THE UNIVERSITY OF MANITOBA

A STUDY OF THE RELATIONSHIP BETWEEN THE STRAHLER BIFURCATION RATIO AND WATER SURPLUS, WITH REFERENCE TO VARIATIONS IN SCALE OF MAPPING

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF ARTS

DEPARTMENT OF GEOGRAPHY

WINNIPEG, MANITOBA

OCTOBER, 1972

ABSTRACT

A study of the statistical relationship between the Strahler bifurcation ratio of a drainage basin and the corresponding water surplus value is undertaken in this thesis. Of importance is the scale of mapping used in the calculation of the bifurcation ratio. Upon establishing an optimum mapping scale, bifurcation ratio values are calculated for physiographic regions in Manitoba. Then, for a number of selected drainage basins bifurcation ratios and water surplus values are derived. By means of various statistical tests, the relationship between these two variables is studied.

Results show that for a given basin, different mapping techniques yield large disparities in calculated morphometric parameters. Stereovisual analysis is demonstrated to be the superior mapping technique when conducting morphometric analyses from maps and aerial photography. Correlation and regression tests show no strong relationship between the Strahler bifurcation ratio and its corresponding water surplus value. Analysis of variance tests substantiate the previous conclusions. The null hypothesis that the four physiographic regions are homogeneous with respect to the Strahler bifurcation ratio cannot be rejected on the basis of the given sample evidence, while the null hypothesis that the regions are homogeneous with respect to water surplus can be rejected at the one percent significance level. In conclusion, the water surplus value is shown to be directly related to precipitation input and inversely related to the infiltration rate and capacity of surficial material.

ACKNOWLEDGEMENTS

I wish to express my gratitude to those individuals who have assisted me in the production of this thesis. I am especially grateful to Dr. W.J.Brown,Head,Department of Geography,for his interest and güidence,particularily in the writing of this thesis. Dr.Brown's valuable suggestions and useful criticisms were much appreciated. Mr.L.P.Stene deserves recognition for initiating and developing my interests in fluvial geomorphology,for supervising my thesis proposal,and for his continuous advice during the preparation of this thesis.

I am grateful to my colleague,Mr.Ross Herrington,for his suggestions in the writing of this thesis and for fieldwork and laboratory assistance. Further thanks are due to Mr. Ed Pachanuk for his cartographic advice,and to other members of the department for their assistance in the preparation of this thesis.

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CHAPTER I

INTRODUCTION

A. REVIEW OF BIFURCATION RATIO DERIVATION AND STREAM ORDERING TECHNIQUES

The foundation of the modern approach to fluvial landform geometry was acknowledged by A.N. Strahler(1964,4-40) in his statement: "Under the impetus supplied by [R.E.] Horton, the description of drainage basins and channel networks was transformed from a purely qualitative and deductive study to a rigorous quantitative science capable of providing hydrologists [and others] with numerical data of practical value."

Horton has provided the first comprehensive scheme of quantitative drainage basin analysis, based on a hierarchical system of stream ordering.

Apart from some early qualitative attempts at stream ordering, the first important hierarchical method was undertaken by H. Gravelius(1914). P.Haggett and R.J.Chorley (1969,p.12) succinctly describe the technique of ordering used by Gravelius as follows:

> Gravelius first identified the trunk stream (order 1) by tracing it, explorer-like, from outlet to source, and at every bifurcation following the branch assumed to have the greatest width, discharge, headward branching or junction angle. This process was repeated for each stream directly tributary to order 1, these being designated order 2 streams, and so on until the most remote fingertip tributaries received the highest order.

However, Horton believed that there were definite disadvantages to this scheme. The subjective decisions which have to be taken at each bifurcation and the fact that stream order number was not systematically related to the magnitude of a given segment led Horton to state that he preferred the converse procedure. Horton(1945,p.281) therefore proposes:

> In this [Horton's] system, unbranched fingertip tributaries are always designated as of order 1, tributaries or streams of the 2d order receive branches or tributaries of the 1st order, but these only; a 3d order stream must receive one or more tributaries of the 2d order but may also receive 1st order tributaries. A 4th order stream receives branches of the 3d and usually also of lower orders, and so on.

After classifying all stream segments, most of the drainage basin must be re-ordered. Starting at the basin mouth and working headwards, the trunk stream is extended at each bifurcation and follows the tributary which is more nearly in line with it, or, if this distinction cannot be made, that which is longer. This re-ordering procedure is repeated for all tributaries of the trunk stream until only fingertip tributaries remain.

Unfortunately, with Horton's system of stream ordering various difficulties arise in that this method possesses a degree of subjectivity in the process of reclassification of tributaries. Also, this system has the disadvantages of assigning to some unbranched fingertip tributaries orders greater than one and different orders to stream segments of equal magnitude.

Horton(1932,p.356) states that "It is evident that the number of tributaries of any given order in a drainage basin increases in a geometrical progression as the order number of the main stream increases. Treated as a geometrical series of ratio r, the sum of the series, or the whole number of streams in a basin would be:

$$N = \frac{(r^{0} - 1)}{(r - 1)} \qquad (1)$$

where 0 is the order of the main stream." Horton then states quite erroneously that if N_1 is the number of tributaries of the first order:

$$r = \sqrt[N-1]{N_1} \qquad (2)$$

This value of r Horton states may be called the bifurcation ratio. However, Horton neglects to declare what N-1 is equal to.

In equation (1), N is stated to be the total number of streams in a basin, and one would assume that N-1 equals a value of one less than this aggregate. This assumption is however incorrect in the case of equation (2), where N-1 apparently is equal to one less than maximum basin order.

In the same article, Horton(p.357) states that, "For a number of drainage basins for which the bifurcation ratio r has been determined it has been found to be nearly constant for tributaries of different orders, although it varies for different basins. It appears to be an important physiographic characteristic of the drainage basin."

Subsequently, Horton(1945,p.280) symbolizes the bifurcation ratio as r_b instead of r, and defines it as the "Ratio of the average number of branchings or bifurcations of streams of a given order to that of streams of the next lower order." This definition is, however, incorrect; it should have been defined as the ratio of the average number of bifurcations of streams of a given order to that of streams of the next higher order for, numerically, bifurcation ratios are usually expressed as values greater than unity.

Equation (1) is now written

$$N = \frac{r_b^{s} - 1}{r_b - 1} \qquad (3)$$

where s is the order of the main stream. (Horton, 1945,p.286).

Within the nested hierarchy of drainage basins, the observed similarity of bifurcation ratios led Horton to formulate the Law of Stream Numbers, which is actually another way in which he defined this ratio. The Law states that "The numbers of streams of different orders in a given drainage basin tend closely to approximate an inverse geometric series in which the first term is unity and the ratio is the bifurcation ratio"(1945,p.291).

The plot, on semilogarithmic paper, of stream numbers against their respective stream orders leads to straight line relationships when lines of best fit are drawn by inspection. The bifurcation ratio can be found by computing or measuring the slope of the regression line, which has the same value. The regression equation,

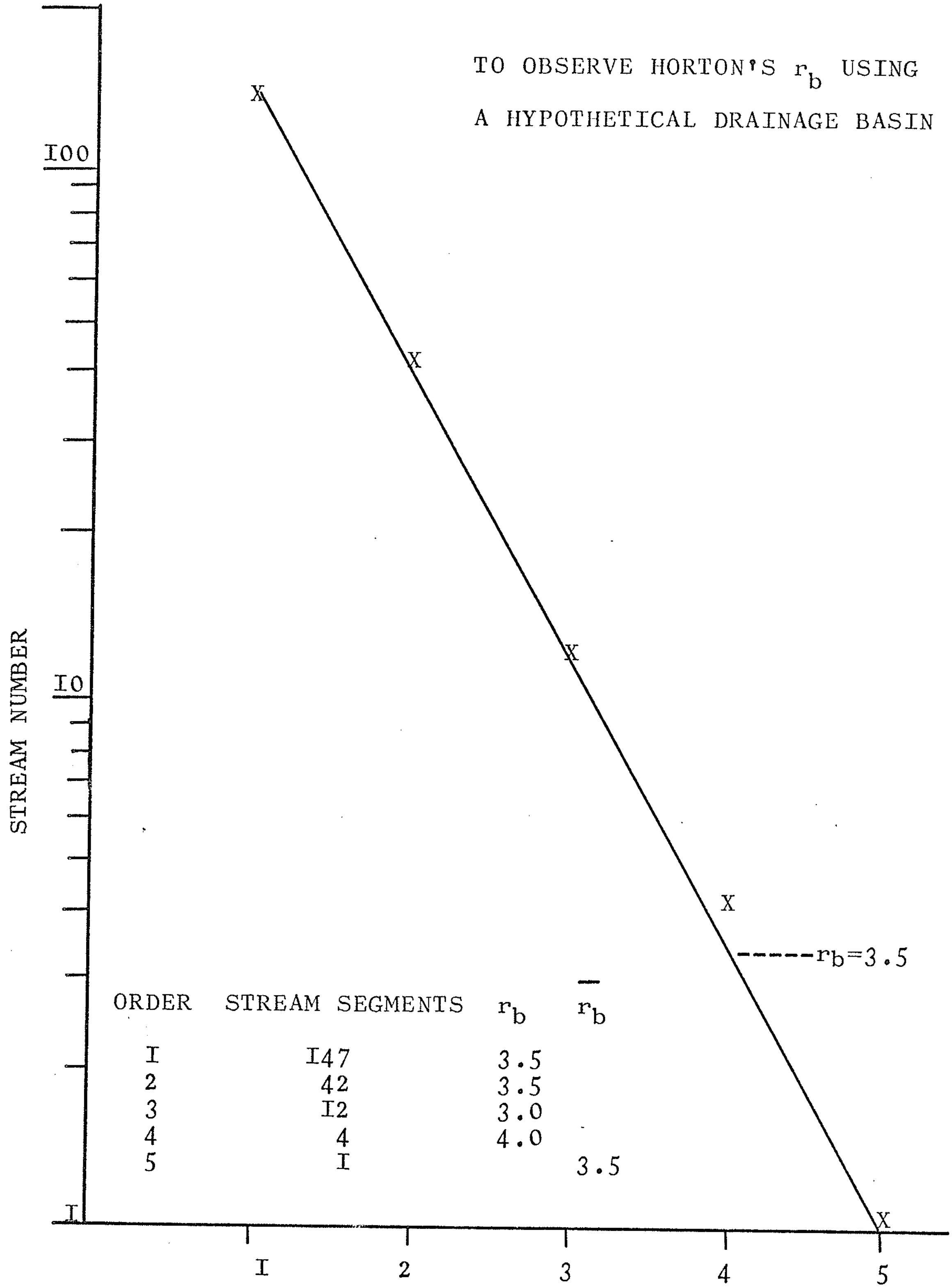
$$N_o = r_b^{(s-o)} \tag{4}$$

where N_o is the number of streams of a given order o, and s is the highest stream order of the basin, is a mathematical expression of Horton's Law of Stream Numbers.

Figure 1-1 illustrates on semi-logarithmic paper a plot of stream numbers versus stream order for a hypothetical drainage network to demonstrate how r_b may be visually determined.

A.N. Strahler modified Horton's system of stream ordering by allowing Horton's provisional scheme to determine the final ordering, such that the smallest or fingertip channels constitute the first order segments. Strahler(1952,p.1120) comments that, "For the most part these carry wet-weather streams and are normally dry." A second order stream segment is formed at the junction of two first order tributaries, while a third order segment is formed by the confluence of two second order streams, etc. "This method avoids the necessity of subjective decisions inherent in Horton's method and assures that there will be only one stream bearing the highest order number."

The subjective decisions inherent in the Horton system are avoided by using Strahler's method of stream ordering.



ORDER	STREAM SEGMENTS	r_b	$\bar{r}_b$
I	I47	3.5	
2	42	3.5	
3	I2	3.0	
4	4	4.0	
5	I		3.5

FIGURE I-I

With the latter method, Haggett and Chorley(1969,p.14) state that similar orders have similar geometrical magnitudes and, for a given drainage network, yields the same maximum basin order as the Horton system. Therefore, the methodology employed by Strahler in ordering a drainage network will be used as a basis for stream ordering in this thesis.

The Strahler bifurcation ratio, R_b, where;

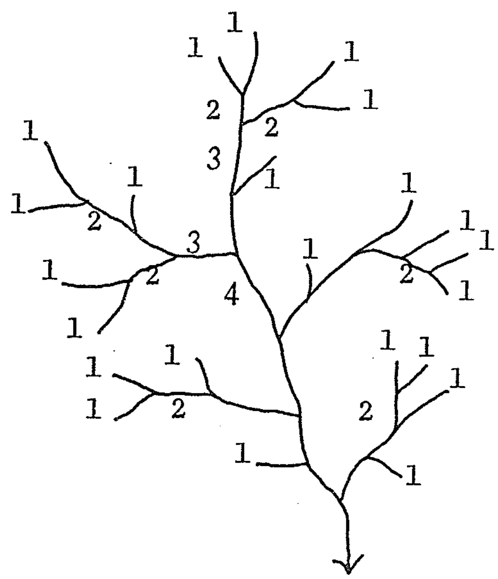
$$R_b = \frac{N_u}{N_u + 1} \qquad (5)$$

will be used, with N_u equal to the number of stream segments of a given order and $N_u + 1$ equal to the number of stream segments of the next higher order. Strahler's method of ordering is applied to a hypothetical drainage basin in Figure 1-2.

B. THE DRAINAGE BASIN AS AN OPEN SYSTEM

The concept of a drainage basin as an open system, which tends to achieve a steady state of operation has been studied by Strahler(1964) and other fluvial geomorphologists. Because matter and energy are imported and exported from the drainage basin, any individual stream, as well as a whole basin, can be considered as an open system. These open systems are characterized by the exchange of material and energy through system boundaries

HYPOTHETICAL EXAMPLE OF STRAHLER'S STREAM ORDERING METHOD



STRAHLER ORDER	NUMBER OF STREAM SEGMENTS	R_b	$\bar{R}_b$
1	23	3.2	
2	7	3.5	
3	2	2.0	
4	1		2.9

FIGURE 1-2

and must transform energy uniformly to maintain operation. Within the drainage basin, precipitation is imported, while mineral matter and runoff leave the system through the basin mouth. Throughout geologic time the rates of import and export of matter and energy across the basin perimeter or system boundary may change substantially but will be balanced so that an equilibrium or steady state is reached. However, during this time (the erosion cycle) there may be short term fluctuations in these rates which yield periods of dis-equilibrium within the system.(Schumm and Lichty,1965) Moreover, the drainage network may be thought of as an expanding open system, because through the progressive development of integrated streams and headward erosion of tributaries, the network may increase in order and size through time, until maximum possible parameters are attained.

In conclusion, "Should controlling factors of climate or geologic material be changed, the steady state will be upset. Through a relatively rapid series of adjustments, serving to re-establish a steady state, appropriate new values of basin geometry are developed." (Strahler,1964,p.4-41)

C. Water Surplus

J.M. Mather(1959), defines 'water surplus' by simply stating that if the amount of precipitation exceeds evapotranspiration, the soil will remain full of water and a water surplus will occur.

A.N. Strahler(1965), utilizes the soil water cycle to more fully define the term 'water surplus'. Assuming a humid, middle-latitude climate, the cycle commences in early spring, when evaporation is low because of low temperatures. The abundance of melting snows and spring rains has restored the soil moisture to a surplus quantity. For the next two months the quantity of water percolating through the soil and entering the ground water keeps the soil pores nearly filled with water. This time is also the season of heavy flooding and in terms of the soil water budget, Strahler notes that a water surplus exists.

A.H. Laycock(1967), declares that when precipitation and temperature data are processed according to Thornthwaite procedures to determine water deficiency patterns, a residual category called'water surplus'develops. Laycock notes that this term is sometimes confused with, or used synonymously with, the terms 'runoff' and 'streamflow'. While runoff may be defined as that part of the precipitation input which together with other water contributions appears eventually in surface streams, streamflow is runoff in which the water occupies a narrow trough confined by lateral banks. Laycock defines 'water surplus' as that water which percolates at levels beyond root depth or moves in surface flow towards streams and depressions after soil-moisture storage capacities have been recharged and which reaches most streams as groundwater inflow,(i.e. baseflow).

Water surplus as used in this thesis will be defined as average depth of water at the ground surface in a drainage basin. Dividing drainage network discharge, converted from cubic feet per second(cfs) to acre-feet, by basin area in acres, yields the uniform depth of water, in feet, to which the entire basin would theoretically be inundated. Moreover, the term 'water surplus' may be expressed by the equation below, where WS symbolizes the 'unit yield' of water surplus, Qd symbolizes mean yearly discharge in cfs. converted to a depth in acre-feet, and Aa symbolizes the area of the drainage basin in acres.

$$WS = \frac{Qd}{Aa} \qquad (6)$$

The water surplus is the surface runoff, less the baseflow recorded as groundwater, available for surface erosive purposes. However, it should be noted that not all this water surplus will induce erosion because parts of this surplus are involved in overcoming the frictional resistance of vegetation, in overland flow and in surface detention, which increases with increasing resistance.

The following section of this chapter deals with bifurcation ratio derivation. A review of the types and causes of surface erosion is undertaken, commencing with a discussion of overland flow and the belt of no erosion.

D. Theories Concerning Bifurcation Ratio Development

There are several schools of thought concerning the characteristics of bifurcation ratios and the causes of their development within certain numerical limits. Fluvial geomorphologists have tried to define the expression'bifurcation ratio' and to describe how and why it develops the way it does under given conditions.

Concerning the erosional development of streams, Horton asserts that this process is not entirely random. Horton(1945,p.335-339) states that when a newly exposed surface is eroded, an initial series of small, shallow, closely spaced shoestring gullies or rill channels is developed. These rills flow parallel to each other and as a result of various causes, the divides between adjacent rills are broken down and water flow in the shallower rill channels is diverted into deeper ones, a process known as micropiracy. Thus, a new system of rills is developed which has a direction of flow at an angle to the initial rill channels and produces a resultant slope towards the initial rill. On newly exposed terrain, stream segments develop first where the length of overland flow exceeds the critical length, that is, just beyond the limit of the belt of no erosion. Stream segments starting at these points generally become the fingertip tributaries.

If the area in which surface runoff occurs is covered with grass or other closely spaced plants, the flow may be subdivided. Horton(1945,p.315-320) feels that part of the water energy available for overcoming resistance to erosion is expended on frictional resistance of the grass blades, or other vegetation, thereby reducing the amount of energy available for expenditure on the soil surface. Because of increased resistance, the depth of surface detention required to produce a given rate of runoff is very greatly increased and the velocity of overland flow is correspondingly decreased.

Horton states that certain physical factors govern soil erosion; these may be grouped as initial resistivity, rain intensity, infiltration capacity and the velocity and energy of overland flow. A vegetal cover generally breaks the force of raindrops, and grass sod that covers the underlying soil inhibits erosion. Fine soil particles adhere to root hairs and plant roots near the surface and act strongly as a soil binder.

Finally, Horton believes that nature develops successive orders of streams by bifurcation essentially in a uniform manner, regardless of geologic controls. Horton(1945,p.303) feels that fundamentally his Law of Stream Numbers is not influenced by inhomogeneity and therefore by lack of isotropy. However, numerical variations in the Law may occur and these may be accredited to geological controls. This statement is substantiated by D.R. Coates(1958) who feels that in nature the minimum bifurcation ratio of two is seldom approached. Of more importance is that Coates feels that the bifurcation ratio usually lies between three and five in basins without dominant differential geological controls. He asserts that the bifurcation ratio only reaches higher values where geological controls favor the development of elongate narrow basins. In following, Strahler(1957) states that the bifurcation ratio is highly stable and shows only a small range of values from region to region, with the mean bifurcation ratio being about 3.5. However, Strahler notes that for drainage networks in regions with steeply dipping bedrock confined between hogback ridges, high bifurcation values may occur.

With reference to the aforesaid insensitivity, R. Shreve(1966,p.18) states that many investigators have shown that independence of the detailed geomorphic processes at work in any given drainage network characterizes the geometric series of the Law of Stream Numbers and therefore, the bifurcation ratio.

Concerning Horton's Law of Stream Numbers, Shreve feels that drainage networks which have developed in the absence of geological controls are topologically random. Shreve does not imply, however, that the lengths, shapes and orientations of links are also random. Thus, although not every attribute is likely to be random, in development, the topology of the drainage network and therefore the bifurcation ratio is. This leads Shreve to the conclusion that the Law is primarily a consequence of the random development of the topology of channel networks, according to the laws of chance.

Shreve states that the bifurcation ratio is independent of other geomorphic and hydrologic variables and of the environment. He explains randomly merging stream channels by means of graphical construction, according to rules of chance. However, because the graphical method for computing the probability of occurrence of a drainage network with a given set of stream numbers has disadvantages, Shreve adapts an alternative definition of randomly merging stream channels. This definition involves only network topology and simple enumeration.(Shreve,1966,p.27)

Shreve shows that stream networks that are similar in topology have equal numbers of links, forks, sources, Horton streams and first order Strahler stream segments. "This suggests equating 'randomly merging stream channels' with a topologically random population within which all topologically distinct networks with given numbers of links are equally likely."(Shreve,1966,p.27). Therefore, of principal significance is the hypothesis that a natural population of stream networks will be topologically random, providing the absence of geological controls. In this way, the definition of topologically random channel networks can predict the Law of Stream Numbers.

Shreve(1966,p.17) asserts that "In a topologically random population the most probable networks approximately obey Horton's law but exhibit certain systematic deviations." Shreve asserts that a geometric mean bifurcation ratio of four would be the ratio most commonly calculated for a basin with a given number of first order tributaries. Moreover,

> For networks with n [sources] and Ω [order] given the most probable networks have the property that the bifurcation ratio of the second-order streams B_2 is always close to 4 and, hence, that the bifurcation ratios respectively decrease, remain unchanged, or increase with order and the corresponding curves on the Horton diagram are respectively concave upward, straight, or concave downward according as the geometric mean bifurcation ratio is less than, equal to, or greater than 4.(Shreve,1966,p.31).

Arthur Strahler expresses the equation to calculate his bifurcation ratio as;

$$\log Nu = a - bu \qquad (7)$$

where the antilog of b is the bifurcation ratio.

However, the usual method employed to calculate the Strahler bifurcation ratio for pairs of adjacent orders and for a given basin makes use of the following equation;

$$R_b s_1 = \frac{Ns_1}{Ns_2} \text{ etc...} \qquad (8)$$

where s denotes the order. (Also see equation 5).

In following, M.J. Woldenberg(cited in Haggett and Chorley,1969,p.15) criticizes Strahler's system of stream ordering and hence bifurcation ratio values, noting that from a hydrological standpoint, his system violates the distributive law, since junctions of lower order segments do not change the order of the main stream.

By utilizing the term 'link magnitude', Shreve(1967, p.178) obeys the distributive law when ordering a drainage network. With Shreve's concept of magnitude each exterior or fingertip tributary has a magnitude of one. If links join then the resultant link downstream has a magnitude equal to the total number of sources tributary to it. Figure 1-3 illustrates Shreve's ordering technique using link magnitudes for a hypothetical drainage network.

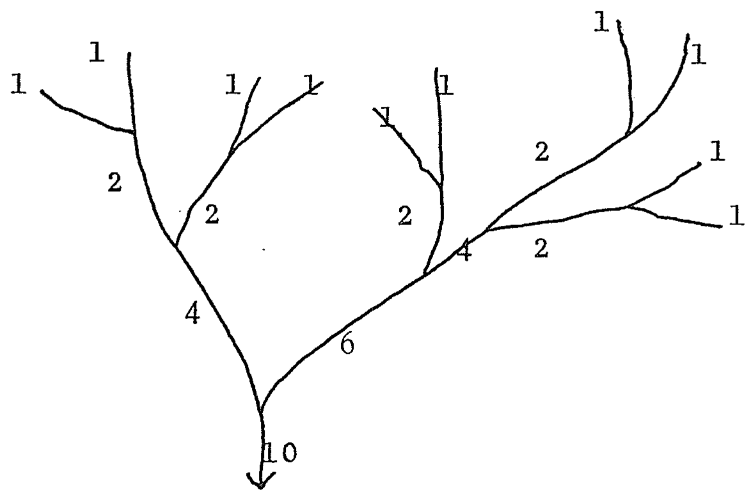


Figure 1-3 Shreve's basin ordering technique.

This method of stream ordering will produce different bifurcation ratios than those calculated by Strahler's method of stream ordering for the same network. This is because there are fewer Shreve links of each order(magnitude), since there are more orders than with Strahler's method.

Strahler's system of ordering produces an inverse geometric series of numbers of stream segments, and Shreve(1964) found that Strahler's numbers of stream segments were fitted better by the series than Horton's frequencies of streams. Using an exponential plot, the Strahler system usually gives smaller root mean square deviations than does the Horton system the Strahler system also gives different basin bifurcation ratios.

E. Giusti and W. Schneider(1965) use Strahler's method of stream ordering and bifurcation ratio calculation when studying the Yellow River basin in Georgia. Using base maps at a scale of 1:2400, they conclude that bifurcation ratios tend to be highly variable. Their study also leads them to conclude that drainage basins with different areas but with equal order usually have the smallest bifurcation ratios in the smallest basins. As basin size increases so does the bifurcation ratio. However, after a certain basin size is reached the bifurcation ratio tends to become constant.

Giusti and Schneider feel that when a drainage basin is ordered by the Strahler method and bifurcation ratios calculated, these ratios tend to increase in a downstream direction. In other words, the orders from which they were computed influence the value of the bifurcation ratio. Similarily, S.A. Schumm(1956) observes that because of chance irregularities the bifurcation ratio between successive pairs of orders differs within the same basin, even if a general observance of the geometric series exists. However, Giusti and Schneider also feel that due to the branching process of stream networks, the bifurcation ratios become smaller if they are computed from higher order subbasins. The reasoning is that as stream order increases there is a diminishing amount of area available within the basin. This causes a higher percentage of streams to join into higher ordered tributaries.

In contrast to Giusti and Schneider, R.J. Eyles(1968) suggests that the bifurcation ratio may under some circumstances be inversely related to order. Eyles feels that recent rejuvenation has disproportionately increased the number of first and second order tributaries, which causes an observable upward concavity in a plot of stream numbers versus order.

Finally, Giusti and Schneider(1965,p.68) assert, "Bifurcation ratios tend to become constant for ratios made between numbers of branches which are two or more orders removed from the order of the main stream." Thus, the variability of bifurcation ratios found in their study indicates that bifurcation must be carefully defined in terms of the two successive orders from which they are computed and the order of the main stream. Moreover, they believe that comparisons of undefined bifurcation ratios may lead to erroneous conclusions concerning the drainage network.

J.C. Maxwell(1955,p.520) defines the bifurcation ratio, B, as "The antilog of the slope of a straight line fitted by inspection equally to all points of a scatter diagram of logarithms of number of channels of each order versus order number." Maxwell uses Strahler's method of stream ordering and fitted the following equation to a plot of stream numbers versus order.

$$\log Nu = k \cdot \log R_b - (\log R_b) \cdot u \qquad (9)$$

The reason Maxwell fits the line to all points instead of requiring the line to pass through the point of highest order is because he feels that in a drainage basin of apparently nth order, the number of higher order channels and the order of the drainage network can vary if one or more first order channels are added or omitted. Therefore, Maxwell feels that plotted points of highest order should not be considered any more reliable than points representing other orders when fitting the regression line to the points on a scatter diagram.

In conclusion, L.E.Milton(1966) states that the bifurcation ratio is predominantly controlled by the drainage density and by stream entrance angles. Concerning stream entrance angles, Schumm(1956,p.617-620) compares young and mature angles of junction and finds a significant difference, which suggests that the angles change during the geomorphic cycle. The ratio of channel slope to ground slope is the primary factor causing two streams of unequal order to join at a given angle. Because of the relatively slower degradation of the higher order channel, the point of junction moves downstream and the junction angle decreases. As the junction angle becomes very small, lateral planation may erode the interfluve and the junction angle migrates upstream. This may cause a significant change in the bifurcation ratio.

Milton states that in regions where the network geometry develops without pronounced structural controls, bifurcation ratios are stable. He stresses however, that natural bifurcation ratios are controlled by geomorphic factors and by chance. Finally, Milton asserts that infiltration capacity, relative relief and geological structure, operating through the morphometric factors of stream orientation, and drainage density, play fundamental roles in determining a drainage network's bifurcation ratio.

D. Objectives of Research

The fundamental objective of this thesis is to demonstrate whether or not there is a meaningful statistical relationship between the Strahler bifurcation ratio of a drainage basin and its water surplus value. Also of importance is the scale of mapping used to calculate the bifurcation ratio.

Having defined fundamental terminology, theories concerning the development and control of bifurcation ratios were reviewed. In the following chapter a morphometric study of a small drainage basin in south-western Alberta is undertaken. It is hoped that this morphometric analysis, which is concerned primarily with stream numbers and orders, will demonstrate the effects of different mapping scales on the calculated bifurcation ratio. On the basis of this study, an optimum mapping scale will be established and employed to calculate mean bifurcation ratios for physiographic regions in Manitoba.

Attempting to devise a measure of water surplus is another important objective of this thesis. By utilizing drainage basin areas and mean annual discharge values, a comparitive mean annual water surplus value for a drainage network may be calculated. Although this water surplus is directly responsible for the development of drainage networks, what are the effects on bifurcation ratio values of differences in water surplus amounts? Statistical analyses of the derived bifurcation ratios and water surplus values should enable conclusions to be drawn concerning the extent to which the Strahler bifurcation ratio is a function of water surplus. This is the main objective of the thesis. Moreover, it is hoped that changes in water surplus values between physiographic regions in Manitoba can be explained in terms of differences in annual precipitation inputs, infiltration rates, natural vegetation and surficial materials.

In the concluding chapter, a re-appraisal of the factors determining bifurcation ratios and a summation of the results and implications regarding the relationship between bifurcation ratios and water surplus will be attempted. Suggestions regarding further studies of bifurcation ratios will be presented.

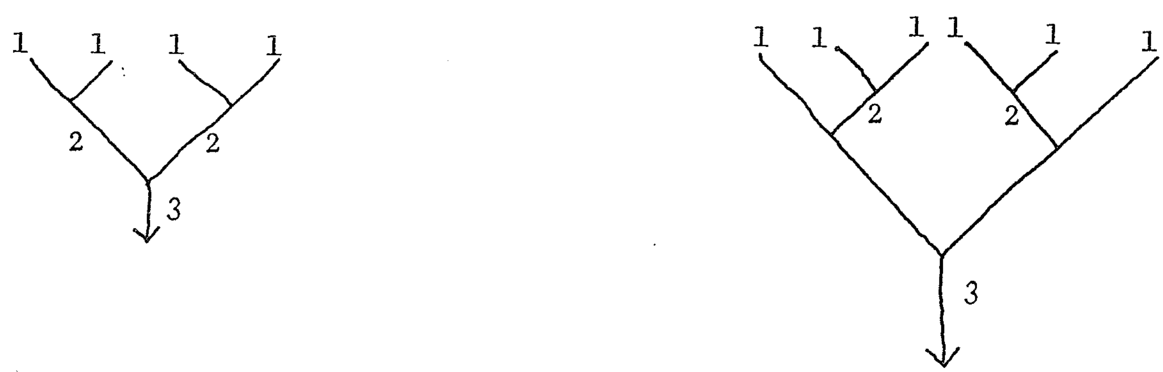
CHAPTER II

THE EFFECT OF MAP SCALE ON BIFURCATION RATIO DERIVATION

A. Introduction

A.E. Scheidegger(1966A,p.56) states that "In any scheme of stream ordering, the order assigned to a given stream segment depends on the scale of the map used to make the drainage basin analyses, since new forkings at the headwaters may become observable as the map scale is increased", thus changing and often increasing the bifurcation ratio. This is illustrated as follows,(Figure 2-1):

Small scale representation   Large scale representation



R_b = 2.0 for the basin R_b = 2.5 for the basin

Figure 2-1. An example of the effects of increased map scale on stream segment order and basin R_b.

Thus, with an increase in scale, two new first order tributaries become visible and the basin's bifurcation ratio is changed.

Map accuracy and scale are of fundamental importance when performing an accurate analysis of the landscape from topographic maps. When a map shows streams as blue lines, a first order segment is assigned from every beginning of a blue line to its junction with another one. No decision is made by the map reader, for the decisions of what in reality is a first order segment have already been made by the cartographer. Unfortunately, a different cartographer might have extended the stream farther headwards or added other segments from contour inflections. This in turn would alter stream numbers and the bifurcation ratio. (Scheidegger, 1966A).

Fluvial geomorphologists have checked drainage networks as depicted on topographic maps with those evident from fieldwork observations. Their results are conflicting and depend on the types of maps used and location of the study areas.

M.A. Melton(1957) studied drainage basins in the western U.S.A. on United States Geological Survey maps at a scale of 1:24000 and finds that a high percentage of first order channels are represented by the smallest contour crenulations. Ninety-five percent of the basins studied required minor network corrections on maps when calculated and checked with fieldwork data.

M. Morrisawa(1957), checked 1:24000 U.S.G.S. maps compiled from air photos with actual field maps for selected areas in the Appalachian Plateau. She concluded that for small basins, total channel lengths were significantly shorter than those obtained by field work.

D.R. Coates(1958) compared 1:24000 U.S.G.S. maps of southern Illinois with his 1:600 field maps; he concluded that first order tributaries are depicted very poorly on the 1:24000 maps, and upon checking, most mapped first order tributaries were actually found to be third order channels. On the average, total stream lengths obtained from the field maps were three to five times greater than shown on the 1:24000 topographic maps. Likewise, drainage density was four times greater.

R.J. Eyles(1966), working in Malaya, compared stream networks inferred from contours at a 50 foot interval on 1:63,360 topographic maps, with those networks visible on airphotos, at scales varying between 1:8000 and 1:25000. Comparing the map and airphoto representation of 50 basins of third to fifth order, Eyles found that only seven basins coinciding in maximum basin order.

B. Schaffer Creek: A Case Study

A study was undertaken in southwestern Alberta to try to determine what the effects of changing map scale on the stream order characteristics of a given drainage network would be. Schaeffer Creek, whose drainage basin lies between latitudes 49° 52' N. and 49° 57' N. and between longitudes 113° 48' W. and 113° 56' W. was chosen for this study. The

Schaeffer Creek drainage network was mapped and ordered by five different methods. Firstly, it was mapped directly from a 1:50000 topographic sheet by the blue line method; secondly, by the additional use of contour crenulations on the same map; thirdly, by using nine by nine inch vertical aerial photographs at a scale of one inch to 0.59 miles (i.e. 1:37382) without using a stereoscope; fourthly, from 1:13306 enlargements of the original nine by nine inch photographs; and fifthly, by analysis of the 1:37382 photographs using a two power Dietzgen mirror stereoscope.

Physical Characteristics of Schaeffer Creek :

The Schaeffer Creek drainage basin is located in the Porcupine Hills of southwestern Alberta, which in turn, may be considered as part of the Alberta Hill Plains or Foothills. The bedrock in this basin consists essentially of Upper Cretaceous and Tertiary sandstones, with some shales. The sandstones have a fine-to medium-grained texture. Because the area was transgressed by the Keewatin ice sheet during the Wisconsin stage of glaciation, ground moraine covers much of the drainage basin.

In the sub-region of Alberta in which Schaeffer Creek is located, January temperatures average 15 degrees Fahrenheit(F.) while July temperatures average 63 degrees F. Total annual precipitation averages 19 inches and mean annual snowfall approximates 70 inches. Characteristic of this area is the cyclonic - induced 'foehn' wind or chinook.

This warm dry wind descends the Rocky Mountain front and travels southeastwards, parallel to the foothills. The warming effect of a chinook can cause a temperature rise of 40° F. within 24 hours during winter months, melting heavy snow covers. In summer, sudden temperature rises of 10° F., dust storms, soil erosion and forest fires accompany this westerly wind.(I. Ashwell,1971). Average actual evapotranspiration is 14-16 inches per year; this value is a measure of actual evaporation and transpiration where average soil moisture storage capacities of four inches are present.

The natural vegetation is predominantly short grasses, which are found on the higher portions of the stream interfluves. (See Plate 2-1). Longer grasses colonize the bottoms of dry stream channels and are densest along the highest order streams. Scrub bush and hawthorne occur along higher order streams. (See Plate 2-2).

Soils are primarily black to dark grey-brown in colour. They are stony, the stones being unsorted in size and angular in shape indicating glacial drift to be the prime parent material. In the Schaeffer Creek basin most of the land is in unimproved pasture, and cattle ranching is the main economic activity.

Plate 2-1
An example of two first order tributaries forming one second order segment. Note the short grass vegetation on lower order interfluves.

Plate 2-2
The fifth order channel of Schaeffer Creek-foreground and junction with a third order tributary. Scrub bush, hawthorne and long grasses are observable along the higher order segment while short grasses characterize the third order tributary.

C. Morphometric Properties Of Schaeffer Creek

Basic Basin Characteristics:

Schaeffer Creek watershed trends northeast-southwest, and has a vectorial basin axis, computed by the method of E.D. Ongley(1968), of 46^{o} East of North and a length of 7.8 miles. (Appendix A, Map 1). The maximum elevation of the drainage basin is 5400 feet, at the head of the valley. The lowest elevation, 3550 feet is located at the basin outlet where Schaeffer Creek flows into Trout Creek. The valley has an average slope of 2.9 degrees along its central axis, as derived from maps, the planimetric area of the drainage basin is 9.76 square miles and its perimeter, by opisometer measurement, is 18.07 miles.

Basin area and perimeter were first determined from a 1:50000 topographic map, National Topographic Series sheet 82H/13W, edition 2 ASE, series A741 by contour inspection. The position of the divide, and hence basin area, were subsequently corrected by utilizing 1:37382 aerial photography. Appendix A, Maps 2 and 3, illustrate basin area and perimeter. Appendix A, Sections I and II present basin area and perimeter measurements at the two scales of mapping. The planimetric difference between the basin areas based on the corrected divide and topographic map basin perimeter respectively was 0.39 square miles. In general, the basin divides as determined from both techniques agree, except in one area adjacent to the stream mouth where the spacing between contours is wide.

Basin Order:

In the field certain criteria may be established for the recognition of stream channels. J.C. Maxwell(1960, p.24) presents four criteria to identify a stream channel in the San Dimas region of California. These criteria are:

1. the presence of stream banks,
2. the presence of suspended and oriented debris,
3. the presence of wash marks,
4. the continuity with a larger channel.

Maxwell believed these four criteria may be universally applicable. To further examine this idea, Maxwell's criteria were tested on the Schaeffer Creek drainage basin.

In his fieldwork, Maxwell found certain problems existed when trying to recognize a stream channel. Since the San Dimas region has a prolonged dry spell each year, stream channels are often indistinct. Secondly, Maxwell noted that linear depressions produced by rolling and sliding rock debris may be mistaken for dry stream channels. Thirdly, Maxwell observed that the dense chaparral vegetation common to the region often camouflages small channels.

In the Schaeffer Creek field reconnaissance only two of Maxwell's four criteria were observable. These were the presence of stream banks and the continuity with a larger channel. At no location were suspended and oriented debris or wash marks observed. Most of the lower order stream channels have flat to gently-concave grass covered beds. In many of the dry valley segments no actual channel or stream banks can be seen. However, the small V-shaped valleys often indicate the existence of ephemeral stream flow. Sometimes a downslope train of small rounded pebbles in a shallow depression may be used as a criterion for channel identification, the assumption being that these particles were being carried down slope and rounded by water action.

When deciding upon what was a first order channel, rills and rivulets were not considered. Only channels greater than an arbitrary ten feet in length and with an observable stream bank were considered. It was felt that stream segments smaller than this would not be visible on the aerial photographs. However, had first order streams developed on areas of exposed soil where individual rivulets could be readily visible, then they would have been ordered. The fact that ninety-five percent of all lower order stream segments were covered in grass, thus hiding the rill or micro-drainage pattern, limited the effectiveness of the criteria for recognizing stream network elements.

In contrast to Maxwell's research, no problems arose in differentiating between channel segments and the effects of mass movement phenomena in this study. No debris chutes or mudflows were observed which might have been mistaken for stream channels. Within the basin, only one example of discontinuous gully development was observed and no problems arose when ordering this channel.

The Schaeffer Creek drainage network was ordered according to Strahler's system, utilizing either different mapping scales or techniques as previously described for five methods. The drainage composition obtained by each ordering of the basin is presented in Table 2-1. According to the method employing only blue lines, the basin has a small number of streams and a very high bifurcation ratio. The net devised from blue lines appears on Map 4 of Appendix A.

The method in which blue line representation of segments of streams are extended by using contour crenulations is somewhat subjective; however, if only sharp (i.e. V-shaped) crenulations in at least two successive contours aligned with blue lines are employed, the subjectivity is not a major problem. This method offers a better representation of the drainage network(Appendix A, Map 5).

The methods which use aerial photographs at scales of 1:37382 and 1:13306 respectively without stereovision, both give higher stream order counts and maximum basin order than do the previously described methods.

The resulting networks are depicted in Appendix A, Maps 6 and 7.

The method of extending streams by stereovisual employment of airphotos at a 1:37382 scale, appears to be the most accurate laboratory method of determining basin order.

STREAM ORDER COMPOSITION

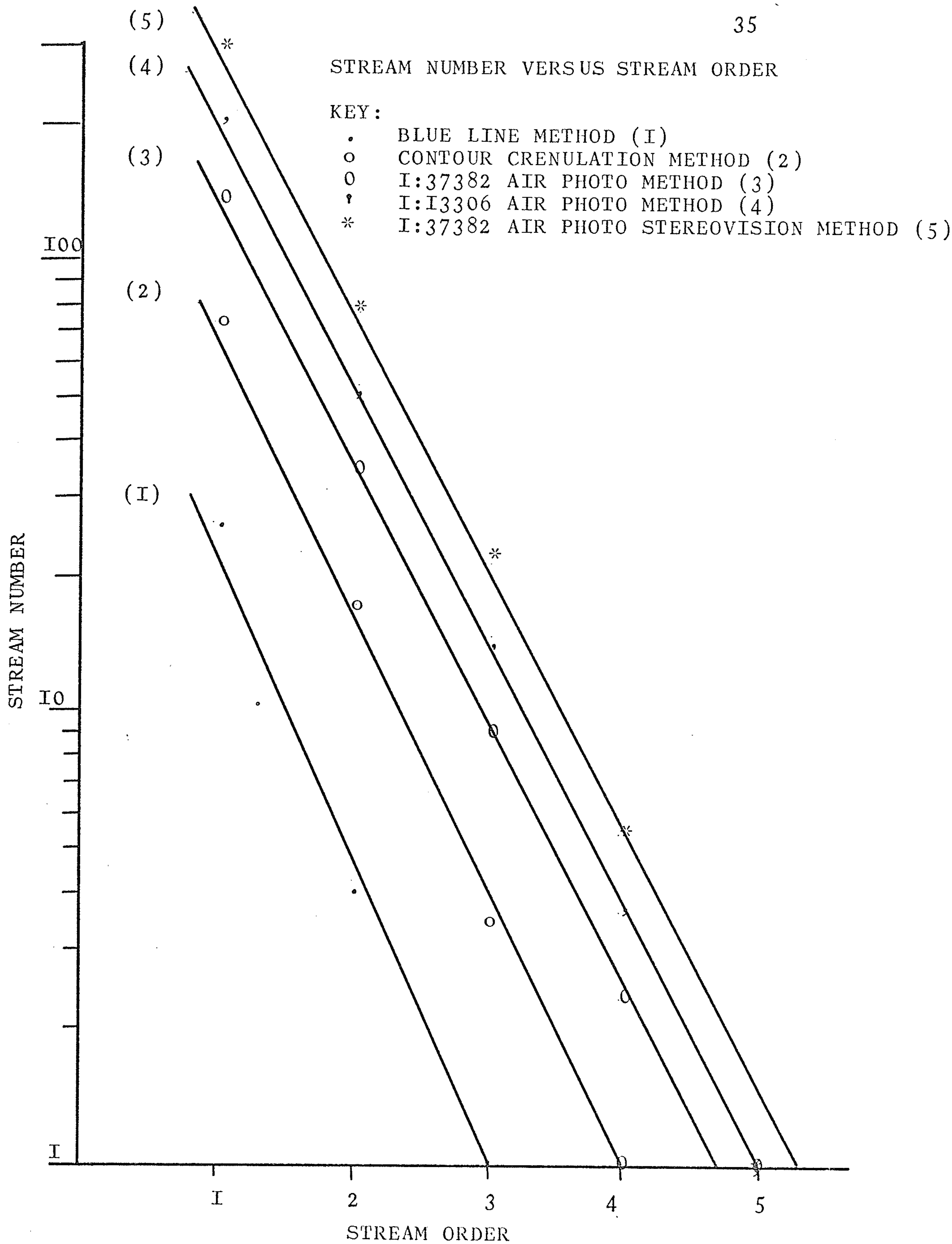
TECHNIQUE OF NETWORK IDENTIFICATION	NUMBER OF STREAMS OF THE FOLLOWING ORDERS AND R_b FOR PAIRS OF CONSECUTIVE ORDERS: ORDER 1	R_b	ORDER 2	R_b	ORDER 3	R_b	ORDER 4	R_b	ORDER 5	BASIN R_b	STREAM SEGMENT TOTAL
BLUE LINES ON 1:50000 MAP	26	6.50	4	4.00	1					5.25	31
BLUE LINES AND CONTOUR CRENULATIONS ON 1:50000 MAP	64	3.76	17	5.67	3	3.00	1			4.14	85
VERTICAL AERIAL PHOTOGRAPHY 1:37382 SCALE	130	3.80	34	3.80	9	4.40	2	2.00	1	3.50	176
VERTICAL AERIAL PHOTOGRAPHY 1:13306 SCALE	211	4.22	50	3.57	14	4.66	3	3.00	1	3.86	279
VERTICAL AERIAL PHOTOGRAPHY 1:37382 USING A 2X MIRROR STEREOSCOPE	278	3.76	74	3.70	20	4.00	5	5.00	1	4.12	378

TABLE 2-1

With this method the total number of stream segments was greatly augmented, (Appendix A, Map 8). This method increases basin order to five from a value of three as determined by the blue line method. Finally, as apparent from Table 2-1, the stereovisual method produced more than four times the number of stream segments obtained from the crenulation method and twelve times the number identified by the blue line method.

The plot of the logarithms of stream numbers against stream order for the drainage network produced from each method of channel identification, enabled good-fitting regression lines to be added by visual inspection.As in the first Law of Drainage Composition, the number of stream segments plotted against basin order tends to form an inverse geometric series. (Figure 2-2).

Several preliminary conclusions may be drawn from the previous reults concerning techniques and scales of mapping drainage nets. A scale of 1:50000 is only adequate for depicting approximate basin shape. This scale does not give a true representation of maximum stream order and stream numbers. Hence, an accurate bifurcation ratio cannot be derived at this scale. The aerial photographic enlargements present a much more accurate representation of the drainage system than do the 1:50000 sheets. The scale of 1:13306 is large enough to show most first order tributaries. Mapping a sub-basin in the field and comparing it with its representation on the photograph revealed that only a few, short, finger-tip tributaries are not visible on the enlargements.



STREAM NUMBER VERSUS STREAM ORDER
KEY:
BLUE LINE METHOD (I)
CONTOUR CRENULATION METHOD (2)
I:37382 AIR PHOTO METHOD (3)
I:I3306 AIR PHOTO METHOD (4)
I:37382 AIR PHOTO STEREOVISION METHOD (5)
(5)
(4)
(3)
(2)
(I)
I00
I0
I
STREAM NUMBER
I
2
3
4
5
STREAM ORDER

FIGURE 2-2

Also, several of the first order stream segments in the basin are longer than their scale equivalents as depicted on the photo enlargements. This may be due to headward extension of tributaries since the time of the flight photography and also to the variation of scale over the entire enlargement. It may be concluded that the air photo stereopairs with an average scale of 1:37382 afford the most accurate representation of the drainage basin.

Bifurcation Ratio:

Table 2-1 shows that the smallest calculated average bifurcation ratio for Schaeffer Creek basin is obtained from the 1:37382 aerial photographs without the use of stereovision, and the largest value of the average ratio for the net is obtained from the blue line mapping technique. The range of bifurcation ratio values within the drainage network is greatest in the least precise methods (2.50 by the blue line method and 2.67 by the crenulation method) and is the smallest (1.24 for the basin), when using 1:37382 air photos with the aid of a stereoscope. This small range helps to substantiate the premise that the fifth method is most precise (providing that the First Law of Drainage Composition applies), since its values of stream numbers exhibit the least scatter.

In Strahler's system of stream ordering, the smallest bifurcation ratio is two, but is rarely approached. In the Schaeffer Creek study the majority of bifurcation ratio values tend to fall between three and five, with the basin having a mean ratio of 4.12, as calculated by the stereovisual method. Since this group of values is low, it would appear that the basin is not characterized by any appreciable lithologic or structural control of the bedrock in spite of the fact that significant alignment of channels occurs towards the head of the watershed.

The Law of Stream Numbers:

Horton's Law of Stream Numbers states that the number of stream segments of successively lower orders in a given basin, tend to form a geometric series, beginning with a single segment of the highest order and increasing according to a constant bifurcation ratio(Horton,1945). Using the 1:13306 map of Schaeffer Creek basin,(Appendix A, Map 7), the Law of Stream Numbers was tested. Table 2-2 contrasts stream segment counts derived by ordering the map net with those calculated by employing Horton's Law of Stream Numbers equation, using the computed mean bifurcation ratio as determined from the analysis. It is obvious that stream counts at the 1:13306 mapping scale and mathematically-derived stream segment values are not in agreement.

The above procedure was then repeated, comparing stream segment counts by stereovisual use of the 1:37382 airphotos with values from the Horton formula,(See Table 2-3).

The values derived by formula and those derived from the 1:37382 air photo mapping with stereovision are very similar. The small variations in stream segment values could be due

COMPARSION OF STREAM SEGMENT COUNTS USING MAP FROM 1:13306 AIR PHOTOGRAPHS AND EMPLOYING HORTON'S LAW OF STREAM NUMBERS FORMULA

STREAM COUNTS	ORDER 1	ORDER 2	ORDER 3	ORDER 4	ORDER 5	TOTAL STREAM SEGMENTS
BY ORDERING 1:13306 MAP NET:	211	50	14	3	1	279
BY FORMULA	222	58	15	4	1	300

TABLE 2-2

COMPARISON OF STREAM SEGMENT COUNTS USING STEREOVISUAL ANALYSIS OF 1:37382 AIR PHOTOGRAPHS AND BY EMPLOYING HORTON'S LAW OF STREAM NUMBERS FORMULA

STREAM COUNTS	ORDER 1	ORDER 2	ORDER 3	ORDER 4	ORDER 5	TOTAL STREAM SEGMENTS
BY ORDERING 1:37382 MAP NET BASED ON STEREOVISUAL ANALYSIS:	278	74	20	5	1	378
BY FORMULA	288	70	17	4	1	380

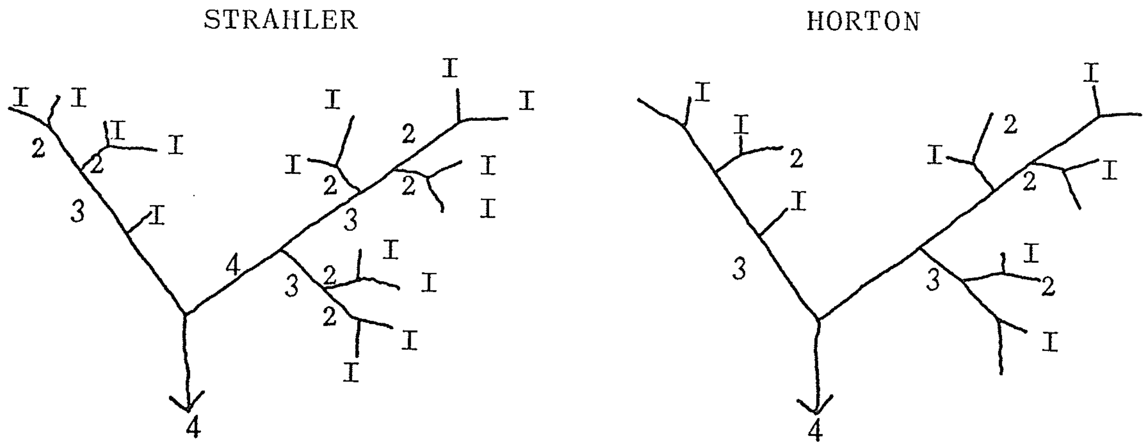
TABLE 2-3

almost solely to operator error in observing and tracing the streams. Also, they may be due to the fact that Horton's laws of drainage composition cannot be applied to drainage networks ordered by the Strahler method, without small deviations in basin order and bifurcation ratio occuring. Figure 2-3 represents a hypothetical drainage network ordered by both methods,(i.e. Horton's and Strahler's). The two methods give different stream segment counts and bifurcation ratio values. This may help to explain why stream counts derived by observations and by formula vary slightly when Horton's laws are applied to Strahler's stream orders.

Stream Frequency:

Stream frequency is defined as the number of stream segments per unit area. Since this parameter is closely related to bifurcation ratio, stream frequency values have been calculated for each of the five mapping methods described previously(Table 2-4). As would be expected, when mapping scale increases, the number of stream segments do likewise, and therefore stream frequency per unit area increases.

STRAHLER'S METHOD OF STREAM ORDERING VERSUS HORTON'S METHOD, FOR A HYPOTHETICAL DRAINAGE NETWORK



STREAM SEGMENT COUNTS AND BASIN BIFURCATION RATIO

METHOD OF ORDERING	ORDER I	ORDER 2	ORDER 3	ORDER 4	TOTAL SEGMENTS	BASIN Rb
STRAHLER	I5	7	3	I	26	2.45
HORTON	8	4	2	I	I5	2.00

STREAM SEGMENT VALUES USING $N_o = r_b^{(s-o)}$

METHOD OF ORDERING	ORDER I	ORDER 2	ORDER 3	ORDER 4	TOTAL STREAM SEGMENTS
STRAHLER	I4.75	6.00	2.45	I.00	24.I5
HORTON	8.00	4.00	2.00	I.00	I5.00

FIGURE 2-3

TABLE 2-4 STREAM FREQUENCY

TECHNIQUE OF NETWORK IDENTIFICATION	STREAM FREQUENCY / MI^2
BLUE LINES ON 1:50000MAP	3.05
BLUE LINES AND CONTOUR CRENULATIONS ON 1:50000	8.70
VERTICAL AERIAL PHOTOGRAPHY 1:37382	18.03
VERTICAL AERIAL PHOTOGRAPHY 1:13306	29.30
VERTICAL AERIAL PHOTOGRAPHY 1:37382 USING 2X MIRROR STEREOSCOPE	38.72

Two other important morphometric characteristics of Schaeffer Creek basin, specifically stream length composition and drainage density, are presented in Appendix A, sections III and IV, and not in the text, as they have, theoretically, only an indirect relationship with bifurcation ratios and stream frequencies.

D. CONCLUSIONS

The morphometric analysis of Schaeffer Creek leads to the following observations and conclusions concerning map scale.

1. A map scale of 1:50000 with blue lines representing the drainage network is not satisfactory for calculating number of stream segments per order, maximum basin order, or the bifurcation ratio of a basin.

2. Using contour crenulations plus blue lines on 1:50000 maps, more accurate stream counts are obtained, but there is still not a satisfactory representation of the drainage basin as apparent in the field.

3. Nine by nine inch air photos at a 1:37382 scale show more detail than does the 1:50000 map, but they are not reliable in that many first order tributaries are not visible. Basin shape and perimeter can be accurately ascertained at this scale.

4. Nine by nine inch aerial photograph enlargements at a 1:13306 scale are excellent for mapping in the field. Stream counts are higher than those obtained by the previous three methods. However, not all tributaries can be seen on the photos.

5. Nine by nine inch stereopairs at a 1:37382 scale when used with a two power Dietzgen mirror stereoscope, provide the best counts of stream number and order, and therefore, the most reliable bifurcation ratios. There is not as much distortion of scale across the photo as there is with the enlargements. However, this method of analysis must be confined to the laboratory, as it is

difficult to carry a mirror stereoscope and complete set of stereopairs in the field. Therefore, for convenience, the enlargements are good for rough fieldwork. By contrast, the most precise laboratory analysis of a basin is that undertaken with stereovisual scrutiny of air photographs.

6. Horton's first law of drainage composition is seen to apply, although constant bifurcation ratios were not found in the Schaeffer Creek analysis.

CHAPTER III

THE DERIVATION OF BIFURCATION RATIOS FOR PHYSIOGRAPHIC REGIONS OF MANITOBA

A. Introduction

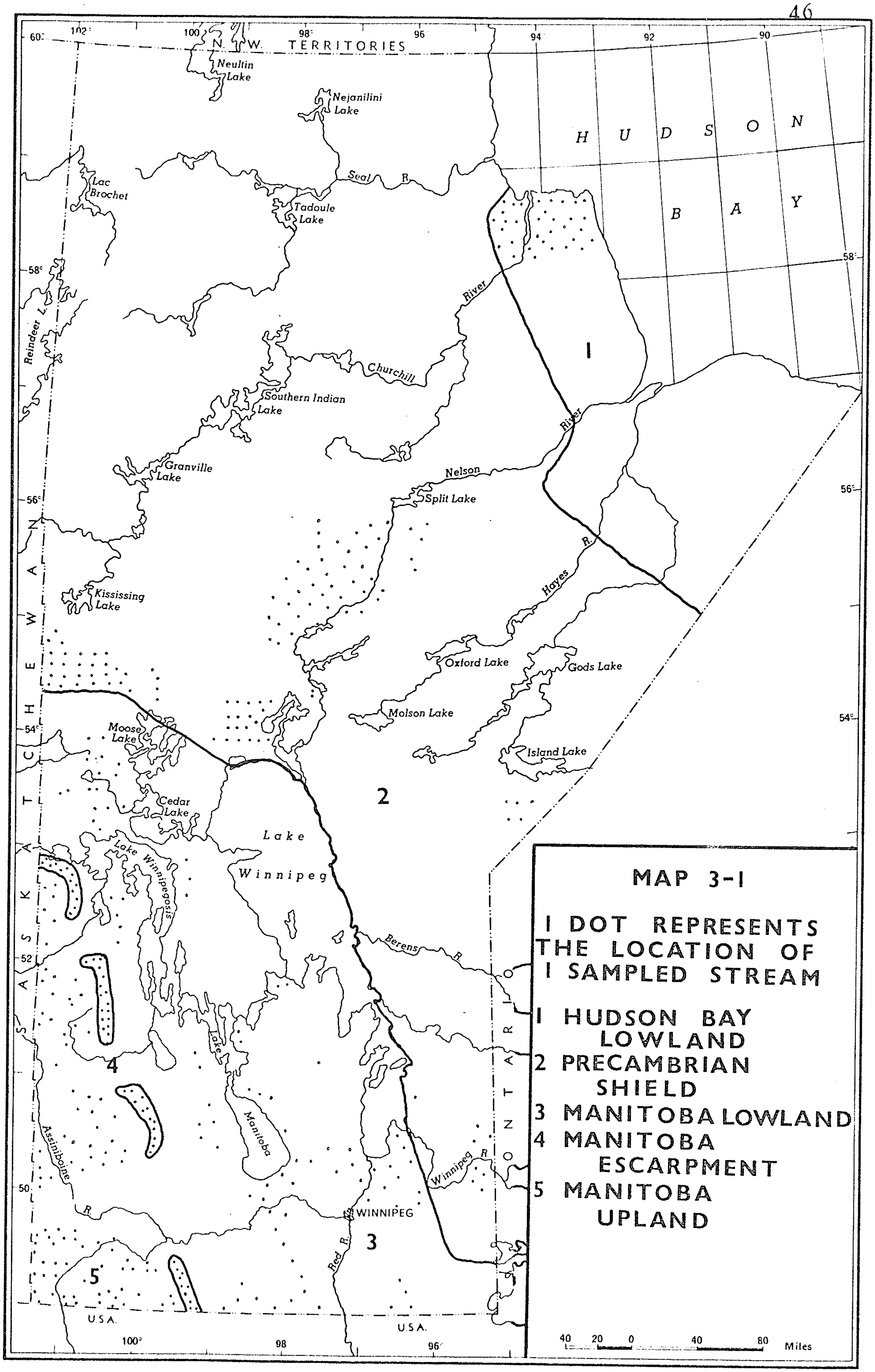
This chapter deals with the methods of analysis undertaken to obtain a mean bifurcation ratio for each physiographic region of Manitoba. These ratios were obtained by employing respectively maps with different scales. Initially, topographic maps at a scale of 1:50000 were employed for ratio derivation. However, as previously demonstrated, this mapping scale does not accurately depict a drainage basin, and the analysis was therefore used primarily as a preliminary study. As described in Chapter II, the most accurate representation of the drainage network of Scaeffer Creek basin was obtained by stereopairs method. Consequently, a more precise analysis of Manitoba networks is undertaken using stereopairs, with a mean scale of 1:24000, representing 20% of the drainage basins originally mapped at a scale of 1:50000. Unfortunately, the aerial photographic coverage of Manitoba was flown during different years, and scales of mapping vary. However, it was felt that, apart from actual field mapping, this method was still the best available to obtain bifurcation ratios.

When the derivation of mean bifurcation ratios for topographically and geologically dissimilar regions of Manitoba was first undertaken in the present study, it was decided that the province should be subdivided into four major physiographic regions; the Hudson Bay Lowland, the Precambrian Shield, the Manitoba Plain, and the Manitoba Upland, also known as the Manitoba Plateau. A detailed description of the physical characteristics of each physiographic region is not undertaken in the text; however, Appendix B, Table 1 presents properties of each region.

It was observed that the drainage networks on the steep eastern margins of the Manitoba Upland differ from those draining the top, in terms of segment lengths and numbers. Therefore, a subdivision was made between the Manitoba Escarpment and the Manitoba Upland, and mean bifurcation ratios derived for five regions within the province. The locations of the sampled streams within these five physiographic regions are shown on Map 3-1.

B. Procedures for the Derivation of Bifurcation Ratios for Physiographic Regions of Manitoba

For each physiographic region, the number of published topographic map sheets at a scale of 1:50000 was counted. Twenty percent of these map sheets were then randomly chosen, and the number of "usable" streams on each was ascertained. A usable stream is a stream which; 1) does not cross from one physiographic region into another, 2) has a drainage basin area depicted on less than two


N.W. TERRITORIES
HUDSON BAY
Neultin Lake
Nejanilini Lake
Lac Brochet
Seal R.
Tadoule Lake
Churchill River
Reindeer L.
Southern Indian Lake
Granville Lake
Nelson River
Split Lake
Kississing Lake
Hayes R.
Oxford Lake
Gods Lake
Molson Lake
Island Lake
Moose Lake
Cedar Lake
Lake Winnipeg
Lake Winnipegosis
Berens R.
Lake Manitoba
Assiniboine R.
Winnipeg R.
WINNIPEG
Red R.
SASKATCHEWAN
ONTARIO
U.S.A.
1
2
3
4
5
MAP 3-1
1 DOT REPRESENTS THE LOCATION OF 1 SAMPLED STREAM
1 HUDSON BAY LOWLAND
2 PRECAMBRIAN SHIELD
3 MANITOBA LOWLAND
4 MANITOBA ESCARPMENT
5 MANITOBA UPLAND
40 20 0 40 80 Miles

topographic sheets, 3) has a basin order of greater than one, 4) has not been canalized, 5) does not continue off the map sheet onto areas for which there are no topographic sheets.

After the number of usable streams on 20% of the 1:50000 topographic sheets had been obtained, this value was converted to yield an estimate of the total number of usable streams in the area mapped at this scale in that region.

By using a stratified random sample, 20% of the usable streams in each region were chosen. The network of each usable stream was then ordered and a mean bifurcation ratio calculated for its drainage basin. By summing these ratio values and dividing by the number of usable stream networks sampled, a mean bifurcation ratio for the physiographic region was obtained.

Calculation of the Mean Bifurcation Ratio for the Hudson Bay Lowland:

For the Manitoban portion of the Hudson Bay Lowlands there are 23 published topographic map sheets at a scale of 1:50000, which consequently cover only a small portion of the region. Approximately 20% of these sheets, i.e. five sheets, were chosen at random and the number of usable streams on each sheet was calculated. On these five sheets there were 36 usable streams, and therefore there are an estimated 165 usable streams on the 23 published map sheets. Thus, for a 20% sample of usable streams in the mapped part of the region, the mean bifurcation ratio of 33 networks had to be calculated.

One stream was randomly chosen from each of the 23 topographic sheets. To choose the remaining ten streams, ten sheets were selected systematically from the total of 23; one more stream was sampled from each of these. Thus, a stratified random sample, which is a well distributed sample of the entire area was obtained.

To sample a stream at random on a single topographic sheet, a grid was constructed consisting of one inch squares consecutively numbered from one to 264. By using a table of 10,000 random numbers and by employing the three middle digits in each column, a stream was randomly chosen. The grid, drawn on tracing paper, was superimposed on the map sheet and a number was randomly selected from the tables. If the selected number fell between one and 264 and if a usable stream channel fell within the chosen square, this stream was sampled. If a usable stream did not occur within this square, another number was not chosen. Instead, the square immediately to the right of that originally chosen was used. If no usable stream segment appeared in the latter square, successive squares on the grid were chosen by moving in a counterclockwise direction about the first chosen square in an ever widening circle until a suitable square was obtained.

By utilizing these sampling procedures, the mean bifurcation ratio for the Hudson Bay Lowland has been calculated to be 3.60 at a mapping scale of 1:50000. See Appendix B, Table2, for data and calculations.

The aforementioned procedures were employed to derive mean bifurcation ratios for the other physiographic regions of Manitoba. Numbers of published maps, usable stream counts, sample size and calculated bifurcation ratios are presented in Table 3-1.

A Case Study of Usable Stream Sampling Procedures and Bifurcation Ratio Derivation:

Topographic sheet 54L/ 15W (Knife Delta) has been chosen to illustrate the procedures of bifurcation ratio derivation. From the sheet, one stream was to be sampled, its network ordered and the basin bifurcation ratio calculated. The grid.of one inch squares was positioned on the 1:50000 map sheet. From the random numbers table, number 244 was randomly chosen; the respective grid square was observed to contain no usable stream segment. The square immediately to the right of the initially sampled one was found to contain a usable stream. The drainage network of the latter was ordered and the mean bifurcation ratio calculated. When ordering this sampled network several problems arose. Firstly, the stream was found to have its headwaters on the adjoining topographic sheet (54L/10W). It was therefore necessary to study both sheets. Problems of low relief, swamps, lakes and intermittent streams complicated the network ordering, hence the bifurcation ratio

DETERMINATION OF THE MEAN STRAHLER BIFURCATION RATIO FOR MANITOBA'S PHYSIOGRAPHIC REGIONS (I:50000 MAPPING SCALE)

PHYSIOGRAPHIC REGION	HUDSON BAY LOWLAND	SHIELD	MANITOBA PLAIN	MANITOBA ESCARPMENT	MANITOBA UPLAND
NUMBER OF PUBLISHED TOPOGRAPHIC SHEETS	23	69	I92	I6	79
% OF REGION COVERED BY I:50000 MAPS	I0	I0	95	I00	I00
NUMBER OF SHEETS RANDOMLY SAMPLED (20%)	5.	I5	39	3	I6
ESTIMATED TOTAL NUMBER OF USABLE STREAMS IN THE MAPPED PORTION OF THE REGION	I65	690	326	256	474
NUMBER OF USABLE STREAMS SAMPLED (IE.20% BY STRATIFIED RANDOM SAMPLE)	33	I38	67	5I	9I
MEAN BIFURCATION RATIO FOR USABLE STREAMS SAMPLED AND THEREFORE ESTIMATED BIFURCATION RATIO FOR THE REGION AT A MAPPING SCALE OF I:50000	3.60	3.40	3.60	3.46	3.I0
FOR STREAM NUMBERS, ORDERS, AND BIFURCATION RATIOS FOR SAMPLED STREAMS IN EACH PHYSIOGRAPHIC REGION SEE APPENDIX B, TABLE-	2	3	4	5	6

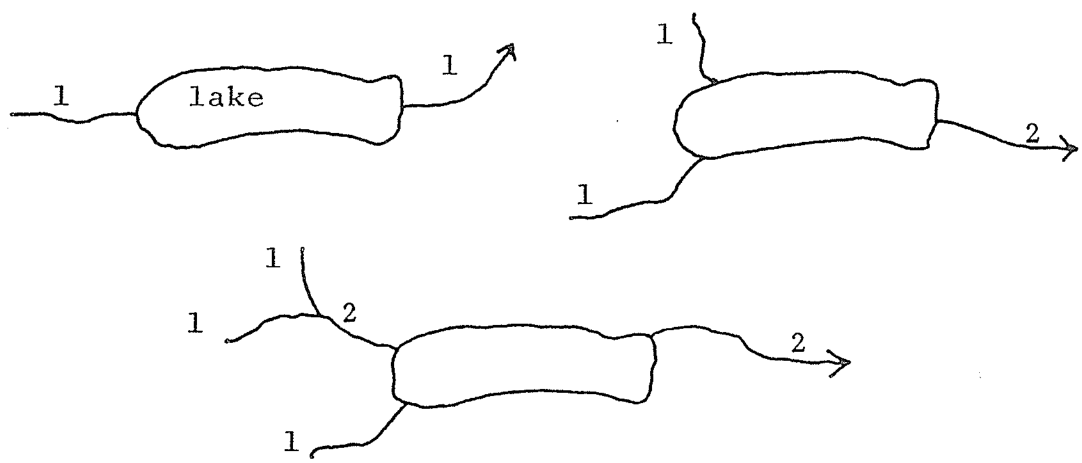
TABLE 3-I

derivation.

C. <u>Problems Encountered in Stream Network Sampling, Ordering, and Bifurcation Ratio Derivation</u>

While certain problems of drainage network ordering and bifurcation ratio calculation were unique to particular physiographic regions, some problems were characteristic of all regions. All regions exhibited, not infrequently, characteristics of intermittent stream flow, islands in the stream channel, streams flowing into lakes, and anastomosing streams.

If two or more streams flow into a small lake, whose outlet is by another stream segment, the orders of the respective inflowing streams determine the order of the outflowing one, as shown in Figure 3-1.



> shows direction of stream flow; numbers indicate segment order.

Figure 3-1

If a stream divides and then rejoins, the entire length of the braided section is considered to be only one stream segment.(Figure 3-2).

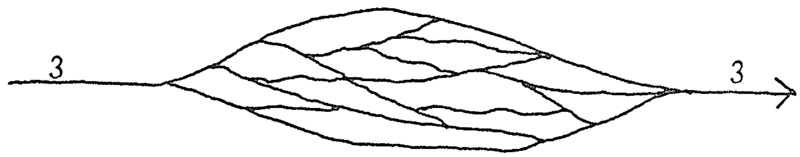


Figure 3-2

Other problems arose which were often characteristic of a specific physiographic region. In the Hudson Bay Lowland, the occurrence of many small lakes within a drainage network, the existence of extremely short stream segments linking lakes and higher order segments, and the general lack of usable streams with convenient basin areas all created stream sampling and ordering problems related to physiography. The availability of only 23 published topographic sheets may have seriously reduced the significance of the analysis since the sample size was too small as was the area studied.

Only ten percent of Manitoba's portion of the Precambrian Shield is represented on published 1:50000 topographic sheets. As with the Hudson Bay Lowland, the sample was too small and too spatially restricted within the Shield region. Other problems imposed by the limitations of topographic maps include the poor cartographic quality and visual effectiveness of provisional map sheets, as for example the camouflaging of intermittent drainage networks in marshland because of the similarity of symbols. From the physiographic aspect, deranged drainage and the abundance of lakes made stream ordering difficult.

Sampling problems for the Manitoba Plain arose due to the paucity of usable streams. Often map sheets which were to be sampled contained no integrated drainage networks. Because the Plain is very flat, many potentially usable streams have been canalized to alleviate drainage problems, thus disqualifying them from this study. Reservoirs, created by the damming of a stream segment were common in this region. These man-made obstructions precluded their associated stream networks from this study.

There is complete coverage of the Manitoba Upland region by published 1:50000 topographic maps. Unfortunately, knob and kettle topography, other glacial depositional landforms, and man-made reservoirs limited the availability of usable streams that could be sampled. Deranged and centripetal drainage networks of first order are common in this region, and they limit the availability of usable streams to be sampled. Occasionally, a randomly chosen topographic sheet had no usable drainage networks.

Streams were easiest to sample and order on the Manitoba Escarpment. The entire escarpment has complete coverage by 1:50000 topographic sheets. Because of appreciable gradients along the entire length of the escarpment, the sampled streams were well-defined. Some man-made dams and instances of canalization at the base of the escarpment caused minor problems in stream sampling, in that drainage networks exhibiting these characteristics were rejected from the sample.

D. The Effect of an Increased Mapping Scale on Bifurcation Ratio Values

Aerial photographs were obtained for 20% of the drainage basins previously studied at a scale of 1:50000 and whose maximum order, stream segment counts and bifurcation ratios had already been computed. As stated previously, a uniform scale of photography was not available for all the basins. Scales varied between 1:15840 and 1:60000. Southern Manitoba has photographic coverage primarily at a scale of 1:15840, whereas the Precambrian Shield portion of the province was mapped mainly at a scale of 1:36000 and the Hudson Bay Lowland at 1:60000.

Using a 2x Dietzgen mirror stereoscope, the stream networks were traced from the photographs and ordered, and new bifurcation ratios were derived. These values were compared with those derived from the same networks depicted on the 1:50000 topographic sheets. As was expected, total stream numbers, basin order and the calculated bifurcation ratio all increased with the employment of aerial photography. The difference in the mean bifurcation ratio for a given physiographic region when mapped by two different techniques was termed the bifurcation ratio 'correction factor'. Appendix B, Tables 7-11, show stream number and bifurcation ratio data based on stereoanalysis of airphotos, while Table 12 demonstrates the derivation of the bifurcation ratio correction factor and Table 13 illustrates the calculation of a new bifurcation ratio for each physiographic region.

Conclusions:

A comparitive analysis of the two previously discussed mapping techniques leads to the following conclusions.

1) The mapping technique utilizing stereoanalysis of airphotos is considered to be superior.

2) With the employment of stereopairs, stream numbers increased; this was especially evident with first order tributaries.

3) The aerial photograph mapping technique resulted in an increase in maximum basin order and mean bifurcation ratio for each physiographic region. However, because different scales of mapping were used, no consistent change in bifurcation ratio with increasing map scale could be calculated and only trends could be observed.

From the results obtained it may be concluded that when airphotos at a scale generally larger than the topographic maps are used along with a mirror stereoscope, the resulting bifurcation ratios are higher than the corresponding values derived from the map analysis. The topographic map-derived mean bifurcation ratios for different physiographic regions of Manitoba are considered as inaccurate.

For the five physiographic regions the corrected mean bifurcation ratio ranged between 3.55 and 4.51. The relief within the province ranges from flat to hilly. These values therefore differ significantly from Horton's stated typical bifurcation ratio values of 2.0 for flat lands and 4.0 for highly dissected or mountainous terrain, as found in New York State(Horton,1945,p.290). The fact that the virtually flat Hudson Bay Lowlands and Manitoba Plain have bifurcation ratios of 4.14 and 3.78 respectively, clearly illustrates this divergence. Unfortunately, Horton states only that measurements were made from U.S.G.S. maps and does not specify the scales used.

One conclusion Giusti and Schneider(1965) come to concerning bifurcation ratios is that they tend to be highly variable both within a basin and in comparison to other basins. Although they do not define the term "highly variable", bifurcation ratios for sub-basins within their study region varied between 2.0 and 11.0. This range in bifurcation ratios is much greater than that(2.8 to 6.1) of the sampled drainage basins in Manitoba; hence their theory of high variability in bifurcation ratios is not strongly substantiated in this study.

Several theories hold true for the bifurcation ratios calculated for Manitoba. Milton(1966) asserts that in a region where the network geometry develops without pronounced lithological or structural controls, bifurcation ratios are highly stable. This was found to apply in Manitoba, and is best exemplified by standard deviations of $\pm$ 0.357 and $\pm$1.192 for bifurcation ratios of stream networks on the Hudson Bay Lowland and Manitoba Plain respectively. Coates(1958) states that a minimum possible bifurcation ratio of two is seldom approached in nature;this hypothesis was found to be true as the tables of R_b derivation indicate and he asserts that bifurcation ratios lie mainly between three and five in basins without dominant geological controls. This is well exemplified by Manitoba Plain and Hudson Bay Lowland bifurcation ratio data. Coates declares that the bifurcation ratio only reaches higher values where geological controls favor the development of elongate, narrow basins; this appears to be the case in Manitoba. Several basins in the Precambrian Shield and Manitoba Escarpment regions had bifurcation ratios greater than five because their streams were either fault-controlled, or because pronounced gradients led to regular close spacing of near-parallel streams. The idea proposed by Eyles(1966) that there is a tendency for the bifurcation ratio to be inversely related to order within a drainage basin was substantiated in the findings of this research, with the Precambrian Shield region exhibiting the strongest relationship. (See Table 3-2).

Finally, Strahler(1957) states that the bifurcation ratio is highly stable and shows only a small range of variations from region to region, with the mean bifurcation ratio of an area being about 3.5. Bifurcation ratios for the five physiographic regions of Manitoba range between 3.55 and 4.51 with the weighted mean bifurcation ratio, based on a stereoanalysis, for the province being 3.84. A standard deviation of $\pm$ 0.301 was calculated for the mean bifurcation ratio values of Manitoba's physiographic regions. Because the bifurcation ratio is a dimensionless property and because drainage systems in homogeneous materials tend to display geometrical similarity, it is not surprising that the ratio shows only a relatively small variation from region to region.

TABLE 3-2 RELATIONSHIP BETWEEN THE BIFURCATION RATIO AND STREAM SEGMENT ORDER

PHYSIOGRAPHIC REGION	NUMBER OF SAMPLED STREAMS >2ND ORDER	NUMBER OF BASINS IN WHICH R_b IS INVERSELY RELATED TO ORDER	% OF TOTAL BASINS WITH DECREASING R_b WITH INCREASING ORDER
HUDSON BAY LOWLAND	25	14	56.0
SHIELD	64	45	70.3
MANITOBA PLAIN	35	23	65.7
ESCARPMENT	31	21	67.6
MANITOBA UPLAND	37	25	67.5

CHAPTER IV

THE RELATIONSHIP BETWEEN THE STRAHLER BIFURCATION RATIO AND WATER SURPLUS

A. Statistical Tests Employed

Statistical analysis of bifurcation ratio and water surplus data will be undertaken in this chapter employing correlation and regression techniques, analyses of variance tests, and the t-test. Following the description of the test results, conclusions pertaining to the relationship between the Strahler bifurcation ratio and water surplus are presented.

B. Methodology

Within the province of Manitoba, a group of drainage networks were selected for study, based on the criteria described below. Information pertaining to the size of drainage basins, periods of stream gauge record, and discharges in cubic feet per second(cfs), for streams and rivers in Manitoba is presented in a series of documents titled, Surface Water Drainage, Manitoba, published by the Department of Energy, Mines and Resources, Ottawa (1965-1971) and Surface Water Supply of Canada, Arctic and Western Hudson Bay Drainage (1925-1963), published by the Department of Northern

Affairs and Natural Resources. Stream networks with basins each of less than 10,000 square miles in area and contained, respectively, within one physiographic region, and possessing periods of record of five years or greater, with complete discharge records, were chosen from these publications for study. Although a five year gauging period is not considered entirely reliable for hydrologic analysis, it was deemed necessary in this study to accept this value in order to obviate employment of a much smaller sample size.

For each network the Strahler bifurcation ratio was derived. This procedure involved ordering the network as it appears on 1:50000 topographic maps and then adding the appropriate correction factor to each. It is felt that the addition of a correction factor to the bifurcation ratio obtained from 1:50000 topographic sheets, yields a ratio equivalent in precision to the value that would have been obtained from stereopairs, had they been used. The basin area, in acres, and the mean annual discharge in cfs., for the period of record for each of the basins were also derived. Thus, for each basin, by obtaining a mean annual discharge value, converting this to acre-feet, and dividing by the basin area (in acres), a water surplus value, in feet was obtained.

Eighty-six drainage networks were studied, having varying periods of record, bifurcation ratio values, basin areas, mean discharges, and therefore water surplus values. Also, 70% of the networks studied were located south of 51°N because the period of record for streams in northern Manitoba is often incomplete or of very short duration,(i.e. less than five years). Appendix C, Table 1 presents the locations of stream gauging stations, and water surplus and basin bifurcation ratio values of the drainage networks studied.

C. Results

To ascertain whether the Strahler bifurcation ratio, (the dependent variable), varies with water surplus,(the independent variable), a Pearson's r correlation test was executed. With n=86, two variables and therefore 84 degrees of freedom, the correlation value required for a 95% level of confidence is 0.211. Statistical analysis of the given data yielded a correlation coefficient of 0.041, hence showing a poor correlation between the Strahler bifurcation ratio and water surplus. The scatter of points on Figure 4-1 further illustrates this poor correlation.

By employing the values of a=3.887 and b=0.253,(as derived from the computer printout of the above correlation test) for the general equation y= a + bx, when the values of x are known, the best fit regression line was obtained for the scatter of data of bifurcation ratios and water surplus. From the slope of this line, b, it is evident that there is a slight tendency for the bifurcation ratio to increase as water surplus increases. However, there is definitely no strong relationship between the Strahler bifurcation ratio

THE STRAHLER BIFURCATION RATIO VERSUS WATER SURPLUS

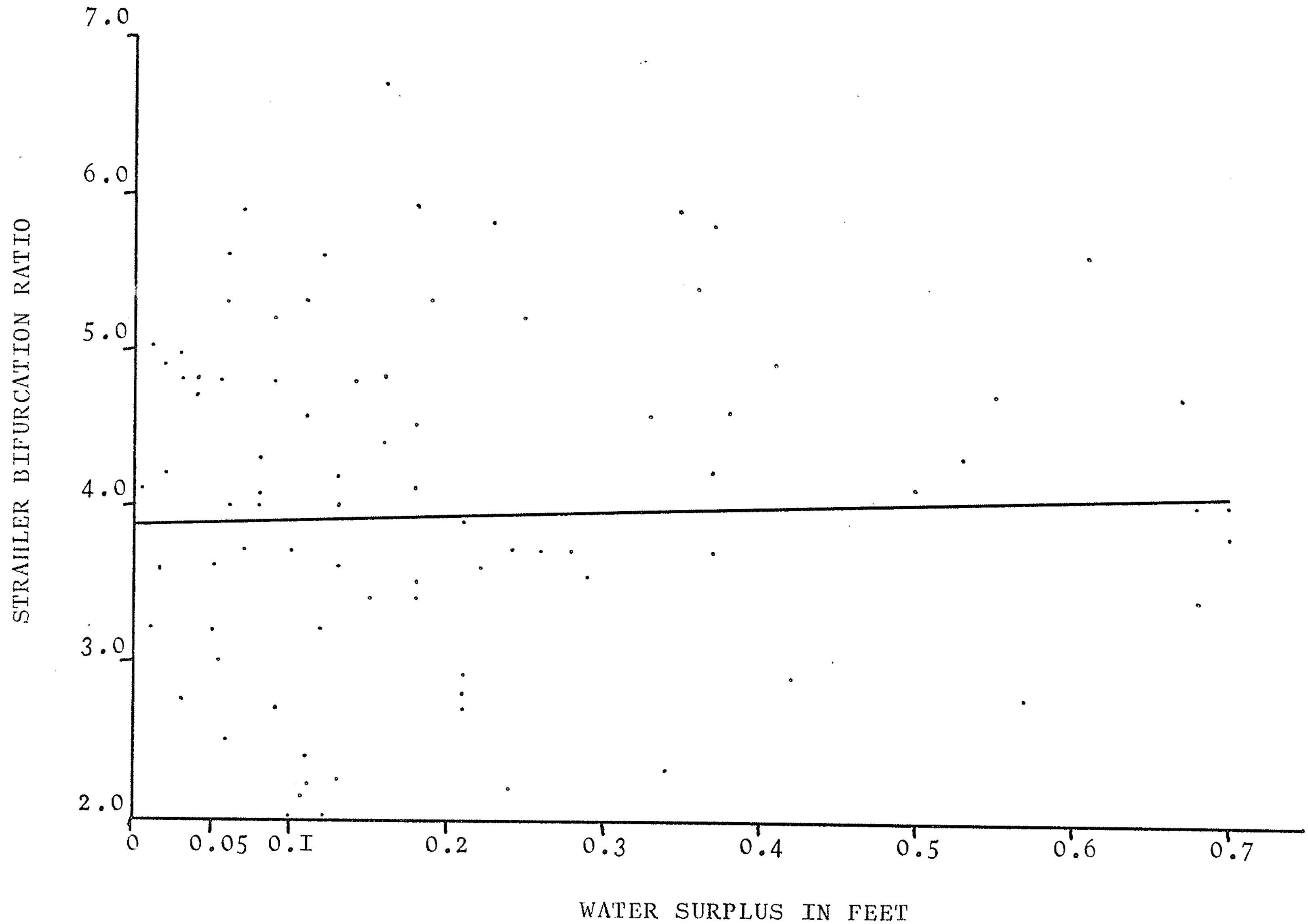


FIGURE 4-I

and water surplus.(See figure 4-1).

On the basis of a Student's t-test value of t=0.376, the ratio of explained variance to unexplained variance is large enough to warrant rejection of the null hypothesis that t=0 at the 95% level of confidence. In other words, there is no relationship between y, the mean bifurcation ratio, and x, water surplus.

To further substantiate the statistical demonstration that there is very little relationship between mean bifurcation ratio and water surplus, analysis of variance tests were conducted. Although 86 streams had originally been sampled, in this portion of the statistical analysis only the 80 networks south of 53^{o}N were utilized. This restriction was employed because of the unreliability of the climatic data north of this latitude(as manifest in the interpolated isohyets of Map 1, Appendix C).

Analysis of variance procedures may appear in a variety of forms. Basically however, the analysis of variance tests consist of a comparison of two independent estimates of the universe variance. If the difference between the two estimates is relatively small, it may be attributed to chance alone and the universe,(population), may be considered as homogeneous. On the other hand, if the difference is large enough to be considered statistically significant, the hypothesis that the two estimates refer to the same homogeneous universe, will be rejected. Accordingly, the sub-groups to which the estimated variances refer are considered to represent different universes. Within this study, the universe is represented by 80 networks in the province of Manitoba, while the sub-groups or different universes are based on the different physiographic regions.

Of the 80 Manitoban stream networks employed in this analysis, three are located in the Precambrian Shield, 28 on the Manitoba Plain, 16 on the Escarpment, and 33 on the Upland. The null hypothesis to be tested on the basis of these samples states that the four physiographic regions are homogeneous with respect to the Strahler bifurcation ratio. Appendix C, Table 2 presents this analysis of variance and illustrates that an observed F ratio of 0.3425 is obtained. Since $n_1 = 3$ and $n_2 = 76$, an F ratio as large or larger than 2.75 would occur by chance five percent of the time, or a value of 4.09 would occur by chance one percent of the time. Consequently, the smaller observed F ratio of 0.3425 would be expected to occur purely by chance even more frequently. Therefore, the hypothesis that the four physiographic regions are homogeneous with respect to bifurcation ratio cannot be rejected on the five percent or one percent significance levels on the basis of the sample evidence. The subgroups to which the estimated variance refer are considered to represent the same universe, that is, there may not be significant differences between mean bifurcation ratio values of the four physiographic regions. This statistical analysis further substantiates previous poor correlation and regression conclusions.

In conclusion, one final analysis is undertaken. It was deemed relevant to test the variance of water surplus values between different physiographic regions. The null hypothesis to be tested states that the four physiographic regions are homogeneous in respect to the average water surplus. If the four sub-universes are the same with respect to the measured characteristic, then the overall mean and the sub-universe means must be identical. Appendix C, Table 3 illustrates that by calculating variation among and within column means, an observed F ratio of 11.8134 is obtained. Since $n_1=3$ and $n_2=76$, a F ratio as large or larger than 4.09 would occur by chance one percent of the time. Consequently, the larger observed F ratio of 11.8134 would be expected to occur purely by chance even less frequently. Therefore, the hypothesis that the four physiographic regions are homogeneous with respect to water surplus can be rejected at the one percent significance level on the basis of the given sample evidence. Thus, the subgroups to which the estimated variances refer are considered to represent different universes.

D. Conclusions

Having proven that water surplus values between each of the four physiographic regions are statistically significantly different, the question arises as to why they differ? What factors cause the Precambrian Shield region of Manitoba to have a mean water surplus value of 0.5050 feet, while the Manitoba Plain, Escarpment, and Manitoba Upland regions exhibit mean water surplus values of 0.2210, 0.1833 and 0.1453 feet respectively? This question may be answered if precipitation, infiltration rate, physiography and surficial materials are considered.

Table 4-1 presents in absolute and percentage forms, frequency values of water surplus for each physiographic region, while Figure 4-2 presents this percentage data in histogram form. From the table it may be observed that the Precambrian Shield region has the highest water surplus values,(66% greater than 0.3500), while the Manitoba Upland has the lowest, with 75% of the values being equal to 0.1500 feet or less. The Manitoba Plain has 64% of its water surplus values between 0.0501 and 0.2500 feet with 36% of the values being greater than 0.2500 feet. The Escarpment has 69% of its water surplus values between 0.0501 and 0.2500 feet with only 25% of the values greater than 0.2500 feet.

Appendix C, Map 1 illustrates by means of isohyets, areas of similar mean annual precipitation in Manitoba. It may be observed that there is a general trend of increasing precipitation in a west to east direction. By interpolation from these isohyets for the area south of 53°N, mean annual precipitation values of 17.5 inches, 19.0 inches, 20.0 inches and 21.0 inches for the Upland, Escarpment, Manitoba Plain, and the Precambrian Shield of Manitoba respectively, have been

CUMULATIVE FREQUENCY OF WATER SURPLUS VALUES

WATER SURPLUS VALUE RANGE (IN FEET)	PRECAMBRIAN SHIELD			MANITOBA PLAIN			MANITOBA ESCARPMENT			MANITOBA UPLAND		
	NUMBER OF OBSERVATIONS	%	CUMUL. %	NUMBER OF OBSERVATIONS	%	CUMUL. %	NUMBER OF OBSERVATIONS	%	CUMUL. %	NUMBER OF OBSERVATIONS	%	CUMUL. %
A≡0.0-0.0I	0	0	0	0	0	0	0	0	0	2	6	6
B≡0.0I0I-0.05	0	0		0	0		I	6	6	I0	30	36
C≡0.050I-0.I0	0	0		4	I4	I4	4	25	3I	6	I8	54
D≡0.I00I-0.I5	0	0		5	I8	32	2	I3	44	7	2I	75
E≡0.I50I-0.20	0	0		4	I4	46	4	25	69	2	6	8I
F≡0.200I-0.25	I	33	33	5	I8	64	I	6	75	I	3	84
G≡0.250I-0.30	0	0		3	II	75	0	0		I	3	87
H≡0.300I-0.35	0	0		2	7	82	0	0		0	0	
I≡+0.35	2	66	99	5	I8	I00	4	25	I00	4	I2	99

TABLE 4-I

HISTOGRAMS - FREQUENCY IN % FOR WATER SURPLUS VALUES

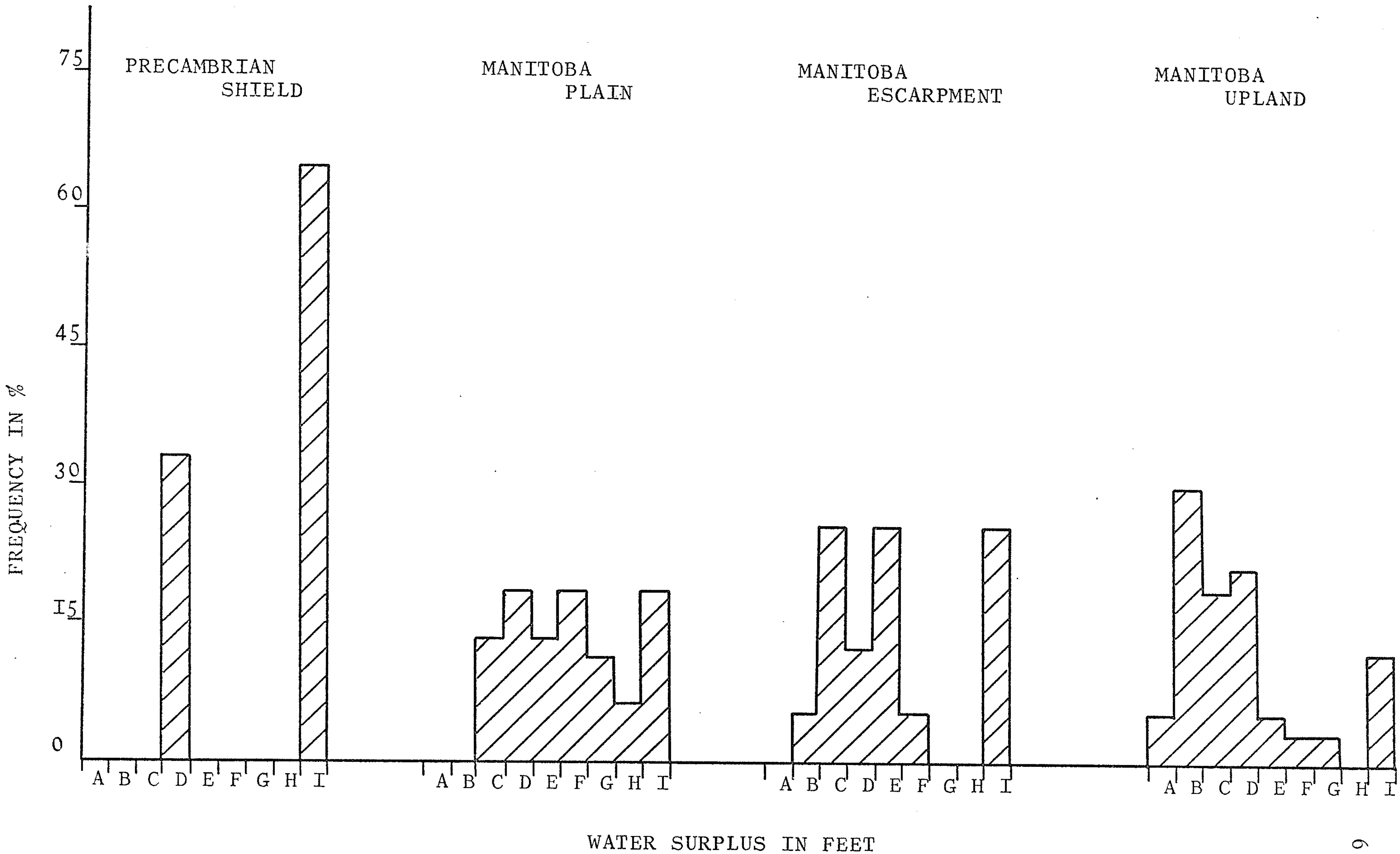


FIGURE 4-2

ascertained. Thus, it is apparent from these physiographic regions that, as mean annual precipitation increases, mean water surplus does likewise.

Obviously, it is meaningless to compare regions with different mean water surplus values, which also have different mean annual precipitation inputs. Therefore, dividing water surplus values(multiplied by 100) by the respective values of mean annual precipitation(in feet), yields a value of water output expressed as a proportion of input. In other words, a measure of the proportion of precipitation that becomes water surplus is derived and may be titled the 'surplus/input coefficient'. As Table 4-2 illustrates, the Precambrian Shield region has the highest surplus/input coefficient (28.85%), while the Manitoba Upland has the lowest(10.20%).

TABLE 4-2
SURPLUS/INPUT COEFFICIENTS

PHYSIOGRAPHIC REGION	MEAN ANNUAL PREC. IN INCHES	MEAN ANNUAL WATER SURPLUS (FEET)	SURPLUS/INPUT COEFFICIENT IN PERCENT
PRECAMBRIAN SHIELD	21.0	0.5050	28.85%
MANITOBA PLAIN	20.0	0.2210	13.32%
ESCARPMENT	19.0	0.1833	11.59%
UPLAND	17.5	0.1453	10.20%

The conclusions derived from Table 4-2 can be explained by considering several interdependent factors: precipitation, infiltration rate, capacity, physiography and surficial materials.

The Precambrian Shield of Southeastern Manitoba is a hilly bedrock and drift plain. Bogs and lakes cover 60% of the surface and yield a high depression storage value. This storage is a result of surface detentions in overland flow, and groundwater and channel storage. The flat to hilly Manitoba Upland has glacial, glaciofluvial and glaciolacustrine deposits. Kettle holes create centripetal drainage networks and depression storage is common. Although depression storage characteristics seem to be similar in the two regions, infiltration rates are not. Precipitation tends to infiltrate much more rapidly in the surficial deposits of the Upland than it does on the abundant rock outcropping of the Shield.

P.E.Packer(1953) notes that factors found to be exerting the most influence on infiltration capacity are total ground cover and maximum size of bare rock or soil openings. He concludes that in order to maximize infiltration capacity, ground cover density should be at least 70% with maximum size of bare openings being four inches or less. These factors characterize the Shield much less than the Upland.

In conclusion, infiltration rates are higher in the Manitoba Upland than in the Precambrian Shield region of Southern Manitoba; therefore, on the Upland there is less water surplus available for runoff. Therefore, the surplus/input coefficient(Table 4-2) is lower for the Manitoba Upland region.

The Manitoba Plain exhibits a higher mean water surplus value than does the Upland or Escarpment. While the Escarpment consists of thick Cretaceous shales with some limestones and bentonite, overlain by till and some glacio-lacustrine deposits in the form of localized beaches, the southern portion of the flat Manitoba Plain is characterized by calcareous glacial till, lacustrine clays, deltaic deposits and areas of muck and peat.

The type of bedrock which characterizes the Escarpment helps to explain the lower water surplus values, since much of the precipitation infiltrates (related to the high porosity and fissibility of shales), and becomes ground water storage or is involved in chemical reactions, particularily those involving clay minerals in the bentonite and shales. Also, the higher evapotranspiration rates associated with the heavier vegetation growth on the Escarpment (mixed woods and broadleaf forest versus the lightly treed grasslands of the Plain), along with the higher infiltration capacities of the region, related to the denser litter cover, yield lower water surplus values.

The overwhelming influence of litter cover in the maintenance of surficial soil conditions favourable to rapid infiltration is repeatedly stressed in the literature,and studies showing decreased infiltration rates with exposure of the bare mineral soil are numerous: [Lowdermilk(1930), Hendrickson(1934), Lunt(1937), Dunford(1954)]. Decreased surface porosity is caused by the destruction of soil structure due to raindrop impact. This splash impact breaks down soil aggregates, throws the soil into suspension and results in the clogging of soil insterstices. A thicker litter mat yields more organic matter, [an important cementing agent in the formation of large water -stable aggregates,(Browning,1937)] , on the Escarpment than on the Manitoba Plain, which in turn increases infiltration capacities and lowers water surplus values.

On the other hand, the extreme flatness of the Manitoba Plain and proximity to regional base level, along with the high clay content of the soils, overlying thick surficial clays, accounts for the higher water surplus values on the Plain. The clays possess low permeabilities and very low infiltration capacities. Much of the precipitation remains on the ground surface as water surplus. Moreover, the accumulation of less litter on the Plain and the compaction of soils by cattle also reduces infiltration capacities and increases water surplus.

In conclusion, water surplus appears to be directly related to the amount of water input, or precipitation, and inversely related to infiltration rate and capacity of the soils. Infiltration rate and capacity are directly dependent on the type of natural vegetation and surficial deposits found in a region. Finally, it has been statistically proven that although bifurcation ratios are not significantly different between physiographic regions, water surplus values do vary significantly. Moreover, statistical analysis has demonstrated that there is only a very slight tendency for the Strahler bifurcation ratio to increase with increasing water surplus and that there is definitely no strong relationship between these variables.

CHAPTER V

CONCLUSIONS

A. Summary and Conclusions

Summaries have been presented at the end of most sections of this thesis, and the present chapter will therefore only briefly survey the major findings of this research. Recommendations concerning further studies of bifurcation ratios will be presented at the end of this chapter.

The primary objective of this study was to establish whether or not a meaningful statistical relationship exists between the Strahler bifurcation ratio of a drainage network and the corresponding water surplus value. Several secondary studies were also undertaken. The term 'water surplus' was defined and presented as a mathematical equation; the effects of various mapping scales on basin order, stream numbers, and bifurcation ratio values were analysed in the Schaeffer Creek study; and mean bifurcation ratios for physiographic regions in Manitoba were calculated.

As described by Strahler, the bifurcation ratio is the ratio of the average number of branchings or bifurcations of streams of a given order to that of streams of the next higher order. Strahler states that his ordering method and determination of the bifurcation ratio never produces a value of less than 2.0 and usually gives a mean value of 3.5 for a given drainage network. In this thesis, Strahler bifurcation ratio values ranged between 2.9 and 6.1 when aerial photography was employed.

Water surplus is defined in this thesis as average depth of water at the ground surface in a drainage basin, and is expressed in terms of the following equation:

$$WS = \frac{Qd}{Aa} \qquad (6)$$

Thus, for a given drainage network, by obtaining a mean annual discharge value, converting this to acre-feet, and dividing by the basin area in acres, a water surplus value in feet is obtained.

Chapter two described the morphometric analysis of Schaeffer Creek, a small drainage basin (9.76 square miles), located in southwestern Alberta. From this study it is concluded that cartographic representation of features and scale are important determinants of the accuracy of morphometric analysis from topographic maps and air photos. Basic morphometric characteristics of the basin were derived and it was observed that as mapping scale varied, so did basin area, basin perimeter, stream segment number, and basin order.

A mapping scale of 1:50000 using blue lines representing the drainage network is not satisfactory for calculation of stream segment number, maximum basin order or bifurcation ratio of a basin. Employment of contour crenulations are more accurate, but still do not satisfactorily depict the drainage network. Utilizing aerial photography at mean scales of 1:37382 and 1:13306 produced higher stream counts than do the previous methods. However, stereovisual analysis of 1:37382 aerial photographs, provided the best counts of stream numbers and therefore the most accurate bifurcation ratio. In conclusion, Horton's first law of drainage composition applies in this study although constant bifurcation ratio values were not found in the Schaeffer Creek analysis.

Subsequent to the study of the control of mapping scales on bifurcation ratios, an attempt was made to derive a mean bifurcation ratio for each physiographic region in Manitoba. For this study, two mapping methods were employed and their results compared. Firstly, 1:50000 topographic maps were utilized in a preliminary study. As had been demonstrated earlier, the most accurate representation of a drainage network is obtained by the stereovisual analysis of air photos. Hence, the latter technique was used to derive bifurcation ratio values and a stratified random sampling procedure was used to calculate the mean bifurcation ratio value for each physiographic region.

Analyses of the two mapping techniques led to the following conclusions:

1) For the five physiographic regions the mean bifurcation ratios ranged between 3.55 and 4.51. The Manitoba Upland, Escarpment, Manitoba Plain,Precambrian Shield and Hudson Bay Lowland region exhibited mean bifurcation ratios values of 3.86, 4.51, 3.78, 3.55, and 4.14 respectively.

Thus, there is no simple relationship between slope and bifurcation ratio values as Horton(1945,p.290) felt existed.

2) Bifurcation ratio values are not considered to be highly variable in the province of Manitoba. They are considered to be stable where the network geometry develops without pronounced lithological and structural controls.

3) A bifurcation ratio of less than three was rarely calculated when stereovisual analyses of airphotos was employed. Values lay primarily between three and five in basins without dominant geological controls. Several basins on the Escarpment and Precambrian Shield region had values greater than five because their streams were either fault-controlled or because pronounced gradients led to regular close spacing of near-parallel streams.

In the fourth chapter, a statistical analysis of bifurcation data for 86 selected drainage networks in Manitoba was undertaken. A number of basins in each physiographic region were chosen, with the determinants being the availability of discharge data, an adequate period of stream gauge record, and appropriate basin area. After calculating the mean Strahler bifurcation ratio and water surplus value for each drainage basin, statistical tests were executed. A Pearson's r correlation test yielded a correlation coefficient of 0.041, hence showing a poor correlation between the Strahler bifurcation ratio and water surplus. Regression analyses of the data demonstrated that there is definitely no strong relationship between the Strahler bifurcation ratio and water surolus. A Student's t-test corroborated this finding.

To substantiate the previous results, analysis of variance tests were conducted on the bifurcation ratio and water surplus data. It was proven that at the five percent significance level, the physiographic regions of Manitoba are homogeneous with respect to the Strahler bifurcation ratio, on the basis of the given sample evidence. Moreover, one final analysis proved that between physiographic regions, water surplus values were statistically different at the one percent significance level, on the basis of the given sample evidence. Water surplus values of 0.5050 feet, 0.2210 feet, 0.1833 feet and 0.1453 feet were obtained for the Precambrian Shield, Manitoba Plain, Escarpment, and Upland regions respectively. Variations in these water surplus values can be explained in terms of the interdependent variables of infiltration rate and capacity, mean annual precipitation, surficial materials, and physiography.

In conclusion, it has been statistically demonstrated that no strong relationship exists between the Strahler bifurcation ratio and water surplus within the limited range of the regions sampled. In turn, the water surplus value of a drainage basin appears to be directly related to the amount of water input and inversely related to the infiltration rate and capacity of the surficial materials.

B. Further Recommendations

Further research on the bifurcation ratio may be oriented along other lines. It has been demonstrated that water surplus does not influence the topologic structure of a drainage network, and hence the Strahler bifurcation ratio. However, it is possible that water surplus values may show a better correlation with bifurcation ratios based on other methods of stream ordering than Strahler's.

Possibly the development of the topologic structure of a drainage network and hence the bifurcation ratio is entirely random, as some geomorphologists believe. On the other hand, although it has been demonstrated that water surplus does not influence the bifurcation ratio value, other variables may. Are basin slope, natural vegetation cover, precipitation and bedrock geology all important factors in determining the basin bifurcation ratio, or is one of these variables of prime importance? It has been proven that the sampled bifurcation ratios of Manitoba are not statistically different, yet the physiographic regions are very distinct. Why then are bifurcation ratios not more varied than they are shown to be in this study? Do mean bifurcation ratio values always range between 3.0 and 5.0 unless structurally controlled? Would an increased sample size (i.e. greater than 86), or a different mapping scale show a greater variance in the mean bifurcation ratio values of a region? These questions may provide the impetus for further research related to the study of bifurcation ratios in Manitoba.

BIBLIOGRAPHY

Ashwell, I. 1971. "Chinook - snow eater from the Rockies." The Geographical Magazine, v.43 no.12 pp.858-64.

Browning, G.M. 1937. "Changes in the erodibility of soil brought about by the application of organic matter." Proceeding of the Soil Science Society of America, v.2 pp.85-96.

Chow, V.T. 1964. "Runoff". Section 14 in Handbook of Applied Hydrology, McGraw-Hill, New York.

Chow, V.T. 1964. Handbook of Applied Hydrology, McGraw-Hill, New York.

Coates, D.R. 1958. "Quantitative geomorphology of small drainage basins of southern Indiana." Office of Naval Research, Project NR 389-042, Technical Report, 10.

Department of Energy, Mines and Resources, 1971. Surface Water Data, Manitoba, Inland Waters Branch, Ottawa, Canada.

Dunford, E. 1954. "Surface runoff and erosion from pine grasslands of the Colorado Front Range." Journal of Forestry, v.52, pp.923-927.

Eyles, R.J. 1966. "Streams representation on Malayan maps." Journal of Tropical Geography, v.22, pp.1-9.

__________ 1968. "Stream net ratios in west Malaya." Bulletin of the Geological Society of America, v.79, pp.701-712.

Giusti, E. and W. Schneider. 1965. "The distribution of branches in river networks." United States Geological Survey, Professional Paper, 422-G.

Gravelius, H. 1914. Flusskunde, Berlin: Goschen'sche Verlagshandlung, cited by J.C. Maxwell, "Quantitative geomorphology of some mountain watersheds of southern California." pp.108-226 in Quantitative Geography Part II Physical and Cartographic Topics. Garrison and Marble, Northwestern University Studies in Geography, 1967.

Haggett, P. and R.J. Chorley, 1969. Network Analysis in Geography, London: Arnold, 348 pp.

Hendrickson, B. 1934. "The choking of pore-space in the soil and its relation to runoff and erosion." Transactions of the American Geophysical Union, v.15, pp. 500-505.

Horton, R.E. 1932. "Drainage basin characteristics." Transactions of the American Geophysical Union, v.13, pp.350-361.

____________ 1945. "Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology." Bulletin of the Geological Society of America, v.56,pp.275-370.

Laycock, A.H. 1967. Water Deficiency and Surplus Patterns in the Prairie Provinces, Report No. 13, Prairie Provinces Water Board, Hydrology Division, P.F.R.A., Regina.

Lowdermilk, W.C. 1930. "Influence of forest litter on runoff, percolation and erosion." Journal of Forestry, v.28,pp.474-491.

Lunt, H.A. 1937. "The effect of forest litter removal upon the structure of the mineral soil." Journal of Forestry, v.35, pp.33-36.

Mather, J. 1959. "The moisture balance in grassland climatology in grasslands." American Association for the Advancement of Science, pp.251-261.

Maxwell, J.C. 1955. "The bifurcation ratio in Horton's law of stream numbers." Transactions of the American Geophysical Union, v.36, pp.520-521.

____________ 1960. "Quantitative geomorphology of the San Dimas experimental forest, California." Office of Naval Research, Geography Branch, Project NR 389-042, Technical Report, 19.

____________ 1967. "Quantitative geomorphology of some mountain chaparrel watersheds of southern California." Quantitative Geography: Part II, Physical and Cartographic Topics, Garrison and Marble, Northwestern Studies in Geography, No. 14.

Melton, M.A. 1957. "An analysis of the relations among elements of climate, surface properties, and geomorphology." Office of Naval Research, Geography Branch, Project NR 389-042, Technical Report,11.

Milton, L.E. 1965. "Quantitative expression of drainage net patterns." Australian Journal of Science, v.27, no.8.

___________ 1966. "The geomorphic irrelevance of some drainage net laws." Australian Geographical Studies, v.4, pp.89-95.

Morisawa, M.E. 1957. "Accuracy of determination of stream lengths from topographic maps." Transactions of the American Geophysical Union, v.38, pp.86-88.

Ongley, E.D. 1968B. "Towards a precise definition of drainage basin axis." Australian Geographical Studies, v.6, pp.84-88.

Packer, P.E. 1953. "Effects of trampling disturbance on watershed condition, runoff, and erosion." Journal of Forestry, v.51, pp.28-31.

Scheidegger, A.E. 1966A. "Effect of map scale on stream orders." Bulletin of the International Association of Scientific Hydrology, v. 11, no.3.pp.56-61.

Schumm, S.A. 1956. "The evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey." Bulletin of the Geological Society of America, v.67, pp.597-646.

Shreve, R.L. 1964. "Analysis of Horton's law of stream numbers." (Abstract). Transactions of the American Geophysical Union, v.45, pp.50-51.

___________ 1966. "Statistical law of stream numbers." Journal of Geology, v. 74, pp.17-37.

___________ 1967. "Infinite topologically random channel networks." Journal of Geology, v.75, pp.178-186.

Strahler, A.N. 1952."Hypsometric (area-altitude) analysis of erosional topography." Bulletin of the Geological Society of America, v.63, pp.1117-1142.

___________ 1957. "Quantitative analysis of watershed geomorphology." Transactions of the American Geophysical Union, v.38, pp.913-920.

___________ 1964. "Quantitative geomorphology of drainage basins and channel networks." Section 4-II in Handbook of Applied Hydrology, V.T. Chow, McGraw-Hill, New York.

___________ 1965. Introduction to Physical Geography, John Wiley and Sons, New York.

Water Resources Branch, 1963. Surface Water Drainage of Canada, Arctic and Western Hudson Bay Drainage, 1925 - 1963, Water Resources Papers, Department of Northern Affairs and National Resources, Ottawa.

ADDITIONAL REFERENCES

Betson, R. 1964. "What is watershed runoff?" Journal of Geophysical Research, v.69, no.8, pp.1541-1552.

Bones, J. and D. Ford, 1971. "Simulating the development of river drainage networks." The Canadian Geographer, v.15, no.3.

Bostock, H. 1964. "A provisional physiographic map of Canada." Geological Society of Canada, Professional Paper, 64-35.

Bowden, K. and J. Wallis, 1964. "Effect of stream ordering technique on Horton's laws of drainage composition." Geological Society of America Bulletin, v.75, pp.767-776.

Branson, E. and J. Owen, 1970. "Plant cover, runoff, and sediment yield relationships on Mancos shale in western Colorado." Water Resources Research, v.6,no.3.

Bruce, J. and R. Clark, 1966. Introduction to Hydrometeorology, Pergamon Press, Oxford.

Chorley, R. 1957B. "Climate and morphometry." Journal of Geology, v.65,pp.628-668.

___________ 1962. "Geomorphology and general systems theory." United States Geological Survey, Professional Paper, 500-B.

___________ and P. Haggett, 1967. Models in Geography. London.

Clarke, J. 1966. "Morphometry from maps." Essays in Geomorphology, Dury: london.

Coffman, D. and A. Turner, 1971. "Computer determination of the geometry and topology of stream networks." Water Resources Research, v.7, no. 2.

Dury, G H. 1966. Essays in Geomorphology, London.

Foster, E. 1949. Rainfall and Runoff, New York.

Glock, W. 1931. "The development of drainage systems: a synoptic view." Geographical Review, v.21, pp.475-482.

Gray, D. 1961. "Interrelationships of watershed characteristics." Journal of Geophysical Research, v.66, pp.1215-1223.

Gregory, K. 1966. "Dry valleys and the composition of the drainage net." Journal of Hydrology, v.4, pp.327-340.

Hare, F. 1966. The Restless Atmosphere, Harper and Row, New York.

Howard, A. 1967. "Drainage analysis in geologic interpretation: a summation." Bulletin of the American Association of Petroleum Geologists, v.51, pp.2246-2259.

Howe, R. 1960. "The application of aerial photographic investigation to hydrologic problems." Photogrammetric Engineering, v.26, pp.85-95.

Johnson, D. 1933. "Development of drainage systems and the dynamic cycle." Geographical Review, v.23, pp.114-121.

King, L. 1969. Statistical Models in Geography, Prentice-Hall, New Jersey.

Kirkby, M. and R. Chorley, 1967. "Throughflow, overland flow and erosion." Bulletin of the International Association of Scientific Hydrology, v.12, no.3, pp.5-21.

Krumbein, W. and F. Graybill, 1965. An Introduction to Statistical Models in Geography, McGraw-Hill, New York.

Langbein, W. 1947. "Topographic characteristics of drainage basins." United States Geological Survey Water Supply Paper, 968-C, pp.125-157.

Leopold, L. and W. Langbein, 1962. "The concept of entropy in landscape evolution." United States Geological Survey, Professional Paper, 500-A.

__________ and M. Wolman, 1957. "River channel patterns: braided, meandering and straight." United States Geological Survey, Professional Paper, 282-B, pp.39-85.

__________, __________, and J.Miller, 1964. Fluvial Processes in Geomorphology, Freeman, San Francisco.

Linsley, R. 1967. "The relation between rainfall and runoff." Journal of Hydrology, v.5, pp.297-311.

MacKay, D. 1966. "Characteristics of river discharge and runoff in Canada." Geographical Bulletin, v.8, no.3, pp.219-227.

Mackin, J. 1948. "Concept of the graded river." Bulletin of the Geological Society of America, v.59, pp.463-512.

Mayer, H. 1970. "On the hierarchical structure of natural drainage systems." Water Resources Research, v.6, no.1, pp.303-309.

McKay, G. 1960. "Climatic maps of the prairie provinces for agriculture." Climatological Studies Number I, Department of Transport, Meteorlogical Branch.

Melton, M. 1958A. "Geometric properties of mature drainage systems and their representation in an E4 phase space." Journal of Geology, v.66, pp.25-54.

__________ 1958B. "Correlation structure of morphometric properties of drainage systems and their controlling agents." Journal of Geology, v.66, pp.442-460.

__________ 1959. "A derivation of Strahler's channel ordering system." Journal of Geology, v.67, pp.345-346.

Milton, L. 1967. "An analysis of the laws of drainage net composition." Bulletin of the International Association of Scientific Hydrology, v.13, pp.4-12.

Morisawa, M.E. 1959. "Relation of quantitative geomorphology to stream flow in representative watersheds of the Appalachian Plateau province." Office of Naval Research, Geography Branch, Project NR 389-042, Technical Report 20.

__________ 1964. "Development of drainage systems on an upraised lake floor." American Journal of Science, v.282, pp.340-354.

__________ 1968. Streams: Their Dynamics and Morphology. New York.

Ogrosky, H. and V. Mackus, 1964. "Hydrology of agricultural lands." Handbook of Applied Hydrology, V.T. Chow, New York: McGraw - Hill.

Potter, W. 1953. "Rainfall and topographic factors that affect runoff." Transactions of the American Geophysical Union, v.34, pp.67-73.

Rains, R. 1969. Some Aspects of the Fluvial Geomorphology of the Whitehead Basin, Central Alberta, Phd. dissertation, Department of Geography, University of Alberta.

Rango, A. 1970. "Possible effects of precipitation modification on stream channel geometry and sediment yield." Water Resources Research, v.6, no.6.

Scheidegger, A.E. 1965. "The algebra of stream order numbers." United States Geological Survey, Professional Paper, 525-B.

____________ 1966B. "Stochastic branching processes and the law of stream orders." Water Resources Research, v.2, pp.199-203.

____________ 1967A. "On the topology of river nets." Water Resources Research, v.3, pp.103-106.

____________ 1968B. "Horton's law of stream numbers." Water Resources Research, v.4, pp.655-658.

____________ 1968C. "Horton's laws of stream lengths and drainage areas." Water Resources Research, v.4, pp.1015-1021.

____________ 1970. "On the theory of evolution of river nets." Bulletin of the International Association of Scientific Hydrology, v.15, no.1, pp.109-114.

____________ 1970. "Dependence of stream link lengths and drainage areas on stream order." Water Resources Research, v.6, no.1.

Schenck, H. 1963. "Simulation of the evolution of drainage basin networks with a digital computer." Journal of Geophysical Research, v.68, pp.5734-5745.

Schneider, W. 1961. "A note on the accuracy of drainage densities computed from topographic maps." Journal of Geophysical Research, v.66.

Schumm, S. and R.Lichty, 1965. "Time, space, and causality in geomorphology." American Journal of Science, v.263, pp.110-119.

Sebert, L. 1970. Every Square Inch, The Story of Canadian Topographic Mapping, The Department of Energy, Mines and Resources, Ottawa, Canada

Seginer, I. 1969. "Random walk and random roughness models of drainage networks." Water Resources Research, v.5, no.3, pp.591-607.

Selby, S. 1964. Standard Mathematical Tables, 14 th edition, The Chemical Rubber Company, Ohio.

Sharp, W. 1970. "Stream order as a measure of sample source uncertainty." Water Resources Research, v.6, no.3.

Sherman, L. 1932. "The relation of hydrographs of runoff to size and character of drainage basins." Transactions of the American Geophysical Union, v.13, pp.332-339.

Smart, J. 1970. "Use of topologic information in processing data for channel networks." Water Resources Research, v.6,no.3.

Smith, H. 1942. "Aerial photographs in geomorphic studies." Photogrammetric Engineering, v.8, pp.129-155.

Strahler, A.N. 1953. "Revisions of Horton's quantitative factors.in erosional terrain." (Abstract). Transactions of the American Geophysical Union, v.34.

Tator, B. 1958. "The aerial photograph and applied geomorphology." Photogrammetric Engineering, v.24, pp.549-561.

Woldenberg, M. 1966. "Horton's laws justified in terms of allometric growth and steady state in open systems." Bulletin of the Geological Society of America, v.77, pp.431-434.

_____________ 1967. "Geography and properties of surfaces." Harvard Papers in Theoretical Geography, v.1, pp.95-189, cited in Network Analysis in Geography, p.15, Haggett and Chorley, London: Arnold.

APPENDIX A.

SCHAEFFER CREEK MORPHOMETRIC DATA

I. BASIN AREA DETERMINATION

A polar planimeter was employed to determine drainage basin area. The planimetric conversion factor was derived by measuring a four square mile area of the 1:50000 topographic sheet. Three trial runs were taken from a fixed point and a mean of 110.5 planimeter units per square mile was obtained. For the three planimeter measures taken, there was a range of only three planimeter units for the calculated basin areas.

The topographic map drainage area was calculated as 10.15 square miles using two sets of three measurements, that is, with the planimeter pivot in two defferent positions. For the six trial runs taken, basin area values differed only by three planimeter units.

The area of the basin, as modified from 1:37382 air photo interpretation of the position of the drainage divide, was then determined from three trial runs with the planimeter pivot fixed. A basin area of 9.76 square miles was obtained. For the three trial runs taken, basin area values differed only by three planimeter units.

II. BASIN PERIMETER DETERMINATION

The basin perimeter was ascertained using the opisometer on the 1:37382 airphoto corrected map of the basin. Three trial runs were made and although it is difficult to assess the operator error involved, this would probably be minimal since the basin divide is not tortuous. In fact, the closeness of the three readings suggests them to be reliable.

TABLE 1 BASIN PERIMETER

OPISOMETER READING	MEAN LENGTH IN INCHES	MEAN LENGTH IN MILES
22.8		
22.9	22.9	18.07
23.1		

OTHER MORPHOMETRIC CHARACTERISTICS OF SCHAEFFER CREEK

III. STREAM LENGTHS

All stream segments of order greater than one were measured by opisometer using the map representing the drainage network as it appears with stereovision, (scale 1:37382). Fingertip tributaries were measured with a pair of dividers since it was felt that the error resulting from measuring 278 short stream segments with an opisometer would be greater than by this method. (See Table 2).

A similar study was undertaken utilizing the map representing the drainage network as it appears on the airphoto enlargements. (See Table 3).

Analysis of the two tables shows that for the same drainage basin mapped at two different scales, large inequalities arise. Total length values are generally higher for the 1:37382 stereopairs than for the aerial photographic enlargements. Because total stream counts are much less than with the stereopairs, along with a greater distortion of lengths on the photos, it is

TABLE 2 STREAM LENGTHS AS CALCULATED FROM AIR PHOTOS WITH STEREOVISION (SCALE 1:37382)

STREAM ORDER	TOTAL STREAM LENGTH (INCHES)	TOTAL STREAM LENGTH (MILES)	STREAM NUMBER	MEAN LENGTH (MILES)	LENGTH RATIO	CUMULATIVE MEAN LENGTH
1	71.50	34.18	278	0.123	---	0.123
2	31.37	14.99	74	0.203	1.65	0.326
3	19.97	9.55	20	0.478	2.35	0.804
4	6.67	3.19	5	0.638	1.33	1.442
5	10.30	4.92	1	4.920	7.71	6.362

TABLE 3 STREAM LENGTHS AS CALCULATED FROM AIR PHOTO ENLARGEMENTS (SCALE 1:13306)

STREAM ORDER	TOTAL STREAM LENGTH (INCHES)	TOTAL STREAM LENGTH (MILES)	STREAM NUMBER	MEAN LENGTH (MILES)	LENGTH RATIO	CUMULATIVE MEAN LENGTH
1	112.2	23.56	211	0.11	---	0.11
2	58.5	12.28	50	0.24	2.18	0.35
3	25.2	5.29	14	0.37	1.54	0.72
4	18.6	3.90	3	1.30	3.51	2.02
5	17.2	3.61	1	3.61	2.77	5.63

felt that these relative inadequacies greatly restrict the more precise calculation of mean and total stream length by the 1:13306 airphotos.

Graph 1 illustrates that the general relationship of total stream length to order forms an inverse geometric series. (See Graph 1).

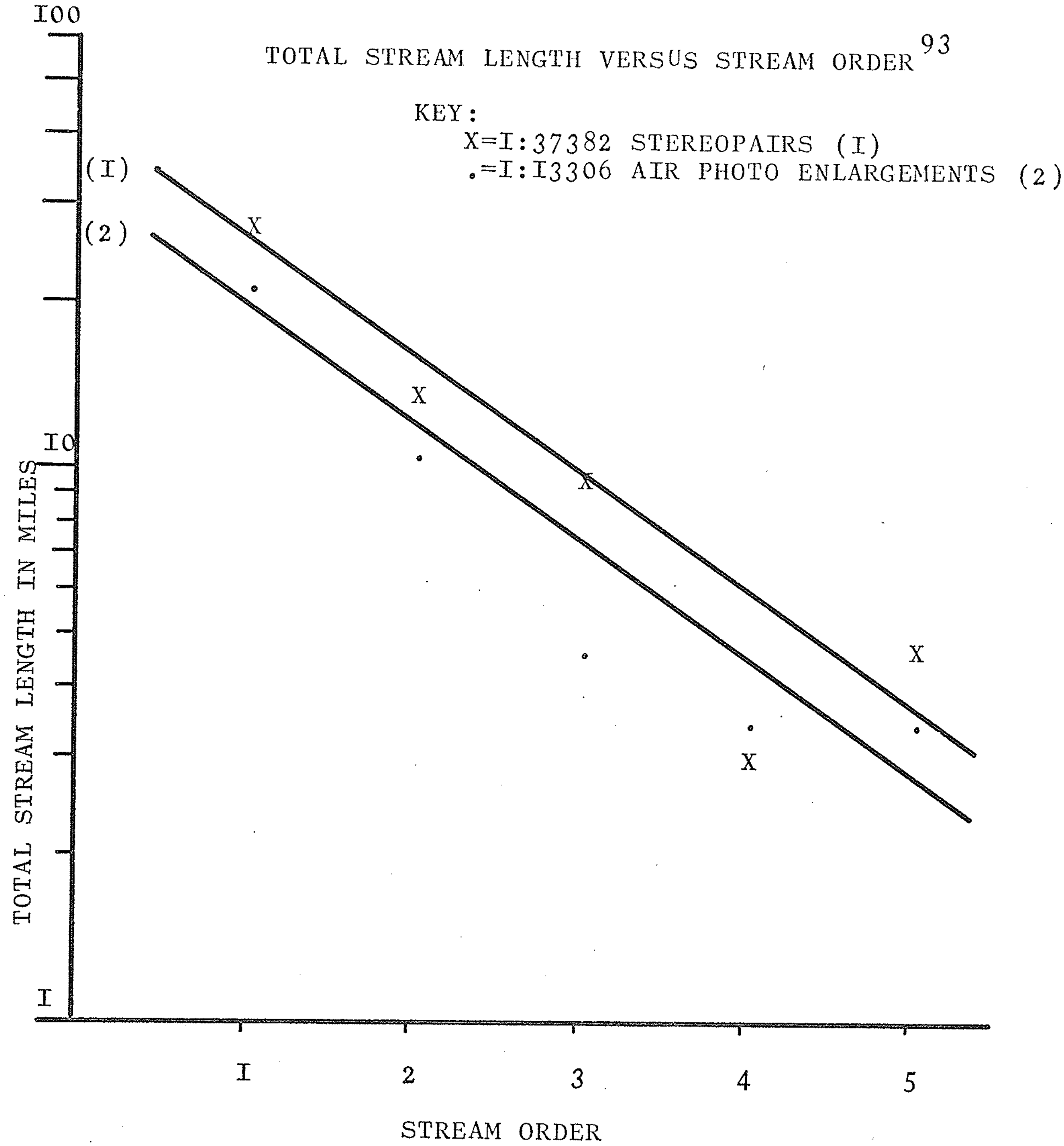
IV. DRAINAGE DENSITY

Drainage density is a measure of the degree of dissection of a drainage basin and is the ratio of the total length of all stream segments to the basin area. Table 4 shows calculated drainage density values for the Schaeffer Creek basin for the five previously described mapping methods.

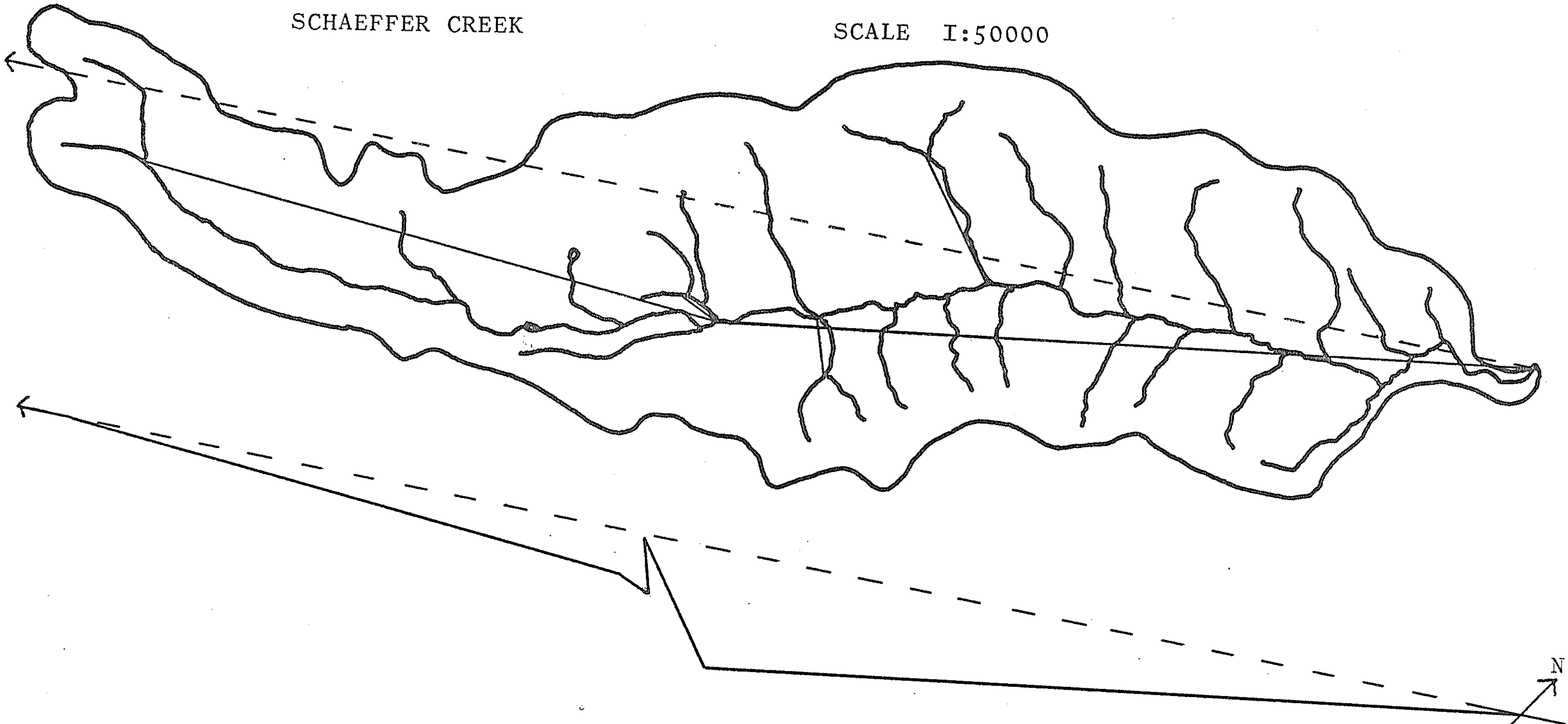
TABLE 4 DRAINAGE DENSITY

TECHNIQUE OF NETWORK IDENTIFICATION	DRAINAGE DENSITY IN MILES OF CHANNEL/MI.^{2}
BLUE LINES ON 1:50000 MAP	2.61
BLUE LINES AND CONTOUR CRENULATIONS ON 1:50000 MAP	3.87
VERTICAL AERIAL PHOTOGRAPHY 1:37382	4.08
VERTICAL AERIAL PHOTOGRAPHY 1:13306	4.98
VERTICAL AERIAL PHOTOGRAPHY 1:37382 USING 2X MIRROR STEREOSCOPE	6.85

As would be expected, drainage density increases with increasing map scale and technique superiority.


TOTAL STREAM LENGTH VERSUS STREAM ORDER
KEY:
X=I:37382 STEREOPAIRS (I)
.=I:I3306 AIR PHOTO ENLARGEMENTS (2)
IOO
IO
I
(I)
(2)
X
TOTAL STREAM LENGTH IN MILES
I
2
3
4
5
STREAM ORDER

GRAPH I



ONGLEY'S BASIN VECTORIAL AXIS

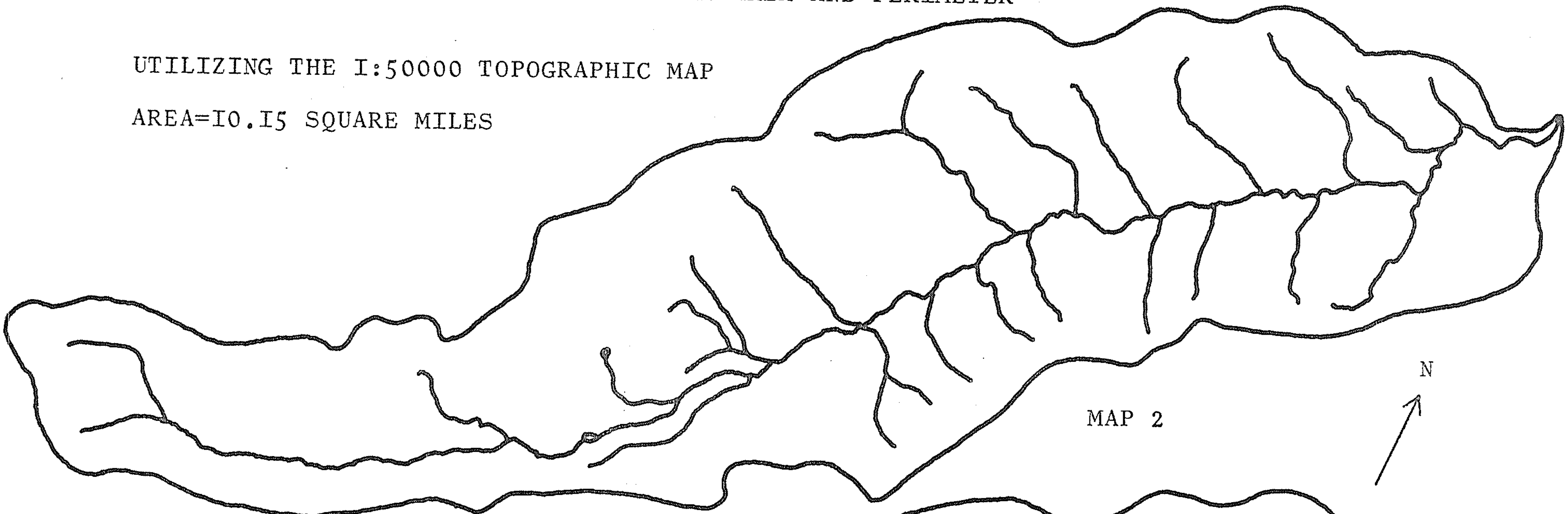
AXIS REPRESENTED BY DASHED LINE

MAP I

SCHAEFFER CREEK BASIN AREA AND PERIMETER

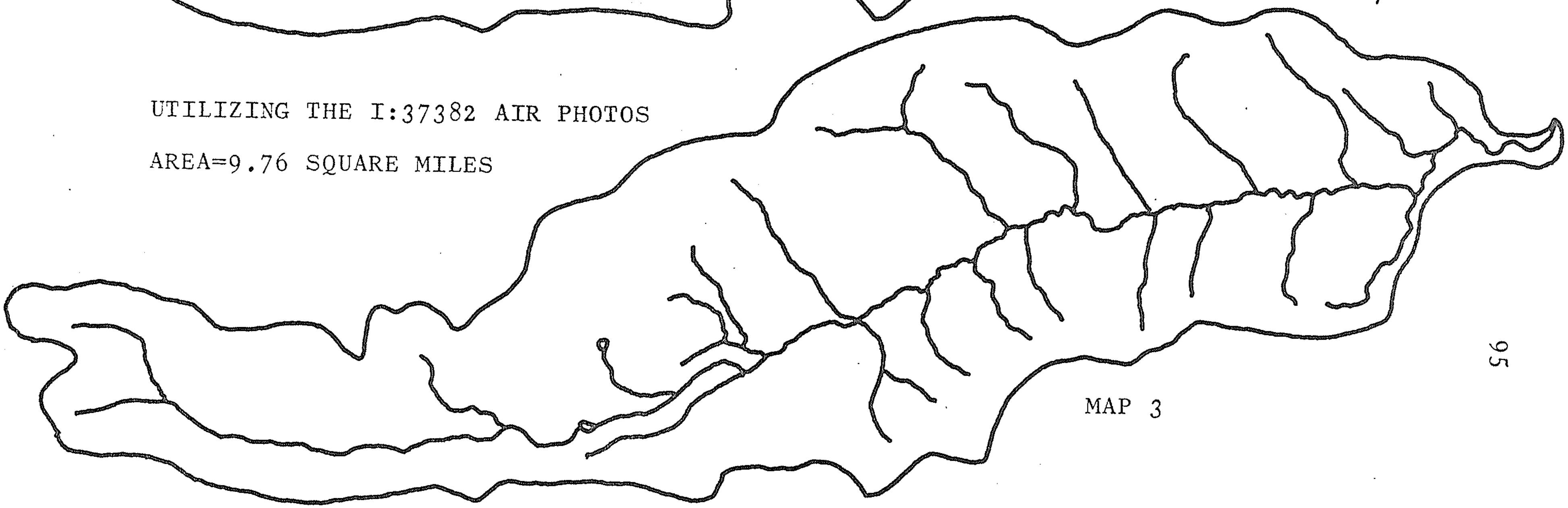
UTILIZING THE I:50000 TOPOGRAPHIC MAP

AREA=I0.I5 SQUARE MILES



UTILIZING THE I:37382 AIR PHOTOS

AREA=9.76 SQUARE MILES



APPENDIX B.

BIFURCATION RATIO DATA FOR MANITOBA

TABLE 1 PHYSICAL CHARACTERISTICS OF MANITOBA'S PHYSIOGRAPHIC REGIONS

PHYSICAL CHARACTERISTIC	HUDSON BAY LOWLAND	PRECAMBRIAN SHIELD	MANITOBA LOWLAND	MANITOBA UPLAND	MANITOBA ESCARPMENT
LOCATION WITHIN THE PROVINCE	------------------- SEE MAP 3-1 -----------------------				
ELEVATION AND RELIEF	0-500 FT. A.S.L. FLAT TO UNDULATING	500-1000 FT. A.S.L. UNDULATING TO HILLY	500-1000 FT. A.S.L. FLAT TO UNDULATING	500- +2000 FT. A.S.L. UNDULATING TO HILLY	1000-1500 FT. A.S.L. HILLY, MAX. RELIEF IN PROVINCE
PHYSIOGRAPHY	SWAMP AND MARSH, A TILL PLAIN	ICE SCOURED UPLAND, ROCK OUTCROPS AND MUSKEG	LACUSTRINE PLAIN, SOME MARSH	MORAINIC UPLAND, A TILL PLAIN END MORAINE AND BEACH RIDGES	AN ESCARPMENT, CUT BY BEACH RIDGES, HIGHLY DISSECTED
BED ROCK GEOLOGY	DOLOMITE, LIMESTONE	PRECAMBRIAN GRANITES, SEDIMENTARIES, SOME VOLCANICS AND INTRUSIVES	SANDSTONES, SHALES, LIMESTONE AND DOLOMITES	SHALES, SANDSTONES, LIMESTONES, BENTONITE	SHALES, LIMESTONE, BENTONITE
SURFACE DEPOSITS	MARINE CLAY ON GLACIAL DRIFT	LACUSTRINE CLAY, BOG, GLACIAL DRIFT	DELTAIC DEPOSITS, LACUSTRINE CLAYS, TILL, ALLUVIUM	GROUND AND END MORAINE LACUSTRINE CLAY, SILTS AND SANDS	SANDS AND CLAYS, SOME GLACIAL DRIFT
SOILS	TUNDRA AND ARCTICMEADOW	GREY WOODED, PODZOLIC	RENDZINA, BLACK, GREY	GREY WOODED, MEADOW	GREY WOODED, BLACK

TABLE 1 (CONTINUED)

PHYSICAL CHARACTERISTIC	HUDSON BAY LOWLAND	PRECAMBRIAN SHIELD	MANITOBA LOWLAND	MANITOBA UPLAND	MANITOBA ESCARPMENT
NATURAL VEGETATION	ARCTIC TUNDRA	CONIFERS, SPRUCE, SOME MIXED FOREST	MIXED GRASSES, LIGHTLY TREED	MIXED GRASSES, BROADLEAF AND MIXED FOREST	MIXED FOREST AND MEADOWS
AVERAGE TEMP. $^{\circ}$F.					
JANUARY	-10 - -20	0 - -10	+4 - -8	+3 - -6	+4 - -6
JULY	+50 - +60	+60 - +66	+64 - +69	+64 - +67	+64 - +68
AVERAGE ANNUAL PRECIPITATION IN INCHES	15.97	17.24	18.50	17.73	18.00
POTENTIAL EVAPOTRANSPIRATION PER YEAR IN INCHES	12.0	14.0	15.0	17.0	17.0

TABLE 2 HUDSON BAY LOWLAND BIFURCATION RATIO DATA EMPLOYING 1:50000 TOPOGRAPHIC SHEETS

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
54K/3E	1	5	
	2	1	5.0
54K/3W	1	5	
	2	2	
	3	1	2.3
54K/4E	1	9	
	2	2	
	3	1	3.3
	1	13	
	2	5	
	3	1	3.8
54K/4W	1	25	
	2	8	
	3	3	
	4	1	2.8
54K/5E	1	18	
	2	5	
	3	1	4.3
54K/5W	1	12	
	2	3	
	3	1	3.5
	1	3	
	2	1	3.0
54K/6E	1	22	
	2	7	
	3	2	
	4	1	2.8
	1	2	
	2	1	2.0
54K/6W	1	24	
	2	8	
	3	2	
	4	1	3.0
54K/12E	1	2	
	2	1	2.0

TABLE 2 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
54K/12W	1	2	
	2	1	2.0
54L/1E	1	10	
	2	3	
	3	1	3.2
	1	15	
	2	2	
	3	1	4.5
54L/1W	1	13	
	2	4	
	3	1	3.6
54L/2E	1	13	
	2	4	
	3	1	3.6
	1	9	
	2	2	
	3	1	3.1
54L/2W	1	16	
	2	6	
	3	1	4.4
54L/7E	1	2	
	2	1	2.0
	1	11	
	2	3	
	3	1	3.3
54L/7W	1	12	
	2	3	
	3	1	3.5
54L/8E	1	23	
	2	7	
	3	1	5.1
	1	26	
	2	2	
	3	1	7.5

TABLE 2 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
54L/8W	1	22	
	2	6	
	3	1	4.8
	1	9	
	2	3	
	3	1	3.0
54L/9E	1	4	
	2	1	4.0
54L/9W	1	8	
	2	2	
	3	1	3.0
	1	5	
	2	1	5.0
54L/10E	1	24	
	2	8	
	3	1	5.5
	1	10	
	2	3	
	3	1	3.2
54L/10W	1	12	
	2	3	
	3	1	3.5
54L/15W	1	11	
	2	4	
	3	1	3.4

A TOTAL OF 33 BASIN BIFURCATION RATIOS.
MEAN BASIN R_b = 3.60

TABLE 3 PRECAMBRIAN SHIELD BIFURCATION RATIO DATA EMPLOYING 1:50000 TOPOGRAPHIC SHEETS

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
52L/6W	1	3	
	2	1	3.0
	1	8	
	2	2	
	3	1	3.0
	1	4	
	2	1	4.0
52L/11E	1	3	
	2	1	3.0
	1	4	
	2	1	4.0
52L/11W	1	2	
	2	1	2.0
	1	3	
	2	1	3.0
53E/15	1	6	
	2	2	
	3	1	2.5
	1	3	
	2	1	3.0
53E/16	1	6	
	2	2	
	3	1	2.5
	1	4	
	2	1	4.0
	1	7	
	2	3	
	3	1	2.6
62A/4	1	31	
	2	8	
	3	3	
	4	1	3.1

TABLE 3 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
62A/4 con't	1	5	
	2	2	
	3	1	2.3
63I/12E	1	7	
	2	1	7.0
	1	2	
	2	1	2.0
63J/7E	1	3	
	2	1	3.0
	1	2	
	2	1	2.0
63J/7W	1	6	
	2	1	6.0
	1	5	
	2	1	5.0
63J/8E	1	5	
	2	2	
	3	1	2.3
	1	3	
	2	1	3.0
63J/8W	1	8	
	2	2	
	3	1	3.0
	1	2	
	2	1	2.0
63J/9E	1	8	
	2	3	
	3	1	2.8
	1	7	
	2	1	7.0
	1	11	
	2	3	
	3	1	3.5

TABLE 3 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
63J/9W	1	10	
	2	3	
	3	1	3.2
	1	6	
	2	2	
	3	1	2.5
	1	6	
	2	1	6.0
	1	5	
	2	2	
	3	1	2.3
63J/10E	1	4	
	2	1	4.0
	1	2	
	2	1	2.0
63J/10W	1	11	
	2	3	
	3	1	3.4
	1	3	
	2	1	3.0
63J/12	1	10	
	2	2	
	3	1	3.5
	1	28	
	2	7	
	3	1	5.5
63J/13	1	15	
	2	4	
	3	1	4.0
	1	19	
	2	4	
	3	1	4.4

TABLE 3 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
63J/15E	1	3	
	2	1	3.0
	1	2	
	2	1	2.0
63J/15W	1	6	
	2	1	6.0
	1	2	
	2	1	2.0
63K/13E	1	3	
	2	1	3.0
	1	3	
	2	1	3.0
	1	3	
	2	1	3.0
63K/13W	1	5	
	2	1	5.0
	1	3	
	2	1	3.0
	1	2	
	2	1	2.0
63K/14E	1	4	
	2	1	4.0
	1	3	
	2	1	3.0
	1	12	
	2	3	
	3	1	3.5
63K/14W	1	2	
	2	1	2.0
	1	7	
	2	2	
	3	1	2.8

TABLE 3 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
63K/14W (con't)	1	4	
	2	1	4.0
63K/15E	1	6	
	2	1	6.0
	1	7	
	2	1	7.0
	1	3	
	2	1	3.0
63K/15W	1	4	
	2	1	4.0
	1	4	
	2	1	4.0
	1	2	
	2	1	2.0
63N/3	1	7	
	2	1	7.0
	1	3	
	2	1	3.0
63N/4	1	14	
	2	3	
	3	1	4.0
	1	4	
	2	1	4.0
	1	3	
	2	1	3.0
63O/1	1	4	
	2	2	
	3	1	2.0
	1	6	
	2	1	6.0
63O/2	1	3	
	2	1	3.0

TABLE 3 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
630/2 (con't)	1	6	
	2	2	
	3	1	2.5
630/8	1	24	
	2	8	
	3	1	5.5
	1	12	
	2	2	
	3	1	4.0
630/9	1	14	
	2	2	
	3	1	4.5
	1	3	
	2	1	3.0
63P/4	1	7	
	2	2	
	3	1	2.7
	1	3	
	2	1	3.0
63P/5	1	15	
	2	4	
	3	2	
	4	1	2.6
	1	4	
	2	1	4.0
63P/6	1	9	
	2	3	
	3	1	3.0
	1	6	
	2	2	
	3	1	2.5
63P/10	1	10	
	2	2	
	3	1	3.5
	1	4	
	2	1	4.0

TABLE 3 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
63P/11	1	7	
	2	1	7.0
	1	6	
	2	2	
	3	1	2.5
63P/12	1	6	
	2	2	
	3	1	2.5
	1	6	
	2	1	6.0
	1	13	
	2	3	
	3	1	3.5
63P/12W	1	11	
	2	4	
	3	1	3.8
	1	9	
	2	2	
	3	1	3.3
63P/13E	1	11	
	2	2	
	3	1	3.7
	1	8	
	2	3	
	3	1	2.8
63P/13W	1	12	
	2	2	
	3	1	4.0
	1	5	
	2	2	
	3	1	2.3
63P/14E	1	5	
	2	1	5.0
	1	13	
	2	4	
	3	1	3.5

TABLE 3 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
63P/14W	1	10	
	2	2	
	3	1	3.5
	1	4	
	2	1	4.0
	1	3	
	2	1	3.0
63P/16	1	9	
	2	2	
	3	1	3.3
	1	8	
	2	2	
	3	1	3.0
64A/1	1	8	
	2	1	8.0
	1	7	
	2	2	
	3	1	2.7
	1	14	
	2	3	
	3	1	3.9
64A/2	1	3	
	2	1	3.0
	1	63	
	2	17	
	3	4	
	4	1	4.2
	1	4	
	2	2	
	3	1	2.0
64A/3	1	14	
	2	3	
	3	1	3.8
	1	4	
	2	2	
	3	1	2.0

TABLE 3 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
64C/6	1	5	
	2	2	
	3	1	2.3
	1	2	
	2	1	2.0
64C/9	1	11	
	2	3	
	3	1	3.5
	1	3	
	2	1	3.0
64C/10	1	14	
	2	3	
	3	1	4.0
	1	3	
	2	1	3.0
	1	8	
	2	2	
	3	1	3.0
64C/4	1	3	
	2	1	3.0
	1	2	
	2	1	2.0
	1	3	
	2	1	3.0
64C/12	1	8	
	2	2	
	3	1	3.0
	1	3	
	2	1	3.0
64C/14	1	3	
	2	1	3.0
	1	2	
	2	1	2.0

TABLE 3 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
64C/15E	1	3	
	2	1	3.0
	1	3	
	2	1	3.0
64C/15W	1	5	
	2	2	
	3	1	2.3
	1	4	
	2	1	4.0
64C/16E	1	5	
	2	2	
	3	1	2.3
	1	3	
	2	1	3.0
64C/16W	1	3	
	2	1	3.0
	1	3	
	2	1	3.0
64F/1	1	21	
	2	5	
	3	1	4.5
	1	12	
	2	2	
	3	1	4.0
	1	13	
	2	4	
	3	1	3.5
64F/2	1	7	
	2	2	
	3	1	2.7
	1	2	
	2	1	2.0
	1	3	
	2	1	3.0

TABLE 3 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
64F/3	1	4	
	2	2	
	3	1	2.0
	1	6	
	2	1	6.0
	1	4	
	2	1	4.0

A TOTAL OF 140 BASIN BIFURCATION RATIOS.
MEAN BASIN R_b = 3.40

TABLE 4 MANITOBA PLAIN BIFURCATION RATIO DATA EMPLOYING 1:50000 TOPOGRAPHIC SHEETS

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
62H/1	1	2	
	2	1	2.0
62H/1E	1	18	
	2	3	
	3	1	4.5
62H/3E	1	7	
	2	3	
	3	1	2.6
62H/3W	1	6	
	2	1	6.0
	1	6	
	2	2	
	3	1	2.5
62H/4E	1	15	
	2	4	
	3	1	4.0
	1	4	
	2	1	4.0
62H/4W	1	12	
	2	2	
	3	1	4.0
	1	13	
	2	4	
	3	1	3.5
62H/5W	1	9	
	2	2	
	3	1	3.3
	1	5	
	2	1	5.0
62H/6W	1	9	
	2	2	
	3	1	3.3
62H/8W	1	8	
	2	2	
	3	1	3.0

TABLE 4 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
62H/8W (con't)	1	9	
	2	2	
	3	1	3.3
62H/12E	1	9	
	2	2	
	3	1	3.3
62H/13W	1	6	
	2	1	6.0
	1	7	
	2	3	
	3	1	2.6
62H/15	1	9	
	2	1	9.0
	1	5	
	2	2	
	3	1	2.3
62H/16W	1	9	
	2	2	
	3	1	3.3
62I/1E	1	8	
	2	3	
	3	1	2.7
	1	5	
	2	1	5.0
62I/1W	1	6	
	2	2	
	3	1	2.5
62I/2E	1	4	
	2	1	4.0
62I/3E	1	2	
	2	1	2.0
62I/3W	1	4	
	2	1	4.0

TABLE 4 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
62I/4E	1	3	
	2	1	3.0
62I/5	1	2	
	2	1	2.0
62I/6E	1	4	
	2	1	4.0
	1	4	
	2	1	4.0
62I/7	1	7	
	2	2	
	3	1	2.7
62I/8	1	4	
	2	1	4.0
	1	2	
	2	1	2.0
62I/9	1	12	
	2	4	
	3	1	3.5
	1	21	
	2	6	
	3	1	4.7
62I/16E	1	8	
	2	2	
	3	1	3.0
62J/1E	1	7	
	2	1	7.0
62J/1W	1	10	
	2	2	
	3	1	3.5
62J/2	1	4	
	2	1	4.0
62J/3E	1	2	
	2	1	2.0

TABLE 4 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
62J/6E	1	5	
	2	1	5.0
62J/7E	1	2	
	2	1	2.0
62J/10W	1	2	
	2	1	2.0
62J/14W	1	5	
	2	1	5.0
	1	6	
	2	1	6.0
62J/16W	1	2	
	2	1	2.0
62O/7	1	2	
	2	1	2.0
	1	3	
	2	1	3.0
62O/16	1	8	
	2	3	
	3	1	2.8
	1	15	
	2	3	
	3	1	4.0
62P/5	1	4	
	2	2	
	3	1	2.0
63B/1	1	5	
	2	1	5.0
63B/7	1	4	
	2	1	4.0
	1	6	
	2	2	
	3	1	2.5

TABLE 4 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
63C/1	1	8	
	2	1	8.0
	1	5	
	2	2	
	3	1	2.3
63C/2	1	4	
	2	2	
	3	1	2.0
	1	8	
	2	2	
	3	1	3.0
63C/7	1	6	
	2	2	
	3	1	2.5
	1	12	
	2	4	
	3	1	3.5
	1	13	
	2	2	
	3	1	4.3
	1	6	
	2	2	
	3	1	2.5
63C/8	1	15	
	2	4	
	3	1	4.0
63C/9	1	11	
	2	3	
	3	1	3.5
63C/10	1	10	
	2	2	
	3	1	3.5
	1	5	
	2	1	5.0

A TOTAL OF 67 BIFURCATION RATIOS.
MEAN BASIN R_b = 3.60

TABLE 5 MANITOBA ESCARPMENT BIFURCATION RATIO DATA EMPLOYING 1:50000 TOPOGRAPHIC SHEETS

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
62G/1E	1	6	
	2	1	6.0
	1	12	
	2	2	
	3	1	4.0
	1	2	
	2	1	2.0
62G/8W	1	7	
	2	2	
	3	1	2.7
	1	4	
	2	1	4.0
	1	6	
	2	1	6.0
62G/9W	1	7	
	2	1	7.0
	1	5	
	2	1	5.0
62G/10E	1	3	
	2	1	3.0
	1	5	
	2	2	
	3	1	2.3
	1	6	
	2	2	
	3	1	2.5
62J/5E	1	11	
	2	4	
	3	1	3.4
62J/6W	1	13	
	2	3	
	3	1	3.5

TABLE 5 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
62J/6W (con't)	1	22	
	2	5	
	3	2	
	4	1	3.0
62J/11W	1	8	
	2	2	
	3	1	3.0
	1	4	
	2	1	4.0
62J/12E	1	13	
	2	3	
	3	1	3.5
	1	7	
	2	2	
	3	1	2.7
	1	12	
	2	3	
	3	1	3.5
62J/13E	1	12	
	2	3	
	3	1	3.5
	1	3	
	2	1	3.0
	1	6	
	2	3	
	3	1	2.5
62J/13W	1	12	
	2	3	
	3	1	3.5
	1	9	
	2	4	
	3	1	3.0
	1	14	
	2	5	
	3	1	4.0

TABLE 5 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
62K/16E	1	8	
	2	2	
	3	1	3.0
	1	9	
	2	2	
	3	1	3.7
	1	2	
	2	1	2.0
62K/16W	1	2	
	2	1	2.0
	1	4	
	2	2	
	3	1	2.0
	1	4	
	2	1	4.0
62N/1E	1	4	
	2	1	4.0
	1	12	
	2	3	
	3	1	3.5
	1	4	
	2	1	4.0
	1	2	
	2	1	2.0
62N/7E	1	15	
	2	4	
	3	1	4.0
	1	4	
	2	1	4.0
	1	8	
	2	3	
	3	1	3.0
62N/10E	1	4	
	2	1	4.0

TABLE 5 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
62N/10E (con't)	1	4	
	2	1	4.0
	1	6	
	2	3	
	3	1	2.5
62N/15E	1	16	
	2	4	
	3	1	4.0
62N/15W	1	5	
	2	2	
	3	1	2.3
	1	7	
	2	2	
	3	1	2.8
	1	26	
	2	7	
	3	2	
	4	1	3.1
63C/2	1	9	
	2	3	
	3	1	3.0
63C/6W	1	4	
	2	1	4.0
	1	3	
	2	1	3.0
	1	3	
	2	1	3.0
63C/14E	1	12	
	2	3	
	3	1	3.5

A TOTAL OF 52 BIFURCATION RATIOS.
MEAN BASIN R_b = 3.46

TABLE 6 THE MANITOBA UPLAND BIFURCATION RATIO DATA EMPLOYING 1:50000 TOPOGRAPHIC SHEETS

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
62F/1W	1	14	
	2	4	
	3	1	3.3
	1	18	
	2	6	
	3	2	
	4	1	2.6
62F/2E	1	8	
	2	3	
	3	1	2.8
	1	19	
	2	5	
	3	2	
	4	1	2.8
62F/2W	1	3	
	2	1	3.0
62F/3E	1	2	
	2	1	2.0
62F/3W	1	2	
	2	1	2.0
62F/6E	1	2	
	2	1	2.0
62F/6W	1	4	
	2	1	4.0
62F/7W	1	2	
	2	1	2.0
62F/8E	1	7	
	2	3	
	3	1	2.6
62F/10E	1	2	
	2	1	2.0
62F/10W	1	13	
	2	4	
	3	1	3.6

TABLE 6 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
62F/11E	1	4	
	2	2	
	3	1	2.0
62F/11W	1	2	
	2	1	2.0
62F/14E	1	14	
	2	2	
	3	1	4.5
	1	3	
	2	1	3.0
62F/14W	1	3	
	2	1	3.0
	1	10	
	2	2	
	3	1	3.5
62F/16E	1	5	
	2	1	5.0
62F/16W	1	4	
	2	2	
	3	1	2.0
62G/2E	1	5	
	2	2	
	3	1	2.3
	1	3	
	2	1	3.0
	1	5	
	2	2	
	3	1	2.3
62G/4E	1	10	
	2	2	
	3	1	3.5
	1	13	
	2	3	
	3	1	3.5

TABLE 6 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
62G/4W	1	7	
	2	1	7.0
	1	5	
	2	1	5.0
62G/5E	1	4	
	2	1	4.0
62G/6W	1	3	
	2	1	3.0
	1	5	
	2	1	5.0
	1	4	
	2	1	4.0
62J/4E	1	6	
	2	2	
	3	1	2.5
	1	2	
	2	1	2.0
	1	2	
	2	1	2.0
62J/4W	1	4	
	2	1	4.0
	1	3	
	2	1	3.0
	1	5	
	2	2	
	3	1	2.3
62K/1E	1	3	
	2	1	3.0
62K/1W	1	3	
	2	1	3.0
	1	2	
	2	1	2.0

TABLE 6 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
62K/2E	1	3	
	2	1	3.0
62K/2W	1	3	
	2	1	3.0
	1	6	
	2	2	
	3	1	2.5
	1	4	
	2	1	4.0
62K/3E	1	5	
	2	2	
	3	1	2.3
	1	6	
	2	2	
	3	1	2.5
62K/3W	1	5	
	2	2	
	3	1	2.3
	1	5	
	2	1	5.0
62K/6E	1	4	
	2	1	4.0
	1	9	
	2	3	
	3	1	3.0
62K/7E	1	5	
	2	1	5.0
	1	3	
	2	1	3.0
62K/7W	1	2	
	2	1	2.0
	1	3	
	2	1	3.0

TABLE 6 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
62K/8E	1	2	
	2	1	2.0
62K/8W	1	3	
	2	1	3.0
	1	2	
	2	1	2.0
62K/9E	1	6	
	2	1	6.0
62K/9W	1	2	
	2	1	2.0
62K/10E	1	4	
	2	2	
	3	1	2.0
62K/11W	1	16	
	2	3	
	3	1	4.0
62K/12E	1	5	
	2	2	
	3	1	2.2
62K/12W	1	2	
	2	1	2.0
62K/10W	1	2	
	2	1	2.0
	1	4	
	2	1	4.0
62K/11E	1	3	
	2	1	3.0
	1	2	
	2	1	2.0
62K/13E	1	2	
	2	1	2.0

TABLE 6 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFYRCATION RATIO
62K/13W	1	3	
	2	1	3.0
62K/14E	1	7	
	2	2	
	3	1	2.7
	1	8	
	2	3	
	3	1	2.7
62K/14W	1	7	
	2	2	
	3	1	2.7
62K/15E	1	11	
	2	2	
	3	1	3.7
	1	4	
	2	1	4.0
62K/15W	1	3	
	2	1	3.0
	1	6	
	2	1	6.0
62K/16W	1	12	
	2	3	
	3	1	3.5
	1	7	
	2	3	
	3	1	2.6
	1	14	
	2	4	
	3	1	3.8
62N/3E	1	2	
	2	1	2.0
	1	3	
	2	1	3.0
	1	5	
	2	2	
	3	1	2.3

TABLE 6 (CONTINUED).

TOPOGRAPHIC SHEET	STRAHLER ORDER	STREAM ORDER FREQUENCY	BASIN BIFURCATION RATIO
62N/6E	1	6	
	2	2	
	3	1	2.5
	1	5	
	2	2	
	3	1	2.4
62N/6W	1	5	
	2	1	5.0
	1	6	
	2	1	6.0
	1	3	
	2	1	3.0
62N/11W	1	10	
	2	4	
	3	1	3.2
	1	12	
	2	3	
	3	1	3.5
	1	6	
	2	2	
	3	1	2.5

A TOTAL OF 91 BIFURCATION RATIOS.
MEAN BASIN R_b = 3.10

TABLE 7 HUDSON BAY LOWLAND BIFURCATION RATIO DATA EMPLOYING STEREOVISUAL ANALYSIS OF AERIAL PHOTOS WITH A MEAN SCALE OF 1:60000

TOPOGRAPHIC SHEET	BASIN R_b EMPLOYING PHOTOS	BASIN R_b EMPLOYING 1:50000 SHEETS	STREAM ORDER EMPLOYING PHOTOS: ORDER	FREQ.	STREAM ORDER EMPLOYING TOPOGRAPHIC SHEETS: ORDER	FREQ.
54K/4E	4.1	3.8	1	16	1	13
			2	3	2	5
			3	1	3	1
54K/5W	4.1	3.5	1	53	1	12
			2	10	2	3
			3	2	3	1
			4	1		
54L/1E	4.7	4.5	1	101	1	15
			2	18	2	2
			3	4	3	1
			4	1		
54L/2W	4.2	4.4	1	340	1	16
			2	89	2	6
			3	20	3	1
			4	5		
			5	1		
54L/8E	4.8	5.1	1	80	1	23
			2	15	2	7
			3	3	3	1
			4	1		
54L/9W	4.5	3.0	1	45	1	8
			2	9	2	2
			3	2	3	1
			4	1		
54L/15W	5.1	3.4	1	114	1	11
			2	30	2	4
			3	8	3	1
			4	1		

TABLE 8 PRECAMBRIAN SHIELD BIFURCATION RATIO DATA EMPLOYING STEREOVISUAL ANALYSIS OF AERIAL PHOTOS WITH A MEAN SCALE OF 1:37400

TOPOGRAPHIC SHEET	BASIN R_b EMPLOYING PHOTOS	BASIN R_b EMPLOYING 1:50000 SHEETS	STREAM ORDER EMPLOYING PHOTOS:		STREAM ORDER EMPLOYING TOPOGRAPHIC SHEETS:	
			ORDER	FREQ.	ORDER	FREQ.
52L/11W	4.7	3.0	1	19	1	3
			2	3	2	1
			3	1		
53E/15	3.9	2.5	1	41	1	6
			2	9	2	2
			3	2	3	1
			4	1		
53E/16	4.0	2.6	1	62	1	7
			2	21	2	3
			3	4	3	1
			4	1		
63J/7E	3.6	3.0	1	45	1	3
			2	12	2	1
			3	3		
			4	1		
63J/8E	3.0	3.0	1	9	1	3
			2	3	2	1
			3	1		
63J/9W	3.9	6.0	1	36	1	6
			2	6	2	1
			3	2		
			4	1		
63J/10E	3.2	4.0	1	32	1	4
			2	8	2	1
			3	3		
			4	1		
63J/12	3.5	5.5	1	146	1	28
			2	37	2	7
			3	10	3	1
			4	3		
			5	1		
63J/15W	5.0	6.0	1	26	1	6
			2	5	2	1
			3	1		

TABLE 8 (CONTINUED).

TOPOGRAPHIC SHEET	BASIN R_b EMPLOYING PHOTOS	BASIN R_b EMPLOYING 1:50000 SHEETS	STREAM ORDER EMPLOYING PHOTOS: ORDER	FREQ.	STREAM ORDER EMPLOYING TOPOGRAPHIC SHEETS: ORDER	FREQ.
63K/13E	3.7	3.0	1	50	1	3
			2	14	2	1
			3	4		
			4	1		
63K/13W	3.8	2.0	1	11	1	2
			2	2	2	1
			3	1		
63K/14W	3.6	2.3	1	47	1	5
			2	11	2	2
			3	3	3	1
			4	1		
63K/15E	6.1	6.0	1	101	1	6
			2	25	2	1
			3	2		
			4	1		
63N/4	3.8	4.0	1	54	1	14
			2	12	2	3
			3	4	3	1
			4	1		
63O/1	4.0	6.0	1	50	1	6
			2	8	2	1
			3	3		
			4	1		
63O/9	4.0	4.0	1	203	1	12
			2	55	2	2
			3	9	3	1
			4	2		
			5	1		
63P/5	4.0	4.0	1	48	1	4
			2	8	2	1
			3	2		
			4	1		
63P/11	3.6	7.0	1	50	1	7
			2	13	2	1
			3	3		
			4	1		

TABLE 8 (CONTINUED).

TOPOGRAPHIC SHEET	BASIN R_b EMPLOYING PHOTOS	BASIN R_b EMPLOYING 1:50000 SHEETS	STREAM ORDER EMPLOYING PHOTOS: ORDER	FREQ.	STREAM ORDER EMPLOYING TOPOGRAPHIC SHEETS ORDER	FREQ.
63P/13E	4.8	3.7	1	87	1	11
			2	22	2	2
			3	6	3	1
			4	1		
63P/14W	3.6	4.0	1	38	1	4
			2	10	2	1
			3	2		
			4	1		
64A/2	4.1	4.2	1	498	1	63
			2	122	2	17
			3	34	3	4
			4	8	4	1
			5	2		
			6	1		
64A/4	4.3	2.3	1	75	1	5
			2	27	2	2
			3	5	3	1
			4	1		
64C/9	2.9	3.0	1	22	1	3
			2	7	2	1
			3	2		
			4	1		
64C/11	4.5	2.0	1	18	1	2
			2	3	2	1
			3	1		
64C/14	3.8	2.0	1	11	1	2
			2	2	2	1
			3	1		
64C/16E	3.8	2.3	1	51	1	5
			2	14	2	2
			3	3	3	1
			4	1		
64F/1	4.0	3.5	1	61	1	13
			2	14	2	4
			3	3	3	1
			4	1		

TABLE 8 (CONTINUED).

TOPOGRAPHIC SHEET	BASIN R_b EMPLOYING PHOTOS	BASIN R_b EMPLOYING 1:50000 SHEETS	STREAM ORDER EMPLOYING PHOTOS: ORDER	FREQ.	STREAM ORDER EMPLOYING TOPOGRAPHIC SHEETS: ORDER	FREQ.
64F/3	3.9	6.0	1	63	1	6
			2	15	2	1
			3	4		
			4	1		

TABLE 9 MANITOBA LOWLAND PLAIN BIFURCATION RATIO DATA EMPLOYING STEREOVISUAL ANALYSIS OF AERIAL PHOTOS WITH A MEAN SCALE OF 1:15840

TOPOGRAPHIC SHEET	BASIN R_b EMPLOYING PHOTOS	BASIN R_b EMPLOYING 1:50000 SHEETS	STREAM ORDER EMPLOYING PHOTOS: ORDER	FREQ.	STREAM ORDER EMPLOYING TOPOGRAPHIC SHEETS: ORDER	FREQ.
62H/4W	4.7	3.5	1	94	1	13
			2	20	2	4
			3	5	3	1
			4	1		
62H/12E	3.4	3.3	1	50	1	13
			2	16	2	4
			3	5	3	1
			4	1		
62H/13W	3.1	2.6	1	27	1	7
			2	8	2	3
			3	2	3	1
			4	1		
62I/1E	3.8	3.0	1	39	1	9
			2	12	2	3
			3	2	3	1
			4	1		
62I/1W	4.8	2.5	1	84	1	6
			2	23	2	2
			3	3	3	1
			4	1		
62I/6E	5.2	4.0	1	26	1	4
			2	6	2	1
			3	1		

TABLE 9 (CONTINUED).

TOPOGRAPHIC SHEET	BASIN R_b EMPLOYING PHOTOS	BASIN R_b EMPLOYING 1:50000 SHEETS	STREAM ORDER EMPLOYING PHOTOS: ORDER	FREQ.	STREAM ORDER EMPLOYING TOPOGRAPHIC SHEETS: ORDER	FREQ.
62I/9	3.2	4.7	1	28	1	22
			2	8	2	6
			3	2	3	1
			4	1		
62J/2W	4.7	4.0	1	17	1	4
			2	7	2	1
			3	1		
62O/7	3.0	3.0	1	9	1	3
			2	3	2	1
			3	1		
62P/5	3.0	2.0	1	23	1	4
			2	5	2	2
			3	2	3	1
			4	1		
63B/1	4.0	5.0	1	49	1	5
			2	12	2	1
			3	2		
			4	1		
63C/2	3.8	3.0	1	196	1	8
			2	46	2	2
			3	12	3	1
			4	4		
			5	1		
63J/1E	3.3	7.0	1	40	1	7
			2	12	2	1
			3	4		
			4	1		

TABLE 10 MANITOBA ESCARPMENT BIFURCATION RATIO DATA EMPLOYING STEREOVISUAL ANALYSIS OF AERIAL PHOTOS WITH A MEAN SCALE OF 1:15840

TOPOGRAPHIC SHEET	BASIN R_b EMPLOYING PHOTOS	BASIN R_b EMPLOYING 1:50000 SHEETS	STREAM ORDER EMPLOYING PHOTOS: ORDER	FREQ.	STREAM ORDER EMPLOYING TOPOGRAPHIC SHEETS: ORDER	FREQ.
62G/8W	3.2	2.7	1	90	1	7
			2	23	2	2
			3	6	3	1
			4	2		
			5	1		
62G/15W	4.8	3.0	1	104	1	3
			2	22	2	1
			3	6		
			4	1		
62J/6W	4.2	3.0	1	260	1	22
			2	60	2	5
			3	24	3	2
			4	6	4	1
			5	1		
62J/12E	4.4	3.5	1	66	1	13
			2	13	2	3
			3	6	3	1
			4	1		
62J/13W	4.2	4.0	1	69	1	14
			2	21	2	5
			3	4	3	1
			4	1		
62K/16E	3.0	2.0	1	25	1	2
			2	7	2	1
			3	2		
			4	1		
62K/16W	4.7	2.0	1	21	1	2
			2	4	2	1
			3	1		
62N/1E	4.2	2.0	1	17	1	2
			2	4	2	1
			3	1		

TABLE 11 MANITOBA UPLAND BIFURCATION RATIO DATA EMPLOYING STEREOVISUAL ANALYSIS OF AERIAL PHOTOS WITH A MEAN SCALE OF 1:15840

TOPOGRAPHIC SHEET	BASIN R_b EMPLOYING PHOTOS	BASIN R_b EMPLOYING 1:50000 SHEETS	STREAM ORDER EMPLOYING PHOTOS: ORDER	FREQ.	STREAM ORDER EMPLOYING TOPOGRAPHIC SHEETS: ORDER	FREQ.
62F/1W	4.6	3.5	1	77	1	13
			2	22	2	5
			3	3	3	2
			4	1	4	1
62F/2E	4.1	2.8	1	60	1	8
			2	17	2	3
			3	3	3	1
			4	1		
62F/7W	3.1	2.0	1	25	1	2
			2	6	2	1
			3	2		
			4	1		
62F/11E	4.5	2.0	1	20	1	2
			2	5	2	1
			3	1		
62F/16W	4.3	2.0	1	80	1	4
			2	19	2	2
			3	4	3	1
			4	1		
62G/4W	4.5	6.0	1	60	1	6
			2	15	2	1
			3	2		
			4	1		
62G/6W	4.3	4.0	1	18	1	4
			2	4	2	1
			3	1		
62J/2E	3.7	2.8	1	47	1	8
			2	11	2	3
			3	4	3	1
			4	1		
62J/4W	5.4	4.0	1	26	1	4
			2	7	2	1
			3	1		

TABLE 11 (CONTINUED).

TOPOGRAPHIC SHEET	BASIN R_b EMPLOYING PHOTOS	BASIN R_b EMPLOYING 1:50000 SHEETS	STREAM ORDER EMPLOYING PHOTOS: ORDER	FREQ.	STREAM ORDER EMPLOYING TOPOGRAPHIC SHEETS: ORDER	FREQ.
62K/2W	3.6	2.5	1	45	1	6
			2	11	2	2
			3	3	3	1
			4	1		
62K/3W	3.6	5.0	1	39	1	5
			2	9	2	1
			3	2		
			4	1		
62K/2E	4.9	4.0	1	23	1	4
			2	6	2	1
			3	1		
62K/8W	4.8	3.0	1	21	1	3
			2	6	2	1
			3	1		
62K/10W	5.3	2.0	1	28	1	2
			2	5	2	1
			3	1		
62K/14E	2.9	2.7	1	77	1	8
			2	18	2	3
			3	7	3	1
			4	2		
			5	1		
62K/15W	4.2	3.0	1	17	1	3
			2	5	2	1
			3	1		
63N/3E	4.0	2.0	1	12	1	2
			2	2	2	1
			3	1		
62N/6W	2.8	5.0	1	20	1	5
			2	5	2	1
			3	2		
			4	1		

TABLE 12 BIFURCATION RATIO CORRECTION FACTOR DERIVATION

PHYSIOGRAPHIC REGION	STREAM NET SAMPLE SIZE	MEAN BASIN R_b BY PHOTOS	MEAN BASIN R_b BY 1:50000 TOPOGRAPHIC SHEETS	R_b CORRECTION FACTOR
HUDSON BAY LOWLAND	7	3.96	4.50	+0.54
PRECAMBRIAN SHIELD	28	3.81	3.96	+0.15
MANITOBA LOWLAND	13	3.66	3.84	+0.18
MANITOBA ESCARPMENT	10	2.84	3.95	+1.11
MANITOBA UPLAND	19	3.35	4.11	+0.76

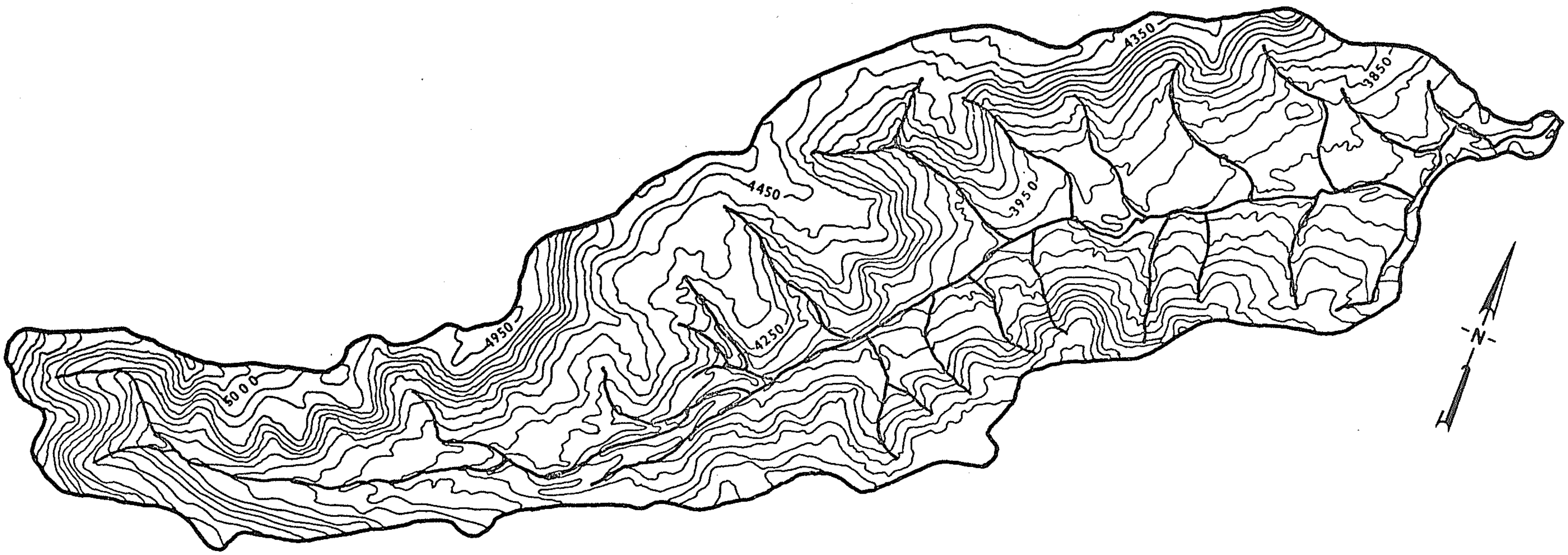
TABLE 13 EMPLOYMENT OF THE CORRECTION FACTOR TO DERIVE MORE PRECISE BIFURCATION RATIOS FOR MANITOBA'S PHYSIOGRAPHIC REGIONS

PHYSIOGRAPHIC REGION	MEAN R_b AS DERIVED FROM TOPO. SHEETS	R_b CORRECTION FACTOR	NEW MEAN R_b
HUDSON BAY LOWLAND	3.60	+0.54	4.14
PRECAMBRIAN SHIELD	3.40	+0.15	3.55
MANITOBA LOWLAND	3.60	+0.18	3.78
MANITOBA ESCARPMENT	3.40	+1.11	4.51
MANITOBA UPLAND	3.10	+0.76	3.86

MAP 4

SCHAEFFER CREEK

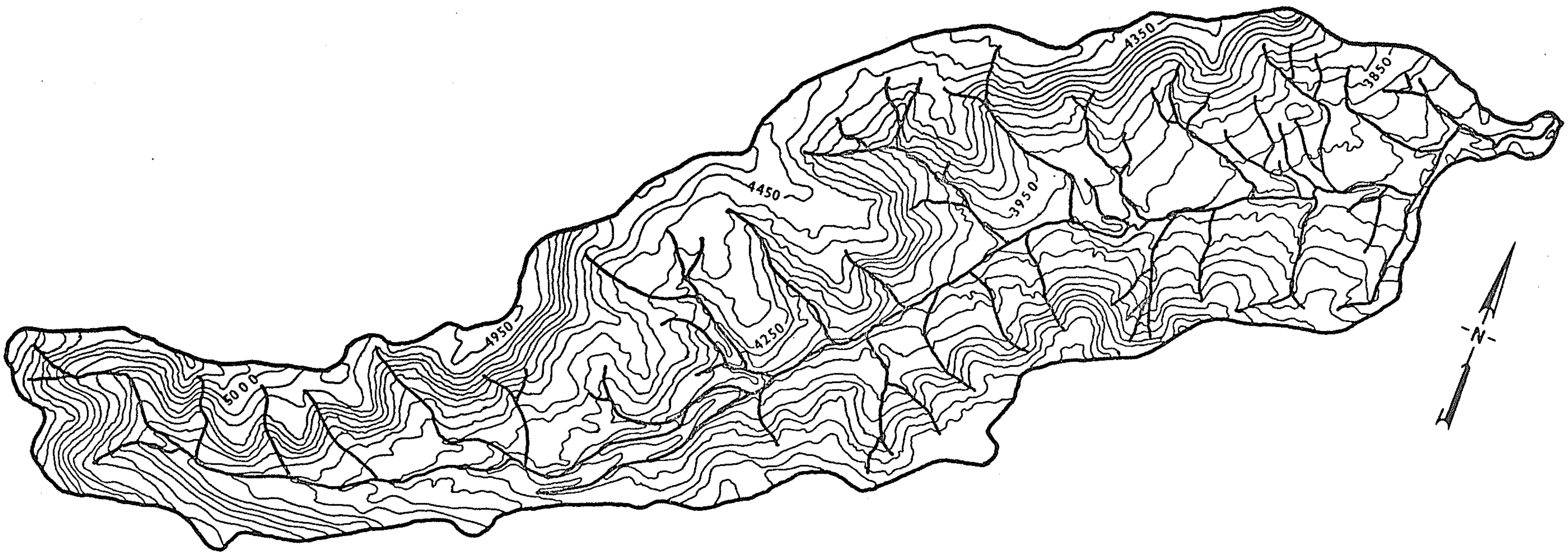
METHOD I



SCALE 1:40000

CONTOUR INTERVAL 50'

MAP 5
SCHAEFFER CREEK
METHOD 2

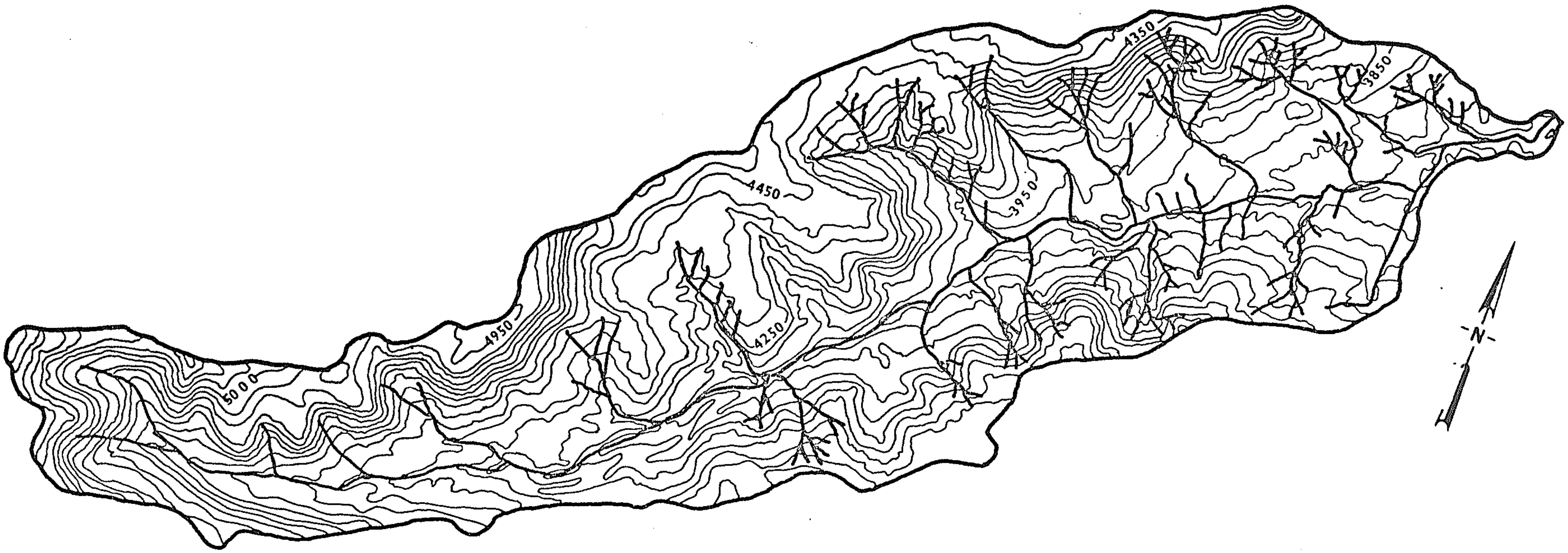


SCALE 1:40000
CONTOUR INTERVAL 50'

MAP 6

SCHAEFFER CREEK

METHOD 3



SCALE 1:40000

CONTOUR INTERVAL 50'

MAP 7

SCHAEFFER CREEK

METHOD 4

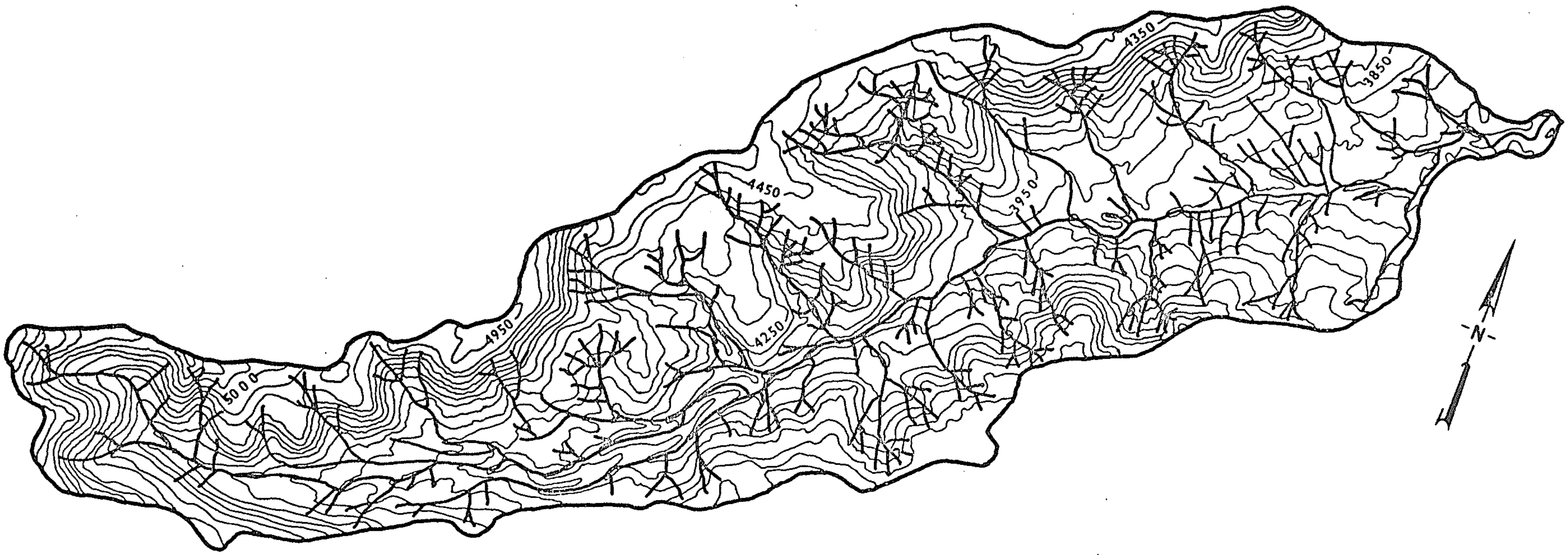
SCALE 1:40000

CONTOUR INTERVAL 50'

MAP 8

SCHAEFFER CREEK

METHOD 5



SCALE 1:40000

CONTOUR INTERVAL 50′

APPENDIX C.

WATER SURPLUS DATA AND STATISTICAL ANALYSES

TABLE 1 DETERMINATION OF BASIN BIFURCATION RATIO AND WATER SURPLUS FOR SELECTED NETWORKS

DRAINAGE NETWORK	LOCATION LATITUDE: LONGITUDE:	BASIN AREA (ACRES)	PERIOD OF RECORD (YEARS)	MEAN DAILY DISCHARGE (C.F.S.)	MEAN YEARLY DISCHARGE (CONVERTED TO ACRE - FEET)	WATER SURPLUS IN FEET	BASIN Rb
MANIGOTAGAN R.	51°00' 96 17	444800	11	330	95,563.63	.2148	3.91
BLACK R.	50 51 96 15	170880	8	162	117,282.64	.6863	3.41
WHITESHELL R.	50 02 95 30	179200	8	152	110,042.97	.6140	5.62
BROKENHEAD R.	49 53 96 21	171520	8	89.7	64,939.80	.3786	4.22
WHITEMOUTH R.	49 56 95 57	928000	12	531	384,426.40	.4142	4.93
BROKENHEAD R. (2)	50 05 96 25	380160	9	175	126,694.20	.3332	4.55
PEMBINA R.	49 12 99 44	88960	10	15.8	11,438.70	.1285	2.78
PEMBINA R. (2)	48 59 97 33	218240	58	166	120,178.50	.0550	3.02
WHITEMUD CREEK	49 08 99 24	129204	10	19.4	140440.90	.1086	2.94
WAKOPA CREEK	49 06 99 50	41344	7	9.2	6660.50	.1610	6.76
BADGER CREEK	49 06 99 19	369920	10	24.3	17592.40	.0475	4.84
LONG R.	49 05 98 58	126080	10	11.1	8036.03	.0637	4.04
CRYSTAL CREEK	49 07 98 56	36160	9	4.2	3040.70	.0840	4.01
PILOT CREEK	49 12 98 57	37952	6	3.6	2606.30	.0686	5.61

TABLE 1 (CONTINUED).

DRAINAGE NETWORK	LOCATION LATITUDE: LONGITUDE:	BASIN AREA (ACRES)	PERIOD OF RECORD (YEARS)	MEAN DAILY DISCHARGE (C.F.S.)	MEAN YEARLY DISCHARGE (CONVERTED TO ACRE - FEET)	WATER SURPLUS IN FEET	BASIN R_b
MARY JANE CREEK	49°14' 98 40	33984	9	8.5	6153.70	.1810	4.11
SNOWFLAKE CREEK	49 01 98 36	222720	7	6.4	4633.40	.0208	4.91
MOWBRAY CREEK	49 00 98 27	60096	7	9.3	6732.90	.1120	3.71
ROSEAU R.	49 11 97 03	1177600	31	363	262800.00	.2231	3.60
SPRAGUE CREEK	48 59 95 39	108160	28	63	45609.90	.4216	2.97
MORRIS R.	49 27 97 26	488320	53	105	76016.50	.1556	3.45
BOYNE R.	49 31 97 56	295040	9	55.3	40035.40	.1356	4.17
SHANNON CREEK	49 21 97 25	134400	9	39.1	28307.10	.2106	2.78
RAT R.	49 12 96 17	121600	8	61.5	44524.00	.3661	5.41
RAT R. (2)	49 27 97 00	450560	26	113	81808.30	.1815	5.92
ELM CREEK #3	49 47 99 00	119040	8	9.2	6660.50	.0559	3.22
ELM CREEK #2	49 48 97 58	166400	9	17.5	12669.40	.0761	5.94
ELM CREEK #1	49 48 97 46	204160	8	36.6	26497.20	.1297	3.24
SHELL R.	51 21 101 15	347520	6	51.2	37067.10	.1066	2.20

TABLE 1 (CONTINUED)

DRAINAGE NETWORK	LOCATION LATITUDE: LONGITUDE:	BASIN AREA (ACRES)	PERIOD OF RECORD (YEARS)	MEAN DAILY DISCHARGE (C.F.S.)	MEAN YEARLY DISCHARGE (CONVERTED TO ACRE - FEET)	WATER SURPLUS IN FEET	BASIN R_b
CONJURING CREEK	50°47' 101 17	21120	10	2.5	1810.00	.0857	4.06
BIRDTAIL CREEK	50 31 100 57	270720	12	42.9	31058.20	.1147	2.41
ARROW R.	50 05 100 57	151040	10	7.4	5357.40	.0354	4.97
GOPHER CREEK	49 47 100 57	76800	10	6.0	4343.80	.0565	4.70
BOSSHILL CREEK	49 50 100 58	49280	10	5.3	3837.00	.0778	3.68
OAK R.	50 01 100 23	316800	10	9.9	7167.30	.0226	4.19
HAMIOTA CREEK	50 10 100 33	11200	8	.53	383.70	.0342	2.76
KENTON CREEK	49 59 100 36	9152	7	1.8	1303.10	.1423	4.76
MINNEDOSA R.	50 01 100 12	966400	13	150.0	108595.00	.1123	4.55
JACKFISH CREEK	50 52 100 02	5056	5	4.0	2895.90	.5727	2.76
LITTLE SOURIS R.	49 43 99 50	180480	8	10.7	7746.40	.0429	4.72
ANTLER R.	49 03 101 02	793600	13	16.4	11873.10	.0148	5.00
GAINBOROUGH CREEK	49 05 101 11	302720	12	5.4	3909.40	.0121	3.24
GRAHAM CREEK	49 15 100 59	186240	11	2.0	1447.90	.0077	4.14

TABLE 1 (CONTINUED).

DRAINAGE NETWORK	LOCATION LATITUDE: LONGITUDE:	BASIN AREA (ACRES)	PERIOD OF RECORD (YEARS)	MEAN DAILY DISCHARGE (C.F.S.)	MEAN YEARLY DISCHARGE (CONVERTED TO ACRE - FEET)	WATER SURPLUS IN FEET	BASIN R_b
TURTLEHEAD CREEK	49° 09' 100 25	23040	5	3.6	2606.30	.1131	5.26
PLUM CREEK	49 37 100 18	1657600	12	10.0	7239.70	.0043	2.85
PIPESTONE CREEK	49 35 100 56	998400	11	23.3	16868.40	.0168	3.60
ELGIN CREEK	49 35 100 14	115840	7	6.1	4416.20	.0381	4.76
OAK CREEK	49 33 99 30	232960	8	18.8	13610.60	.0584	2.76
EPINETTE CREEK	49 43 99 16	120320	6	9.4	6805.30	.0564	5.31
STURGEON CREEK	49 52 97 16	105600	7	43.3	31347.80	.2968	3.53
SEINE R.	49 46 96 56	316800	20	69.1	50026.10	.1579	4.83
COOKS CREEK	50 08 96 49	161920	11	78.0	56469.40	.3487	2.30
NETLEY CREEK	50 19 97 02	188800	9	35.7	25845.60	.1368	2.25
OSIER CREEK	50 34 97 01	63360	6	11.5	8325.60	.1314	3.98
ICELANDIC R.	50 57 97 02	282240	10	93.5	67328.90	.2385	2.18
FISHER R.	51 21 97 30	335360	7	54.5	39456.20	.1176	5.57
EAST FISHER R.	51 13 97 32	97280	6	31.6	22877.40	.2351	3.72

TABLE 1 (CONTINUED).

DRAINAGE NETWORK	LOCATION LATITUDE: LONGITUDE:	BASIN AREA (ACRES)	PERIOD OF RECORD (YEARS)	MEAN DAILY DISCHARGE (C.F.S.)	MEAN YEARLY DISCHARGE (CONVERTED TO ACRE - FEET)	WATER SURPLUS IN FEET	BASIN R_b
WHITEMUD R.	50° 09' 98 41	1510400	10	202	146241.30	.0968	4.77
NEEPAWA CREEK	50 13 99 32	39680	10	14	10135.50	.2554	3.66
JORDAN CREEK	50 23 99 02	13952	9	4.5	3257.90	.2335	5.76
PINE CREEK	50 03 98 56	157440	10	40	28958.70	.1839	3.38
W. SQUIRREL CREEK	49 58 98 56	20992	6	10.6	7674.00	.3655	5.76
MOSSY RIVER	51 27 99 58	2208000	8	259	187507.40	.0849	4.36
TURTLE R.	50 56 99 31	267520	12	78.9	57121.00	.2135	2.91
McKINNON CREEK	50 48 99 28	19200	10	10	7239.70	.3770	4.61
SCOTT CREEK	50 50 99 32	16640	10	12.1	8760.00	.5264	4.31
VERMILLION R.	51 11 100 00	167040	12	64.0	46333.90	.2773	3.73
EDWARDS CREEK	51 07 100 02	32128	12	24.3	17592.40	.5475	4.71
WILSON R.	51 12 100 00	228480	12	61.1	44234.40	.1936	5.28
VALLEY R.	51 16 100 00	736000	12	97.8	70804.00	.0962	5.20
PLEASANT CREEK	51 06 100 52	76160	5	9.4	6805.30	.0893	2.74

TABLE 1 (CONTINUED).

DRAINAGE NETWORK	LOCATION LATITUDE: LONGITUDE:	BASIN AREA (ACRES)	PERIOD OF RECORD (YEARS)	MEAN DAILY DISCHARGE (C.F.S.)	MEAN YEARLY DISCHARGE (CONVERTED TO ACRE - FEET)	WATER SURPLUS IN FEET	BASIN R_b
MINK R.	51°25' 100 21	52480	13	9.8	7094.90	.1351	3.56
FISHING R.	51 26 100 02	72960	12	4.7	3402.70	.0466	3.60
FORK R.	51 31 100 23	67200	13	16.3	11801.00	.1756	4.47
PINE R.	51 49 100 32	53760	12	33.1	23963.30	.4457	4.56
GARLAND R.	51 51 100 14	141440	11	31.4	22732.60	.1607	4.38
SWAN R.	52 11 101 03	972800	8	149	107871.10	.1108	2.21
ROARING R.	52 09 101 03	209280	8	72.9	52777.20	.2521	5.16
WOODY R.	52 15 101 08	525440	12	156	112938.90	.2149	2.74
BIRCH R.	52 22 101 06	39040	11	29.5	21357.00	.5470	4.11
BELL R.	52 36 101 02	41600	9	39.1	28307.10	.6804	3.96
STEEPROCK R.	52 43 101 06	92800	10	85.8	62116.70	.6693	4.70
RED DEER R.	52 52 101 02	3526400	6	870	629851.20	.1786	3.45
OVERFLOWING R.	53 09 101 06	672000	11	388	280899.20	.4180	3.96
GRASS R.	54 07 99 58	806400	11	410	296826.40	.3680	3.74
BURNTWOOD R.	55 44 97 53	4038400	11	3870	2801752.10	.6937	4.01

TABLE 2 ANALYSIS OF VARIANCE FOR BIFURCATION RATIO VALUES

PRECAMBRIAN SHIELD	MANITOBA PLAIN	MANITOBA ESCARPMENT	MANITOBA UPLAND	TOTAL	
3.91	4.93	4.04	2.78	15.66	
3.41	4.22	4.01	2.94	14.58	
5.62	4.55	5.61	6.76	22.45	
	3.02	4.11	4.84	11.97	
	3.60	4.91	4.06	12.57	
	2.97	3.71	2.41	9.09	
	3.45	2.91	4.97	11.33	
	4.17	4.61	4.70	13.48	
	2.78	4.31	3.68	10.77	
	5.41	4.71	4.19	13.77	
	5.92	5.28	2.76	13.96	
	3.22	5.20	4.76	13.18	
	5.94	4.38	4.55	14.87	
	3.24	2.21	2.76	8.31	
	3.53	4.11	4.72	12.36	
	4.83	3.45	5.00	13.28	
	2.30		3.24	5.59	
	2.25		4.14	6.39	
	3.98		5.26	9.24	
	2.18		2.85	5.03	
	4.77		3.60	8.37	
	3.38		4.76	8.14	
	5.76		2.76	8.52	
	5.57		5.31	10.88	
	3.72		3.66	7.38	
	3.73		5.76	9.49	
	5.16		2.74	7.90	
	2.74		3.56	6.30	
			3.60	3.60	
			4.47	4.47	
			4.56	4.56	
			3.96	3.96	
			4.70	4.70	
12.94	111.32	67.56	134.81	326.14	TOTAL
4.31	3.97	4.22	4.08	4.14	MEAN

The null hypothesis to be tested states that the 4 physiographic regions are homogeneous with respect to the Strahler bifurcation ratio.

TABLE 2 (CONTINUED).

VARIATION AMONG COLUMN MEANS:

$N1\ (\bar{X}1 - \bar{\bar{X}})^2 + N2\ (\bar{X}2 - \bar{\bar{X}})^2 + N3\ (\bar{X}3 - \bar{\bar{X}})^2 + \ldots.,$ therefore,

$3(4.31 - 4.14)^2 + 28(3.97 - 4.14)^2 + 16(4.22 - 4.14)^2 + \ldots$

= 1.1171. The estimated variance of the universe is 1.1171 / 3 = 0.3723. Since the variation is measured by the 4 column means, with 1 restriction represented by the grand mean of the sample, the number of degrees of freedom is nl - k = 4-1 = 3.

VARIATION WITHIN COLUMNS:

ie. $\left[(3.91 - 4.31)^2 + (3.41 - 4.31)^2 + (5.62 - 4.31)^2\right] + \left[(4.93 - 3.97)^2 + (4.22 - 3.97)^2 + \ldots\right]$ etc. = 2.69 + 35.57 + 10.50 + 33.83 = 82.59. Degrees of freedom = 80 - 4 = 76, therefore the second estimate of the universe variance is 82.59/76 = 1.0867. Total variation = 1.1171 + 82.59 =83.70. Observed F ratio = 0.3723/1.0867 = 0.3425. Since N1 = 3 and N2 = 76, an F ratio as large or larger than 2.75 or 4.09 would occur 5% or 1% of the time. Consequently, the smaller observed F ratio of 0.3425 would be expected to occur purely by chance even more frequently. Therefore, the hypothesis that the 4 physiographic regions are homogeneous with respect to bifurcation ratio cannot be rejected on the 5% or 1% significance levels on the basis of the given sample evidence. The subgroups to which the estimated variance refer are considered to represent the same universe.

TABLE 3 ANALYSIS OF VARIANCE FOR WATER SURPLUS VALUES

PRECAMBRIAN SHIELD	MANITOBA PLAIN	MANITOBA ESCARPMENT	MANITOBA UPLAND	TOTAL	
0.2148	0.4142	0.0637	0.1285	0.8212	
.6863	.3786	.0840	.1086	1.2575	
.6140	.3332	.0686	.1610	1.1768	
	.0550	.1810	.0475	0.2835	
	.2231	.0208	.0857	.3296	
	.4216	.1120	.1147	.6483	
	.1556	.3770	.0354	.4045	
	.1356	.5264	.0565	.5691	
	.2106	.5475	.0778	.8148	
	.3661	.1936	.0226	.9362	
	.1815	.0962	.0342	.4093	
	.0559	.1607	.1423	.2944	
	.0761	.1108	.1123	.3491	
	.1297	.5470	.5727	.8132	
	.1579	.1786	.0429	.8867	
	.3487		.0121	.3514	
	.1368		.0077	.1445	
	.1314		.1131	.2445	
	.2385		.0043	.2428	
	.0968		.0168	.1136	
	.1839		.0381	.2220	
	.3655		.0584	.4239	
	.1176		.0564	.1740	
	.2351		.2554	.4905	
	.2773		.2335	.5108	
	.2521		.0893	.3414	
	.2149		.1351	.3500	
			.0466	.0466	
			.1756	.1756	
			.4457	.4457	
			.6804	.6804	
			.6693	.6693	
1.5151	6.1905	2.9339	4.7954	14.8850	TOTAL
.5050	.2210	.1833	.1453	.2722	MEAN

The null hypothesis to be tested on the basis of these samples states that the 4 universes (physiographic regions), are homogeneous in respect to the average water surplus.

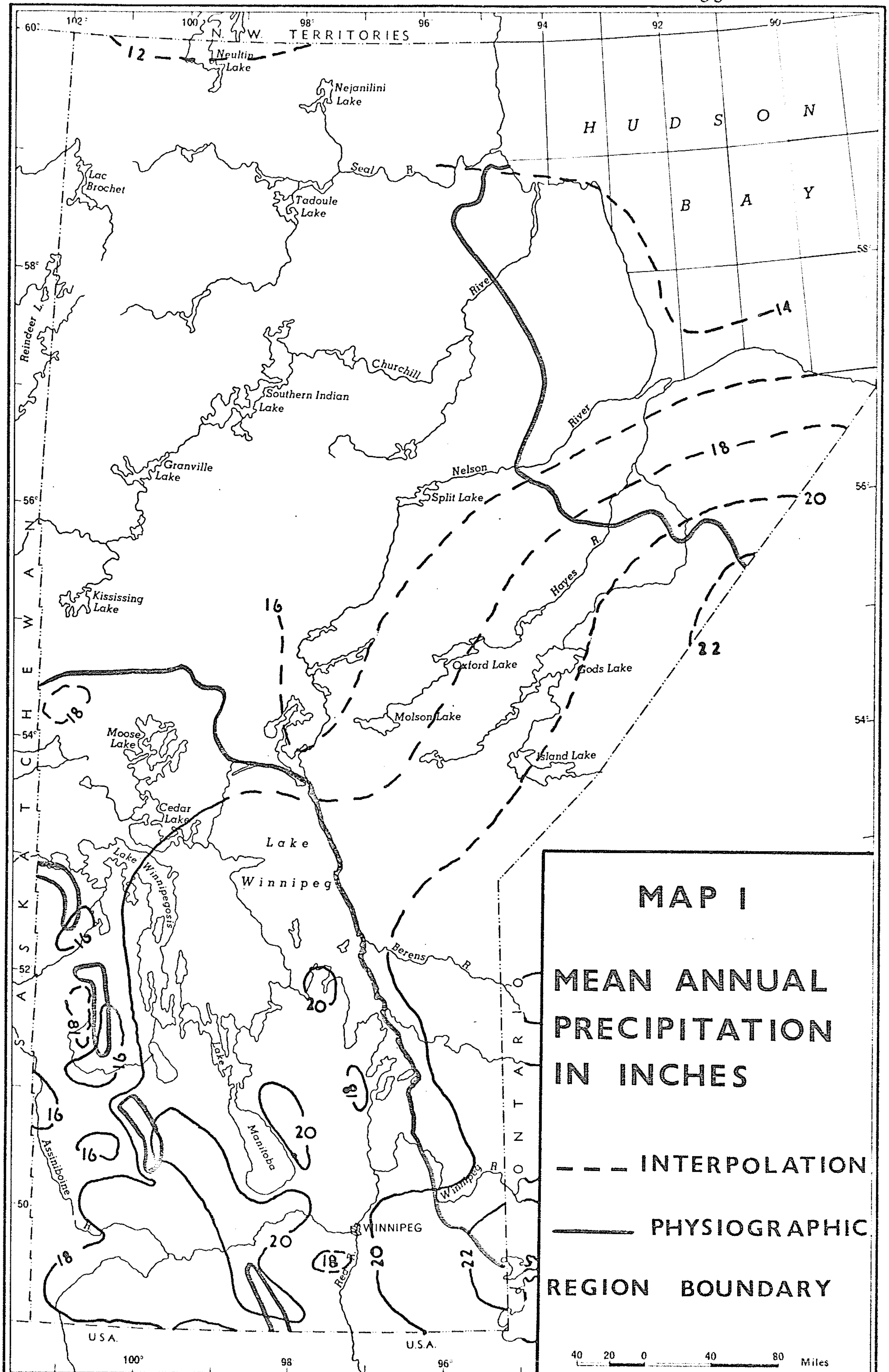
TABLE 3 (CONTINUED).

VARIATION AMONG COLUMN MEANS:

$N1\ (\overline{X1} - \overline{\overline{X}})^2 + N2\ (\overline{X2} - \overline{\overline{X}})^2 + N3(\overline{X3} - \overline{\overline{X}})^2 + \ldots.,$ therefore $3(.5050 - .2722)^2 + 28(.2210 - .2722)^2 + 16(.1833 - .2722)^2 \ldots$ $= 0.8931$. The estimated variance of the universe is 0.8931/ 3 = 0.2977. Since the variation is measured by the 4 column means, with 1 restriction represented by the grand mean of the sample, the number of degrees of freedom is $n1 - k = 4-1=3$.

VARIATION WITHIN COLUMNS:

ie. $\left[(.2148 - .5050)^2 + (.6863 - .5050)^2 + (.6140 - .5050)^2\right] + \left[(.4142 - .2214)^2 + (.3786 - .2214)^2 + \ldots.\right]$ etc. = .1288 + .3055 + .4751 + 1.0130 = 1.9224. Degrees of freedom = 80 - 4=76, therefore the second estimate of the universe variance is 1.9224/76 = 0.0252.Total variation = 0.8147 + 1 9224 = 2.7371. Observed F ratio = 0.2977/0.0252 = 11.8134; Since N1 = 3, and N2 = 76, an F ratio as large or larger than 4.09 would occur by chance 1% of the time. Consequently, the larger observed F ratio of 11.8134 would be expected to occur purely by chance even less frequently. Therefore, the hypothesis that the 4 physiographic region are homogeneous with respect to water surplus <u>can</u> be rejected at the 1% significance level, on the basis of the given sample evidence. The subgroups to which the estimated variances refer are considered to represent different universes.


MAP I
MEAN ANNUAL PRECIPITATION IN INCHES
INTERPOLATION
PHYSIOGRAPHIC REGION BOUNDARY
N. W. TERRITORIES
HUDSON BAY
SASKATCHEWAN
ONTARIO
U.S.A.
Neultin Lake
Nejanilini Lake
Seal R.
Lac Brochet
Tadoule Lake
Reindeer L.
Churchill River
Southern Indian Lake
Granville Lake
Nelson River
Split Lake
Kississing Lake
Hayes R.
Oxford Lake
Gods Lake
Molson Lake
Island Lake
Moose Lake
Cedar Lake
Lake Winnipegosis
Lake Winnipeg
Berens R.
Lake Manitoba
Assiniboine R.
Winnipeg R.
Red R.
WINNIPEG
12
14
16
18
20
22
40 20 0 40 80 Miles