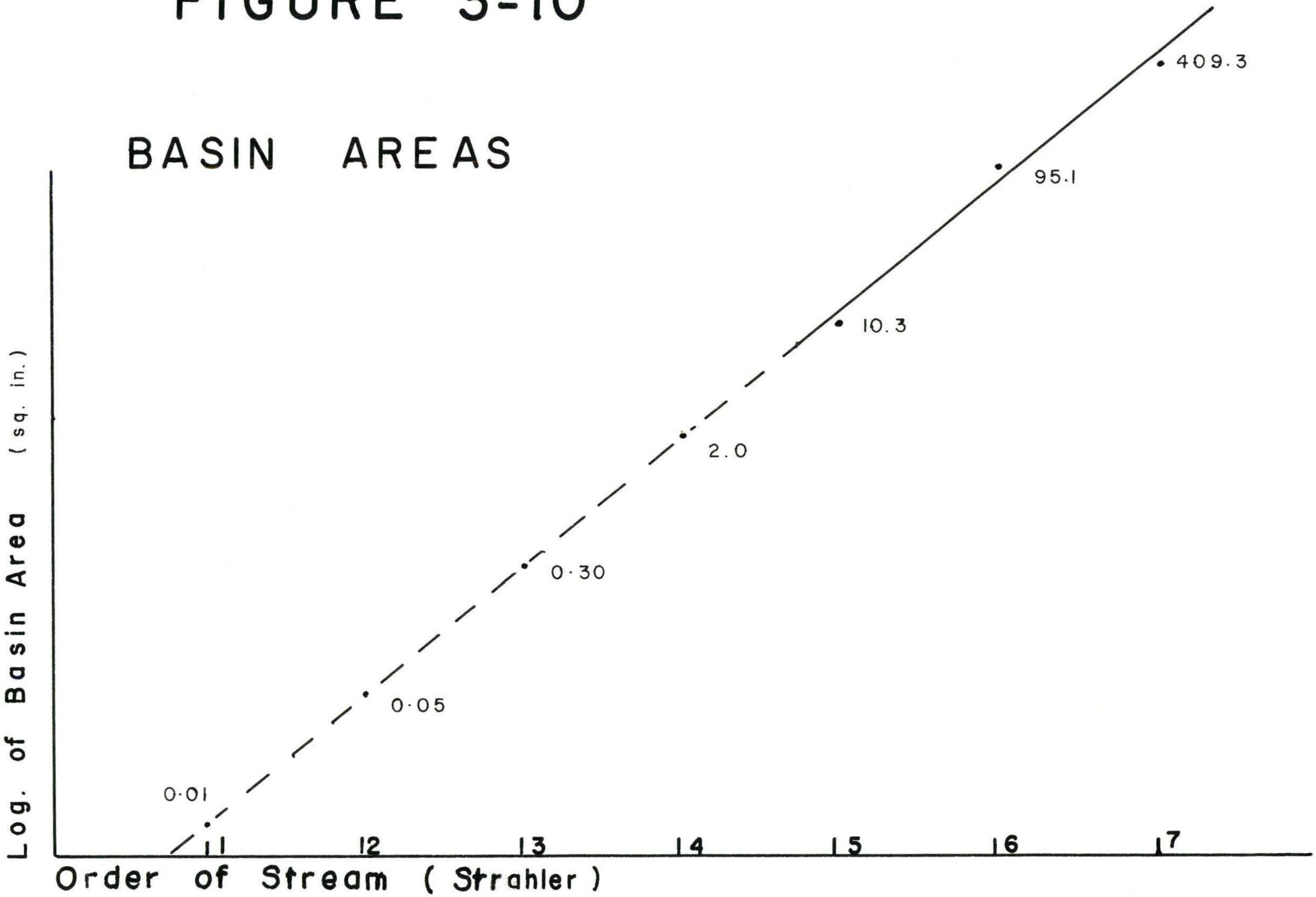


FIGURE 3-11

AIR PHOTOGRAPH of FLUTES

Basin. A very strong pattern of lineation across the figure is evident. The linearity is noticeable in varying degrees over scattered portions of the region. The pattern influences the route of fluvial drainage and, therefore, the basin shape and network parameters.

In order to analyze stream orientation caused by lineations in drift, a control is required with which to compare Mallot River data. Morisawa (1963) used a flat surface of homogeneous rock to study the probable direction of stream flow. Her results indicated that stream direction is equally random in all directions. Deviations from this ideal distribution of flow direction must be caused by local topography or geology.

Mechanical orientation measures of three basins within the research area were made using the McMaster C.D.C. 6400 computer and the W.A.T.E.R. system of morphometric stream analysis programs. A basin was chosen arbitrarily from each of the northern, central, and southern portions of the Mallot system. The "Azmuth" subroutine determined the orientation of each Strahler stream segment.

Rose diagrams of preferred orientation were constructed using a 15 degree interval. Cumulative lengths of segments specify the magnitude of the interval. The data in FIGURE 3-12 was displayed using formats developed by Curray (1956; 117-118) and Williams

FIGURE 3-12a

STREAM SEGMENT ORIENTATION

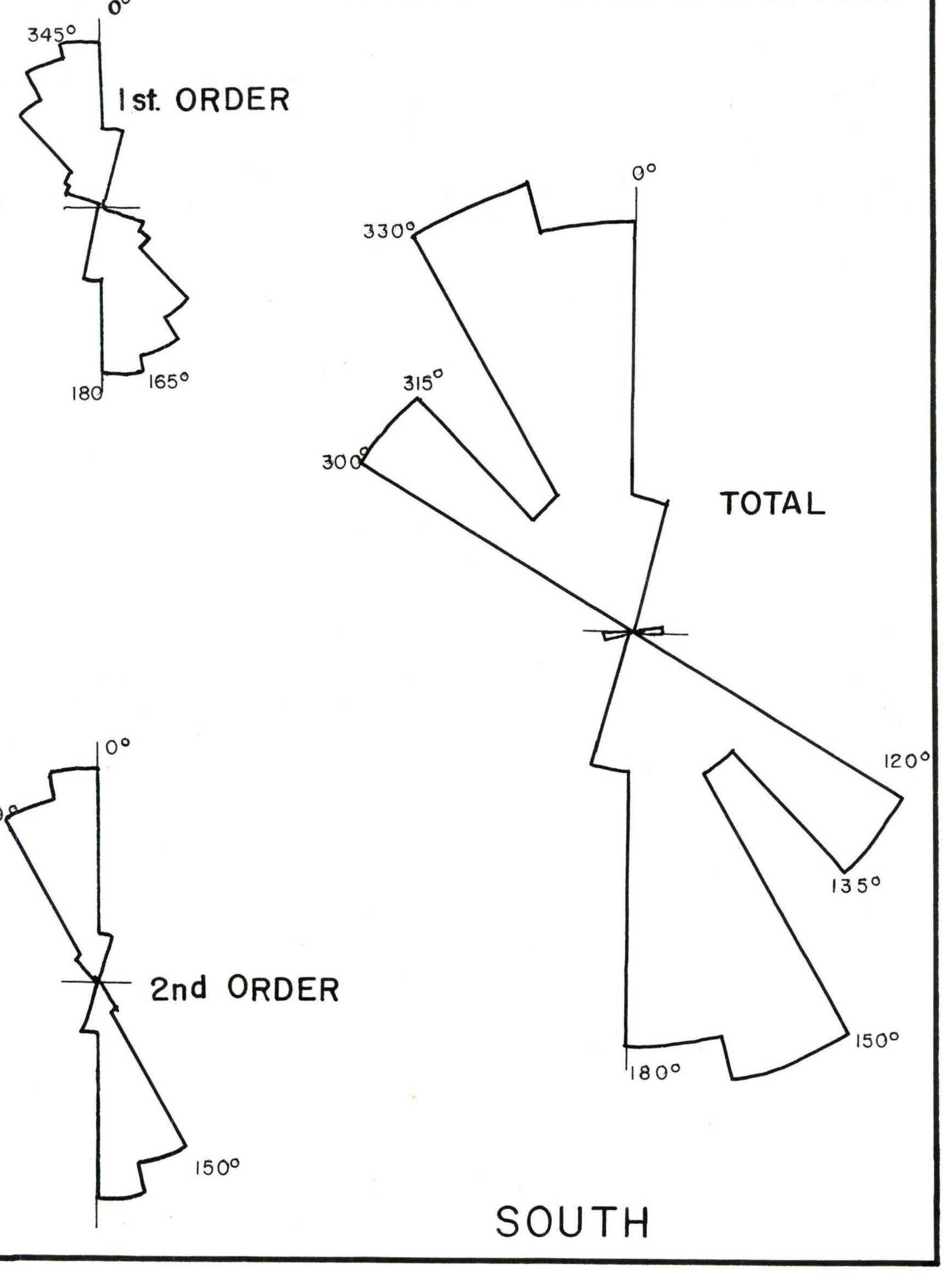
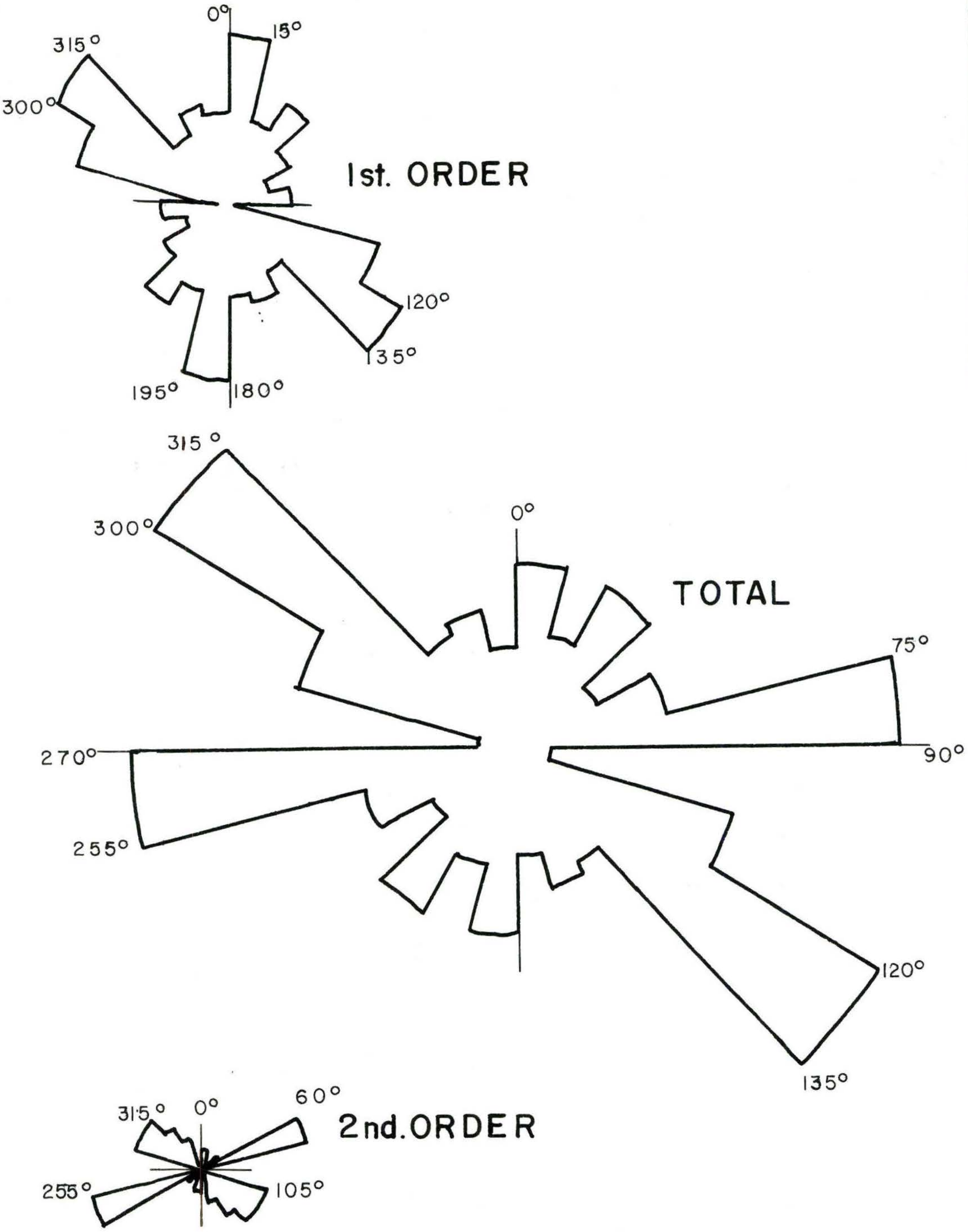


FIGURE 3-12b

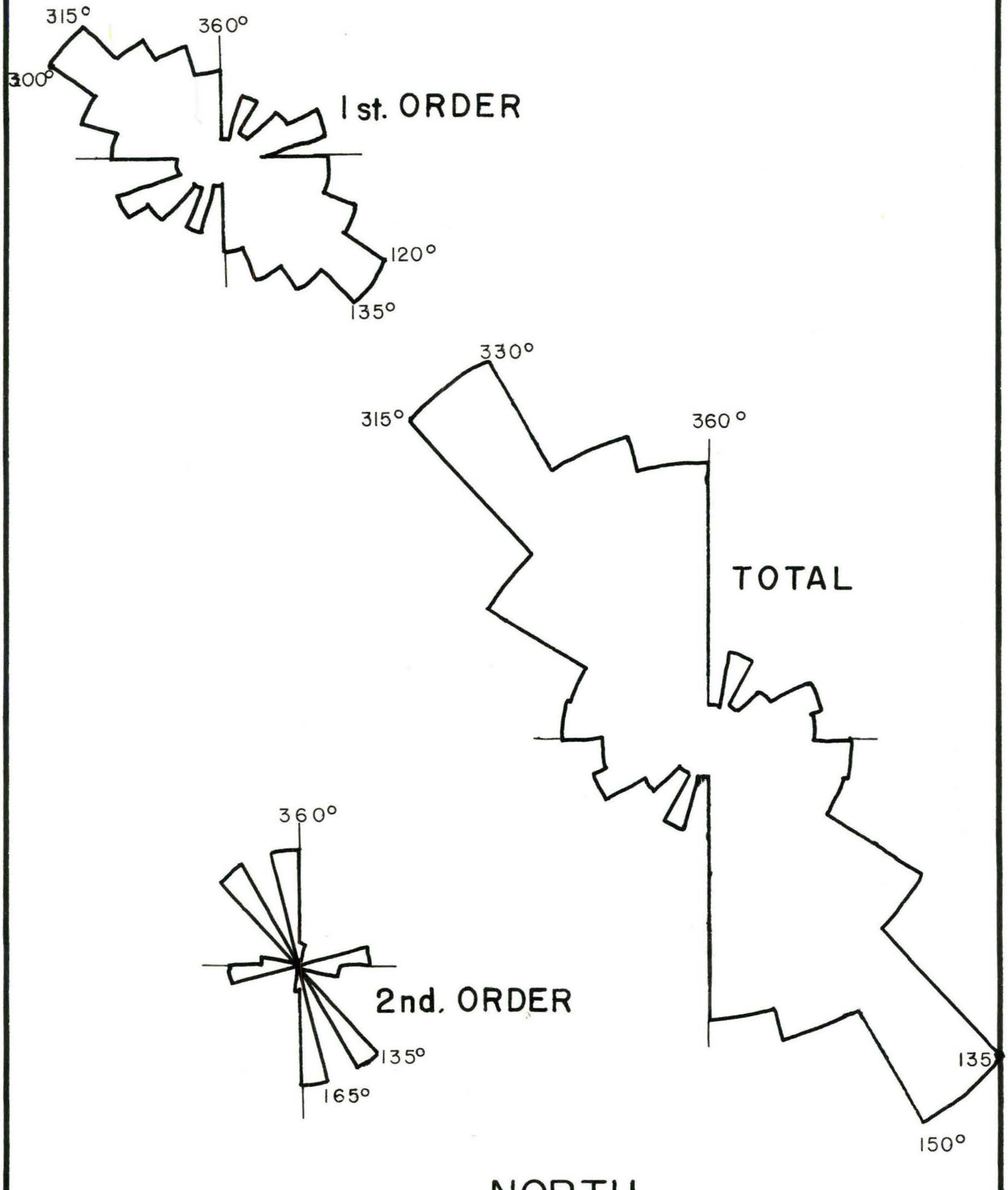
STREAM SEGMENT ORIENTATION



CENTRAL

FIGURE 3-12c

STREAM SEGMENT ORIENTATION



(1972: 779).

The figures indicate that there is a strong preferred orientation within the Mallot Basin. In the south, both the 1st and 2nd Order segments are generally oriented between 150 and 180 degrees. The totals for the basin, which include greater orders, indicate similar orientation. The central example has 1st Order streams of preferred orientation between 0-15 and 105-135 degrees. The 2nd Order segments again have the N.W.-S.W. orientation, but also have an additional grouping at 60-75 degrees. When the 4th Order segment is removed the only significant deviation in the summation of the values is the 120-135 degree sector. The northern-most basin has a preferred orientation of N.W.-S.E. in the 1st and 2nd Orders. Tendencies toward 80 and 170 degrees are lost in the figure of cumulative values. There is a very pronounced preferred orientation in Mallot River stream segments between 120 and 165 degrees. A one-tailed Chi-square test proved the significance of the distinction between the observed and expected (Morisawa, 1963) values. Although the influence of the orientations on drainage has been noted, the cause has yet to be determined.

The flutes in the Mallot River Basin are visible as low to rolling hills with little more than ten feet of relief. There does not appear to be a plain with superimposed ridges but a regular rolling topography. The flutes have the appearance of those observed elsewhere.

Gravenor and Meneley (1958) working in northern and central Alberta and Hack (1965) in northern Michigan observed similar flutings. Flutes are described as shallow grooves on till plains. Gravenor and Meneley found most flutes on till, but a few were eroded into the Precambrian bedrock. Thus, an erosional origin is proven.

Flute wavelength can be defined as the distance between the crests of adjacent ridges. Alberta flutes were found to have a preferred wavelength of 300 to 400 feet. Similar results were obtained by Hack. Mallot Basin flutes have a mean wavelength of 413 feet.

Alternatively, lineation could be caused by regional isostatic movement during the immediate postglacial period or from ongoing movements. Harris (1969) used isostatic recovery to explain localized deglacial landforms and deposits to the south-east of the Mallot. The tilt could have caused steep slopes which would initiate linearfluvial erosion. These gullies may today be in a different gradient. It is possible that the flutes are fossils of fluvial adjustment to a localized isostatic adjustment. Harris noticed three preferred orientations (92, 105, and 108 degrees) which are close to the flute orientation at the Mallot Basin, which is up the glacial ice stream from Harris' area.

Moore (1948: 708) provides data which indicates regional crustal movements at odds with the assumptions of isostacy made by Harris. The entire Great Lakes region is shown to be subsiding in distinct contrast to isostatic rebound. The line of no tilt is at a bearing of roughly 135 degrees. This subsidence may have provided the paleo-slope which initiated fluvial gullying now observed as flutes. Moore's observation is remarkably consistent with that of flute orientation. Isostacy does not necessarily explain the origin of fluting. A fluvial development theory is more complex than a neater possibility discussed below.

What does not influence the origin of flute orientation is the local relief. Flutes have been observed on highlands, lowlands and hillslopes. The topography may direct the glacier and, therefore, only indirectly the flutes. Gravenor and Meneley (1958: 726) hypothesized that alternate high and low pressure depositional zones cause a buildup of material. The most likely explanation is that of secondary currents within the periodically readvancing ice mass during the deglacial phase. An analogy can be successfully made to existing secondary current literature.

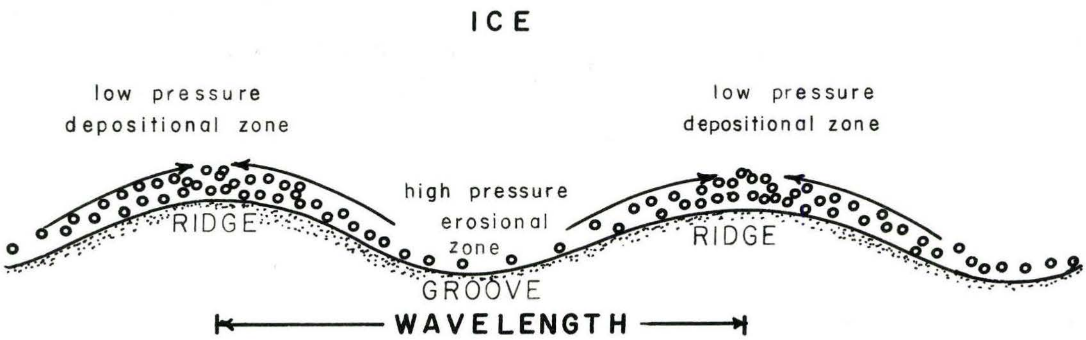
Convolute laminations found in turbidite deposits are explained by forces known to exist in turbidity currents (Dzulynski & Smith, 1963: 616). Longitudinal patterns of troughs and ridges seem to be caused by "isolated vortices and nearby stationary water rollers" explainable as secondary currents. Model studies using a slurry of plaster-of-paris introduced to a water tank with a settled mud floor produced sole markings not dissimilar to the pattern of flutes on a drift surface (Dzulynski, 1965: 196).

There is only a scale change between the two environments. FIGURE 3-13a gives the Gravenor and Meneley theory while 3-13b shows the probable role of secondary currents. Flutes may be expected to have an origin similar to that of the analogous phenomena. The complex assortment of moraines to the south-east attest to late readvances over the Mallot Basin (Harris, 1969; Chapman & Putnam, 1966). This may explain local occurrences of flutes.

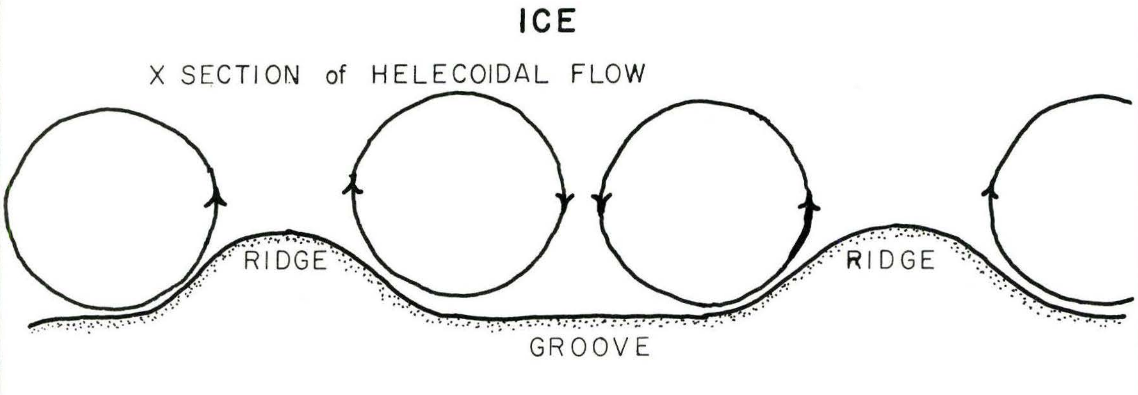
Glacial lineation can be seen to hierarchically influence stream direction. Low order streams are regularized by fluting. Higher order stream direction was regularized by the meltwater-caused channelization. In FIGURE 3-1, Orders 2-4 and 6-7, respectively, delimit the two groups.

FIGURE 3-13

a. ORIGIN of FLUTES GRAVENOR and MENELY



b. SECONDARY CURRENT THEORY



Stream Entrance Angles

Stream entrance angles are another property of shape within a basin. Horton(1945: 350) noted there to be a downstream change in angles which is a function of slope. Schumm (1956; 618) found at Perth Amboy a mean angle of 65.2 degrees for young streams, while mature streams entered at 46.2 degrees. Bones and Ford (1971) observed with experimental models that there was an increase in entrance angle with decreasing slope. The initial entrance of "a tributary to a channel of higher order develops with an entrance angle dependent on the ratio between channel and ground slope" (Schumm, 1956: 619). Since the main channel degradation is slower than that of the tributary, as the tributary gradient continues to lower, the junction angle changes as lateral planation removes the intervening divide allowing the junction to move upstream.

Angles of stream bifurcations can indicate the existence of geologic controls. The W.A.T.E.R. program generated stream junction angle statistics from three sub-basins of the Mallot River system. TABLE 3-3 displays the results of the analysis.

No consistent variation is observed for any of the basins nor for any order within the basins. The range of variation for all orders is consistently high. The mean angle of incidence tends to rise with the size

TABLE 3-3a

THE WATER SYSTEM

COMPUTER PROGRAMS FOR WATERSHED ANALYSES
DEVELOPED AT
UNIVERSITY OF TORONTO PURDUE UNIVERSITY
TORONTO, ONTARIO LAFAYETTE, INDIANA

DRAINAGE BASIN BEING ANALYZED IS MALLOT BASIN TRIBUTARIES SOUTH

INFORMATION FOR THIS BASIN WAS COLLECTED FROM AIR PHOTO SOURCE, 1955 ONT. COVERAGE

THE SCALE OF THE SOURCE MATERIAL IS 1/17400.

TABLE SHOWING STREAM JUNCTION ANGLE STATISTICS.

ORDERS OF JOINING SEGMENTS		NUMBER OF ANGLES	MEAN ANGLE (DEGREES)	MAXIMUM ANGLE (DEGREES)	MINIMUM ANGLE (DEGREES)	RANGE (DEGREES)	VARIANCE (DEGREES) (SQUARED)	STANDARD DEVIATION (DEGREES)
HIGHER	LOWER							
1	1	19.000	76.894	151.134	15.785	135.349	2345.	48.422
2	1	38.000	58.083	173.989	15.858	158.132	2044.	45.214
2	2	6.000	79.108	142.048	33.009	109.040	2391.	48.894
3	1	10.000	77.538	149.686	18.545	131.141	1366.	36.966
3	2	2.000	44.709	47.001	42.417	4.584		
3	3	1.000	41.267	41.267	41.267	0.000		
4	1	10.000	94.961	168.834	26.110	142.724	3536.	59.464
4	2	5.000	92.772	171.938	24.006	147.932	3479.	58.982
4	3	4.000	49.704	82.867	24.927	57.941		

TABLE 3-3b

```
**********************************************
*                                            *
*        T H E   W A T E R   S Y S T E M     *
*                                            *
*  COMPUTER PROGRAMS FOR WATERSHED ANALYSES  *
*               DEVELOPED AT                 *
*  UNIVERSITY OF TORONTO  PURDUE UNIVERSITY  *
*    TORONTO,ONTARIO     LAFAYETTE,INDIANA   *
*                                            *
**********************************************
```

DRAINAGE BASIN BEING ANALYZED IS MALLOT BASIN TRIBUTARIES CENTRAL

INFORMATION FOR THIS BASIN WAS COLLECTED FROM AIR PHOTO SOURCE, 1955 ONT. COVERAGE

THE SCALE OF THE SOURCE MATERIAL IS 1/17400.

TABLE SHOWING STREAM JUNCTION ANGLE STATISTICS.

ORDERS OF JOINING SEGMENTS: HIGHER	LOWER	NUMBER OF ANGLES	MEAN ANGLE (DEGREES)	MAXIMUM ANGLE (DEGREES)	MINIMUM ANGLE (DEGREES)	RANGE (DEGREES)	VARIANCE (DEGREES) (SQUARED)	STANDARD DEVIATION (DEGREES)
1	1	25.000	74.114	139.970	32.458	107.512	842.	29.022
2	1	21.000	83.221	169.045	38.812	130.234	1147.	33.870
2	2	6.000	79.835	126.491	23.839	102.652	1572.	39.647
3	1	14.000	90.117	139.185	59.490	73.695	814.	28.525
3	2	5.000	97.702	138.180	71.565	66.615	628.	25.055
3	3	1.000	129.805	129.805	129.805	0.000		
4	1	21.000	86.970	119.745	46.312	73.433	632.	25.147
4	2	8.000	98.112	124.624	73.589	51.035	358.	18.917
4	3	4.000	108.554	171.656	71.565	100.091		

TABLE 3-3c

THE WATER SYSTEM

COMPUTER PROGRAMS FOR WATERSHED ANALYSES
DEVELOPED AT
UNIVERSITY OF TORONTO PURDUE UNIVERSITY
TORONTO, ONTARIO LAFAYETTE, INDIANA

DRAINAGE BASIN BEING ANALYZED IS MALLOT BASIN TRIBUTARIES NORTH

INFORMATION FOR THIS BASIN WAS COLLECTED FROM AIR PHOTO SOURCE, 1955 ONT. COVERAGE

THE SCALE OF THE SOURCE MATERIAL IS 1/17400.

TABLE SHOWING STREAM JUNCTION ANGLE STATISTICS.

ORDERS OF JOINING SEGMENTS		NUMBER OF ANGLES	MEAN ANGLE (DEGREES)	MAXIMUM ANGLE (DEGREES)	MINIMUM ANGLE (DEGREES)	RANGE (DEGREES)	VARIANCE (DEGREES) (SQUARED)	STANDARD DEVIATION (DEGREES)
HIGHER	LOWER							
1	1	23.000	81.526	155.496	26.169	129.327	932.	30.535
2	1	10.000	84.546	139.107	38.689	100.418	1299.	36.045
2	2	5.000	81.343	101.387	62.066	39.321	288.	16.970
3	1	17.000	73.097	141.299	28.640	112.659	1205.	34.720
3	2	6.000	70.975	113.653	26.466	87.187	1375.	37.081
3	3	1.000	74.705	74.705	74.705	0.000		
4	1	12.000	82.981	138.848	30.115	108.732	1009.	31.768
4	2	7.000	99.754	142.411	62.680	79.731	654.	25.582
4	3	3.000	103.653	143.413	73.656	69.757		

of stream. The angle of incidence has a slight tendency to decrease over the Mallot Basin from the north to the south.

The generally high values of incidence and great variation in angle may be typical of glaciated regions. No powerful geologic controls operate in the Mallot system. A very slight decrease in average slope in the southern portion of the Mallot Basin is suggested (Bones & Ford, 1971). No correlation with fluting is directly interpretable.

"RATIOMETRIC" PROPERTIES

Numerical, linear and areal properties of the Mallot Basin morphometry have been investigated. More valuable information concerning basin structure can be obtained from "ratiometric" techniques than from raw measures. Ratios, independent of scale, can be used to compare one basin with another. Melton (1958) states that the "'appearance' of a region is not so much related to the size of geomorphic elements as to these ratios and angular measurements".

Bifurcation Ratio

The bifurcation ratio (Rb) was developed by Horton (1945: 286) to measure the branching nature of a stream. The value gives a quantitative indication of how many times the tributaries divide. It is defined as the number of streams of one order divided by the number of streams in the next larger order.

Shreve (1966) contended that the most probable network is that which makes the geometric mean ratio closest to 4.0. Abrahams (1972) feels that as relief is lowered there is a stronger tendency for the basin ratio to approach the minimum value which is 2.0. Werner (1971) found that streams in natural channels commonly have a range of Rb between 3.5 and 4.0. From statistical theory he argued that if chance alone creates a channel net, then a ratio of 3.618 will be produced.

Varying bifurcation values are found in glaciated till plains of Southern Ontario. TABLE 3-2 displays bifurcation data of the Grand River system of Ontario determined from the blue lines of 1:50,000 topographic maps. The ratios range from a low of 3.34 to a maximum of 5.07. The readjusted Grand River data is higher at a value of 5.3. Thus these rivers on till plains seem to bifurcate more often than those of non-glaciated areas. Mallot River data, TABLE 3-4, supports this observation. If Abrahams is correct, then the "youthful" nature of drainage systems on these till surfaces is shown.

Erosion has yet to reduce the relief sufficiently to produce a lower ratio; i.e., to approach 2.0. If the basin erosion is producing changes in the ratio,

TABLE 3-4

BIFURCATION RATIOS - MALLOT BASIN

Location \ Order	1-2	2-3	3-4	4-5	5-6	6-7
Seventh Order	3.71	4.23	4.16	4.74	7.6	6.0
Sixth Order						
1	3.88	4.32	3.17	3.00	2.0	-
2	3.99	3.64	4.23	5.20	5.0	-
3	3.82	4.56	3.38	2.67	3.0	-
4	3.67	4.15	5.84	4.17	6.0	-
5	3.79	4.27	3.28	3.60	5.0	-
6	3.64	4.33	4.61	5.41	17.0	-
Fifth Order						
1	3.68	3.58	4.53	6.0		
2	3.56	4.00	5.40	5.0		
3	3.32	4.70	5.75	4.0		
4	3.33	4.18	5.50	2.0		
5	3.36	4.41	5.67	3.0		
6	3.32	3.13	3.00	5.0		
7	3.75	4.57	3.50	6.0		
8	3.14	5.00	2.80	5.0		
9	3.22	6.83	3.00	2.0		
10	3.68	3.60	5.00	4.0		
11	2.79	3.63	4.00	2.0		
12	3.65	4.20	5.50	8.0		
13	3.76	5.00	3.75	4.0		
14	3.40	3.75	4.00	2.0		
15	6.32	4.67	3.00	2.0		
16	4.80	3.75	2.00	2.0		
17	3.51	4.41	5.67	6.0		
18	3.33	3.00	3.00	2.0		
19	3.10	4.20	2.50	2.0		
20	4.11	3.27	2.75	4.0		
21	3.44	4.28	3.60	5.0		
22	4.07	7.33	3.00	2.0		
23	3.46	3.77	8.67	3.0		
24	3.87	4.73	2.75	4.0		
25	3.60	4.24	4.25	4.0		
26	3.68	4.97	7.75	4.0		

TABLE 3-4

BIFURCATION RATIOS - MALLOT BASIN
(Continued)

Order / Location	1-2	2-3	3-4	4-5
Fifth Order (Continued)				
27	3.65	4.33	3.00	2.0
28	3.90	2.90	5.00	2.0
29	3.67	3.71	7.00	4.0
30	3.80	3.68	4.40	5.0
31	3.30	3.88	4.00	2.0
32	3.55	4.71	3.50	2.0
33	2.90	3.23	6.50	2.0
34	3.64	2.75	2.00	2.0
35	3.74	4.33	3.00	3.0
36	3.76	5.90	5.00	2.0
37	3.52	3.57	3.50	2.0
38	3.22	4.13	3.43	7.0
39	3.79	4.04	5.00	5.0
40	3.76	3.21	3.50	4.0
41	3.26	3.80	3.33	3.0
42	3.53	3.68	4.70	10.0
43	4.12	3.09	3.67	3.0
44	4.00	3.29	3.50	2.0
45	4.08	4.45	5.50	2.0
46	3.63	3.43	2.33	3.0
Fourth Order (Selected)				
a	3.5	4.4	7.0	
b	2.8	6.0	4.0	
c	3.6	3.5	10.0	
d	3.4	3.5	2.0	
e	3.2	6.5	2.0	
f	4.3	5.0	2.0	
g	4.0	5.5	2.0	
h	3.8	4.0	3.0	
i	4.5	3.8	5.0	
j	4.5	2.5	4.0	
k	3.5	2.0	2.0	
l	3.9	4.0	2.0	
m	3.7	2.3	3.0	

TABLE 3-4

BIFURCATION RATIOS - MALLOT BASIN
(Continued)

Order / Location	1-2	2-3	3-4
Fourth Order (continued)			
n	4.4	2.7	3.0
o	4.5	6.0	2.0
p	3.9	5.5	2.0
q	3.8	6.0	3.0
r	3.4	3.3	3.0
s	3.7	5.0	3.0
t	4.6	3.8	4.0
u	3.3	3.3	3.0
v	4.3	3.5	4.0
w	3.3	4.5	4.0
x	3.4	4.0	8.0

a state of equilibrium in the basin units can not be considered to exist. 2.0 is approached assymptotically. Accepting Abrahams, until the Mallot Rb's tend toward a value of 3.618 (Werner) an equilibrium should not exist. All vestiges of the underfit system will have been eroded away when the randomly generated values are attained in the Mallot.

Bifurcation ratios for individual basins within the Mallot system are shown in TABLE 3-4. All Fifth and selected Fourth Order basins were individually studied, totalling 70 basins.

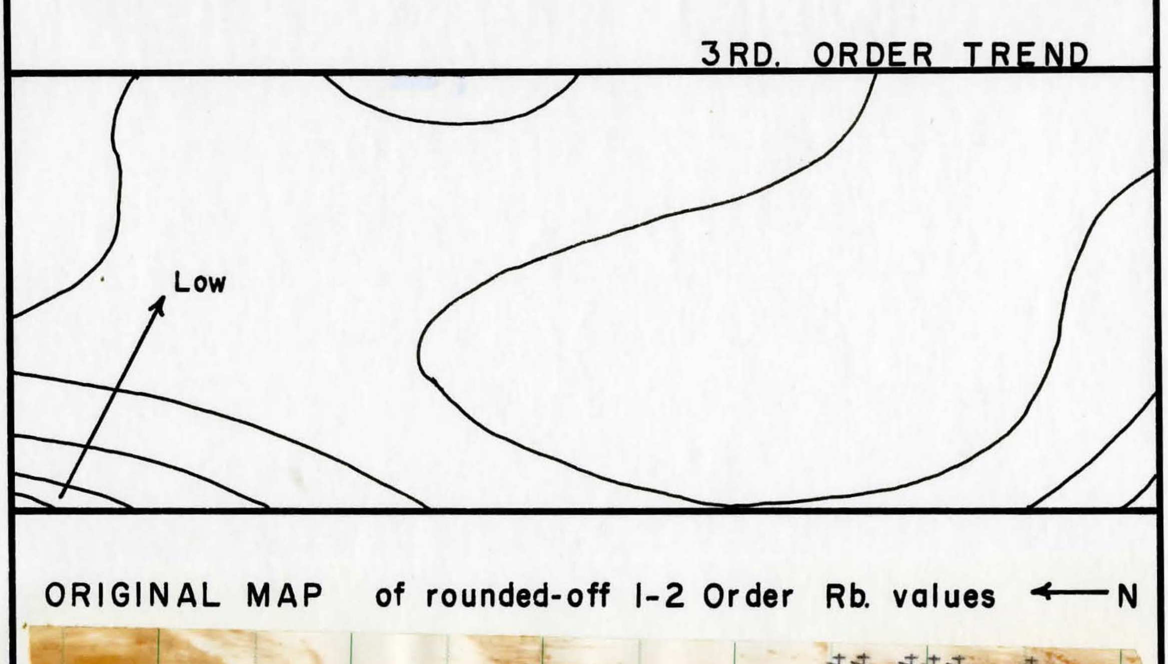
Trend surface analysis is the best available means to determine if simple patterns of variation exist. Regular topographic discontinuities would be depicted. The seventy individual basins each have a specific value for each order to be plotted. To avoid spurious weighting toward small basins, 274 data points were reapportioned on the basis of basin surface area. The number of points assigned each basin was located within its perimeter. Each point has the mean value of that basin's bifurcation ratio for each order. The Fourth Order basins were selected from areas not covered by Fifth Orders. Original maps with a few rounded off data points are shown in FIGURE 3-14.

TABLE 3-5 displays the results of the investigation. For ease of reference, the trend surface values

FIGURE 3-14a Rb. T.S.A. (1-2)

RESIDUAL MAP

3RD. ORDER TREND



ORIGINAL MAP of rounded-off 1-2 Order Rb. values ← N

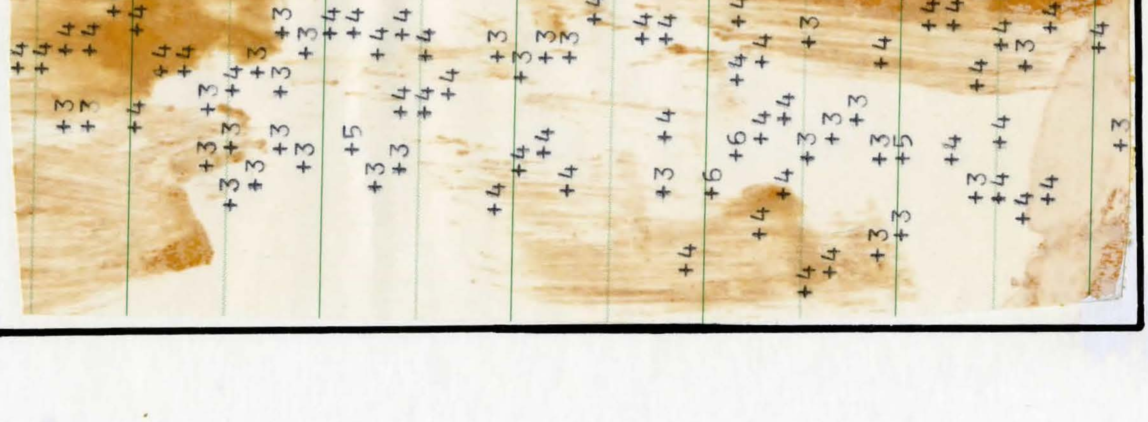


FIGURE 3-14b Rb. T.S.A. (2-3)

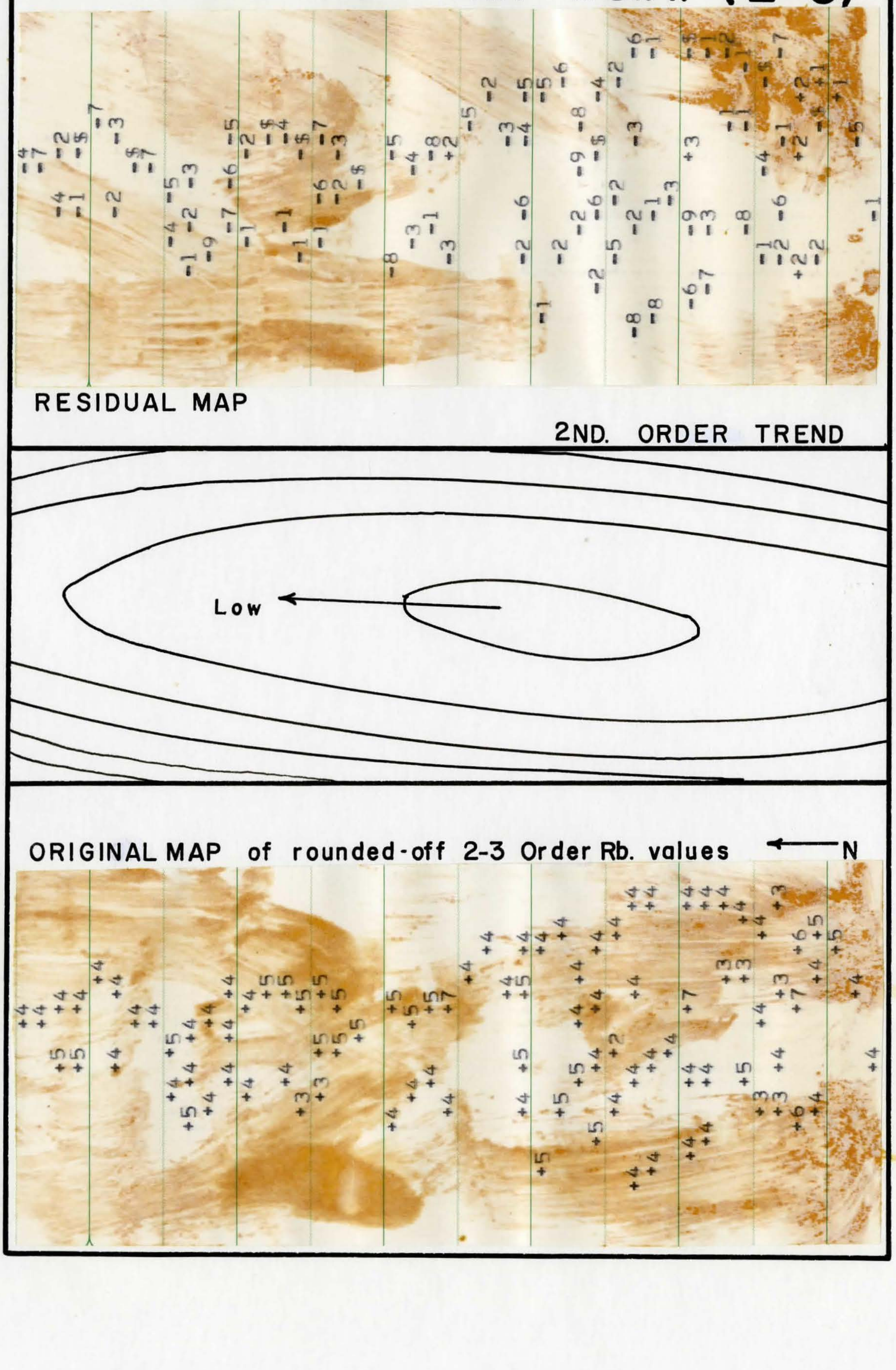
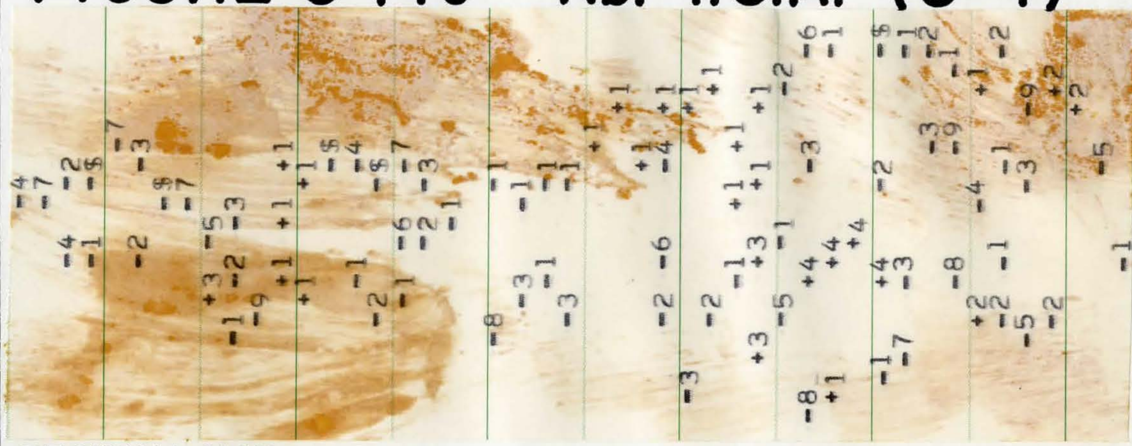
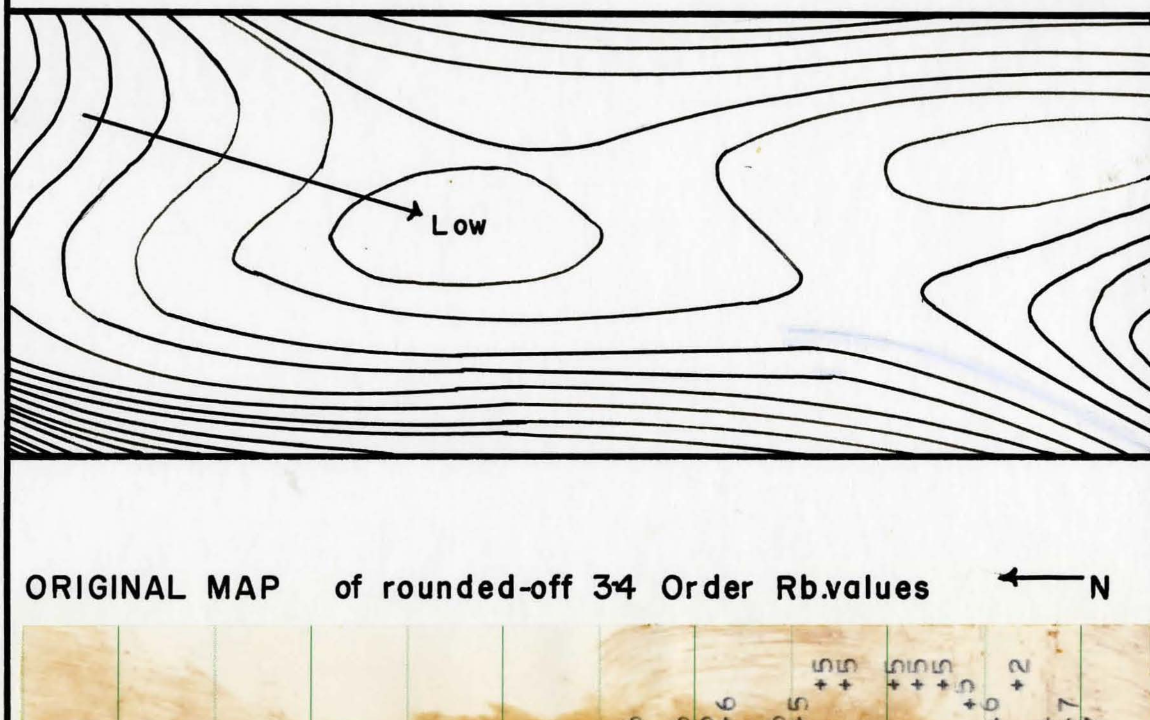


FIGURE 3-14c Rb. T.S.A. (3-4)



RESIDUAL MAP

3RD. ORDER TREND



ORIGINAL MAP of rounded-off 3-4 Order Rb.values ← N

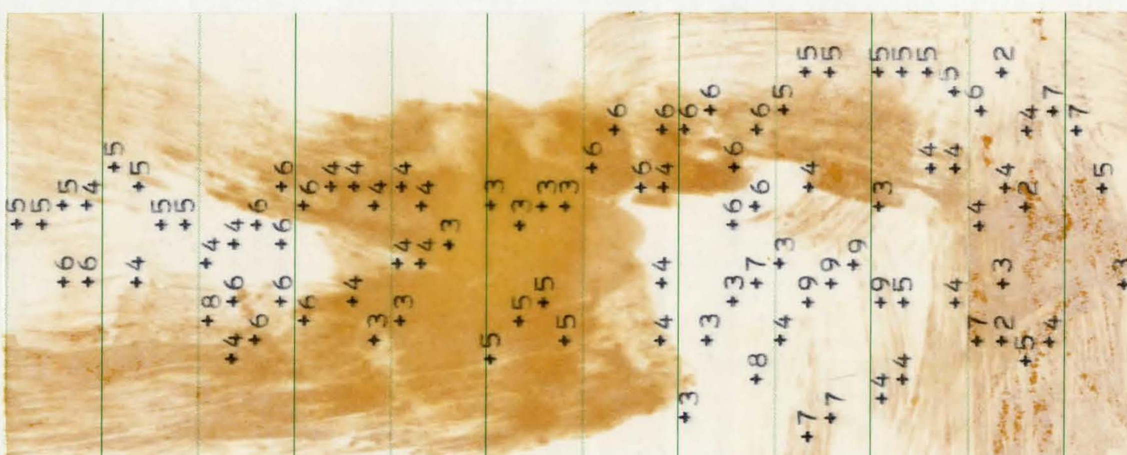
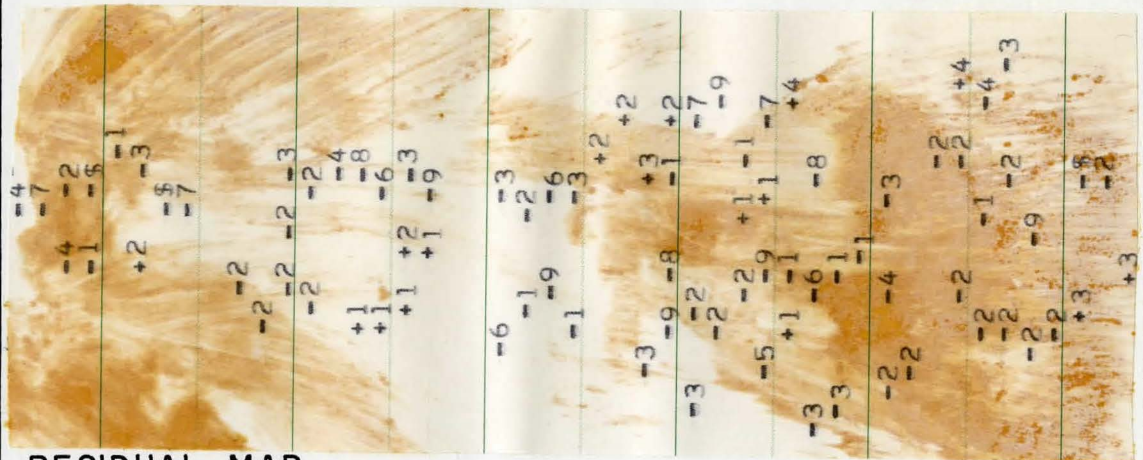
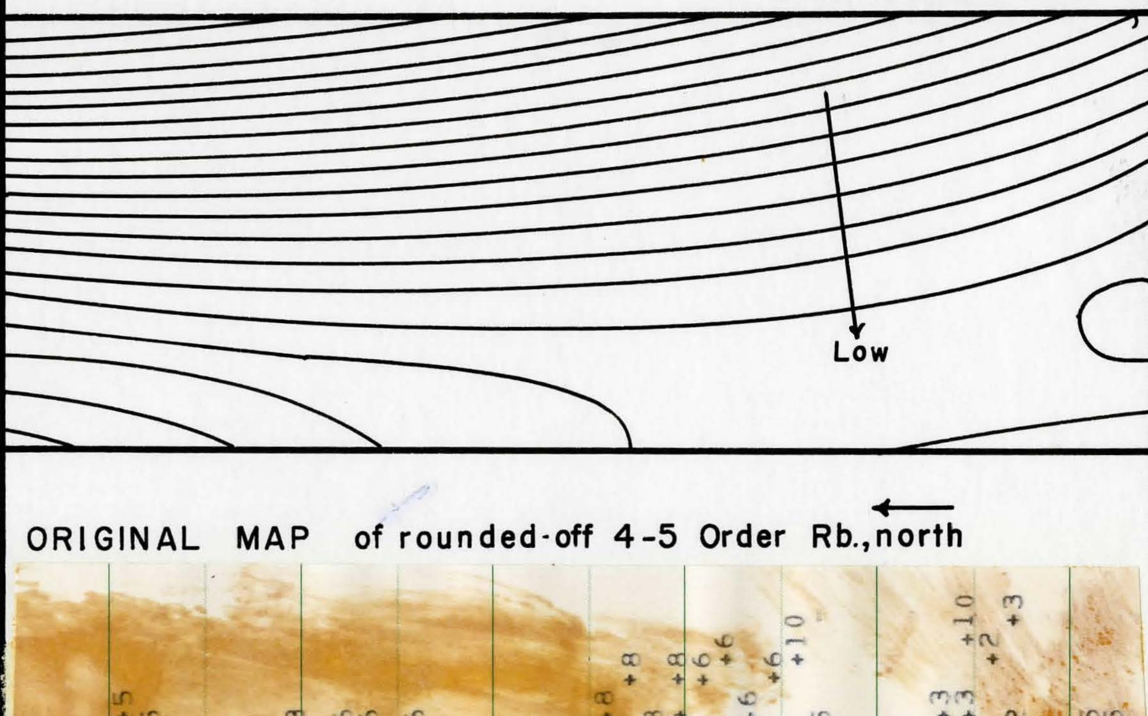


FIGURE 3-14d Rb. T.S.A. (4-5)



RESIDUAL MAP

2 ND. ORDER TREND



ORIGINAL MAP of rounded-off 4-5 Order Rb., north

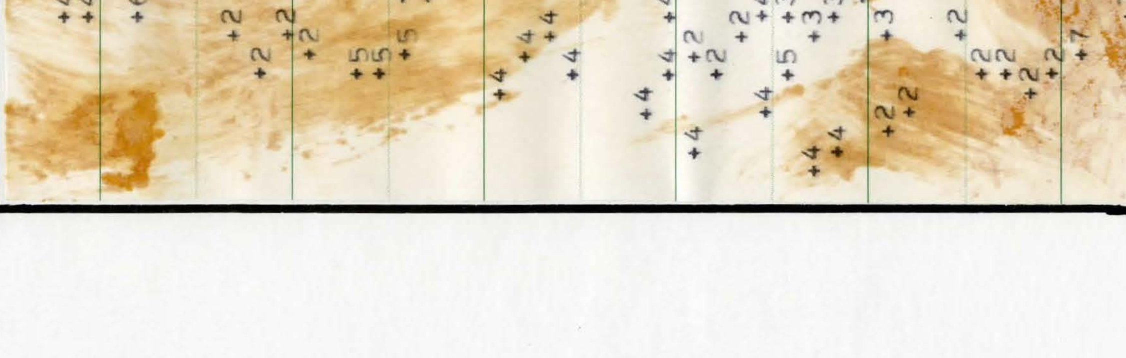


TABLE 3-5

TREND SURFACE ANALYSIS RESULTS FROM BIFURCATION RATIO DATA

	Random Numbers (Source: Howarth, 1967)	1-2	2-3	3-4	4-5	1-3
Percent of Variation Explained by Linear Surface	0.6	2.50	0.1	4.4	16.9	1.3
Percent of Variation Explained by Linear and Quadratic Surfaces	12.0	4.80	3.5	8.0	19.6	4.2
Percent of Variation Explained by Linear Quadratic, and Cubic Surfaces	16.2	12.15	10.7	12.4	24.1	9.4

produced, where random numbers were used, are given on the same table (Howarth, 1967). The results consistently show, at each order, that there is no pattern of Rb change over the large basin. The values of percentage explained at each level of complexity is not significantly different from random. Residuals of Third Order trends indicate no pattern (FIGURE 3-14). The method does not prove that there will not be a very high correlation were a fourth level of analysis used, but the likelihood is remote, given the extremely low correlations. There is no simple pattern of change depicted by the bifurcation ratios.

It is concluded that Rb's on a drift surface are patternless, generally higher and more irregular than those in non-glaciated area. It is suggested that the high value and irregularity are products of the glacial and pro-glacial features. Fluting can influence the bifurcation ratio. The trough collects lower order tributaries in a trellis array which raises the branching ratio. The superimposed organization allows more than a random number of channel entrances to the interflute conduit. This situation is analogous to the rise in bifurcation ratio due to the spillway trough.

Length Ratio and Cumulative Length Ratio

The Length Ratio (R_L) was developed by Horton (1945: 286-287). It parallels the bifurcation ratio. The parameter is defined as the average length of an order of stream divided by the average length of channel of an order one magnitude smaller:

$$R_L = \bar{L}_u/\bar{L}_{u-1} .$$

Values for the Length Ratio are given in TABLE 3-6. The range of variation, between 1.4 and 4.3, is high. This analysis has no significant meaning when the Strahler system of ordering is used. Only by accumulating lengths does an approximation to Horton values result. The Cumulative Length Ratios (R_{CL}) vary only between 2.08 and 3.94. The reduction of scatter is related to the more significant correlation coefficient for cumulative values (FIGURE 3-4). The R_{CL} is greater for the greater orders than it is for the lower ones.

Sixth and Fifth Order values are greater as a direct result of the underfit channels. Channel lengthening is reiterated as was previously discussed. The relative shortness of lower orders is less distinguishable, but could in part be due to fluting where segments normal to the flute are necessarily short. It may be concluded that variations in Length Ratio or

TABLE 3-6

LENGTH AND AREA RATIOS

LENGTH RATIO

Order	Mean Length	Length Ratio	Cumulative Mean Length	Cumulative R_L
7	29.500		50.400	
		1.89		2.41
6	15.600		20.900	
		4.25		3.94
5	3.670		5.300	
		3.90		3.25
4	0.940		1.630	
		2.60		2.36
3	0.360		0.690	
		1.86		2.08
2	0.194		0.330	
		1.41		2.41
1	0.138		0.138	
		$\bar{x}$ = 2.65		$\bar{x}$ = 2.74

AREA RATIO

Order	Mean Area	Area Ratio	Order	Mean Area	Area Ratio
7	709.3		4	(2.0)	
		4.30			(6.67)
6	95.1		3	(0.3)	
		9.23			(6.00)
5	10.3		2	(0.05)	
		(5.15)			(5.00)
4	(2.0)		1	(0.01)	

Cumulative Length Ratio over the basin are greater on drift surfaces due to surface irregularities.

Area Ratio

The Area Ratio (R_A) parallels the bifurcation and length ratios. The value is defined as the average area of a basin of an order divided by the average basin area of an order one magnitude smaller:

$$R_A = \bar{A}_u / \bar{A}_{u-1} .$$

Mallot Basin areas have been determined for only 3 orders. There is insufficient available data to warrant observations or conclusions.

Relief Ratio

The Relief Ratio is an expression comparing basin relief and length. Schumm (1956: 612) used the change in basin relief from summit to mouth and the longest basin dimension parallel to the principal drainage line to determine the value.

The Mallot Basin is 179,360 feet (34 miles) long and has a relief of 350 feet. A slope of 0.002 or Relief Ratio of 512.5 occurs.

Ground and channel gradients achieve a form which is best adapted to maintaining a steady state in the removal of debris (Strahler, 1950: 688). In order to distinguish properties of relief within the Mallot Basin, the "Law of Stream Fall" proposed by Yang (1971) was adopted. It is possible to investigate changes in relief by order. The "law" states that under the condition of dynamic equilibrium, the ratio of average fall between any two different orders of stream in the same river basin is unity. Yang claims that the excellent agreement between theory and observation is due in part to the production of the least rate of energy expenditure. The Strahler ordering system is compatible with the method.

Two data sources were used in the Mallot Basin. Field surveys generated vertical measures, whilst air photographs and field notes provided length data. The least accurate portion of the differentiation is between First and Second Order segments. These values of relief were divided equally and so show the perfect relationship artificially. These particular elements are in parentheses in the table of surveyed data (TABLE 3-7).

Other than the artificial correlation, there is no evidence of relief similarity between adjacent orders in the Mallot. Yang (1971: 320) postulated that when the fall ratio is less than unity "the equilibrium profile will have a higher elevation than the theoretical profile". Mallot Basin is not in equilibrium according to Yang's model. There are many possible causes for the

TABLE 3-7

RELIEF RATIOS (YANG)

Change in Relief Values / Order	7		6		5		4		3		2		1
Main Stream													
Value (in feet)	42.6		111.1		60.0		10.1		7.5		9.4		3.4
Ratio		0.4		1.8		5.9		1.3		0.79		2.8	
Western Tributary													
Value					48.9		5.3		4.0		11.0		11.0
Ratio						9.2		1.3		0.4		(1.0)	
Rothsay Tributary													
Value					61.4		-		10.3		41.3		41.3
Ratio										0.2		(1.0)	
Highway 9 Tributary													
Value					6.3		32.1		3.7		3.7		3.7
Ratio						0.2		8.7		(1.0)		(1.0)	
Woodham Tributary													
Value					31.9		5.4		17.7		2.8		2.8
Ratio						5.9		0.3		6.3		(1.0)	
Average Values	42.6		111.1		41.7		13.2		8.6		13.6		12.4
Ratio		0.4		2.7		3.2		1.5		0.6		1.1	

lack of correlation. The existence of the underfit valley seems most important. The 5th Order segment often rises out of an oversized valley toward its source. The fall ratio is great, reflecting this discontinuity. In the case of the Highway 9 tributary, the 5th Order segment crosses the wide floodplain allowing the 4th Order segment to rise out of the spillway valley. The fall ratio is affected by the unusually long 6th Order segment of basin 6 (FIGURES 3-15, 3-16, and 3-17).

Deviations in the fall ratio could distinguish disequilibrium. The greatest variation of value is with the higher orders, where knickpoints of major streams erode into the underfit valley slope. A lesser percentage of smaller streams are also eroding the sluiceway valley slope. In the latter case, less material is eroded due to the lower power of smaller channels. The model cannot accurately distinguish variations in lower order values.

As a conclusion, the Yang model when applied to the Mallot Basin can be seen to emphasize the obvious lack of equilibrium at the knickpoint of the underfit, and to a lesser extent at other locations throughout the system.

FIGURE 3-15
6th ORDER BASINS

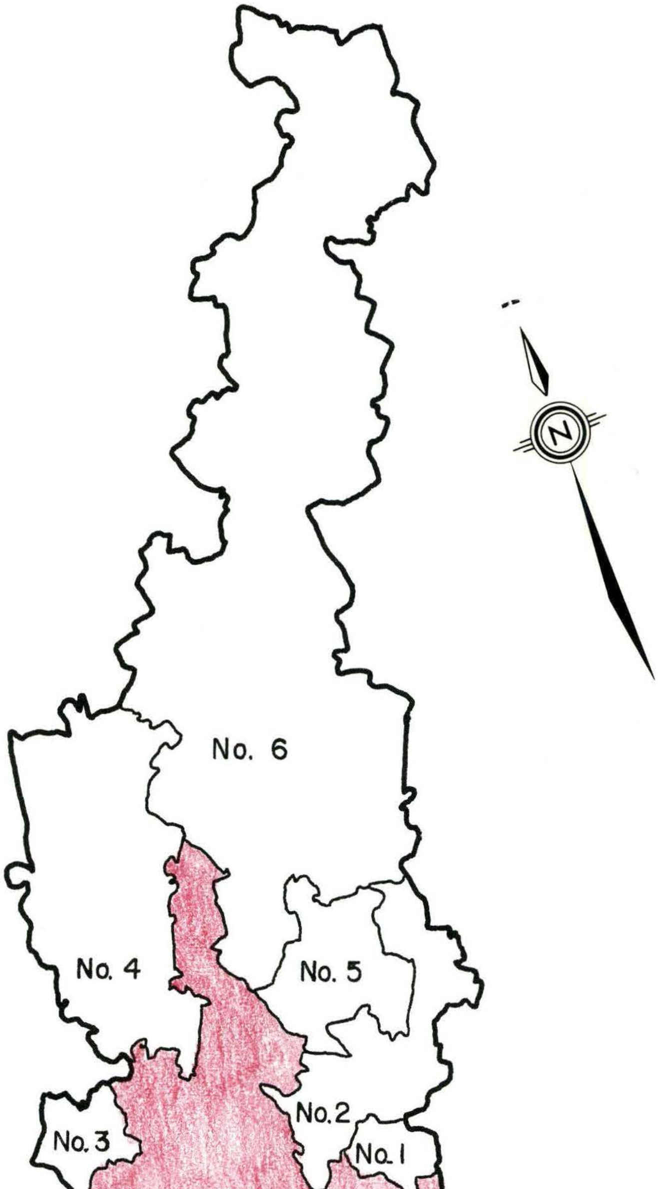


FIGURE 3-16

5th ORDER BASINS

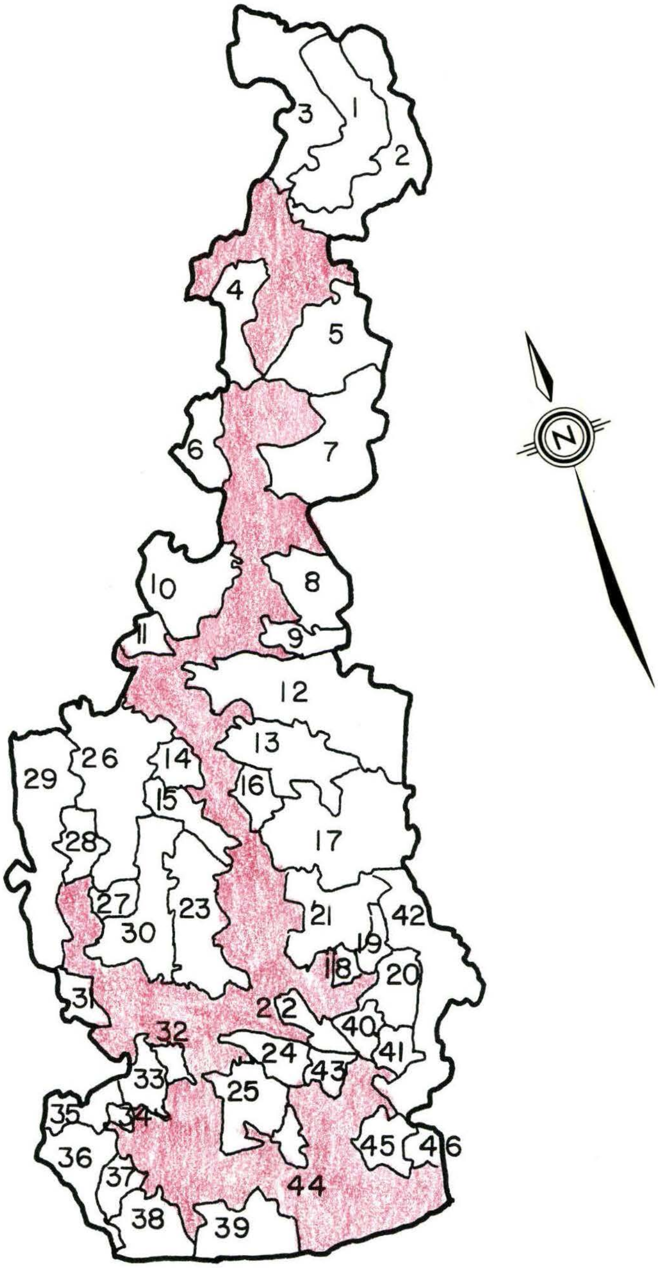
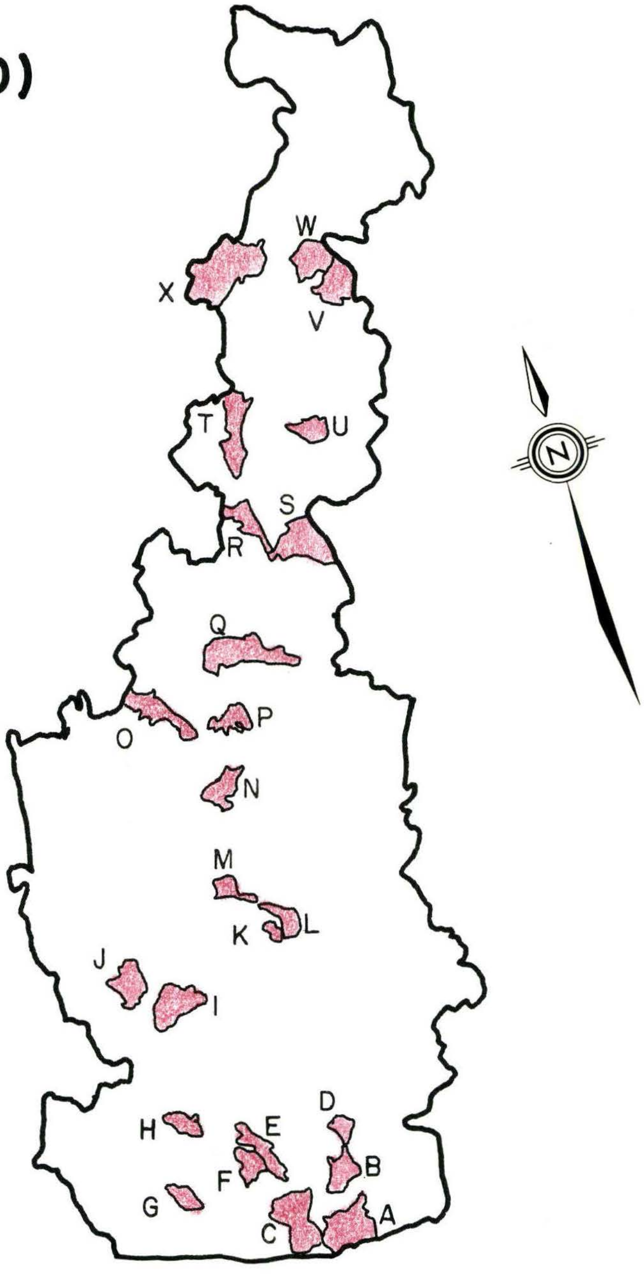


FIGURE 3-17
4th ORDER
BASINS
(SELECTED)



Drainage Density

Drainage density has been one of the most popular and useful parameters for the analysis of drainage basins. Horton (1945: 283) defines density as the sum of stream lengths divided by the area of the enclosing basin. The measure gives an indication of drainage development (Langbein, et al, 1947: 133). The "Constant of Channel Maintenance" is an equivalent parameter described by Schumm (1956: 607) and Strahler (1957) as the inverse of drainage density. The basin area is divided by the sum of channel lengths.

Drainage density has been correlated with many aspects of basin morphometry. Research in unglaciated basins has related it to relief (Leopold & Miller, 1956), land use, rock type, physiographic characteristics, hydrology, paleo-conditions, sediment yield (Gregory & Walling, 1968), average monthly flow (Carlston, 1963), and climate (Carlston, 1966). Orsborn (1970), using topographic maps to study three drift covered basins found influences similar to those in non-glaciated areas. A high value was associated with major floods, high annual runoff and a low ground water contribution to discharge. The converse for low values was similarly noticed. Observations by Flint (1962) and Wilson (1971) in very shallow tills may not be congruent with areas covered by deep till deposits.

Langbein et al recognize difficulties in applying the parameter. They used topographic blue lines as the basis of network delimitation. Not only will the subjectivity of the topographer and cartographer distort map detail, but the true density of water bearing channels will vary with the weather. During storms the density will be extremely high; during drought the density will plummet. No arbitrary definition of density can be obtained until the initial problem of First Order stream definition is resolved. A partial resolution of the problem is discussed below.

Drainage density has an inverse relationship with the length of overland flow. Overland flow on a permeable surface does not react in the fashion of sheet flow hypothesized by Horton (Kirkby & Chorley, 1967: 5). The Horton model is applicable to clay badlands with low infiltration capacity and little or no vegetation or weathered cover. Kirkby and Chorley produced a model of overland flow which emphasizes infiltration capacity. They envisage that Horton's and their own model are the end points of a continuum.

Ground conditions in the Mallot Basin suggest that it is located within the continuum. There is important local variation of conditions. In the Spring, there is much erosion on open ground in the cultivated fields that contain many lower order channels. The floodplain flanking higher order segments is in permanent grass which reduces both the drainage density and the opportunity to observe channelization from the air. Drainage density cannot be mapped at equivalent scale in the woodlands, but because their areal extent is less than 5 percent of the basin, the effect is not significant.

Density can be studied areally over a basin. Leopold and Miller noticed that density decreases downstream in areas of uniform rock and climate because headwater slopes are greater. The length of overland flow is necessarily lesser in the headwaters than in lateral tributaries. The highest point in the basin would be expected to be located in the headwaters. Central basin divides are indeed lower in most commonly observed basins. Vegetation type, land use and the effects of Man, alter the resistance of the material to erosion and thus the length of overland flow. The mechanical resistance of rock is acted upon by the DuBoys force which also influences overland flow length. Drainage density is related to the relative strengths of the erosive force and its resistance.

Although efforts have been made to reduce errors in length values, they remain at many orders. An equivalent method of drainage density determination, the "Line Intersection Method", was modified to provide measurements of the Mallot network which avoids this type of error. The method is given in APPENDIX THREE.

Hack (1957) indicated that there would be no change in drainage density between orders within a basin. To investigate this, five areas of the Mallot Basin were measured in detail. TABLE 3-8 gives the values for these subregions. N values of between 128 and 273 readings give a range of values between 6.0 and 10.2 miles of channel per square mile.

Two zones of drainage density are distinguished in the analysis. The north, the north-central and west-central readings are in the range 6.0 - 7.0 miles per square mile. The south basin and east-central basin readings range between 9.5 and 10.5. Horton's 4 - 8 mile per square mile value for temperate regions does not take into account channels below the resolution of his maps. It is probable that the change in type of till from loam to clay-loam is responsible for the shift. The infiltration capacity of the soil has seemingly been altered to radically increase overland flow on the clay-loam, and hence, density. Percent clay content in soils increases from 14 (Listowel Silt-Loam), 11.2 (Harriston Loam) and 18 (Perth Silt-Loam) in the northern portion of the basin to 24 (Huron Loam) in the southern portion. The divergence between the groups is greater than can be accounted for by the random placement of the

TABLE 3-8

DRAINAGE DENSITY

DENSITY OF MALLOT BASIN DRAINAGE BY LOCATION

Location	N - Number of Sample Intersections	Density in Miles of Channel/square mile
Upper Basin (Area of Headwater Tributaries)	183	6.5
North-Central Basin (North of Highway 9)	145	6.8
West-Central Basin (Area of 6th Order Basin 4)	128	6.0
East-Central Basin (Area of 6th Order Basin 5)	216	10.2
Southern Basin (South of Moorefield)	273	9.6

HIERARCHY OF DRAINAGE DENSITY

Order	N-Number of Sample Intersections	Density in miles of channel per square mile
1	945	5.56
2	440	2.59
3	219	1.29
4	125	0.74
5	44	0.26
6	21	0.12
7	8	0.05

Correlation coefficient of Order versus log Drainage Density is 0.998.

template in areas of forest or pavement.

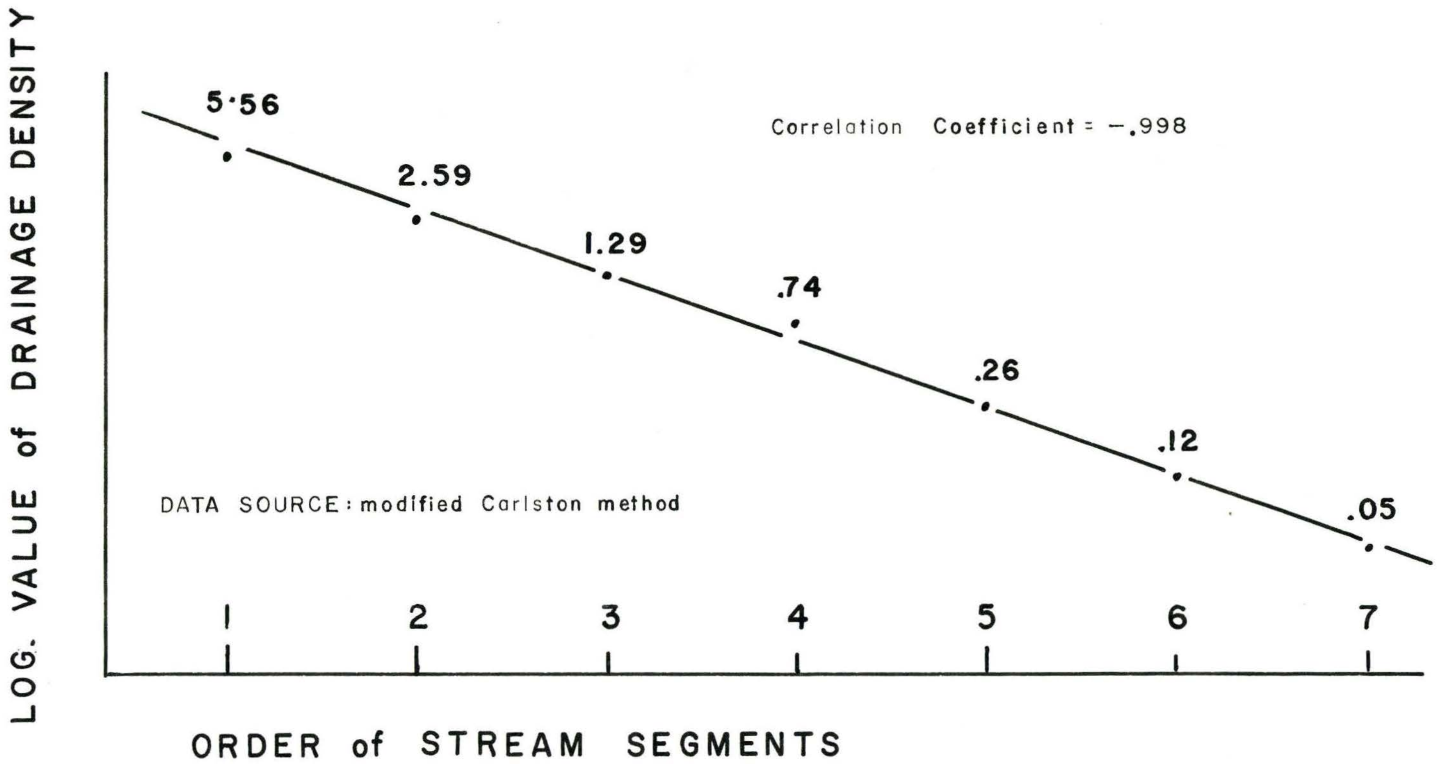
It is possible to consider hierarchies of drainage density. Using the method discussed in APPENDIX THREE a drainage density value was calculated for each order of stream. The method is equivalent to cumulatively summing successive magnitudes of total stream length and dividing by the total Mallot Basin area for each order. TABLE 3-8 presents the hierarchical values. FIGURE 3-18 gives them in a semi-logarithmic graph. The absolute values are less important than the fit of the line.

Drainage density changes as a negative power function of basin order. This has not previously been noted in the literature. There is a change in value by order that would suggest another in the series of Hortonian "laws", the "Law of Stream Density". The Law of Stream Density predicts an inverse change in density with order. This law will have the same shortcomings that are associated with the other laws. The function may be supposed to have been created by simple enlargement of the channel system resolution which itself is a random process, as discussed by Shreve.

Leopold has compared basins within the same system at different scales. The implementation of the hierarchy of drainage density will allow correlations to be made more easily between values originating from different scales. A continuum of drainage density,

FIGURE 3-18

HIERARCHY of DRAINAGE DENSITY



depicted by the straight line on the semi-logarithmic graph is hypothesized. The relative position of density values on the continuum represents stream development. Maps of a specific scale may consistently produce density values plotted on the y-axis which correspond to a particular value on the x-axis.

Channel Sinuosity and Valley Sinuosity

Channel sinuosity is a parameter used in the descriptive analysis of many channel patterns. Schumm (1963) defines it as the ratio of stream length to valley length. A straight stream would have a value of 1.0. The value increases with departure from the straight line. The increase could have two causes: random stream movements, and regular repetitive channel oscillations or meanders.

Meanders have been described as minimizers of variability (Langbein & Leopold, 1966). The meander is more stable than a straight channel because depth, velocity and slope are adjusted to decrease the variation of shear force. Under uniform climate, meanders are favoured by low slope, small discharge, small width/depth ratio and high homogeneity and cohesiveness in channel boundaries (Leopold & Wolman, 1957 and 1960)

The cut-off of a meander creates an oversteepened reach which becomes longer, thus initiating a further meander (Brush & Wolman, 1960). The process of over-steepened reach adjustment was discussed in Chapter Two. The underfit Mallot River has been unable to significantly alter the fossil topography.

A differentiation must be made between a sinuous or meandering stream and one that is acted upon by only random lateral forces. Leopold and Wolman (1957) developed a method amplified in Leopold, Wolman and Miller (1964). Because sinuosity of real rivers is usually between 1.0 and 4.0, the authors suggest that a value of 1.5 should arbitrarily indicate sinuosity. A value greater than 1.5 would indicate a meandering river. The widely used method of channel form identification is both subjective and arbitrary in origin.

A method developed by Mueller (1968) uses more than just two indicators of channel pattern form. Random variations, what Davis (1913) calls unavoidable inequalities of the land surface, change the flow direction of a "straight" river. This is topographically controlled sinuosity. The properties inherent in flowing water which cause lateral channel migration, hydraulic sinuosity, are caused by the channel itself. Thus a stream may be considered to have two components of sinuosity, hydraulic and topographic. A "youthful" stream has almost total topographic sinuosity. The stream and valley midline are congruent. Hydraulic sinuosity is negligible since stream sinuosity "...is a direct function of the sinuosity of the valley" (Mueller, 1968). At the "old age" state, it is the topographic influences that are negligible. Mueller, therefore, defines a Topographic Sinuosity Index (T.S.I.) and an Hydraulic Sinuosity Index (H.S.I.). A river with no floodplain would have a T.S.I. of 100.0 and an H.S.I. of 0.0, even if the channel was not straight.

The method of analysis discussed in APPENDIX FOUR was applied to the Mallot Basin using six 6th Order basins and the 7th Order basin. TABLE 3-9 depicts the results. The Mallot has only a third of its sinuosity (H.S.I. = 33.2) caused by the channel. Sixth Order H.S.I. ranges from 2.7 to 48.0, while topography accounts for 52-97.3 percent of basin sinuosity.

The three largest basins, the 7th Order and 6th Orders #2 and #6 possess the greatest hydraulic sinuosity. Basins #1 and #3 are small in areal extent and, therefore, have not yet had great enough flow to generate a floodplain. The remaining basins, #4 and #5, are of intermediate size and have corresponding values.

Although some stream sinuosity was missed in measurement, causing H.S.I. values to be conservative, Mueller's analysis confirms what was already known: the greatest fluvial sinuosity exists in the underfit valleys; lateral tributaries have very low hydraulic

TABLE 3-9

MUELLER'S SINUOSITY INDEX

Values Basin	CL	VL	Air	CI	VI	HSI (%)	TSI (%)
7th Order	77.25	68.20	50.00	1.55	1.36	33.2	66.8
6th Order							
#1	6.50	5.95	3.45	1.88	1.72	18.1	81.9
#2	17.36	15.50	12.30	1.41	1.26	36.8	63.2
#3	6.30	6.25	4.45	1.42	1.40	2.7	97.3
#4	19.96	17.00	14.47	1.22	1.15	29.8	70.2
#5	10.98	9.88	6.75	1.63	1.46	26.0	74.0
#6	55.75	47.00	37.50	1.49	1.25	48.0	52.0

sinuosity.

The Mueller method of stream analysis is potentially powerful in studies of underfit streams, where valley and stream sinuosity have been investigated. The effect of sinuous valleys can be subtracted from total channel sinuosity, leaving an indication of modern channel sinuosity. The scaling and interaction of meanderning streams within meandering valleys has long been the basis of underfit stream analysis. It has been argued that an underfit stream need not be in a meandering valley, the valley may be quite straight (p. 40). The lower Mallot is of this form. Were a stream of the Osage type encountered, a "straight" channel could exist in a "straight" valley and still be an underfit by definition of reduced flow.

Laboratory studies have shown straight channels to have meandering thalwegs. The same relationship can be expected between existing rivers and paleo-channels. The Mallot valley spillway would be expected to have had a meandering thalweg. The modern channel may or may not become entrenched within the restrictions of the paleo-thalweg. Although the existing stream may be an underfit, it may not be with respect to the confining thalweg. Entrenchment and rejuvenation would periodically occur along its length. Deposition would still occur over much of the length. Dury (1958) has observed this property although not given this interpretation. We would argue that the thalweg restricted the river. Unable to meander across the existing floodplain, downward erosion would occur.

It is suggested, therefore, that there are three classes of meanders to be observed in a glacially-caused, underfit river system: i. the valley meanders, with a large wavelength; ii. the paleo-thalweg meanders, in which the modern channel flows; iii. modern meanders, a channel possesses hydraulic sinuosity, if the existing situation allows. The last two classes may exist either together, separately or not at all.

The relative dimensions of existing and paleo-channel meanders may be measured for comparison. Dury has observed channel widths and lengths so the two flow environments may be contrasted. The wavelength of meanders has been shown by Inglis (1949) to be proportional to the square root of "dominant discharge". Thus, existing and paleo-conditions can be compared as a ratio. Dury (1953) discovered that a ratio of about 10:1 exists between valley and channel wavelength (L and l, respectively) where there is an underfit condition.

Measurements taken in the Mallot Basin were from the central basin where paleo-meanders are clearly observable. The Mallot appears to indicate a very different environmental change than was found by Dury because the ratio in the meandering valley segment is 16.9:1. Existing meanders are much smaller than their ancestors. The magnitude of the dominant discharge has decreased more in the Mallot system than in Dury's English examples.

From TABLE 2-2, the average annual spring runoff produces a discharge of about 136 cusecs. The flow at the time of the deglacial can be shown to be significantly greater by using figures proposed by Cogley (1973). Given 1,000 feet of ice which is retreating 200 feet a year, a discharge of 21.2 cubic meters per second or 8,734 cubic feet per second would be produced for every kilometer of ice width. The Mallot Basin is over seven kilometers at its maximum width, and therefore could produce over 61,000 cusecs given the conservative assumptions.

Southern Ontario rivers in the Wisconsin deglacial phase had great discharge due to two factors: water originating from the decaying ice front, and a pluvial increase in rainfall. Dury's Cotswolds merely had a pluvial period to account for the high paleo-discharge. The Mallot River data, when compared to Dury's, shows the emphatic significance of Wisconsin meltwaters in moulding the meandering valley topography.

Stream channel widths (TABLE 3-10) are indicative of dominant discharge (Leopold & Wolman, 1960). An aver-

TABLE 3-10

WIDTH-MEANDER WAVELENGTH VALUES

Valley Meander Wavelength	$\overline{L}$ = 7,370 feet
Stream Meander Wavelength	$\overline{l}$ = 274 feet
Valley Width	$\overline{W}$ = 900 feet
Stream Width	$\overline{w}$ = 22 feet

Meander Wavelength Ratio

$\overline{L}/\overline{l}$ = 26.9:1

Width Ratio

$\overline{W}/\overline{w}$ = 40.9:1

Paleo-Width-Meander Wavelength Ratio

$\overline{L}/\overline{W}$ = 8.2:1

Existing Width-Meander Wavelength Ratio

$\overline{l}/\overline{w}$ = 12.5:1

Width-Meander Wavelength Ratio Comparison

$\overline{L}/\overline{w}$ =335.0:1

age stream width of 22 feet contrasts with an average valley or paleo-channel width of 900feet. The values were respectively obtained from field measures and air-photo interpretation (Dury's Method). The method is subjective, but permits fair comparisons with Dury's results. Dury used 14 comparisons of modern and paleo-channel width to find that Width Ratio was between 2.7 and 4.1:1. The central Mallot Basin has a Ratio of 40.9:1, or at least ten times greater than Dury's observations. A far greater paleo-discharge appear to have occurred than would be expected from his calculations.

River channel width and meander wavelength in rivers that are not underfit have been compared to each other by Inglis (1949) and Dury (1953). Leopold and Wolman (1957: 58-59) report that European engineers have a "rule-of-thumb" that a meander wavelength is fifteen times that of the channel width. Dury (1966: 22) indicates that the ratio is commonly 10:1 and rarely falls outside of the range 8 to 12:1. Mallot Basin values for paleo- and existing flow is 8.2:1 and 12.5:1, respectively, and thus is similar to the expected. Both regimes of discharge meander regularly. Underfit valleys have a ratio between valley wavelength and observed bedwidth of approximately 32.5:1 (Dury, 1966). The central Mallot Basin has a ratio of 335.0:1, which is again ten times greater than that observed by Dury.

The Mallot River is clearly an underfit by Dury's classification. The quantity of paleo-discharge, so much greater than his expectation, was due to glacial meltwaters and greater precipitation. Dury (1973) in a reply to Cogley (1973) refuses to accept the glacial theory for the increase in flow.

Basin Shape Parameters

The shape of a drainage basin has important effects upon the hydrology and geomorphology. Basins on glacial till in Southern Ontario are noticeably long and narrow. An elongated basin produces a different, less peaked hydrograph from that of a more round basin. Potential energy in the form of rainfall will produce a minimum of point erosion, since lower flows are extended over longer periods of time.

Morisawa (1958) has proven the statistical worth of the Elongation and Circularity Ratios. Values are dimensionless and independent of scale (Morisawa, 1962). The Elongation Ratio was developed by Schumm (1952 and 1956). It is defined as the ratio between d, the diameter of a circle with the same area as the basin, and L_m, the maximum length of the basin parallel to the principal drainage line:

$$E = d/L_m .$$

Miller's (1952) Circularity Ratio is defined as the ratio of the basin area, A_b, to the area of a circle having the same perimeter, A_c:

$$C = A_b/A_c \ .$$

The latter will not be used, since a basin with an irregular perimeter may skew the results.

There is a wide variation in observed Elongation Ratio values. The 7th Order basin has a value of 0.34, which is indicative of the long narrow shape. Sixth Order stream basins vary from elongated in the north to rounded near the mouth. There is no systematic change with order, but change with area is possible. Small basins are more rounded while larger basins are elongated. A weak correlation exists. The most remarkable observation concerning the data is not the variance with size, but the great magnitude of the variance.

It is most probable that basin elongation results from fossil landforms. The spillway valley has caused 7th and 6th Order basins to be unnaturally extended. Smaller basins are not affected by the spillway. Were accurate values obtainable for the smallest basins, elongation due to glacial fluting would be expected. It is clear that factors which influence stream length also determine basin shape.

It may be argued that a river system in equilibrium should have basins of similar shape if the bed material is homogeneous. Following this line of reasoning, the river systems in the Mallot Basin appear to be in acute disequilibrium.

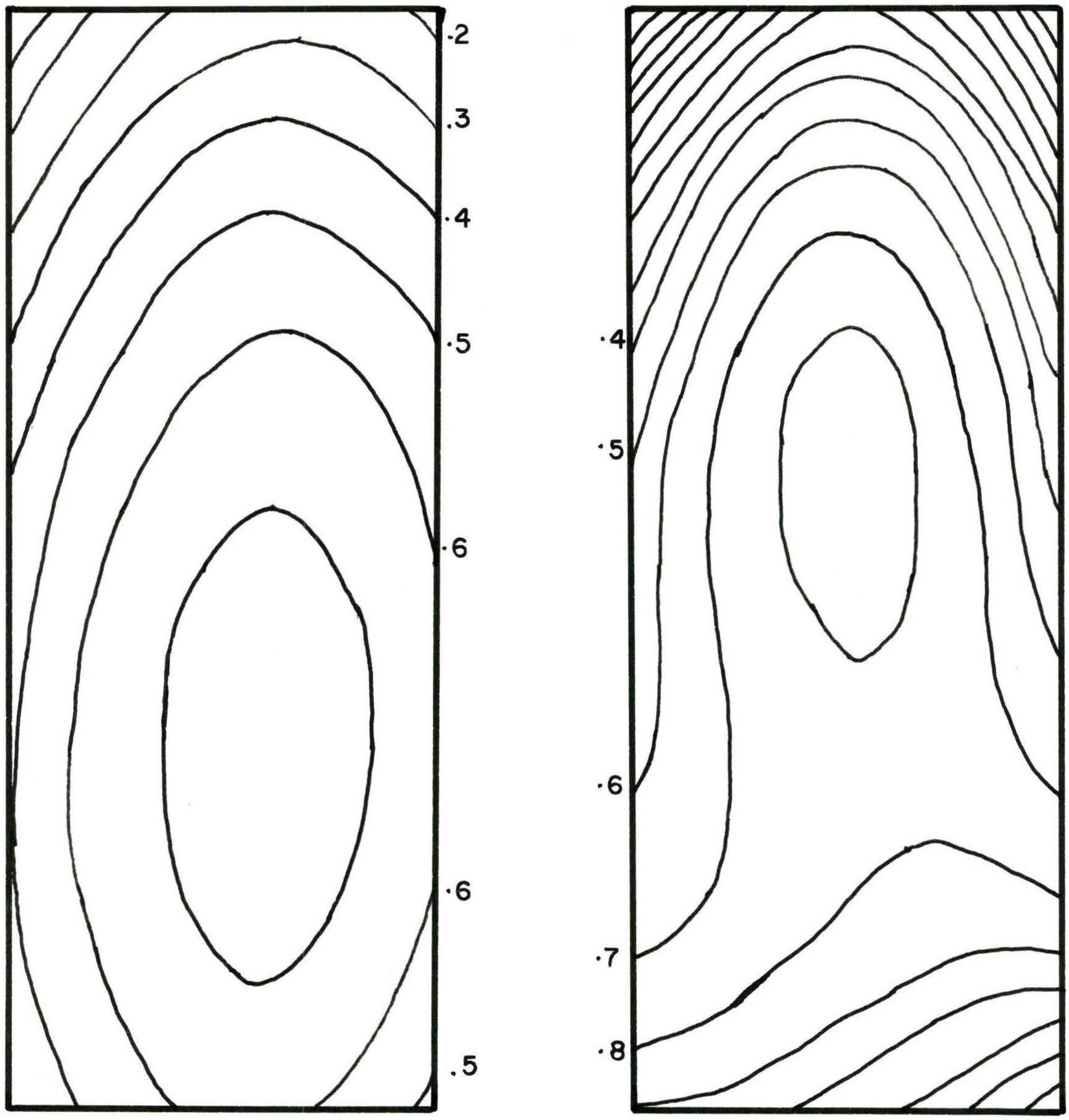
A correlation between Elongation Ratio and underfit valley may be indicated in a trend surface analysis of ratios. FIGURE 3-19 shows the result when 5th Order basin values are tested. A maximum of 27.0 percent of the variation is explained using the cubic surface, which is marginally greater than the 16.2 percent indicative of randomness. Although a very weak correlation exists, the pattern of the trend is remarkable. A change seems to take place which roughly corresponds to the basin topography. The figure is an elongated basin. There exists a change of slope in the south which corresponds to the major change in Mallot River direction. Towards the underfit valley the Elongation Ratio is lower than towards the periphery of the basin. This observation supports the earlier contention that the existence of the underfit valley influences the shape of component Fifth Order basins.

Fifth Order streams flow most of the year. Slope-induced changes in erosion may produce the elongation along the sides of the spillway/underfit valley. Longer streams and, therefore, basins are created as discharge flows down the main valley sides. Basins of the same order near the Mallot periphery are generated by the same conditions on similar materials, but are not influenced by an increase of

FIGURE 3-19

ELONGATION RATIO

T.S.A.



2nd Order Trend

21.3 % Correlation

3rd. Order Trend

27.0 % Correlation

slope at their mouth. Elongation is reduced with the omission of the terminal reach. The shape of the drainage basin has an influence on most other parameters of the basin.

CHAPTER FOUR

A SYNTHESIS OF EQUILIBRIUM

Geomorphic dynamic equilibrium or quasi-equilibrium has been hypothesized as the condition of maturity for fluvial systems (Yang, 1971). Variance will be defined as a deviation from that of an equilibrium situation. Equilibrium with respect to the stream longitudinal profile is defined as a smooth concave upwards curve rising from the mouth to the basin top. Equilibrium in morphometric analysis is the smooth progression of a parameter when plotted against the order of stream.

On a glacial till plain it has been suggest here that two types of disequilibrium will exist. The first is that directly associated with the underfit valley. The paleo-channel produced a fossil landform, the valley, which now holds the main channel of the existing river. Most tributaries are not contained by the fossil. A change in process and thus form occurs between the underfitted and unaffected areas of the basin.

The second disequilibrium is of a more subtle form. There will be a downstream progression of equilibrium stochastically by order. There is very little relief upon a glacial till plain, permitting First Order streams and their basins to come to equilibrium first. With time and downwearing, a larger basin will adjust itself and its components to the existing environment. Basin equilibrium will then progress downstream until it encompasses the largest basin of which it is a member. It must be noted that as in CHAPTER ONE, this hypothesis does not conflict with that of headward erosion of knickpoints.

The equilibrium which proceeds downstream from the lowest orders was sought in the various parameters discussed in CHAPTERS TWO and THREE. Evidence for the existence of this form of equilibrium progression was not found. Results of the review of evidence are given in order of presentation above.

The transverse valley profiles cannot be used alone to demonstrate equilibrium conditions in the Mallot River. The three primary zones of the river are quite clearly depicted. The upper river has V-shaped valleys which appear to be of modern fluvial origin. The mid-valley has the scars of large spillway paleo-meanders extended over a wide plain. The Mallot River is a classic, manifestly underfit stream meandering within the bounds of more extensive meanders. The lower basin has the greatest valley relief. The existing underfit both meanders and forms pool and riffle within the floodplain. Transverse profiling can distinguish the location of a spillway, but does not indicate down-valley changes in equilibrium.

Horton-Strahler numerical analysis of the Mallot system is detailed in CHAPTER THREE. Sixth and lower Orders produce uniformly straight lines on their semi-logarithmic plots, when the number of segments is plotted against order. Although variation is great in a couple of basins, no pattern common to many basins is discovered. The 7th Order basin contains more 4th and 5th Order segments, and fewer 1st and 2nd Order segments than expected. The additional data of the Grand River system clarifies the slope of the graphed line. The additional points add credibility to the slope of the graphed equation.

The surplus of 4th and 5th Order streams indicates a disequilibrium condition associated with the underfit valley. The long narrow spillway valley imposed on the basin acts to capture more lesser tributaries than would a purely dendritic system. The deficit of lower orders could be due to a readjustment in keeping with the downstream progression of equilibrium. It is also possible that interpretation errors could account for the variation. Many 1st and 2nd Order streams may have been missed when mapping. Forest cover, for example, would account for some of the unmapped channels. In conclusion, analysis of stream numbers has depicted the underfit disequilibrium, but only depicts a possible differentiation of the point of discontinuity.

The analysis of stream length indicated a distinct break of trend between 4th and 5th Orders. Fifth and larger segments are longer than would be expected from the trend of the lower four orders. This is an effect of the underfit valley. The underfit geomorphology, thus indicates a disequilibrium condition, but there is no deviation in segment length which would indicate a downstream progression of equilibrium.

The loam till - clay-loam till interface is obvious in the longitudinal profile. Spillway meander cutoffs remain today as over steepened reaches only slightly modified by existing discharge. The change of slope caused by the underfit valley is shown in the profiles of the lateral tributaries and main channel north of Highway 6. Lesser relief changes cannot be discerned because of increasing variation with relief toward the basin periphery.

Equations of river longitudinal profiles have not yet reached a usable state. The mathematical modelling now available is too simplistic to describe a river system in sufficient detail to allow contrast to be made between observed and expected profiles. Equations such as those of Brush have no application to the study of equilibrium.

Studies of basin area have been of insufficient accuracy to produce comparable data. This parameter fails to distinguish variation of any kind due to its inherent method of measurement.

There are greater variations of bifurcation ratio between basin locations than there are between each order. No homogeneity can be expected. The high Rb values and irregular distribution are consistent with values and patterns determined for the entire Grand River system.

A proof of the random nature of the bifurcation ratios was given by a trend surface analysis. The low correlation of values for each order indicates no systematic change over the basin. Deviations from "normal" occur equally throughout the system.

An attempt was made to separate a low order deviation by weighting the variance. A ratio was calculated between the number of 1st and 3rd Order segments which would in effect lump deviations between 1st and 2nd and between 2nd and 3rd Orders into a single grouping. Even with this averaging, as shown in TABLE 3-4, no pattern of significance results.

Two parameters were not useful. The length ratio has no meaning in a Strahler system and, therefore, was not used. The area ratio was not used due to a lack of precise data. The cumulative length ratio values may be interpreted as recognizing underfit disequilibrium but not the downstream progression.

Yang's relief ratio does not show the expected close correlation. Values are widely divergent and only artificially similar between lower orders. There seems to be a wider divergence in the 4th and 5th Orders than between other orders. The influences of the underfit visible in the longitudinal profiles of lateral tributaries is emphasized here. The largest change in the valley is only moderately depicted by the analysis, and no other changes can be discerned.

Drainage density analysis is similarly unable to indicate changes over the basin. The effects of change of till type are strongly indicated, but not equilibrium variations.

Analysis of stream sinuosity involved only the highest order streams. The underfit river can be seen to be sinuous. Smaller streams have little hydraulic sinuosity, being topographic in origin. Equilibrium or disequilibrium is not expressed by sinuosity.

Basin shape parameters show wide deviations with order and, therefore, lack the resolution to depict small variations. Mean basin length for the 6th Order is skewed by the very long basin #6. No decision concerning basin equilibrium can be clearly made using shape parameters.

The disequilibrium of the river profile has been clearly shown in many of the parameters. The unmistakable oversteepened reaches negate equilibrium in the largest channels.

The down-valley progression of equilibrium remains unsubstantiated. If till to a depth of only a few yeards had been eroded over the whole basin since the Pleistocene, then only the lowest orders would be expected to be modified to the extent of being in equilibrium. The 1st, 2nd or 3rd Orders should indicate a distinct point of statistical discontinuity between the two zones. They do not do so in any clear and consistent fashion. The hypothesis of a progression of equilibrium downstream should be rejected at this time as unproven.

Rejection does not mean that the concept need be discarded absolutely. To reject a valid hypothesis is a Type II error which is possible here. Rejection depended not on contravening data, but upon a lack of sensitive parameters.

Morphological data were chosen as basin indicators in keeping with a bias toward the application of remotely sensed data. According to Smart (1972) the Hortonian analysis "...gives useful information about individual networks," but is usually "...ineffective in distinguishing differences in network structure due to lithologic controls and degree of maturity". Randomness and the averaging of detailed variation accounts for this problem (Shreve, 1956). Smart argues that parameters derived from statistical geometric similarity such as his exterior and interior link lengths, provide better information.

Smart is only partially correct. The gross forms of relief are indeed depicted by a morphological approach as was shown in CHAPTER THREE. While it is true minor differences may be averaged out if only a single measure is used, Mallot River data is displayed with many individual measures within the larger unit. Less averaging and loss of resolution results. Although a detailed explanation of Smart's unproven concept is not warranted here, the method is based on the same weaknesses in the original definition of the network that is problematic with Hortonian analysis. Morphological approximations are still made with his method.

It may yet be possible to prove the existence of the down-basin change in equilibrium that has been sought in this thesis and locate statistically the point of discontinuity by using hydrologic information. Were a basin of appropriate size suitably instrumented, a differentiation might be obtained. Time, equipment and potential usefulness were not available to complete the necessarily detailed experiment.

Equilibrium has yet to be demonstrated empirically in fluvial geomorphology. A clear differentiation between environments in equilibrium and in disequilibrium is not yet possible. In this chapter, indices have been presented which indicate the lack of equilibrium in the 7th, 6th, 5th and many 4th Order Horton streams. The existence of equilibrium in lower order streams has only been hinted at. From the example of the Mallot River, no stronger statements can be made concerning fluvial equilibrium upon glacial till plains.

CHAPTER FIVE

CONCLUSIONS

The conclusions of this thesis are set out in four parts: the topic and method of study, the results, a comparison with similar studies in non-glaciated areas and some implications of the study.

TOPIC AND METHOD

The basic task of this thesis was to investigate aspects of fluvial geomorphology on a glacial till plain using an example in Southern Ontario. Few general papers have previously been concerned with discharge on local till surfaces.

This report contains a collection of studies of many individual basin parameters within a small representative area. Underfit streams, although referred to, have not previously been investigated in any detail in Ontario. Morphometric analysis is used as a tool to describe the area. The method is far from new, but it is united with literature concerning equilibrium data which may predict deviations in fluvial adjustment. The morphometric approach is applied areally to obtain information concerning regional variables.

Longitudinal and transverse profiles were measured in quantity and more than thirty miles of channel were profiled. The detailed survey avoided the simplistic results which are read from topographic maps.

The topic of fluvial adjustment on a till plain satisfies a valid need in geomorphic investigations. The method combines laboratory and field work to produce a result which is comparable with similar existing research, and which satisfactorily describes the area.

THE RESULTS

A major change in climate after the recession of the Pleistocene ice led to reduced discharge and an underfit stream. The underfit channel is of the manifest type in its middle reaches and the Osage type in the lower reaches. It has been strongly suggested that the reduction of discharge in this Ontario stream was much greater than the reductions suggested by Dury from his studies of Southern English systems.

A change in valley shape characteristics is linked to till type by an oversteepened reach at the point of interface by levelling. The longitudinal profile shows the transition clearly. Meander scars similar to those discovered by Macar (1934) exist as fossil, oversteepened reaches. The underfit valley is clearly depicted by lateral tributary profiles and the main channel near the basin top. Transverse profiles amplify deviations within the valley. Study of these profiles indicated the regional change in till type and thus morphology which was not readily noticeable in the field nor air photographs.

Knickpoints in the upper and central basin indicate a lack of equilibrium in these zones. The lower Mallot River profile is artificially smooth despite pool and riffle. This segment may possibly be in grade with respect to the paleo-channel, but not necessarily with the existing channel. Equilibrium has been associated with stream morphometry here for the first time, in order to distinguish basin controls. The inter-relationship of underfit streams and disequilibrium is given significant support. A proposal is made of downstream progression of equilibrium with Horton order.

The base map of the Mallot Basin is a major study base from which to study fluvial adjustment to climatic change. Hortonian analysis was completed for the common parameters without unusual results. The high bifurcation values noticed in the Mallot Basin are consistent with similar values for Southern Ontario drainage systems.

A hierarchy of drainage density has been developed, which has led to the proposing of a further Horton law. This proposal is allowed by the unique combination of an easily available method of obtaining drainage density and the availability of a detailed ordered map with known values. Since the concept of density is as arbitrary as the definition of a First Order tributary, the hierarchy suggests a continuum with order, which will assist in geomorphic areal interpretation.

Drainage density interpretation is a direct function of ground moisture. The definition of a First Order stream determines drainage density in the existing literature. A wet weather definition of channel must be incomplete since minute channels exist. The requirement of an indentation with developed banks to define a channel is necessarily arbitrary. The problem is sidestepped (APPENDIX ONE) by using a mechanical level of resolution defferentiation. This less subjective method produces a network pattern probably more accurate than if eroded channels are mapped.

The measured parameters of the basin did not show any marked, consistent change at the boundary of distinct channels and wet courses (swales) in unchannelled ground. The Hortonian principles of geometric arrangement have been demonstrated to operate in the zone that Horton would define as the overland flow zone.

Flow patterns due to lineations (flutes) are depicted and explained. The related property of stream junction angles on a till surface has been similarly clarified. Secondary currents beneath the periodic readvances of the retreating ice sheet can explain the lineations.

COMPARISON WITH NON-GLACIATED BASINS

For comparison, a few important papers have been selected that dealt in detail with non-glaciated terrains and their findings are discussed where they relate to this thesis. TABLE 5-1 shows many of the common parameters.

Morisawa (1962) analyzed fifteen watersheds on the unglaciated Allegheny Plateau, a region of varying lithology. The number of streams in each basin was displayed utilizing the same format for both studies (FIGURE 3-2). Little visual difference exists between variations from the expected Hortonian values for each of the two areas. The related Rb values are higher in the Mallot River system. Morisawa (1962:1029) states:

> ...if the bifurcation ratio of a watershed is constant, the bifurcation ratio of a smaller watershed within the larger one should not differ significantly from that of the total basin.

The Mallot system does not conform to Morisawa's conclusion, the component basins vary considerably. Both variations and absolute value of Rb are greater within the glaciated basin. The lineations within the glaciated basin may explain the deviation. Flutes must tend to raise the Rb in the lower orders since the network has been elongated. Larger orders are similarly influenced by the spillway valley. The decrease in discharge over the complete system has resulted in elongated Sixth and Seventh Order basins. The easily eroded till permits rapid changes in basin shape, and thus Rb, which are not possible on the more resistant plateau.

Similar morphometric analysis was performed by Schumm (1956) at Perth Amboy, New Jersey. The study was conducted in badland clays which can represent, with a scale change, unglaciated terrain of homogeneous and readily erodible lithology. The relief ratio, far greater at Perth Amboy, is the major distinction between the two environments.

Schumm discovered a high Rb of 4.87 on the unglaciated materials which corresponds to similar values in glaciated terrain. Low values do not appear unique to all unglaciated areas.

Elongation ratios of the badlands are low at 0.602, but are high in the similarly unglaciated Gulf Coastal Plain at 0.975. Variance between unglaciated areas suggests that glaciation is not necessarily a causitive factor, other influences (geologic controls, e.g. flutes) must be involved.

Schumm presents a great variation in drainage density values for different basins. Data acquisition for density values is not always comparable so the significance of the variation is low. An analysis of a value's position on the hierarchy of density values may permit useful comparisons.

Schumm (1963) studied sediment, a topic not field tested in the glaciated Mallot Basin, and morphological character in the Great Plains. The author correlates valley history with sinuosity; in some localities valley gradient. Sediment has been deposited in valleys cut into bedrock during the Pleistocene.

The progression of clay-silt, sand and gravel which extends downward from the surface can be expected to be similar to the probable build up of the lower Mallot River sediment. During alluviation of the spillway:

> ...the dimensions and the shape of the channels changed in response to a decrease in discharge and changed sediment-load characteristic....An increase in sinuosity would be accompanied by a decrease in width-depth ratio. Channels which are still straight underwent only a decrease in width and depth as discharge decreased.
>
> (Schumm, 1963: 1097)

Deposition near the mouth has changed the Mallot stream pattern since the post-Pleistocene. Elsewhere in the basin only small changes in erosion and deposition are indicated by the existing meander cut-off scars.

Zakrzewska (1971) investigated the driftless areas of Wisconsin and Indiana; unglaciated regions which have undergone the same gross changes of climate and discharge as the Mallot Basin. The driftless areas provide an excellent control with which to compare fluvial adjustment on a till surface.

The valleys are extremely flat, exceptionally broad and contain small streams, entrenched meanders and terraces. Zakrzewska suggests that there was excessive alternate filling and erosion in sluiceway valleys in response to the advance and retreat of ice sheets. Rapid adjustment of tributaries produced alternate upstream filling and partial erosion of their routes. Meltwaters encroached into the lower reaches of the lateral tributaries. The same process could easily have occurred in the glaciated regions as well. Features and patterns associated with the spillway would be similar in both glaciated and non-glaciated environments since alluvium is of paramount importance. On the plains beside and above the sluiceway, different patterns exist due to different materials.

"Through Valleys" of the driftless areas correspond to the Mallot spillway. The valleys are broad and deeply filled. The lower portions of the tributaries are wide and similarly filled. There is a lack of distinct valley walls. Ponding was prevalent in the area. Much of the Mallot sluiceway could be equivalently described.

"In Valleys" described by Zakrzewska denote lateral tributaries to the major discharge. These valleys have the widest variety of forms because local effects appear important. The streams are described as simple, dendritic and

TABLE 5-1

MORPHOMETRIC COMPARISON

Parameter / Origin	No. of Streams	Rb	R_L	R_A
Mallot River, Southern Ontario	15,753			
		3.71	1.41	5.00
	4,249			
		4.23	1.86	6.00
	1,004			
		4.16	2.60	6.67
	218			
		4.74	3.90	5.15
	46			
		7.60	4.25	9.23
	6			
		6.00	1.89	4.30
	1			
Allegheny Plateau, (Morisawa)	5,966			
		3,90	3.48	3.04
	1,529			
		4.05	2.63	5.67
	378			
		5.56	3.10	7.08
	68			
		5.23	2.85	5.57
	13			
		4.33	2.83	7.11
	3			
		3.00	0.41	2.28
	1			
Perth Amboy (Schumm)	214			
		4.76	4.00	4.04
	45			
		5.63	5.99	6.88
	8			
		4.00	6.86	6.19
	2			
		2.00	2.13	2.12
	1			

TABLE 5-1

MORPHOMETRIC COMPARISON
(Continued)

Parameter / Origin	No. of Streams		Rb	R_L	R_A
Niagara Pen. (Vanderhoff)	Clay	17			
			5.67	1.00	1.71
1(c) - Clay		3			
1(s) - Sand			3.00	1.76	-
		1			
	Sand	10			
			3.33	1.70	1.95
		3			
			3.00	1.73	-
		1			

TABLE 5-1

MORPHOMETRIC COMPARISON
(Continued)

Parameter Origin	Drainage Density	Channel Slope	Stream Entrance Angles
Mallot River, Southern Ontario	5.56 2.59 1.29 0.74 0.26 0.12 0.05	0.002	2nd & 3rd Order: 58-87 degrees. 4th & 5th Order: 41-129 degrees.
Allegheny Plateau (Morisawa)	3.49 3.41 3.31 - - - 2.92	0.1850 0.0910 0.0540 0.0220 0.0080 0.0013 0.0002	
Perth Amboy (Schumm)	602.00		Young: 65.2 - 59.9 degrees. Mature: 46.2 - 43.0 degrees.
Niagara Pen. (Vanderhoff) 1(c) - Clay 1(s) - Sand	Sand 2.29 Clay 5.84		

highly alluviated. No detailed Hortonian morphometric analysis is available for the unglaciated area, but were a study as detailed as that of the Mallot in existence, worthwhile information comparing the two classes of environments could be gleaned.

IMPLICATIONS

Glacial till presents a virgin surface for channelization. The pattern of drainage has a superficial resemblance to the non-glaciated driftless areas despite an organization of drainage pattern by the fossil forms, remnants of the deglacial period. Glaciation itself appears to have less effect on drainage than does the resultant post-glacial fluvial discharge. Major pre-glacial fluvial patterns may have an indirect effect on the position of the largest existing channels.

Hortonian analysis has displayed its strengths and weaknesses. Low resolution of detail is problematic in some aspects, but time consuming analysis can be accomplished by a computer which quickly produces detailed morphometric results to be interpreted.

A result of the Mallot study concerns areal variance. The investigation of spatial distribution of 5th Order basin parameters has not produced strong patterns for the widely fluctuating values. Another problem, the amount of variance is not mentioned in the literature. It has been previously assumed that deviations from the mean are small and do not become significant (Morisawa: 1962).

The Mallot River study is unique to studies of Ontario drainage. Highly detailed data sources have been used to investigate properties of fluvial adjustment. The methods and results of the study have been reviewed. A comparison to non-glaciated areas of a few types were made. The study could be truly calibrated were similar control basins analyzed with corresponding vigour within the drift-less areas.

The results and methods of this thesis have application to an advanced research project concerning a different environment within the North West Territories. The Ram Plateau study involves a tremendous increase in vertical scale and thus Relief Ratio from that of the Mallot. Experience gained from studying stream morphometry on a till surface does have tremendous application to the western study. There appears to be superficial evidence that underfit streams flow in the area. Transverse and longitudinal profiling may produce equally valuable data for both studies. Airphoto analysis, valuable to the Mallot River study, will be vital in order to properly investigate the Ram Plateau. The geometrical bias of this thesis will have application to the canyons with their dry limestone gravel floors.

APPENDIX ONE

MAP PRODUCTION

The main drainage map fold-out (FIGURE 3-1) is the basis of the Mallot River morphometric analysis. The creation of this map, and its accuracy is, therefore, basic to the validity of the foregoing analysis.

The photographs used in map production are Government of Ontario 1955 coverage, 1:15,800 scale. The timing of the photography, imeediately following a storm is fortuitous, since moist ground enhances the drainage pattern. The 1955 coverage is thus more advantageous than the drier 1966 coverage. The recent storm is indicated because normally dry steep tributaries to the main stream have white water on the photograph. Swale patterns can be used to indicate the drainage network. Locally high zones quickly dry, while lower areas retain their moisture. The zones are depicted by distinctions in image density.

Map construction originated with the original photographs. To protect the emulsion and the interpretability of the photograph, the fluvial pattern was drawn on the overlay while being viewed stereoscopically. Magnification of 1X, 3X, and 8X was used. Progressively smaller channels were distinguished as the author proceeded through the paired series of photographs. Major channels were first interpreted so that detail would be added equally over the complete basin, producing homogeneous results. Drainage density variations are minimized. Over-familiarity with specific localities at a setting could perpetuate errors.

When a completed pattern is obtained, ground truth varified the patterns. At all road culverts and intersections within the basin, the actual direction of flow was determined. Where the level of discharge was too low to give direct evidence of direction, indirect indices were used. The orientation of long grass or position of debris accumulation can indicate flow direction.

Field investigation also varified the location of many First Order channels. Those channels in grass were usually directly observable in the field. First Order swale patterns were not necessarily discovered as depicted. Changes in crop or cultivation since 1955 would eradicate the already difficult to distinguish pattern.

The corrected pattern was applied to a base map. Optical distortions are possible since a Mapograph was used to transfer information from the photograph to the map. Errors in fitting the photographed road pattern to the base map pattern are minor, but tend to correct machine distortion over the whole basin. A series of minor adjustments on the base map is preferable to compounded errors were no base map employed. Working maps were obtained by taking blue-print copies of the original at a slightly different scale. The final map resulted from a trace of the base map. The road pattern was omitted from the final draft although the linear pattern of roadside ditches is distinguishable. Positioning on the map is aided by the labelled highways. FIGURE 2-2, a political map indicates details of the road patterns.

The smallest tributary depicted is defined as a First Order stream. This differentiation is critical to the interpretation of morphometric properties. If a swale pattern or channel indicator of any sort was visible on the photograph, it was reproduced on the map. A physical cut-off resulted, which is related to the quality of the emulsion. This level of visibility is roughly equivalent for all the photographs and thus the basin. This method, although involving interpretor error, is less arbitrary than most methods of network delimitation. Only one operator was involved. No subjective decisions which question channel size are necessary. The channel either is or is not visible.

Measurements of basin parameters were made from working copies of the original. The number of segments in each order were individually, manually counted after the complete system was ordered. Length of streams was obtained with a set of dividers, of known separation, walked down the map. Areas were determined from the average of three readings of a polar planimeter. Basin outline was obtained from the fine drainage definition. Sinuosity figures were obtained using dividers and ruler. Drainage density was obtained using the modified Carlston method.

Some problems were encountered in map production and interpretation. Air photographs, 1955 coverage, were not available for the extreme top and bottom of the basin. 1966 coverage replaced earlier photographs for the basin top. Since the soil moisture was low it was difficult to obtain exact similitude in drainage definition. Topography was used as a network indicator. The omitted southern coverage was not replaced. A band approximately a quarter mile in extreme width is missing.

The interpretation of fluvial pattern was hindered by ground conditions. Forests prevented the interpretation of low order channels. High order channels may be depicted by the subtle changes in density due to vegetation changes and tree breaks.

The pattern itself has been altered moderately by human creations: draglines have straightened river sections; bridges, culverts and roadside ditches artificially regulate discharge. Despite Man-made organization, drainage is still space filling. The amount of Man induced change is minor relative to the whole basin system.

APPENDIX TWO

TREND SURFACE ANALYSIS TECHNIQUES

Data cards were obtained using the Ruscom model 21 digitizer of the Department of Geography, McMaster University. X, Y values and appropriate Z values were placed on each card. The program picked up the appropriate Z value in separate computer runs. An alteration of control cards was all that was required.

Variation may be due to three factors: 1. Measurement errors due to interpolation of data from the topographic maps; 2. apparently random local fluctuations; and 3. possibly distinct, highly significant patterns. Averaging of data in the technique can mask important deviations or occurrences as large as the river (Whitten, 1959: 844). Krumbein (1963: 5869) recognizes that "...where small scale fluctuations are prominent, it may not be possible to estimate the complete trend satisfactorily". Despite these problems, good results evolve from the tests.

Before the data can be interpreted, its significance must be studied. Howarth's (1967: 619) randomly generated significance levels (6.0, 12.0, and 16.2 percent) explained) for the first three orders, must be surpassed. CHAPTER TWO's values of topographic, bedrock and overburden analysis all easily surpass CHAPTER THREE's values of bifurcation ratio are generally close to values obtained by Howarth. If randomly generated numbers can produce the above values, to be statistically significant, the data must produce results which exceed these values. It may be concluded that the CHAPTER TWO data is significant, while CHAPTER THREE data is either non- or marginally significant.

Chayes (1970: 1273-1278) discusses which surface to use in an interpretation, "...unless the term of order (K+1) significantly improves the fit, it is dropped, and the fitting rests at order K (Occam's Razor)". This method was employed to determine the order shown in FIGURE 2-4. A further improvement in fit with order is required, not just the further construction of fancy maps (Chayes, 1970). In CHAPTER TWO, linear, quadratic, and quadratic trends were respectively used to present the data for the three surfaces, since there was little increase in percent variation explained beyond these levels. In CHAPTER THREE, the significance level was so low that the cubic surfaces presented only illustrate the lack of interpretability.

A last factor affecting interpretation is that of the contour interval. FIGURE 2-4 has a ten foot interval for the surface and bedrock trends, while a five foot interval was used for the overburden. There was less variation in depth with the till. On the residual maps for this figure, a 25 foot interval was employed to avoid mapping minor variations. No attempt was made to contour CHAPTER THREE's data.

APPENDIX THREE

CALCULATION OF DRAINAGE DENSITY

Carlston and Langbein (1960) claim their "Line Intersection Method" of drainage density determination to be the most rapid and accurate means. The density is the reciprocal of the mean distance between channels. A line of known length (L) can be drawn on a map intersecting a number (N) of stream segments. The distance between the channels is:

Sine 45 degrees = L/N,

where 45 degrees is the mean angle 0-90 degrees of intersection.

The density is the reciprocal of this. Therefore,

Drainage density (D) = 1.41 N/L.

Carlston suggest that an N value of at least 50 is required. The line should be randomly oriented to compensate for possible directional orientation.

An improvement in the method was made for the Mallot study. A clear plastic circle of known circumference (10") was placed over the map and the resultant intersections quickly enumerated. The closed curve resolves the problems of orientation mentioned above. The result is a truly random selection of orientation. The minimum N value of 50 was surpassed in the drainage density determination.

A hierarchy of drainage density can be obtained using the modified Carlston method. An "N" value is recorded for each order in the river system. The number of intersections of a specific order is totaled from each test area in the large basin. The Third Level of drainage density may be found by letting N equal the sum of the intersections with 7th, 6th, and 5th Order segments. A Fourth Level can be determined using the number of intersections with 7th, 6th, 5th, and 4th Order channels. A significantly large "N" may be obtained for a small area by moving the plastic template a very short distance to sample a new population.

APPENDIX FOUR

CALCULATION OF MUELLER'S SINUOSITY INDEX

Mueller defines the Topographic Sinuosity Index (T.S.I.) and the Hydraulic Sinuosity Index (H.S.I.) as follows:

T.S.I. = % equivalent of (VI - 1)/(CI -1),

H.S.I. = % equivalent of (CI - VI)/(CI - 1),

where

CI = Channel Index
= CL/Air
= the total sinuosity of the channel due to topographic and hydraulic causes,

VI = Valley Index
= VL/Air
= the total sinuosity caused by topography,

CL = the length of the stream channel considered,

VL = the valley length along the stream length (the line is midway between the valley walls, so will equal CL where valley walls extend directly to the water),

Air = the shortest air distance between the source and mouth of the stream.

H.S.I. and T.S.I. are each calculated as percentage of total sinuosity, therefore, one may be achieved from the other by subtraction from 100 percent.

APPENDIX FIVE

W.A.T.E.R. DATA

Three sub-basins within the Mallot System were analyzed using W.A.T.E.R. subroutines. A basin, one from each of the northern, central and southern parts of the Mallot System, was chosen. A First Order segment used in the program is a Second Order segment on FIGURE 3-1 (data appears on the following pages).

THE WATER SYSTEM

COMPUTER PROGRAMS FOR WATERSHED ANALYSES
DEVELOPED AT
UNIVERSITY OF TORONTO PURDUE UNIVERSITY
TORONTO, ONTARIO LAFAYETTE, INDIANA

DRAINAGE BASIN BEING ANALYZED IS MALLOT BASIN TRIBUTARIES SOUTH

INFORMATION FOR THIS BASIN WAS COLLECTED FROM AIR PHOTO SOURCE, 1955 ONT. COVERAGE

THE SCALE OF THE SOURCE MATERIAL IS 1/17400.

STRAHLER STREAM ORDER STATISTICS

STRAHLER STREAM ORDER	NUMBER OF SEGMENTS	BIFURCATION RATIO	LENGTH (MILES)	FALL (FEET)	GRADIENT (FEET/MILE)	AZIMUTH (DEGREES)
1	96		MEAN = .042 MAXIMUM= .250 MINIMUM= .004 RANGE = .246 VAR.= .1596E-02 STD.DEV.= .040	MEAN = 0.000 MAXIMUM= 0.000 MINIMUM= 0.000 RANGE = 0.000 VAR.= 0. STD.DEV.= 0.000	MEAN = 0.000 MAXIMUM= 0.000 MINIMUM= 0.000 RANGE = 0.000 VAR.= 0. STD.DEV.= 0.000	MEAN =211.743 MAXIMUM=472.485 MINIMUM=117.700 RANGE =354.784 VAR.= .6350E+04 STD.DEV.= 79.687
		5.053				
2	19		MEAN = .158 MAXIMUM= .451 MINIMUM= .007 RANGE = .443 VAR.= .1739E-01 STD.DEV.= .132	MEAN = 0.000 MAXIMUM= 0.000 MINIMUM= 0.000 RANGE = 0.000 VAR.= 0. STD.DEV.= 0.000	MEAN = 0.000 MAXIMUM= 0.000 MINIMUM= 0.000 RANGE = 0.000 VAR.= 0. STD.DEV.= 0.000	MEAN =198.817 MAXIMUM=364.358 MINIMUM=132.999 RANGE =231.359 VAR.= .4454E+04 STD.DEV.= 66.736
		3.167				
3	6		MEAN = .185 MAXIMUM= .463 MINIMUM= .061 RANGE = .402 VAR.= .2482E-01 STD.DEV.= .158	MEAN = 0.000 MAXIMUM= 0.000 MINIMUM= 0.000 RANGE = 0.000 VAR.= 0. STD.DEV.= 0.000	MEAN = 0.000 MAXIMUM= 0.000 MINIMUM= 0.000 RANGE = 0.000 VAR.= 0. STD.DEV.= 0.000	MEAN =217.387 MAXIMUM=447.913 MINIMUM=161.874 RANGE =286.039 VAR.= .1282E+05 STD.DEV.=113.225
		6.000				
4	1		LENGTH = 1.730	FALL = 0.000	SLOPE = 0.000	AZIMUTH=131.318

THIS DRAINAGE NETWORK OF ORDER 4 CONTAINS A TOTAL OF 122 SEGMENTS.

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*************************************************
*                                               *
*      T H E   W A T E R   S Y S T E M          *
*                                               *
*  COMPUTER PROGRAMS FOR WATERSHED ANALYSES     *
*               DEVELOPED AT                    *
*  UNIVERSITY OF TORONTO   PURDUE UNIVERSITY    *
*     TORONTO,ONTARIO       LAFAYETTE,INDIANA   *
*                                               *
*************************************************
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DRAINAGE BASIN BEING ANALYZED IS MALLOT BASIN TRIBUTARIES SOUTH

INFORMATION FOR THIS BASIN WAS COLLECTED FROM AIR PHOTO SOURCE, 1955 ONT. COVERAGE

THE SCALE OF THE SOURCE MATERIAL IS 1/17400.

LENGTHS OF ORDERED SEGMENTS

ORDER	VALUES							
1	.039	.018	.016	.027	.065	.025	.032	.011
	.052	.049	.043	.029	.026	.030	.118	.021
	.018	.025	.053	.016	.051	.050	.022	.004
	.026	.052	.006	.016	.029	.009	.016	.009
	.013	.022	.074	.021	.078	.126	.083	.011
	.064	.041	.007	.098	.052	.093	.012	.035
	.014	.019	.007	.008	.015	.250	.009	.005
	.043	.009	.062	.124	.073	.009	.056	.061
	.019	.024	.019	.030	.029	.015	.071	.051
	.007	.044	.020	.011	.092	.147	.014	.009
	.082	.029	.044	.071	.042	.011	.014	.016
	.073	.168	.074	.017	.031	.098	.013	.053
2	.245	.335	.189	.416	.198	.104	.042	.007
	.059	.041	.157	.074	.273	.080	.089	.102
	.014	.117	.451					
3	.061	.463	.063	.132	.277	.114		
4	1.730							

THE WATER SYSTEM

COMPUTER PROGRAMS FOR WATERSHED ANALYSES
DEVELOPED AT
UNIVERSITY OF TORONTO   PURDUE UNIVERSITY
TORONTO, ONTARIO   LAFAYETTE, INDIANA

DRAINAGE BASIN BEING ANALYZED IS MALLOT BASIN TRIBUTARIES SOUTH

INFORMATION FOR THIS BASIN WAS COLLECTED FROM AIR PHOTO SOURCE, 1955 ONT. COVERAGE

THE SCALE OF THE SOURCE MATERIAL IS 1/17400.

AZIMUTHS OF ORDERED SEGMENTS

ORDER	VALUES							
1	177.117	296.579	173.638	140.000	157.499	140.000	326.361	221.211
	170.313	154.528	142.334	132.998	132.267	380.339	159.536	149.685
	128.758	140.000	175.805	179.999	292.484	289.902	194.056	292.484
	172.318	168.283	123.947	140.000	359.999	191.241	179.999	266.976
	303.947	194.056	131.019	149.685	166.917	145.664	117.700	472.484
	146.361	140.000	228.570	161.097	155.836	179.999	225.396	325.857
	320.000	174.572	228.570	250.000	159.999	173.781	191.241	278.788
	312.998	233.023	264.024	188.632	187.276	215.515	160.992	157.281
	320.000	192.494	320.000	196.052	150.606	126.769	159.227	146.016
	271.430	163.674	299.660	207.515	164.163	157.766	179.999	128.758
	145.234	169.393	151.476	146.361	406.548	401.211	140.000	140.000
	348.865	362.364	351.748	314.113	193.230	174.408	303.947	302.280
2	168.992	174.169	162.569	163.427	167.097	140.975	167.772	228.570
	181.819	194.989	171.196	321.375	167.637	174.944	193.230	163.737
	132.998	364.358	337.653					
3	181.655	161.873	168.623	179.999	164.257	447.912		
4	131.318							

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*      T H E   W A T E R   S Y S T E M       *
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*  COMPUTER PROGRAMS FOR WATERSHED ANALYSES  *
*               DEVELOPED AT                 *
*  UNIVERSITY OF TORONTO   PURDUE UNIVERSITY *
*    TORONTO,ONTARIO      LAFAYETTE,INDIANA  *
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DRAINAGE BASIN BEING ANALYZED IS MALLOT BASIN TRIBUTARIES CENTRAL

INFORMATION FOR THIS BASIN WAS COLLECTED FROM AIR PHOTO SOURCE, 1955 ONT. COVERAGE

THE SCALE OF THE SOURCE MATERIAL IS 1/17400.

STRAHLER STREAM ORDER STATISTICS

STRAHLER STREAM ORDER	NUMBER OF SEGMENTS	BIFURCATION RATIO	LENGTH (MILES)	FALL (FEET)	GRADIENT (FEET/MILE)	AZIMUTH (DEGREES)
1	106		MEAN = .068 MAXIMUM= .570 MINIMUM= .014 RANGE = .556 VAR.= .4743E-02 STD.DEV.= .069	MEAN = 0.000 MAXIMUM= 0.000 MINIMUM= 0.000 RANGE = 0.000 VAR.= 0. STD.DEV.= 0.000	MEAN = 0.000 MAXIMUM= 0.000 MINIMUM= 0.000 RANGE = 0.000 VAR.= 0. STD.DEV.= 0.000	MEAN =168.832 MAXIMUM=356.634 MINIMUM= 0.000 RANGE =356.634 VAR.= .9295E+04 STD.DEV.= 96.417
		4.240				
2	25		MEAN = .101 MAXIMUM= .390 MINIMUM= .020 RANGE = .370 VAR.= .8919E-02 STD.DEV.= .094	MEAN = 0.000 MAXIMUM= 0.000 MINIMUM= 0.000 RANGE = 0.000 VAR.= 0. STD.DEV.= 0.000	MEAN = 0.000 MAXIMUM= 0.000 MINIMUM= 0.000 RANGE = 0.000 VAR.= 0. STD.DEV.= 0.000	MEAN =180.471 MAXIMUM=347.471 MINIMUM= 22.479 RANGE =324.992 VAR.= .8751E+04 STD.DEV.= 93.546
		4.167				
3	6		MEAN = .259 MAXIMUM= .518 MINIMUM= .012 RANGE = .507 VAR.= .4562E-01 STD.DEV.= .214	MEAN = 0.000 MAXIMUM= 0.000 MINIMUM= 0.000 RANGE = 0.000 VAR.= 0. STD.DEV.= 0.000	MEAN = 0.000 MAXIMUM= 0.000 MINIMUM= 0.000 RANGE = 0.000 VAR.= 0. STD.DEV.= 0.000	MEAN =134.750 MAXIMUM=276.992 MINIMUM= 22.380 RANGE =254.612 VAR.= .9342E+04 STD.DEV.= 96.655
		6.000				
4	1		LENGTH = 1.869	FALL = 0.000	SLOPE = 0.000	AZIMUTH=231.189

THIS DRAINAGE NETWORK OF ORDER 4 CONTAINS A TOTAL OF 138 SEGMENTS.

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*       T H E   W A T E R   S Y S T E M             *
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*   COMPUTER PROGRAMS FOR WATERSHED ANALYSES        *
*                  DEVELOPED AT                     *
*   UNIVERSITY OF TORONTO   PURDUE UNIVERSITY       *
*     TORONTO,ONTARIO       LAFAYETTE,INDIANA       *
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DRAINAGE BASIN BEING ANALYZED IS   MALLOT BASIN TRIBUTARIES   CENTRAL

INFORMATION FOR THIS BASIN WAS COLLECTED FROM   AIR PHOTO SOURCE, 1955 ONT. COVERAGE

THE SCALE OF THE SOURCE MATERIAL IS 1/17400.

LENGTHS OF ORDERED SEGMENTS

ORDER	VALUES							
1								
	.050	.024	.029	.049	.037	.019	.017	.050
	.016	.070	.107	.286	.187	.152	.164	.143
	.135	.051	.078	.078	.096	.154	.113	.014
	.024	.020	.079	.033	.152	.056	.036	.022
	.028	.045	.015	.014	.017	.081	.063	.037
	.024	.133	.061	.055	.017	.017	.082	.016
	.047	.025	.021	.031	.060	.063	.061	.018
	.054	.039	.054	.133	.114	.047	.025	.030
	.020	.020	.022	.029	.042	.058	.110	.133
	.087	.031	.062	.107	.174	.053	.137	.570
	.110	.061	.025	.043	.103	.015	.034	.018
	.038	.098	.081	.028	.018	.036	.014	.066
	.056	.078	.047	.125	.036	.091	.039	.039
	.139	.111						
2								
	.046	.047	.028	.063	.070	.025	.025	.036
	.047	.198	.390	.068	.076	.134	.030	.052
	.318	.020	.205	.124	.095	.050	.052	.182
	.143							
3								
	.369	.012	.160	.444	.050	.518		
4								
	1.869							

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*          T H E   W A T E R   S Y S T E M         *
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*  COMPUTER PROGRAMS FOR WATERSHED ANALYSES        *
*                 DEVELOPED AT                     *
*  UNIVERSITY OF TORONTO   PURDUE UNIVERSITY       *
*    TORONTO,ONTARIO      LAFAYETTE,INDIANA        *
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DRAINAGE BASIN BEING ANALYZED IS MALLOT BASIN TRIBUTARIES CENTRAL

INFORMATION FOR THIS BASIN WAS COLLECTED FROM AIR PHOTO SOURCE, 1955 ONT. COVERAGE

THE SCALE OF THE SOURCE MATERIAL IS 1/17400.

AZIMUTHS OF ORDERED SEGMENTS

ORDER	VALUES							
1	190.007	215.537	221.195	141.842	162.897	135.000	198.434	173.659
	0.000	174.805	148.495	34.528	35.355	113.749	141.842	184.566
	206.565	257.471	83.894	129.289	68.838	97.253	122.005	168.690
	35.537	56.309	14.036	85.236	28.072	110.224	0.000	82.874
	95.710	122.735	21.801	101.310	9.462	100.885	182.489	206.565
	215.537	184.763	256.607	264.289	288.435	260.537	185.906	224.999
	176.633	220.601	129.805	44.999	40.601	85.030	93.179	51.340
	135.000	155.224	170.134	253.367	287.878	176.633	0.000	275.194
	236.309	195.945	90.000	311.185	277.594	251.564	175.710	286.821
	349.045	10.304	257.195	273.012	271.061	258.111	268.697	233.498
	59.743	95.194	12.528	129.805	135.000	338.198	28.610	333.434
	233.130	238.671	153.434	78.689	218.659	0.000	233.130	182.385
	226.974	302.005	356.633	344.744	328.240	85.236	135.000	270.000
	323.130	341.565						
2	154.983	159.443	191.309	118.810	135.000	270.000	347.471	112.619
	93.366	87.878	218.480	46.974	139.398	218.853	185.194	251.564
	271.753	303.690	296.965	313.994	22.479	176.820	273.012	90.000
	31.701							
3	99.462	44.999	179.012	185.654	22.380	275.992		
4	231.188							

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*          T H E   W A T E R   S Y S T E M            *
*                                                     *
*  COMPUTER PROGRAMS FOR WATERSHED ANALYSES           *
*                   DEVELOPED AT                      *
*  UNIVERSITY OF TORONTO   PURDUE UNIVERSITY          *
*     TORONTO,ONTARIO      LAFAYETTE,INDIANA          *
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DRAINAGE BASIN BEING ANALYZED IS MALLOT BASIN TRIBUTARIES NORTH

INFORMATION FOR THIS BASIN WAS COLLECTED FROM AIR PHOTO SOURCE, 1955 ONT. COVERAGE

THE SCALE OF THE SOURCE MATERIAL IS 1/17400.

STRAHLER STREAM ORDER STATISTICS

STRAHLER STREAM ORDER	NUMBER OF SEGMENTS	BIFURCATION RATIO	LENGTH (MILES)	FALL (FEET)	GRADIENT (FEET/MILE)	AZIMUTH (DEGREES)
			MEAN = .081	MEAN = 0.000	MEAN = 0.000	MEAN =211.353
			MAXIMUM= .352	MAXIMUM= 0.000	MAXIMUM= 0.000	MAXIMUM=360.000
1	85		MINIMUM= .010	MINIMUM= 0.000	MINIMUM= 0.000	MINIMUM= 48.073
			RANGE = .343	RANGE = 0.000	RANGE = 0.000	RANGE =311.927
			VAR.= .5102E-02	VAR.= 0.	VAR.= 0.	VAR.= .6833E+04
			STD.DEV.= .071	STD.DEV.= 0.000	STD.DEV.= 0.000	STD.DEV.= 82.663
		3.696				
			MEAN = .106	MEAN = 0.000	MEAN = 0.000	MEAN =204.483
			MAXIMUM= .355	MAXIMUM= 0.000	MAXIMUM= 0.000	MAXIMUM=332.680
2	23		MINIMUM= .013	MINIMUM= 0.000	MINIMUM= 0.000	MINIMUM= 79.107
			RANGE = .343	RANGE = 0.000	RANGE = 0.000	RANGE =253.574
			VAR.= .8851E-02	VAR.= 0.	VAR.= 0.	VAR.= .5250E+04
			STD.DEV.= .094	STD.DEV.= 0.000	STD.DEV.= 0.000	STD.DEV.= 72.456
		4.600				
			MEAN = .408	MEAN = 0.000	MEAN = 0.000	MEAN =168.339
			MAXIMUM= 1.070	MAXIMUM= 0.000	MAXIMUM= 0.000	MAXIMUM=204.791
3	5		MINIMUM= .026	MINIMUM= 0.000	MINIMUM= 0.000	MINIMUM=149.570
			RANGE = 1.043	RANGE = 0.000	RANGE = 0.000	RANGE = 55.221
			VAR.= .1708E+00	VAR.= 0.	VAR.= 0.	VAR.= .4888E+03
			STD.DEV.= .413	STD.DEV.= 0.000	STD.DEV.= 0.000	STD.DEV.= 22.109
		5.000				
4	1		LENGTH = 2.049	FALL = 0.000	SLOPE = 0.000	AZIMUTH=224.205

THIS DRAINAGE NETWORK OF ORDER 4 CONTAINS A TOTAL OF 114 SEGMENTS.

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#     T H E   W A T E R   S Y S T E M            #
#                                                #
#  COMPUTER PROGRAMS FOR WATERSHED ANALYSES      #
#               DEVELOPED AT                     #
#  UNIVERSITY OF TORONTO  PURDUE UNIVERSITY      #
#    TORONTO,ONTARIO      LAFAYETTE,INDIANA      #
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DRAINAGE BASIN BEING ANALYZED IS MALLOT BASIN TRIBUTARIES NORTH

INFORMATION FOR THIS BASIN WAS COLLECTED FROM AIR PHOTO SOURCE, 1955 ONT. COVERAGE

THE SCALE OF THE SOURCE MATERIAL IS 1/17400.

LENGTHS OF ORDERED SEGMENTS

ORDER	VALUES							
1	.048	.084	.067	.072	.232	.030	.079	.044
	.010	.027	.117	.033	.051	.062	.050	.117
	.126	.042	.059	.136	.211	.156	.036	.025
	.112	.029	.025	.030	.064	.067	.065	.038
	.050	.037	.014	.152	.041	.017	.058	.056
	.083	.070	.048	.017	.084	.071	.024	.352
	.023	.025	.143	.080	.019	.130	.112	.261
	.211	.146	.029	.065	.019	.310	.118	.022
	.019	.142	.094	.139	.051	.017	.299	.030
	.035	.024	.081	.067	.036	.040	.080	.022
	.183	.146	.020	.089	.019			
2	.060	.029	.034	.059	.081	.215	.121	.031
	.019	.332	.119	.116	.355	.104	.045	.152
	.044	.196	.017	.157	.057	.013	.088	
3	.461	.386	.026	1.070	.098			
4	2.049							

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*        T H E   W A T E R   S Y S T E M        *
*                                               *
*  COMPUTER PROGRAMS FOR WATERSHED ANALYSES     *
*                 DEVELOPED AT                  *
*  UNIVERSITY OF TORONTO  PURDUE UNIVERSITY     *
*     TORONTO,ONTARIO      LAFAYETTE,INDIANA    *
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DRAINAGE BASIN BEING ANALYZED IS MALLOT BASIN TRIBUTARIES NORTH

INFORMATION FOR THIS BASIN WAS COLLECTED FROM AIR PHOTO SOURCE, 1955 ONT. COVERAGE

THE SCALE OF THE SOURCE MATERIAL IS 1/17400.

AZIMUTHS OF ORDERED SEGMENTS

ORDER	VALUES							
1	251.517	235.131	247.222	158.752	104.510	359.999	128.639	139.106
	209.999	180.000	249.280	150.000	182.680	253.289	271.574	160.440
	155.075	163.372	203.413	211.740	106.102	134.651	359.999	59.999
	122.609	139.106	70.893	166.102	224.920	227.783	306.308	190.893
	245.496	194.920	179.999	101.650	179.999	145.285	48.072	140.034
	155.817	131.741	131.517	94.714	121.626	147.795	76.996	128.065
	174.182	360.000	155.496	72.008	158.213	255.934	140.633	197.647
	239.230	273.417	335.496	287.269	209.999	296.958	293.234	340.893
	180.000	244.306	200.750	297.055	247.994	334.715	315.665	193.897
	168.258	316.996	264.182	346.102	276.586	331.945	180.000	319.106
	306.890	321.939	313.897	346.102	319.106			
2	83.413	150.000	243.963	213.304	190.158	136.711	176.236	248.948
	120.000	165.591	147.355	79.106	146.379	161.387	264.791	172.552
	284.391	262.482	256.102	283.897	272.754	310.893	332.680	
3	172.901	149.570	158.948	155.482	204.791			
4	224.204							

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