THE USE OF HIGH ALTITUDE PHOTOGRAPHY AS AN IMPROVED DATA SOURCE FOR DRAINAGE SYSTEM ANALYSIS

BY

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THE USE OF HIGH ALTITUDE PHOTOGRAPHY AS AN IMPROVED DATA SOURCE FOR DRAINAGE SYSTEM ANALYSIS

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ABSTRACT

Studies to date involving the network properties of drainage systems have been theoretical in nature; and the environmental implications of these network characteristics have not been exploited to the extent that would appear warranted. This situation exists due to the lack of an accurate data source. Many studies have recognized this inadequacy of the conventional data sources to meet the necessary requirements of efficiency (in data production and handling), accuracy, consistency and uniformity.

The present study demonstrates that high altitude, small scale colour infrared photography is capable of providing drainage network data that fulfill all these basic requirements. Data derived from the three drainage basins, mapped from a variety of data sources, demonstrate three important points. The level of detail obtained from the small scale colour infrared photography far exceeds that available from more traditional data sources. Secondly, these network data are statistically consistent with the traditional data sources. Thirdly, the basin characteristics derived from the high altitude data source show a marked association with the known surficial environments and an expected variation from one surficial environment to another.

CHAPTER I

INTRODUCTION

1.1 Introductory Remarks

The concepts of network and system in relation to the distribution of streams have long been accepted. To date, applications of these concepts have focused upon methods which describe, classify and compare drainage networks on the basis of their geometry and topology. This research has resulted in the development of a wide range of geometric and topologic measures applicable to branching networks. Through the development of these measures, an objective basis has been established for the characterization and comparison of drainage networks.

Unfortunately, a major obstacle to concise and accurate analysis of stream patterns in the environment has been the lack of a statistically consistent and accurate data source on which to base the measurements. Topographic maps, at various scales, have been the most common source of stream pattern data; this data however, has proven to be generally unreliable, inconsistent and disproportionate to actual stream networks (Morisawa, 1957). Research in the 1960's (Sternberg, 1961 and Eyles, 1966), has shown that conventional medium scale panchromatic vertical aerial photography provides information that is superior in consistency and accuracy to that derived from topographic maps. With the advent of high altitude small scale photography for civilian use in 1969, studies have successfully demonstrated the advantages of this medium as a data source for drainage network studies (Howarth and Bruce, 1972).

As an extension of this work the present study seeks to investigate the usefulness of high altitude photography by mapping larger and more complex drainage systems over a wider area than has hitherto been undertaken. More specifically, the aims of this study are two fold; to examine and evaluate stream network data derived from the high altitude photography recorded over various physiographic environments, and to assess the data source for its value in the hydrologic and geomorphic interpretation of such environmental factors as the surficial deposits upon which the networks have developed.

1.2 Photography

The photography which forms the basis of this study was recorded in overflights of the National Aeronautics and Space Administration/ United States Geological Survey, (N.A.S.A./U.S.G.S.) Test Site 239. This covers the Lake Ontario Basin. The mission, flown at 60,000 feet produced 1:60,000 and 1:120,000 high altitude colour infrared photography. The photography was flown on various dates to include seasonal variations, over a period of three years (Table I) and was available as 9 inch x 9 inch (23 cm x 23 cm) positive film transparencies in roll form. The advantage anticipated in the small scale of the photography lies in the regional perspective it allows. This should lead to improved efficiency in data collection and in turn, allow continuity of interpretation.

The film type used was Kodak Aerochrome Infrared film (type 2443). This is a false colour reversal film which has a high dimensional

TABLE I

DRAINAGE BASIN DATA SOURCES

Site	Data Source	Scale	Date
Forty Mile Creek	Topographic Map	1:50,000	-
Forty Mile Creek	High Altitude Colour Infrared Photography	1:60,000	May 1971
Forty Mile Creek	High Altitude Colour Infrared Photography	1:120,000	May 1971
Forty Mile Creek	High Altitude Colour Infrared Photography	1:120,000	July 1970
Forty Mile Creek	High Altitude Colour Infrared Photography	1:120,000	October 1970
Bowmanville Creek	Topographic Map	1:50,000	-
Bowmanville Creek	High Altitude Colour Infrared Photography	1:120,000	May 1971
Bowmanville Creek	High Altitude Colour Infrared Photography	1:120,000	July 1970
Bowmanville Creek	High Altitude Colour Infrared Photography	1:120,000	October 1970
Duffin Creek	Topographic Map	1:50,000	-
Duffin Creek	High Altitude Colour Infrared Photography	1:120,000	June 1972
Duffin Creek	High Altitude Colour Infrared Photography	1:120,000	October 1970

stability. The false colour or colour infrared film is different from ordinary colour film in that the three layers of the emulsion are sensitive to green, red and near infrared reflected radiation, instead of the usual blue, green and red of the visible spectrum. The blue portion of the visible spectrum is removed by using a Wratten number 12 yellow filter. By using this filter, the effect of atmospheric haze is reduced and the film emulsions, sensitive to blue light, are not affected. The result is a clearer image providing a greater degree of contrast than that which could be obtained without the filter.

The colour infrared film is considered to be the most appropriate for this study due to its ability to enhance the contrast between areas of varying moisture content. The film thus holds a high potential for recording stream network data.

1.3 Areas of Study

To investigate the capability of using stream network patterns for distinguishing between different types of physical environments the test sites were selected from a variety of slope, form and material environments. These site locations are shown in Figure 1. All the basins drain into Lake Ontario and have been studied by the Ontario Ministry of Natural Resources as part of their input to the International Hydrologic Decade. The surficial deposits of the areas have been described and mapped (Chapman and Putnam, 1966).

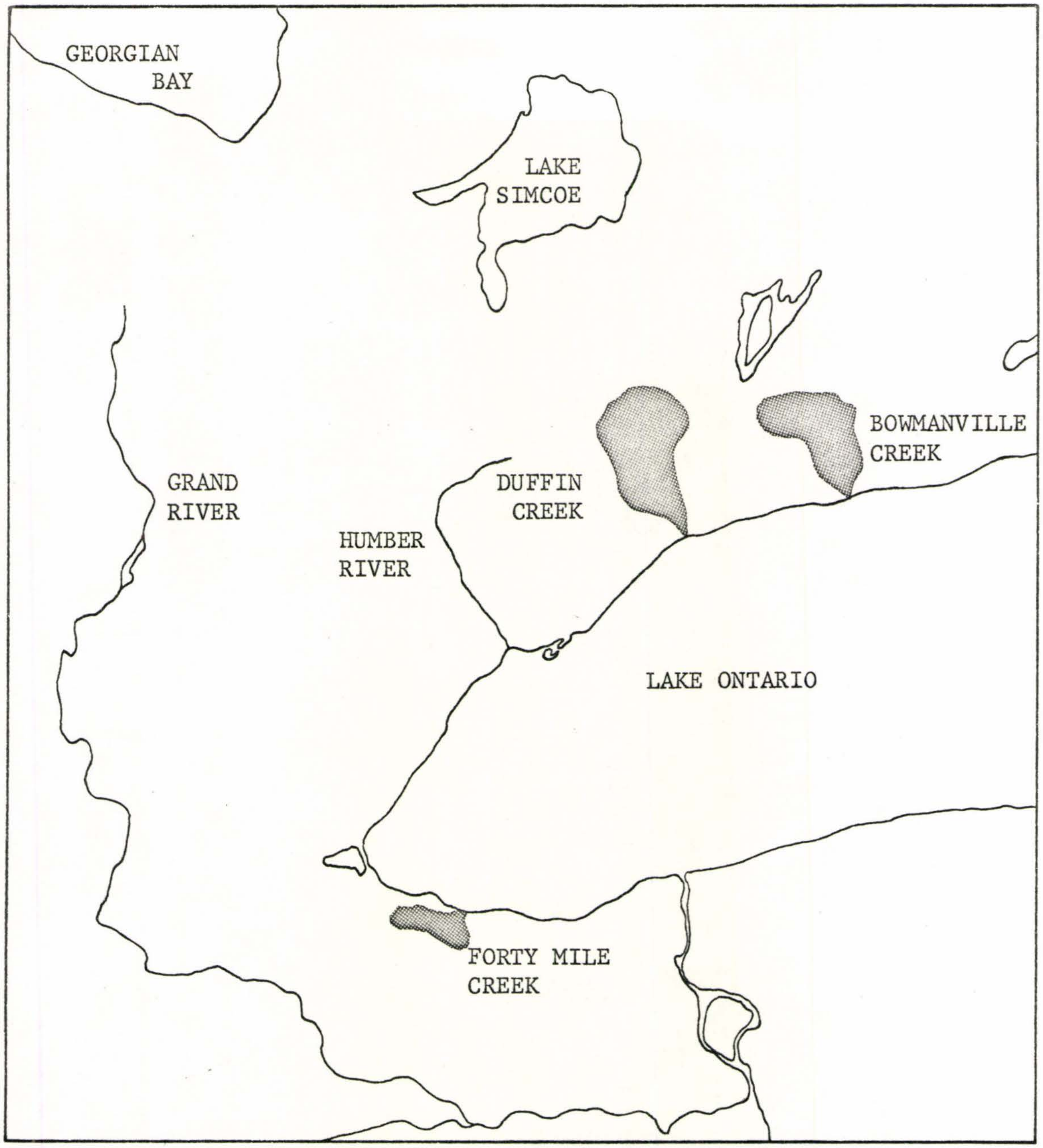


FIGURE 1: THE LOCATION IN SOUTHERN ONTARIO
OF THE THREE DRAINAGE BASINS
UNDER STUDY

SCALE: 1 INCH TO 20 MILES

1.3.1. Forty Mile Creek Drainage Basin

The Forty Mile Creek drainage basin is situated near the southwest shore of Lake Ontario and its waters flow into the lake at the town of Grimsby. The creek drains an area of approximately 20 sq. miles (52 sq. km). The principal topographic feature in this study area is the Niagara Escarpment which separates the Iroquois Plain below the escarpment from the Haldimand Clay Plain above. The escarpment trends approximately east-west paralleling the south shore of Lake Ontario. It consists of a relatively resistant dolomite formation which has produced a vertical scarp face averaging 290 feet (90 m) in height (Ostry, 1971). At its base the Iroquois Plain slopes gently to the lake shore. The plain consists of red shale overlain by clay till and includes surface patches of thin lacustrine sand (Figure 2).

The area of the drainage basin above the escarpment lies upon a gently undulating till plain (Haldimand Clay Plain) and the overland flow has been modified by drainage ditches in the upper reaches of some of the lower order streams. This plain is broken by the Vinemount Moraine, a narrow ridge immediately south of, and parallel to, the Niagara Escarpment.

Above the escarpment and south of the moraine, the Creek has an approximate average gradient of 7.4 feet per mile (1.4 m/km) (Ostry, 1971). The boundary of the basin is confined by minor topographic highs in the surrounding till plain. Minor local relief and associated shallow topographic gradients, in conjunction with the heavy clay tills at the surface, result in poor drainage within the basin.

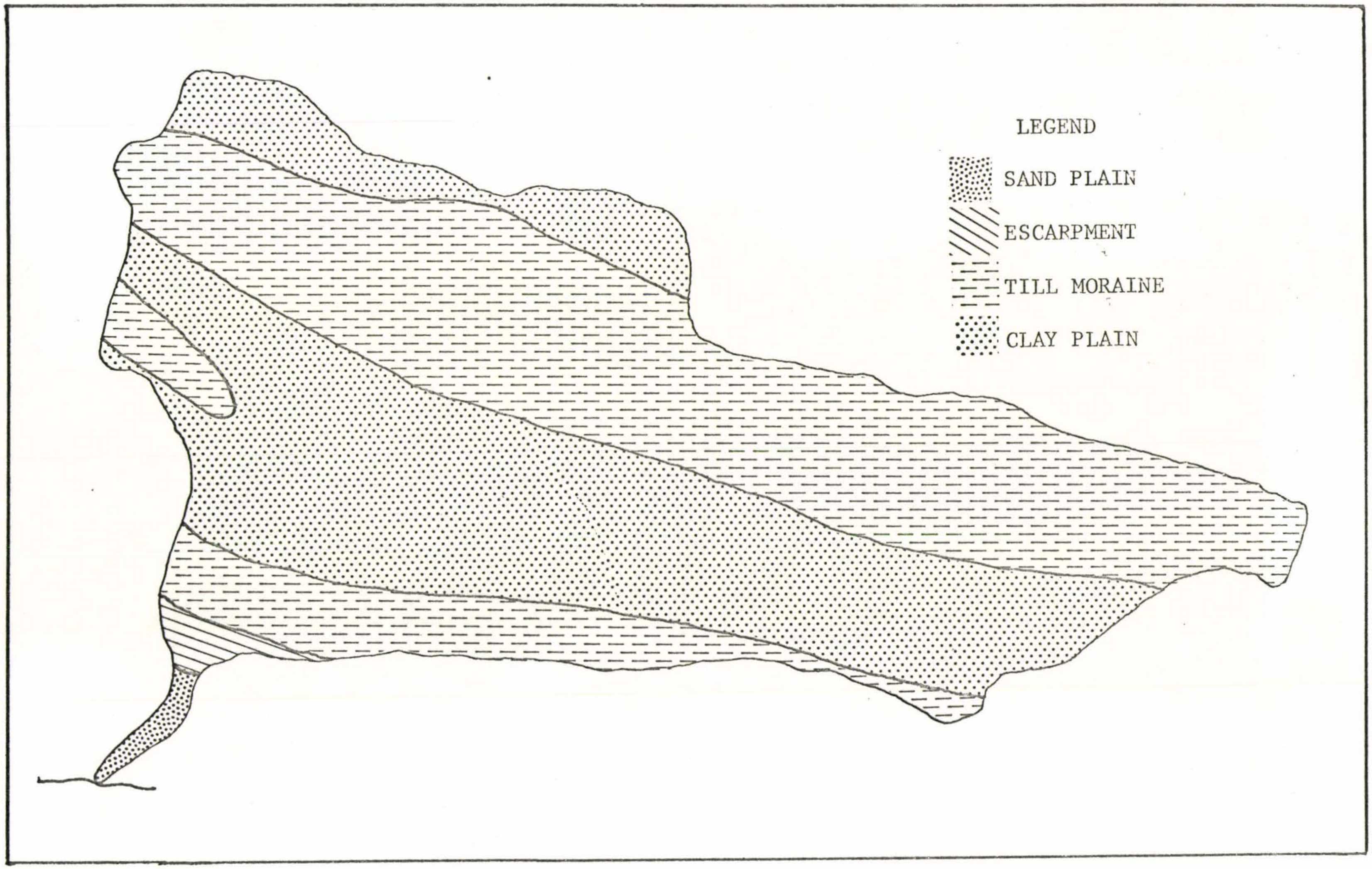


FIGURE 2: SURFICIAL DEPOSITS IN THE FORTY MILE CREEK BASIN

1.3.2. Duffin Creek and Bowmanville Creek Drainage Basins

Both these drainage basins contain a variety of surficial deposits and exhibit varied relief. The two basins have their source in the hilly knob-and-basin relief of the Oak Ridges physiographic region (Chapman and Putnam, 1966). The hills are mainly composed of sandy or gravelly materials, but some of the highest ridges consist of boulder clay.

From this region,the creeks flow towards the south,dropping approximately 1,000 feet (305 m) in elevation before entering Lake Ontario. The creeks pass over the drumlinized tills of the South Slope physiographic region, dropping 600 feet in a distance of 7 to 8 miles (183 m in 11 to 13 km). The drumlins are scattered with their long axes parallel to the direction of slope. The streams have cut small steep sided valleys in the till.

Beyond the South Slope physiographic region, the creeks drop a further 400 feet (133 m) across the Iroquois Plain to Lake Ontario. The modified glacial till is predominantly sandy in the northern parts of this latter region and has a higher clay content towards the lake. Bowmanville Creek drains an area of approximately 67 sq. miles (173 sq km) while Duffin Creek covers 117 sq. miles (303 sq km). (See Figures 3 and 4, for physiographic units).

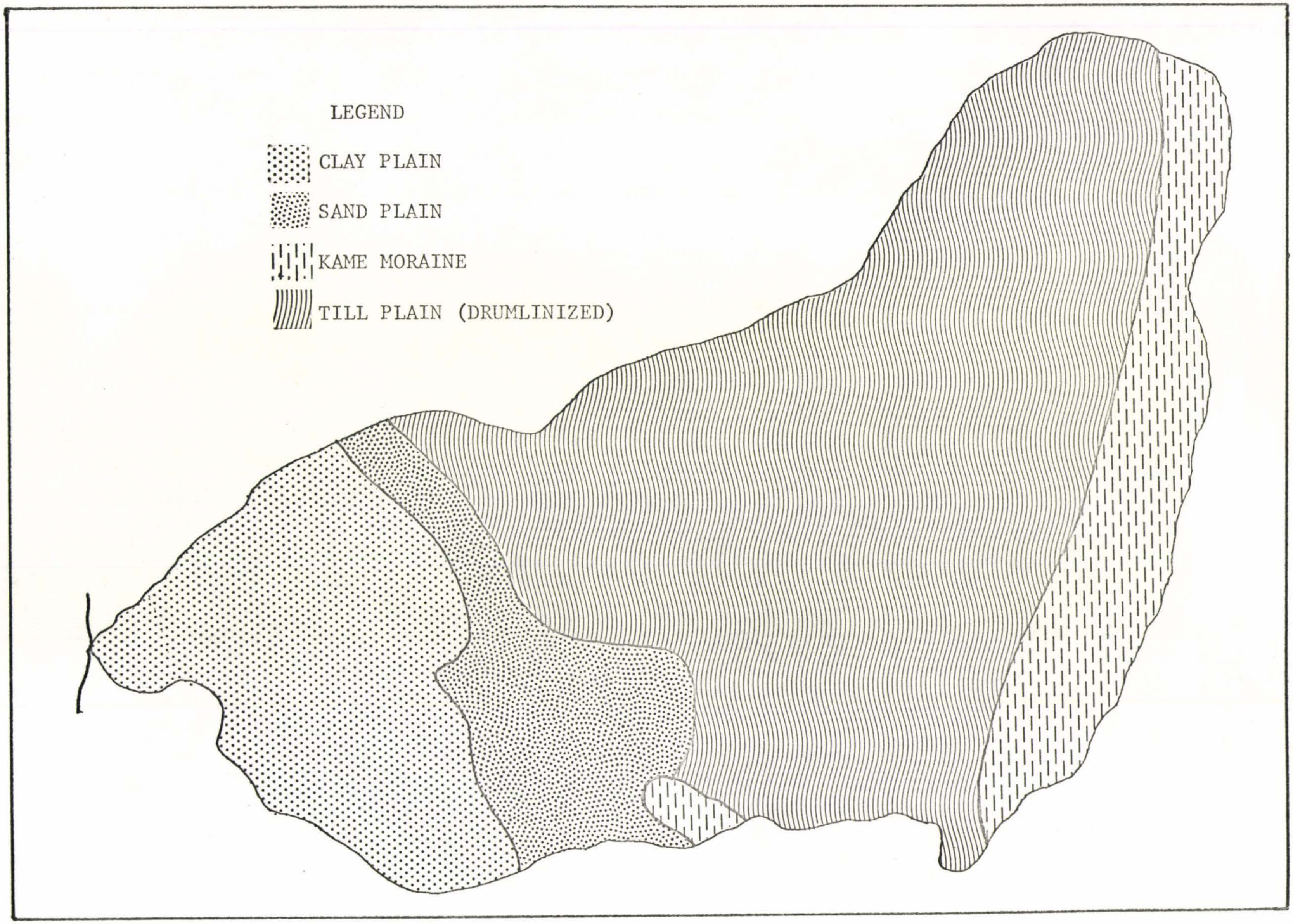


FIGURE 3: SURFICIAL DEPOSITS IN THE BOWMANVILLE CREEK BASIN

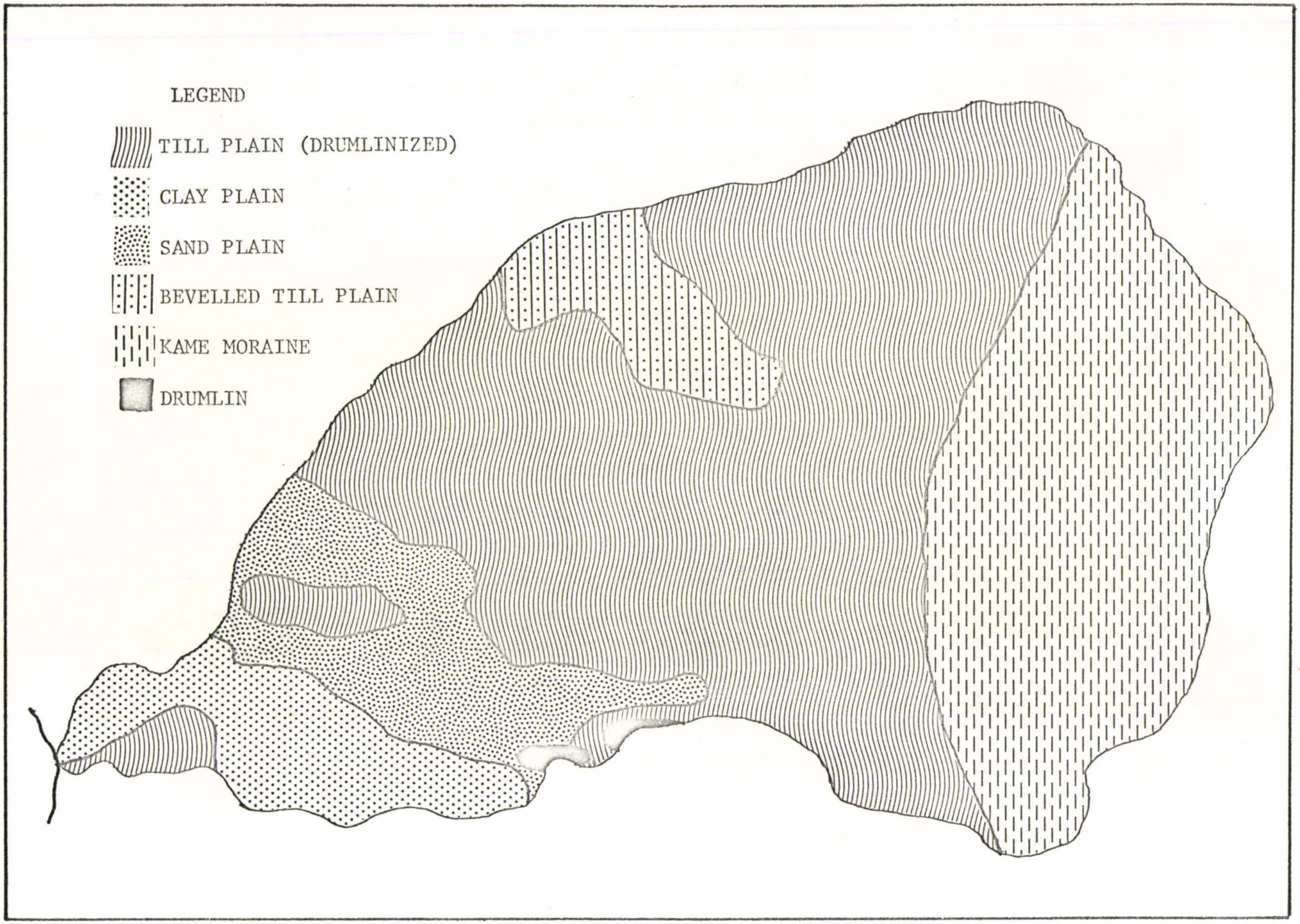


FIGURE 4: SURFICIAL DEPOSITS IN THE DUFFIN CREEK BASIN

1.4 Outline of the Research

The following discussion is concerned with providing a comprehensive and objective evaluation of high altitude photography as a data source for drainage network studies. Chapter II presents a review of the progress of research into the nature of drainage networks and discusses the early recognition of environmental controls that exist in drainage network development. This chapter in turn examines the need for an adequate data source to further such studies and outlines data source evaluations published to date. From these discussions, conclusions are drawn.

Chapter III outlines the nature of the information content of the photography that was of interest to this study, and in turn, the methods of research undertaken to extract this data. Chapter IV discusses the results and consequent analysis; the final chapter presents a summary of the research and conclusions drawn.

CHAPTER II

LITERATURE REVIEW

2.1 History of Drainage Network Studies

Man's interest in river systems and their drainage basins, both on a theoretical as well as a practical basis, has grown considerably in the last half century. With the abandonment of the concept of the cataclysmic origin of rivers in the 1700's the comprehension of the systematic pattern and orderliness of river systems has evolved. This evolution has progressed from an initial intuitive acceptance through qualitative description to rational statements of empirical fluvial laws. Today, utilizing the recognized topologic and geometric properties of drainage systems, attempts are being made to relate these properties to environmental factors.

Early notions concerning the development of fluvial systems were synthesized by William Morris Davis. These were incorporated into his model of cyclic erosion, outlined in his now classic papers (1889, 1890, 1909). He elaborated upon the fundamental observations and ideas of such investigators as Dutton (1882) and Hutton (1795), utilizing these earlier works as a supplement to his own ideas. This resulted in the inclusion of a generic classification of land forms within his Geographical Cycle. This major descriptive model then became the foundation for many landform studies of the next half century.

The generic description of fluvial processes dominated the thinking of investigators until the mid-twentieth century when Zernitz (1932), Horton (1945), Strahler (1952) and others investigated the geometry and topology of river networks in an attempt to quantitatively rather than qualitatively describe and classify these systems. As the quantitative study of stream networks progressed, the number of parameters used to determine and test the complicated interrelationships in stream networks likewise grew. Strahler (1957) reviewed and classified many of these measures and grouped them into three types of measurements:

1 Those properties measured or counted solely from the channel network and basin outline reduced to the horizontal
2 Those properties relating to the aerial measurement of the basins
3 Those properties of the systems involving differences in elevation.

By the 1960's a handful of laws of stream composition had been proposed and numerous coding and labeling systems had been set out as mechanisms for describing and identifying streams. These original laws and coding systems have, in most cases, been studied, modified and expanded. Such investigators include Maxwell (1960), Melton (1959), Schreve (1964), Schumm (1954), Broscoe (1959), Bowden and Wallis (1964), and Morisawa (1959). For the extent of this work see Tables II and III.

From their work many systems of taxonomy have resulted. All, however, are based on channel network topology, and there now exists a wide range of topologic and geometric measures, based on a varying number of stream parameters that are applicable to branching networks. Attempts have been made to correlate these indices with such known physical characteristics of drainage basins as surficial deposit type

TABLE II

LAWS OF DRAINAGE COMPOSITION

Law	Author
Law of Stream Numbers	Horton, R.E. (1945)
Law of Stream Lengths	Horton, R.E. (1945)
Law of Stream Slopes	Horton, R.E. (1945)
Law of Stream Areas	Schumm, S.A. (1954)
Law of Basin Relief	Maxwell, J.C. (1960)
Law of Basin Diameters	Maxwell, J.C. (1960)
Law of Path Numbers	Haggott, P. (1967)
Law of Link Lengths	Gosh, A.K. and A.E. Scheidegger (1971)
Law of Average Stream Fall	Yong, C.T. (1971)

Source: Bruce, 1974.

TABLE III

BASIN PROPERTIES OF GEOMETRY AND TOPOLOGY

Linear Measures

Property	Author
Bifurcation Ratio	Horton, R.E. (1945)
Basin Order	Horton, R.E., Strahler, A.N. (1952)
Stream Length Ratio	Horton, R.E., Strahler, A.N. (1952)
Total Length of all Channels in a Basin	Horton, R.E., Strahler, A.N. (1952)
Channel Segment Frequency	Horton, R.E., Strahler, A.N. (1952)
Stream Junction Angle	Horton, R.E., Lubowe, J.K. (1964)
Basin Perimeter	Smith, K.G. (1950)
Strahler Stream Order	Strahler, A.N. (1952)
Main Stream Length	Jack, J.T. (1957)
Fineness Ratio	Melton, M.A. (1957)
Cumulative Length of Segments of order u	Broscoe, A.J. (1959)
Basin Length	Maxwell, J.C. (1960)
Consistent Stream Order	Scheidegger, A.E. (1965)
Absolute Stream Order	Woldenberg, M.J. (1966)
Number of Segments of order u	Haggett, P. (1967)
Link Magnitude	Shreve, R.L. (1967)
Wandering Ratio	Smart, J.S., Surkan, A.J. (1967)
Mesh Length of Main Stream	Smark, J.S., Surkan, A.J. (1967)
Proportional Stream Order	Stall, J.B., Fok, Y. (1968)
'E' Index	Jarvis, R.S. (1972)

...continued

TABLE III---continued

BASIN PROPERTIES OF GEOMETRY AND TOPOLOGY

Property	Author
Area Measures	
Drainage Density	Horton, R.E. (1945)
Circularity Shape Ratio	Miller, V.C. (1954)
Drainage Basin Area	Schumm, S.A. (1956)
Stream Area Ratio	Schumm, S.A. (1956)
Constant of Channel Maintenance	Schumm, S.A. (1956)
Elongation Shape Ratio	Schumm, S.A. (1956)
Unity Shape Factor	Smart, J.S., Surkan, A.J. (1967)
Height Measures	
Gradient of Segments of order u	Horton, R.E. (1945)
Stream Slope Ratio	Horton, R.E. (1945)
Basin Relief	Strahler, A.N. (1952)
Relief Ratio	Schumm, S.A. (1954)
Ruggedness Number	Melton, M.A. (1957)
Relative Relief	Melton, M.A. (1957)
Main Channel Slope Index	Benson, M.A. (1962)

Source: Bruce 1974

or discharge. The point of such analysis has been to provide an objective basis for comparison of drainage networks in various hydrologic and geomorphic environments.

Given the current usage of topologic and geometric data as a basis for quantitative stream pattern analysis, the need for a reliable and accurate data source is apparent; inaccurate data is a major limitation to any investigation, as the validity of results is a direct function of the accuracy of the data base. Therefore, the absence of a reliable data source has limited the practical application of research into the environmental factors involved in river network development. This has tended to negate the impact of such useful tools as network analysis.

2.2 Sources of Drainage Network Data, A Review

Drainage network data has traditionally been derived from three sources: Topographic maps, Ground surveys, and Aerial photography. As stated, stream network data, derived from topographic maps, is too inaccurate and inconsistent and these maps are therefore, an inadequate data source for any but the most cursory network study. Morisawa (1959), utilizing 1:62,300 scale U.S.G.S. topographic sheets demonstrated their unreliability for measuring all drainage characteristics except area. Leopold, Wolman, and Miller (1964) reinforced such conclusions demonstrating that the utilization of various map scales produced different values for stream network parameters. In an attempt to derive positive alternative approaches to increase the quality and quantity of the data provided by topographic maps, Strahler (1957) developed the method of V's. This approach, extending tributaries by the use of contour line configuration, however, proved to be highly subjective in that it produced uncertainties as to the classification of the smallest segments extended. All this evidence substantiates the contention that stream pattern data from topographic maps are unreliable, inconsistent, and generally are incapable of showing a drainage system which is proportional to the real network.

Due to the past failures of the previous approaches, it has been concluded that a detailed field survey is the most accurate data source available for network studies. Such surveys however, are constrained by time and monetary costs. In addition, they tend to be too subjective and therefore not widely applicable. As a consequence, the value of network data produced via this method is limited when compared with the overall perspective and detail available in an aerial photograph.

Although large and medium scale panchromatic aerial photography for large areas has been available since the 1920's, it was not until the 1960's that its potential was realized for the specific purpose of drainage mapping (Sternberg, 1961). Until this time drainage features had been simply used as an aid to geologic and geomorphic interpretation, i.e. linear drainage channels were used to interprete joints and fractures in the bedrock (Verstappen,1955, Melton, 1959). Also, drainage density and alignment were used to determine the parent material and underlying bedrock of an area, and the dip of those beds (Zernitz, 1932, Lueder, 1959). For example, the highest drainage densities were found to occur in shales, medium densities in phyllites, granites, sandstones and siltstones, while the lowest densities occured in limestones and gravels. It was also proven that if the sources feeding a system appeared to be asymmetrically distributed, the layers of the bedrock were known to dip at an angle from one to six degrees (Zernitz 1932).

While the restriction of aerial photography to such narrow usage was in part due to the lack of recognition of its potential, the major drawback to wider use was the physical limitations of the film. The differentiation of land and water was based solely on shades of gray and therefore, the quantity and quality of the data available for more extensive applications was poor.

Large and medium scale black and white infrared photography has also been utilized in drainage mapping and has proven itself superior to panchromatic photography (Parry and Turner, 1971). The advantage of this infrared film lies in the strong tonal contrast produced on the positive prints due to the lack of reflection in the near infrared segment of the spectrum from water bodies and the normal reflection, in these same wavelengths, from land bodies. Thus, the land-water interface is enhanced on the positive prints showing dark areas for water and lighter tones for the land.

The advantages of colour photography has also been demonstrated with reference to the colour presentation itself (Parry, 1969). The most useful photographic film developed for purposes of drainage mapping has proven to be colour infrared film (Marshal, 1968).

This false colour film, because of its near infrared detection capabilities, enhances the contrast between areas of varying soil moisture content. This is not only useful for separating water-filled channels from the surrounding land surface, but is also of use in differentiating those channels which retain a higher soil moisture content than the surrounding area even though "dry". In addition, colour infrared photography also emphasises vegetation contrasts which are as useful an indicator of low order drainage segments as the land/water contrasts.

All the above mentioned photography contains a number of disadvantages. Due to the scales employed (large or medium), a large number of prints are required to cover even a moderately sized area. This necessitates relatively large expenditures of time and money to acquire, print and handle the data. Such expenditures are, however, considerably less than those required for field surveys. Secondly, it is rare that large areas are covered in a single low altitude mission; an important prerequisite when one considers the highly dynamic nature of hydrologic processes. Even with these considerations, colour infrared film provides the most practical and valuable information of any photographic sensor system considered to this point.

Recent work (Howarth and Bruce, 1973) has demonstrated the superiority of an alternate drainage network data source, i.e. high altitude, small scale photography. The practical benefits of this small scale colour near infrared photography have proven to be two-fold. First, the small scale offers improved recognition of regional trends due to the fact that each frame covers a large ground area. The drainage mapping is thus facilitated by the small quantity of prints to be handled. For example, one 1:120,000 scale, 9 inch x 9 inch (23 cm x 23 cm) high altitude print covers an area of 290 sq. miles (751 sq. km) while a 1:15,000 scale 9 inch x 9 inch (23 cm x 23 cm) photograph only covers 4.5 sq. miles (11.7 sq. km). Thus, at the larger scale, without stereo coverage, over 90 photographs are needed to cover the same area as the one high altitude print. The uniform colour and tone characteristics of this one print, as opposed to the medium and large scale mosaics of the same area, also facilitate ease in interpretation, and improved efficiency and continuity of mapping.

The second advantage of small scale colour near infrared photography is the apparent financial practicality of obtaining drainage network information at desired times within the hydrologic year as a reduction in scale results in a reduction in time and monetary costs. This would facilitate drainage network research to a degree hitherto impossible. Therefore, of the data sources available to date, high altitude false colour photography is proving itself to be the most statistically accurate, consistent and economically viable data source for the purpose of furthering research in the hydrologic and geomorphic interpretation of drainage systems.

CHAPTER III

DRAINAGE NETWORK MAPPING AND COMPUTER PROCESSING

3.1 Mapping Attributes and Data Sources

A major problem to date in drainage mapping has been the difficulty in defining what constitutes a first order tributary. It must be realized that the definition of such a first order or primary tributary is arbitrary, as the actual order of a channel is a dynamic phenomenon which depends upon seasonal variations within the drainage basin. The temporal nature of the aerial photography therefore, allows for the recognition of these seasonal fluctuations in first order tributaries. That is, any drainage maps, produced from these data sources, will vary depending upon the time of year in which the photography was flown.

For the purpose of this study, the mapping data was derived from high altitude coverage flown during the spring (May), summer (June) and fall (October) to demonstrate its temporal variability and to allow the author to statistically assess the accuracy of data derived from the above source and compare it to that derived from alternate inconsistent sources, i.e. topographic maps. Drainage maps were subsequently compiled for the three selected basins from the above applicable data sources. While three basins were selected for study however, coverage at one scale (1:120,000), in all three seasons, was only available for Forty Mile Creek and Bowmanville Creek. This scale was preferred over the alternate

1:60,000 scale because of the latter's incomplete coverage between flight lines for the desired basins, and because much of the research to date has concentrated on 1:60,000 scale drainage mapping from the high altitude data source. From the initial inspection of the photography it was the author's contention that the 1:120,000 scale data source would prove to be as accurate as the 1:60,000 scale data source for the purpose of drainage mapping. Table I contains the photographic specifications for each basin mapped.

In addition to the above, Forty Mile Creek was also mapped from the 1:60,000 scale photography to compare the accuracy of this scale with the 1:120,000 scale photography data. The stream network data for all the basins was also acquired from 1:50,000 scale topographic map sheets. This latter scale was selected as the base scale from which to compare all the data sources, as mapping at this scale is both efficient in mapping time and allows a significant amount of detail to be mapped. The uniform scale also facilitated both a visual and statistical comparison of the data sources.

3.2 Instrumentation for Mapping

The stream network data was obtained from the photography by the use of a Bausch and Lomb Zoom Transfer Scope. Through the use of this instrument, the photography was optically enlarged and superimposed on the 1:50,000 scale topographic base map. Compensation for scale errors was accomplished by optically stretching the photographic image to match the 1:50,000 scale base map. Once the photography was optically corrected to the topographic base map, the drainage pattern data from the photography was delineated on an overlay, (of the base map) by viewing this superimposed photography through the optical system. Drainage network details were checked using a Bausch and Lomb 240 R Stereoscope.

3.3 Mapping Technique

On the colour infrared photography the water bodies and stream networks stand out in much darker tones than the surrounding landscape. As stated, this is due to the lack of reflected radiation from the water surfaces in the near infrared wavelengths. This facilitates mapping the stream networks by enhancing the contrast between the channels and the surrounding environment, even when the channels contained little or no surface water. This was due to the higher moisture content associated with these channels producing a tonal contrast on the film that could be identified as a stream channel.

Mapping proceeded from the mouth to all the sources of each network. Interpretation of these drainage systems was extended to the point where primary tributaries broke down into interlocking networks. Such network forms are typical of areas which possess a high soil moisture content but no developed branching pattern. On occasions where the network was obscured due to terrain or vegetation the location of the network was interpolated (Figure 5 is an example of the photographic data source).

3.4 Computer Processing

Once suitable maps of the drainage basins had been obtained,

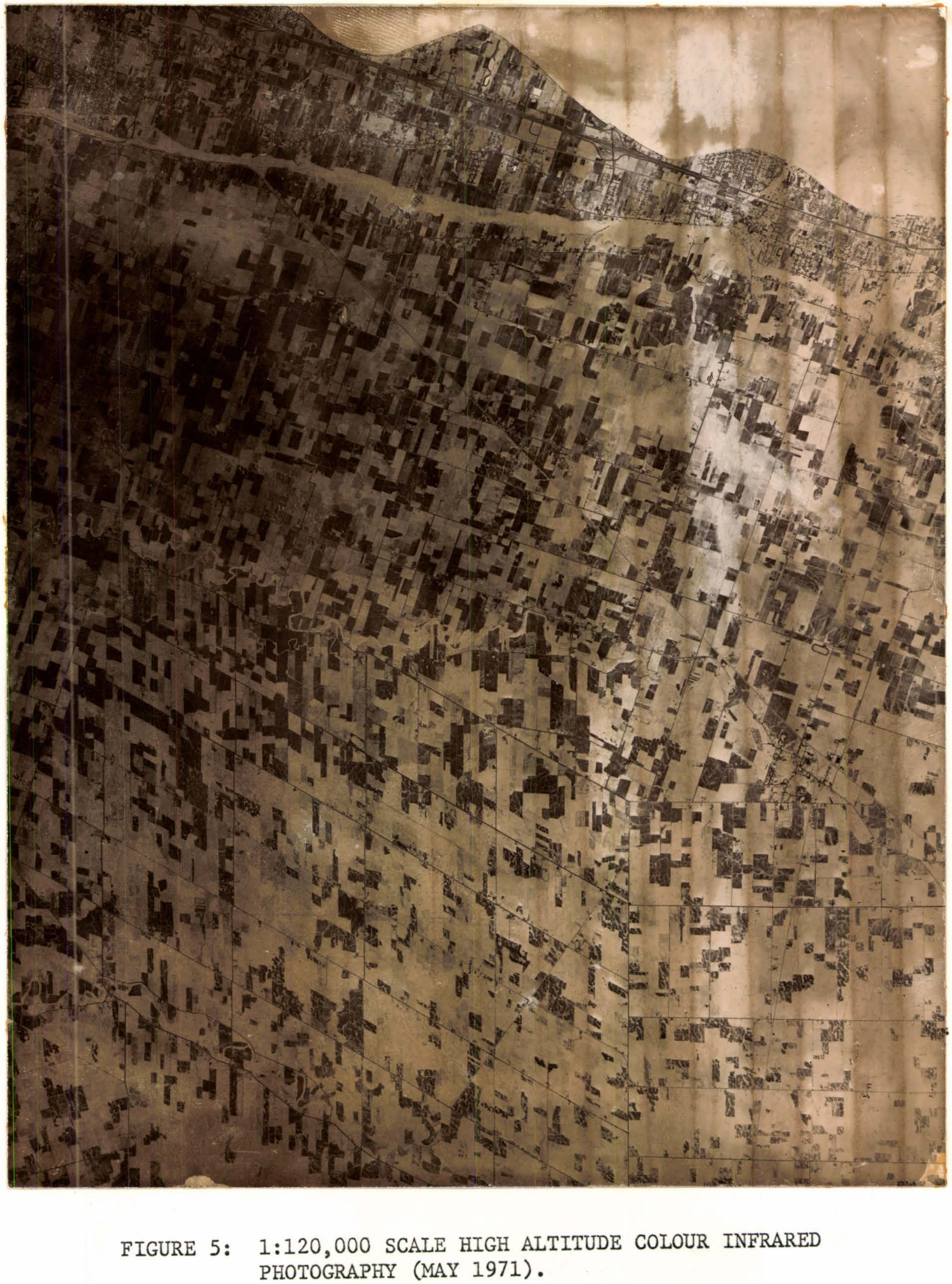


FIGURE 5: 1:120,000 SCALE HIGH ALTITUDE COLOUR INFRARED PHOTOGRAPHY (MAY 1971).

streams and basin boundaries were coded to facilitate statistical analysis. A Ruscom-Logics Digitizer was used to accomplish the analog-digital transformation.

The basic input requirements for the statistical routine used are the coordinates of a series of control points on the drainage network maps and a 'point code' defining the function of each control point. These point codes are used to define the topology of a network while the coordinates of each point define network geometry. In order for the network to be uniquely delimited, the points must be located according to a pre-defined sequence. The Ruscom-Logics Digitizer electronically encodes the coordinates of each control points while the operator codes that point function, i.e. stream mouth, junction, midpoint or end point. The data is automatically transferred to cards, through an IBM 29 Key punch, for computer analysis.

The data were analysed using the W.A.T.E.R. system of computer programmes; (Coffman, Turner, Melhorn, 1971). The input was initially compiled in a pre-run sequence which produced a plot of the basin (Appendix A). This was essentially undertaken as an echo-check of input data to ensure that all points had been coded correctly. The complete range of drainage network statistics for each basin, were then derived and displayed in tabular form through the main program sequence.

Due to the limited data handling capacity of the W.A.T.E.R. system and the large quantity of data derived for each basin, it was only possible and practical to perform a detailed analysis of one whole drainage system, i.e. Forty Mile Creek (Table IV). Comparative statistics were therefore only available for this one system (Table V). Figures

6 through 10 show the drainage network maps derived for the Forty Mile Creek basin.

3.5 Drainage Density Sampling and Mapping Network Variations

The mapped data for all three basins was utilized to demonstrate the usefulness of the photography for interpreting environmental factors of the drainage networks. This was accomplished through a random sampling of drainage densities and associated relief on known surficial deposits at sites depicted on the drainage network maps. This procedure consisted of recording drainage densitites and relief (slope in feet per mile) for square mile grid cells. Each included grid cell was selected by the use of random number tables. The cells were generated until all types of surficial deposits had been covered.

The anticipated variation in drainage densities were verified and the associations between drainage density, its material environment and slope analysed. In turn, an attempt was made to visually map the marked variations in drainage densities and configurations to compare these results with the physiographic units outlined by Chapman and Putnam. The latter analysis was conducted on all three basins using the 1:120,000 spring photography as the data source. This allowed for consistency in the comparative study.

Due to the low topographic gradient and extensively man modified environment of the Forty Mile Creek basin, the analysis of the results of the drainage density/slope data, and the analysis of the visual mapping results was conducted on the Bowmanville and Duffin Creek drainage maps.

CHAPTER IV

ANALYSIS AND RESULTS

4.1 The Validity of the Data Source

The analysis to substantiate the quality of detail and accuracy of the high altitude data source was conducted on the data obtained from the Forty Mile Creek basin (Figures 6 through 10). The details of the data sources which were used in the comparison are presented in Table IV. Fifteen basin characteristics for the subject basin, derived from the statistical analysis for each data source are compared in Table V. Only the drainage system parameters which aided in emphasizing significant similarities and differences among the various data sets have been included. Upon examination, these figures reveal that major variations between basin parameters arise when comparing the topographic map data and the high altitude photography data. It appears that the May 1:120,000 scale photography permitted the most detailed drainage mapping.

The proportionality and comparability of all these results was examined by Chi-Square analysis of the fifteen selected basin parameters. The test was conducted twice to minimize any bias due to the definition of expected and observed values; the topographic map data and then the May 1:60,000 data were treated as the expected values. From the results (Table VI) it may be seen that the data sources fall into two categories;

TABLE IV

FORTY MILE CREEK DATA SOURCES

Data Source	Scale	Date
Topographic Map	1:50,000	-
High Altitude Colour Infrared Photography	1:60,000	May 1971
High Altitude Colour Infrared Photography	1:120,000	May 1971
High Altitude Colour Infrared Photography	1:120,000	July 1970
High Altitude Colour Infrared Photography	1:120,000	July 1970

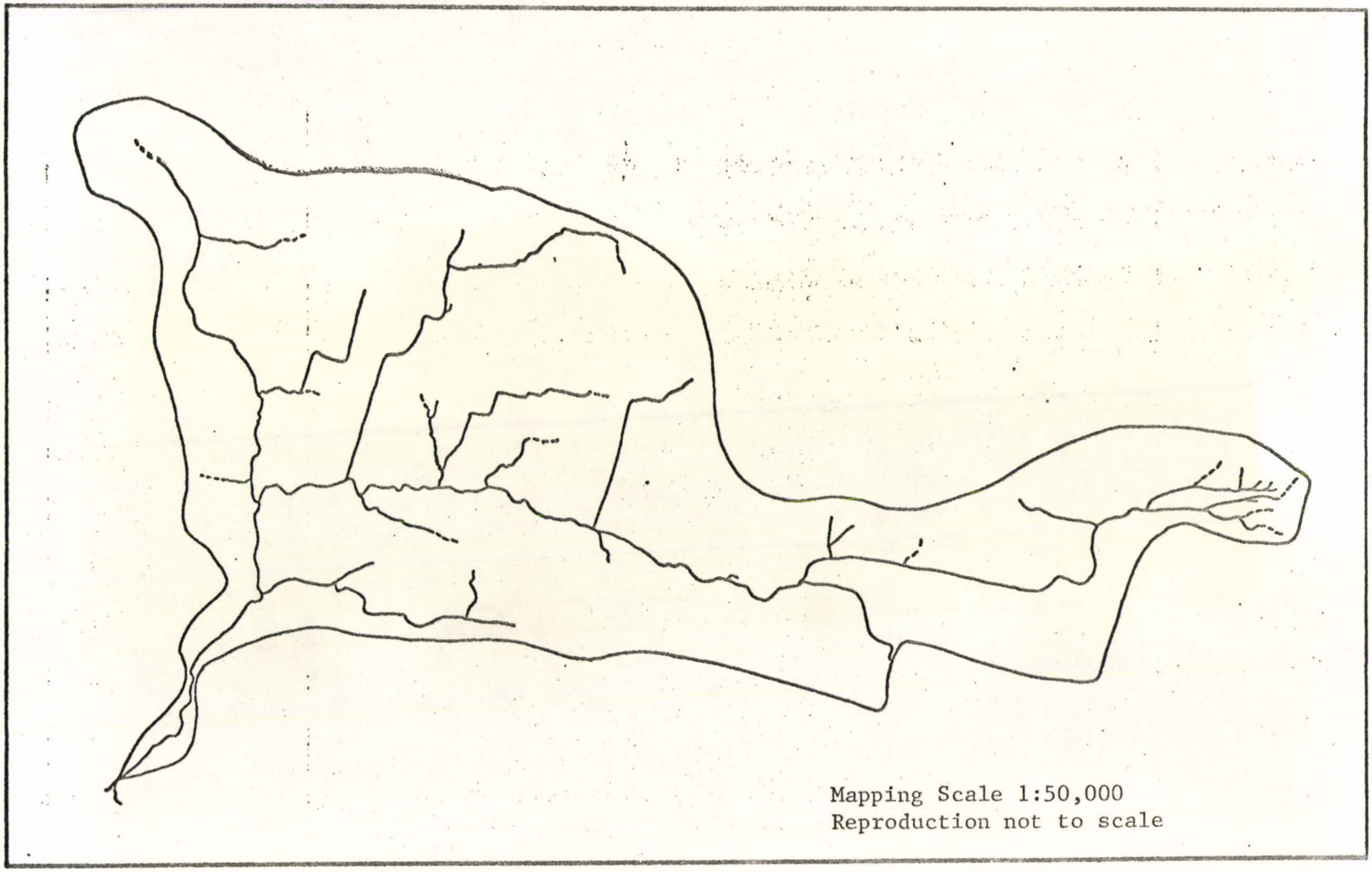
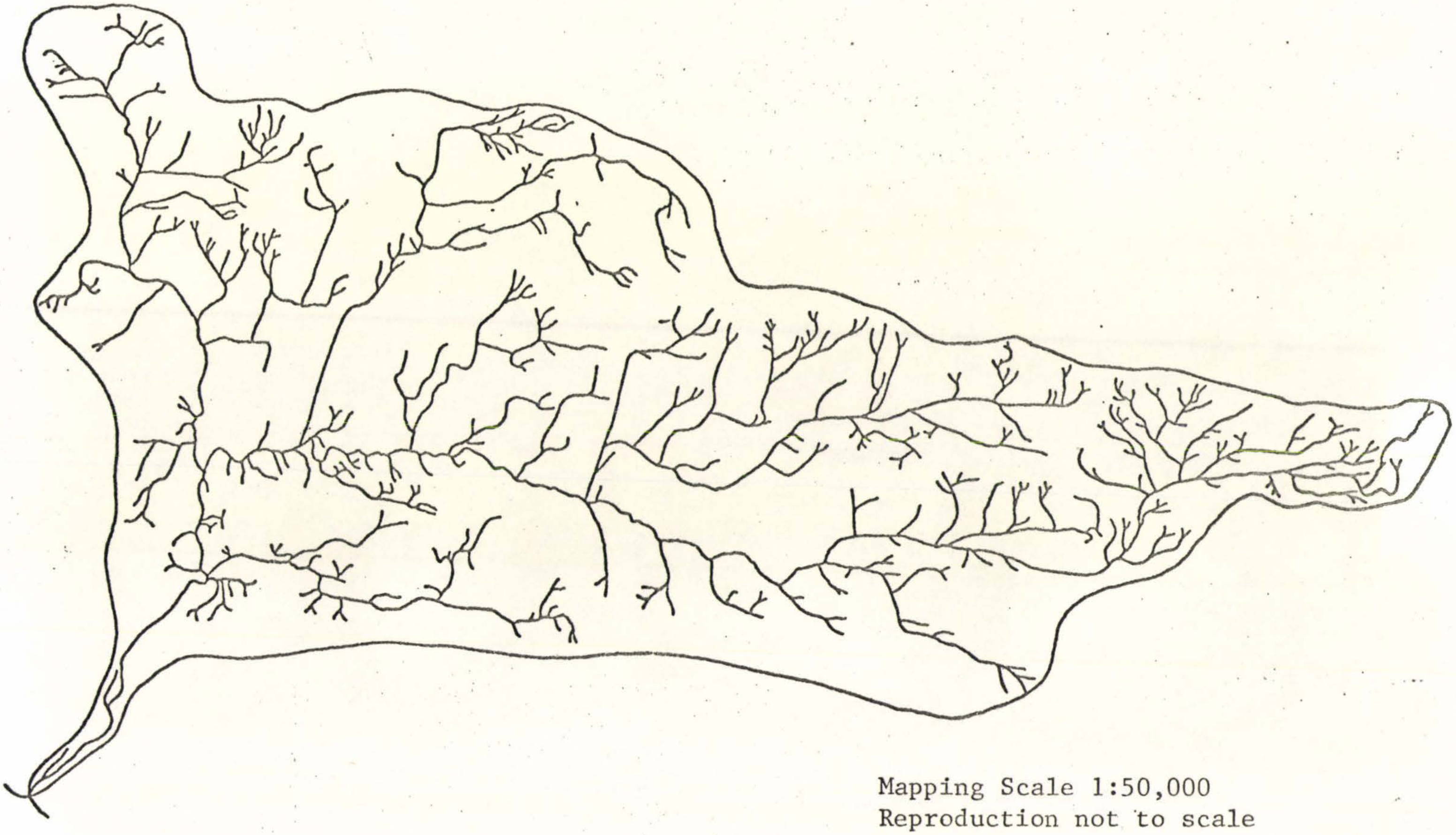


FIGURE 6: DRAINAGE MAP FOR FORTY MILE CREEK
FROM 1:50,000 SCALE TOPOGRAPHIC
MAP SOURCE



Mapping Scale 1:50,000
Reproduction not to scale

FIGURE 7: DRAINAGE MAP FOR FORTY MILE CREEK
FROM 1:60,000 SCALE PHOTOGRAPHY
(MAY 1971)

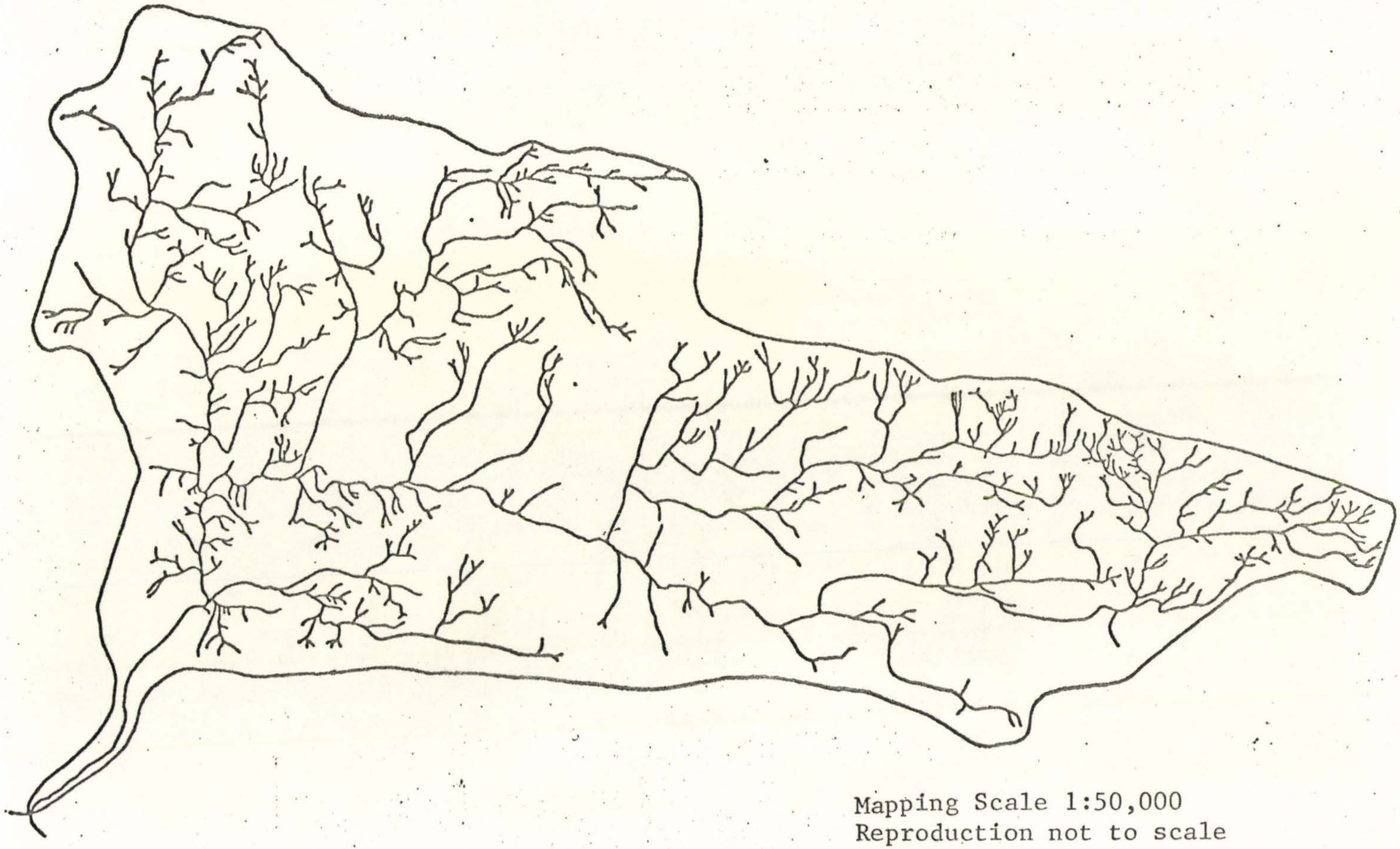


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FIGURE 8: DRAINAGE MAP FOR FORTY MILE CREEK
FROM 1:120,000 SCALE PHOTOGRAPHY
(MAY 1971)

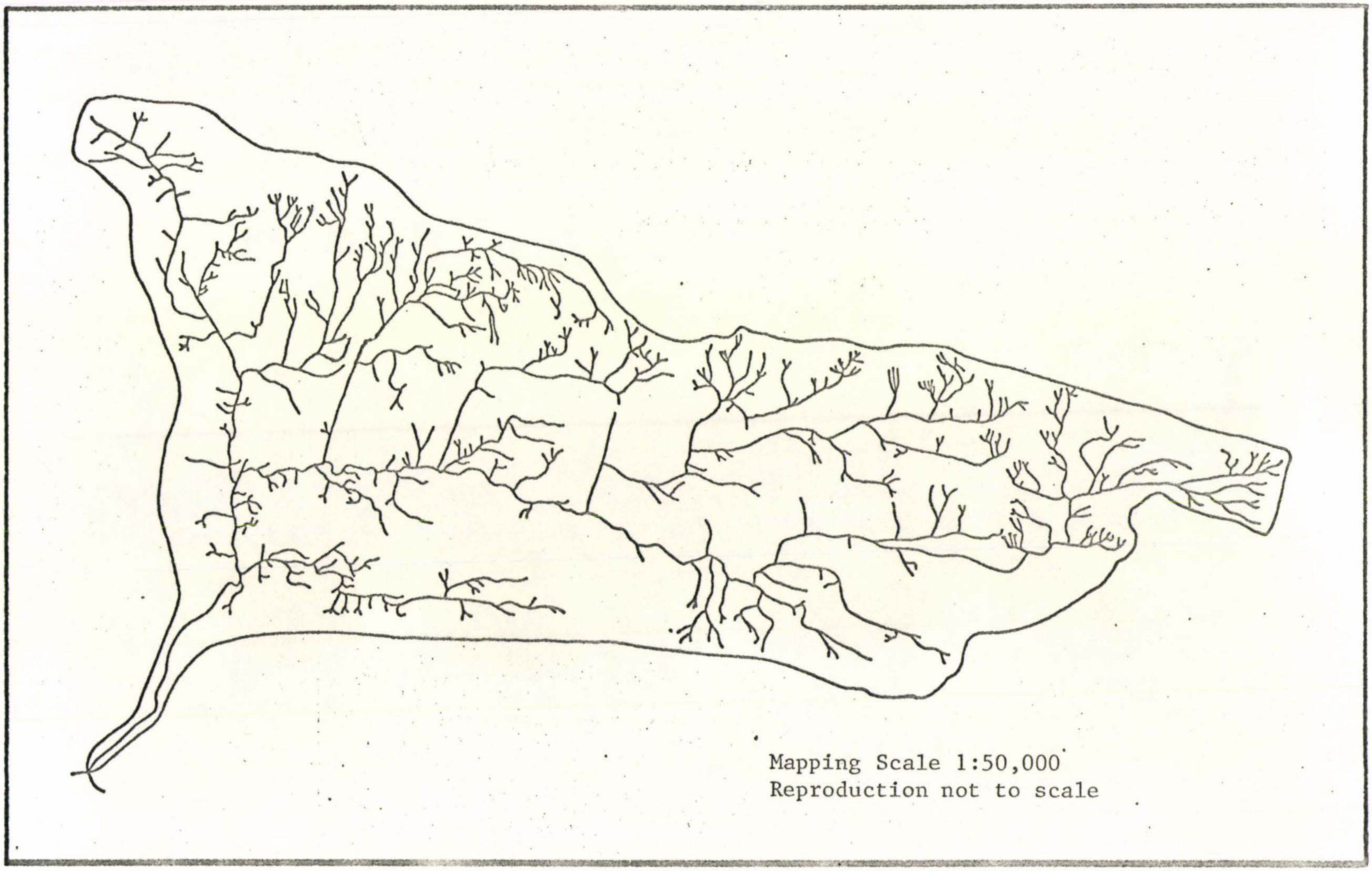

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FIGURE 9: DRAINAGE MAP FOR FORTY MILE CREEK
FROM 1:120,000 SCALE PHOTOGRAPHY
(JULY 1970)

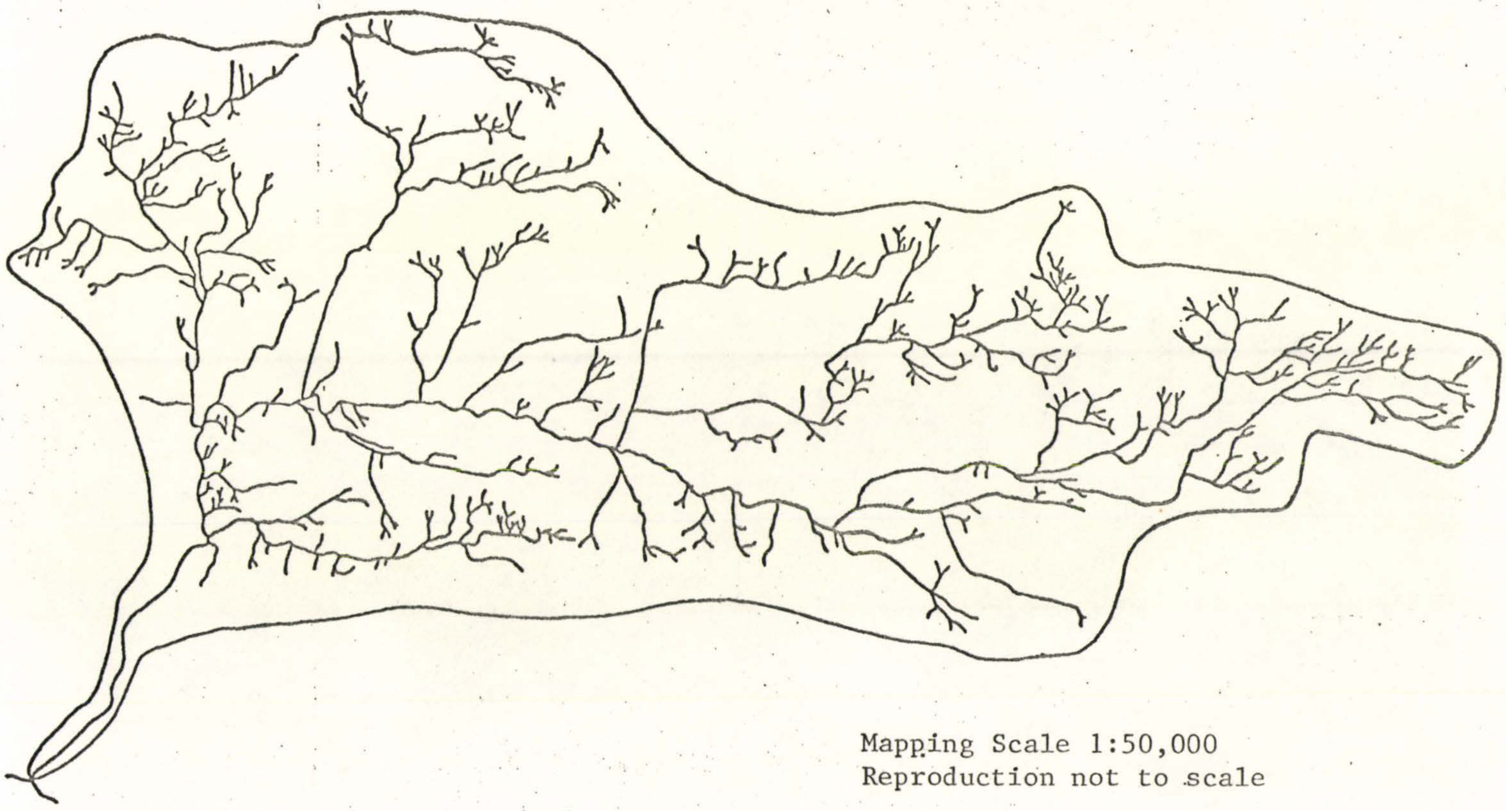

FIGURE 10: DRAINAGE MAP FOR FORTY MILE CREEK
FROM 1:120,000 SCALE PHOTOGRAPHY
(OCTOBER 1970)

TABLE V

SUMMARY AND COMPARISON OF BASIN CHARACTERISTICS FOR FORTY MILE CREEK

Parameters	Units	1:50,000 Topographic Map	May 1:60,000 Photography	May 1:120,000 Photography	July 1:120,000 Photography	October 1:120,000 Photography
Basin Order	Dimensionless	4	6	6	6	6
Number Segments each Order	Dimensionless	50	540	640	574	601
Total Length all Channels	Miles	38.86	114.11	124.26	106.97	106.07
Main Stream Length	Miles	11.83	12.33	11.91	11.68	11.66
Straight line length (mainstream)	Miles	9.16	9.62	9.22	9.29	9.33
Wandering ratio (mainstream)	Dimensionless	1.29	1.28	1.29	1.26	1.25
Basin Perimeter	Miles	27.78	27.08	26.75	26.19	24.71
Basin Length (diameter)	Miles	9.31	9.72	9.41	9.42	9.43
Basin Area	Square Miles	20.38	23.75	24.24	21.93	23.40
Drainage Density	Miles/sq. mile	1.91	4.81	5.13	4.87	4.53
Area of Circle with Basin Perimeter	Square Miles	61.36	58.35	56.92	54.60	48.57
Diameter of Circle with Basin Area	Miles	5.09	5.50	5.56	5.28	5.46
Basin Circularity	Dimensionless	.33	.41	.42	.40	.48
Elongation Ratio	Dimensionless	.55	.57	.59	.56	.58
Unity Shape Factor	Dimensionless	2.06	1.99	1.91	2.01	1.95

TABLE VI

CHI-SQUARE TESTS FOR FORTY MILE CREEK DATA

Test 1

Expected values = Topographic map data

Observed:

1	May	1:60,000	$x^2 = 4953.9$
2	May	1:120,000	$x^2 = 7205.8$
3	July	1:120,000	$x^2 = 5617.5$
4	Oct.	1:120,000	$x^2 = 6152.4$

Degrees of Freedom = 14

Critical x^2 value = 23.68 (.995 level)

Test 2

Expected values = May 1:60,000 data

Observed:

1	May	1:120,000	$x^2 = 19.5$
2	July	1:120,000	$x^2 = 3.1$
3	Oct.	1:120,000	$x^2 = 8.9$
4	Topographic Map		$x^2 = 497.4$

Degrees of Freedom = 14

Critical x^2 value = 23.68 (.995 level) the first consisting of the high altitude photography and the other consisting of the topographic map source. All the data derived from the high altitude photography sources appear to be proportional to each other.

4.1.1. Variations in Data Due to the Level of Detail Available from the Data Source

The basin parameters which appear to be least affected by the source of the data are those which are related to the mainstream properties of the basin. For example, the mainstream wandering ratio and the straight line length of the mainstream show a very high degree of proportionality between all five data sources. Conversely, the values of the characteristics that do show a wide variation appear to be dependent on the differing level of detail of lower order tributaries available from the topographic map source and the high altitude data source. This is demonstrated by the extreme variation in the number of segments of channels of each order for the various data sources. In particular, the lower order channels (Table VII) show a wide variation in number between the topographic map data and the high altitude data. Thus, the greater detail available from the high altitude photography is a function of the ability to map a greater number of lower order tributaries from this data source than from the topographic maps.

The variation in data at the interface between basins (the basin boundaries) is again due to the more detailed mapping potential of the high altitude photography source. This compares to the estimation of the basin boundary by "height of ground" from the topographic map source. The disparity between the data sources indicated by the

TABLE VII

SEGMENT NUMBER VS. ORDER FROM FORTY MILE CREEK DATA SOURCES

Order	Topographic Map 1:50,000	May 1:60,000	May 1:120,000	July 1:120,000	October 1:120,000
1	36	382	448	406	427
2	10	116	142	125	132
3	3	32	38	30	31
4	1	7	9	9	8
5		2	2	3	2
6		1	1	1	1

Chi-Square tests can therefore be seen to result from the higher level of detail derived from the high altitude photography.

It is important to determine if these levels of detail are proportional to each other. Given the assumption that these variations are due to different data resolution limits for the two sources, it may be hypothesized that the semilogarithmic plots for each data set should show a parallel relationship to each other (Strahler, 1957); a lag between individual plots would therefore represent variations in these levels of detail. This may be explained by the fact that when the logarithm of the length of segments of a given order is plotted against the corresponding order, most drainage basins yield a linear plot indicating a regular geometric progression. A similar but inverse relationship exists between the semilogarithmic plots of stream segment number verses stream order. Both of these data plots for the Forty Mile Creek data exhibit a parallel relationship and likewise show a lag as is suggested above, (Figures 11 and 12). The greater detail of the high altitude data source, as opposed to the topographic map source, is therefore made evident by this lag. The approximate correlation between the number of high altitude data source segments of each order confirms that the physical superiority of the small scale data source lies predominantly in its representation of lower order channels.

4.1.2. Variations in Data Due to Changes in Scale

The variations in detail recorded between the 1:60,000 and 1:120,000 scale photography appears to be a function of the quality of

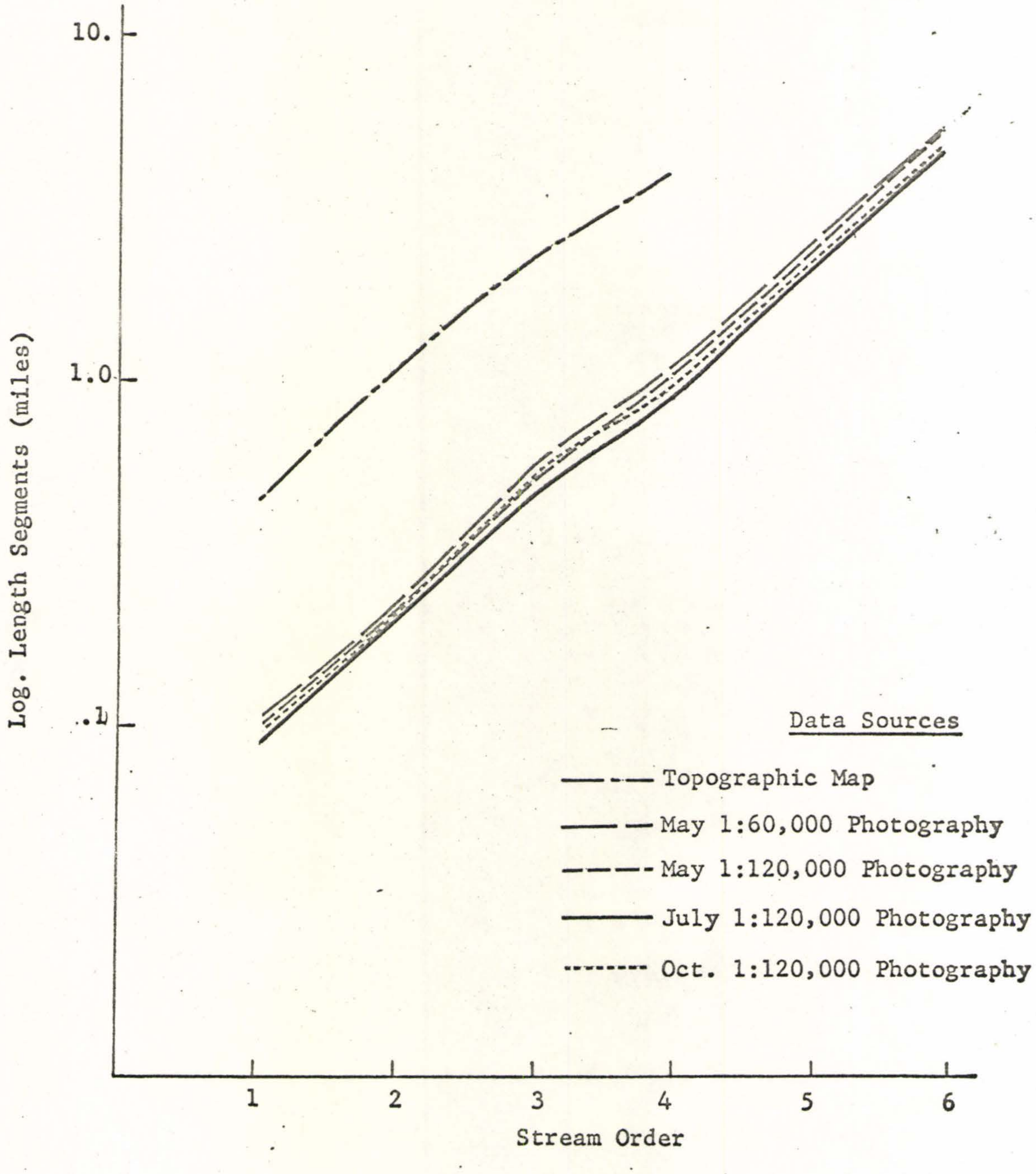

FIGURE 11 - STREAM SEGMENT LENGTH V STREAM ORDER FOR FORTY MILE CREEK DATA SOURCES.

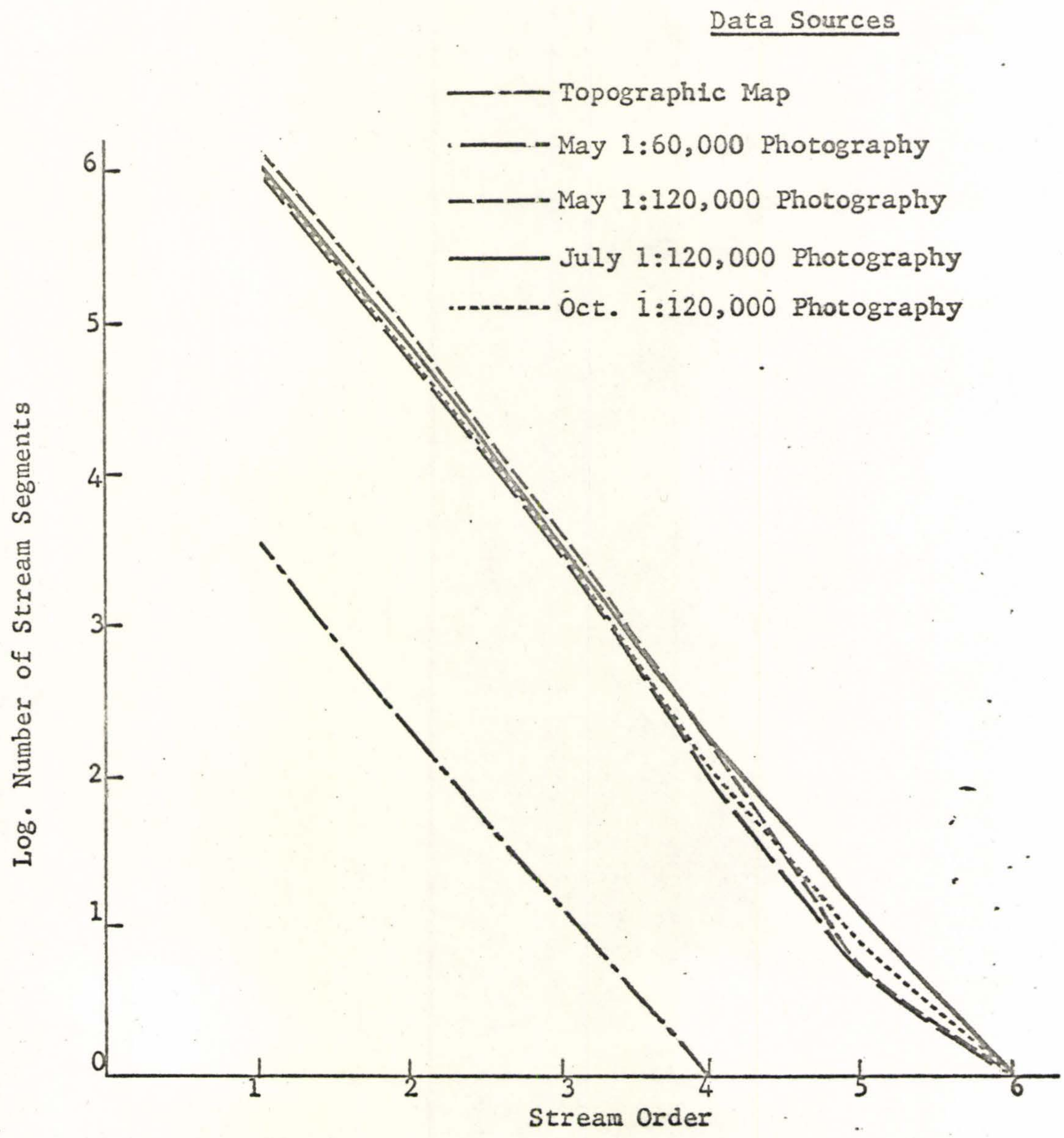

FIGURE 12 - STREAM SEGMENT NUMBER V STREAM ORDER FOR FORTY MILE CREEK DATA SOURCES.

the photography and is not significant. The 1:120,000 scale photography did provide a better regional perspective and reduced interpretation time as fewer photographs were used to cover the same basin area. This reduction in photographs and flight line miles offers an economic advantage over the 1:60,000 scale photography.

4.1.3. Variations in Data Due to Seasonal Fluctuations

The seasonal variations in stream channel networks are readily visible in the spring (May), summer (July), and fall (October) coverage which represents major contrasts in moisture content and stream flow conditions. The May photography was somewhat more useful for differentiating the first order channels, although in areas of low topographic gradient, a high moisture content at this time of year did result in some difficulty in distinguishing true channel drainage from transient wetlands.

The presence of heavy leaf canopies in the July photography made channel recognition in woodlots difficult. In this photography, and in the October coverage identification of the low order dry channels was somewhat more difficult (than in the spring photography).

4.2 The Potential of the Data Source for Interpreting Environmental Factors of Drainage Networks

The data for this analysis was derived from sample statistics taken from the following sources:

- High altitude colour Infrared photography 1:120,000 May (Forty Mile Creek)

-High altitude colour Infrared photography 1:120,000 May (Bowmanville Creek)
-High altitude colour Infrared photography 1:120,000 October (Duffin Creek)

The densities and slopes derived are for square mile sample cells derived by using random number tables on known surficial deposits. The results of this sampling are shown in Table VIII. The May photography was used as the source of data as it represented the most comprehensive and detailed networks. Of the drainage maps of Duffin Creek available (June and October) the latter was the most comprehensive.

Stream density is the total length of all channel segments per unit area, (miles per square mile). The stream densities of the sample sites range from 6.84 to 17.62 miles per square mile. Other factors being equal a high drainage density indicates a more effective operation of the agencies of stream erosion. Greater erosion for example, would be associated with steep land slopes. The opportunity for erosion would be greater where most of the discharge occurs as surface runoff rather than as ground water. Thus, the more impervious the surface material the greater the drainage density.

The stream density and slope results derived from the samples may be seen to demonstrate this. The means of the drainage density on each surficial deposit increase as the deposit type becomes more impervious (Table VIII). For example, the Sand Plain exhibited a drainage density of 7.59 while the Clay Plain had a relative drainage density of 14.50.

The magnitude of the drainage densities, from 6.84 to 17.62 may be seen to reflect the increased quantity and quality of the data

TABLE VIII

RELATIONSHIP OF SURFICIAL ENVIRONMENT TO DRAINAGE DENSITIES FOR TEST SITES FROM BOWMANVILLE CREEK AND DUFFIN CREEK

Surficial Deposit Type	Mean Drainage Density for Sample Sites	Standard Deviation of Samples
Sand Plain	7.58	.465
Till Moraines	11.81	.548
Till Plain (Drumlinized)	12.17	1.746
Clay Plain	14.51	2.582
Kame Moraines	15.19	2.000

derived from the high altitude colour infrared photography. For example, the overall drainage density of Forty Mile Creek derived from the topographic map source, was 1.9 miles per square mile, while drainage density calculated from the 1:120,000 May photography, for the same basin, was 5.1 miles per square mile.

The association between drainage density, slope and surficial deposit type (Figure 13) was evaluated by graphing the data. However, no direct relationship is demonstrated between an increase in slope and drainage density for any material except the Kame Moraines. This was due to the fact that all other deposits existed in a regular sloping but subdued topographic environment. The direct relationship between drainage density and slope for the Kame Moraines may be seen to result from the hummocky nature of the deposit where a large number of steep interfluves have developed.

The attempt at mapping the boundaries between surficial deposits by a visual analysis of the drainage network demonstrates the existence of wide transition zones in drainage pattern characteristics from one deposit to another (Figure 14). Although the material transition may be abrupt, the stream network must adjust to the new type of material over a variable distance, this distance being a function of both the new and old material over which streams of the network flow. Thus, the drainage pattern may be seen to change gradually over space and the sharp delineation of material types is, in most cases, difficult if not impossible to identify (Figure 15).

Sharp breaks in slope and small localized anomolies in the physical environment are visible, both of which may produce a radically

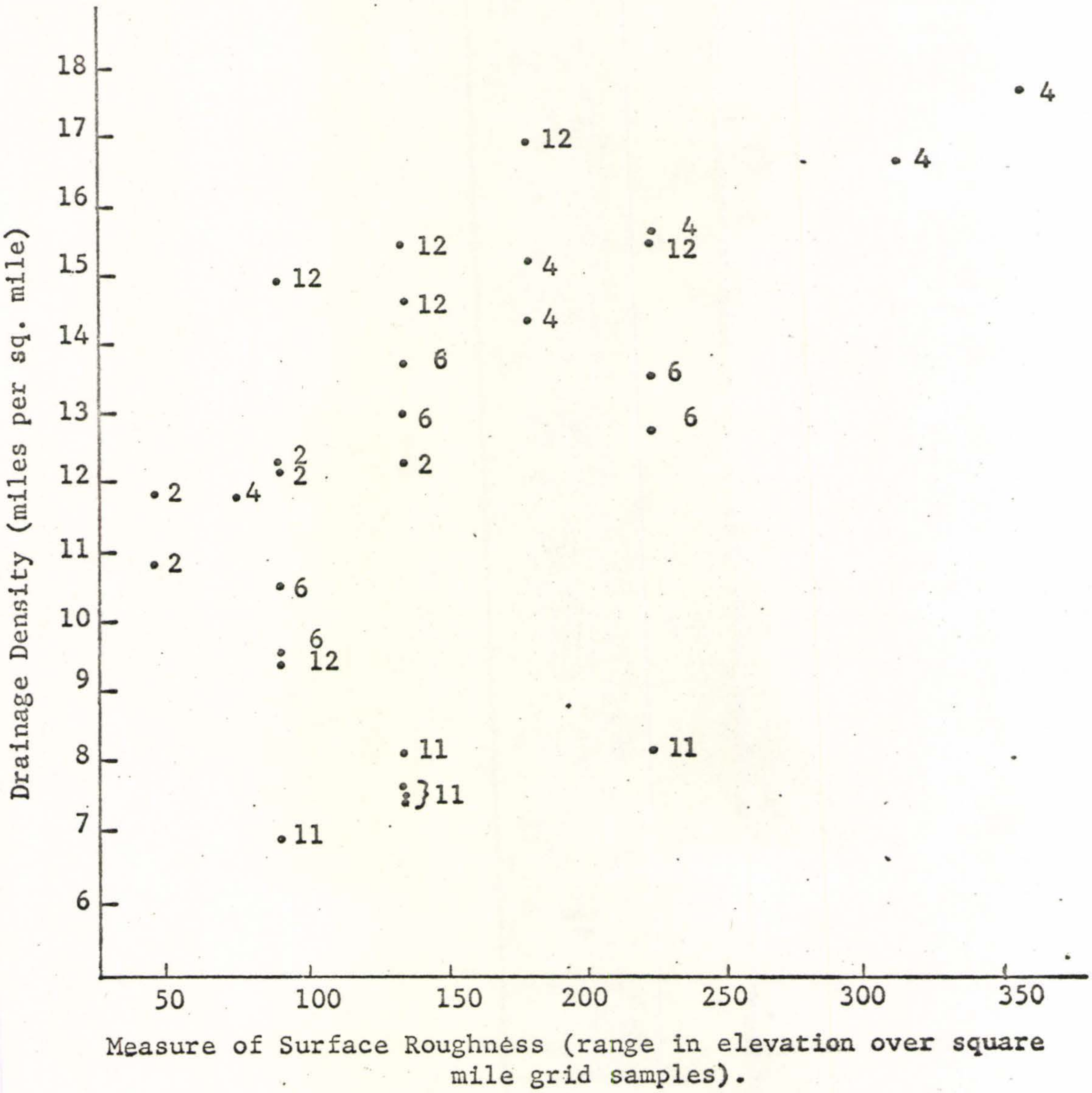

FIGURE 13 - THE RELATIONSHIP BETWEEN DRAINAGE DENSITY AND TOPOGRAPHIC GRADIENT FOR RANDOM SAMPLE SITES IN KNOWN PHYSIOGRAPHIC ENVIRONMENTS.

FIGURE 13---continued

LEGEND

Surficial Deposit Type	Codes as Designated by Chapman and Putnam, 1966
Till Moraine	2
Kame Moraine	4
Till Plain (Drumlinized)	6
Sand Plain	11
Clay Plain	12

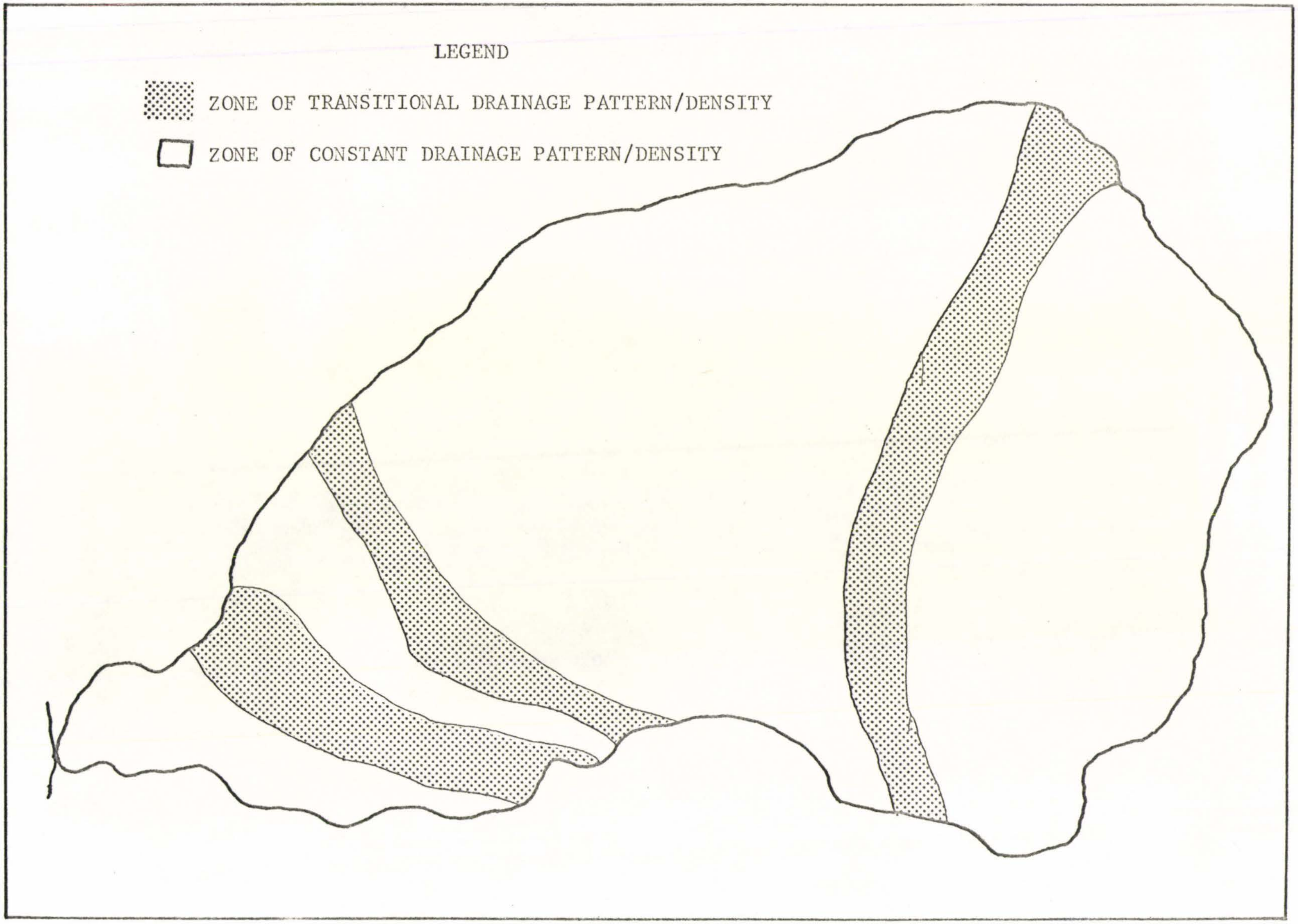

FIGURE 14: VISUAL MAPPING OF CHANGES IN DRAINAGE NETWORK PATTERN FOR DUFFIN CREEK

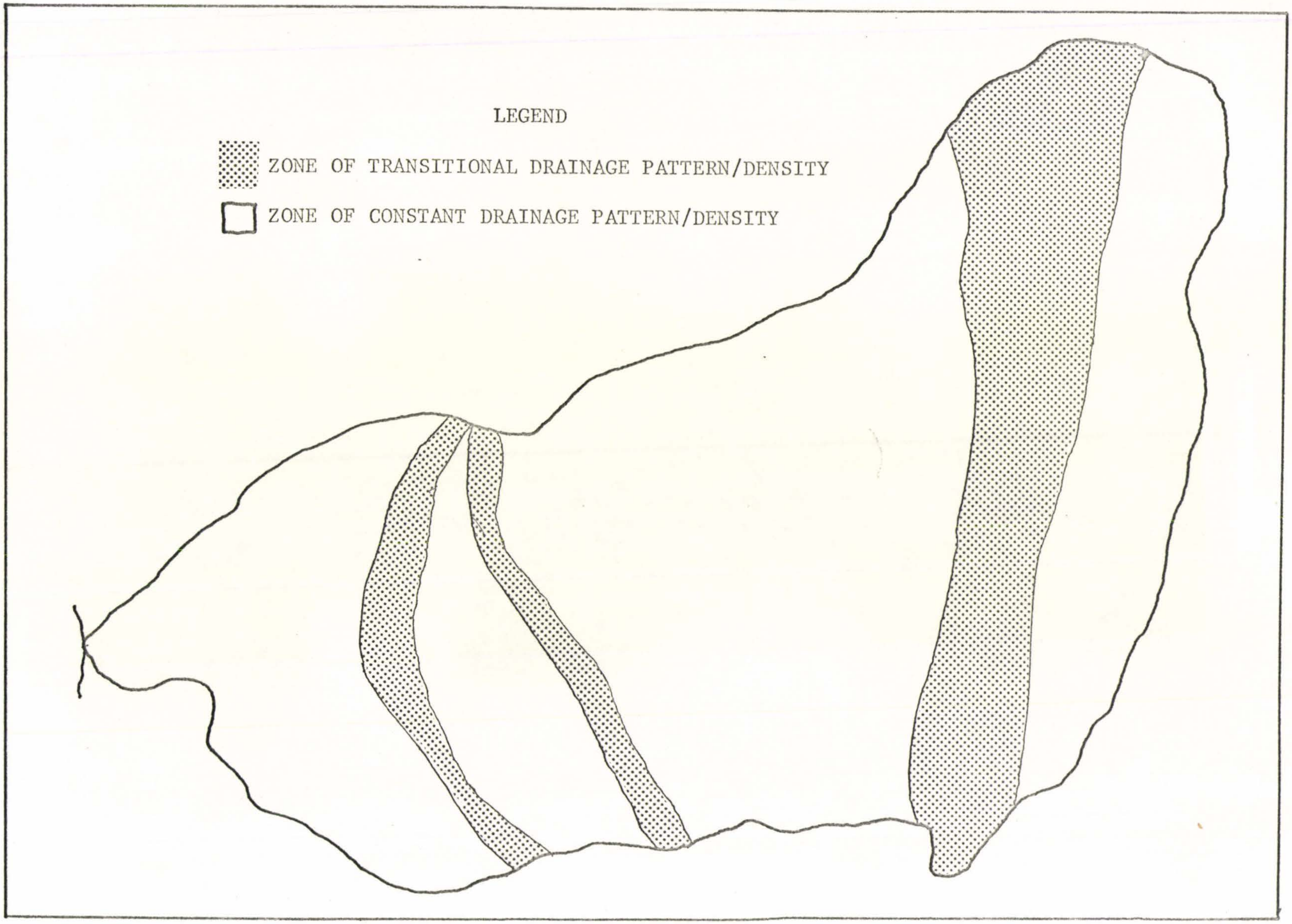

FIGURE 15: VISUAL MAPPING OF CHANGES IN DRAINAGE NETWORK PATTERN FOR BOWMANVILLE CREEK

different drainage pattern in a confined area. The latter may often be associated with the presence of man in modifying the drainage pattern. For example, the low lying areas of the Forty Mile Creek basin are modified by man's desire to control the drainage, producing a rectilinear pattern in the north-west corner of the basin.

In general, this human modification of the Forty Mile Creek environment and the generally very low topographic gradient lead to a marked lower drainage density in this basin when compared to the drainage densities found in Bowmanville Creek and Duffin Creek. Due to this fact the visual mapping of changes in drainage pattern and density were carried out on Bowmanville Creek and Duffin Creek.

CHAPTER V

SUMMARY AND CONCLUSIONS

5.1 Summary

The results of any research are no better than the quality of the original data. This is particularly true in the study of stream patterns and geometry. The major problem in meaningful and comparative drainage network analysis has been the lack of a statistically accurate data source. Recent studies have demonstrated the potential of high altitude colour infrared photography as a data source for drainage basin studies. The author investigated this potential by a statistical comparison of drainage network data derived from 1:50,000 scale topographic maps, 1:60,000 scale and 1:120,000 scale colour infrared high altitude photography. In turn, the derived network data was investigated to determine its value in interpreting environmental variables of drainage basin development.

5.2 The Advantage of High Altitude Colour Infrared Photography as a Data Source for Drainage Studies

From the analysis of the various data sources for the Forty Mile Creek drainage basin, it may be seen that very detailed and accurate drainage network data can be obtained from high altitude colour infrared photography. The drainage network data from this small scale photography are considerably superior in detail to that obtained from topographic map sources. Of the two high altitude photography scales under consideration, (1:60,000 and 1:120,000), the latter proved to be a more efficient source of data as the small number of frames produced resulted in a greater degree of uniformity of interpretation. The spring photography proved to facilitate a slightly higher level of detail but the summer and fall photography displayed a degree of proportionality that would validate using any of the 1:120,000 coverage as a data source for studies requiring general drainage network data. No problems arose from mapping drainage basins located in the various physiographic environments of the test sites.

The level of detail obtained in the mapping process might be better utilized on 1:25,000 scale base maps, rather than maps of the 1:50,000 scale, as the drainage systems tended to become to complex to analyse at the latter scale. The abundance of data did lead too a data handling problem as the W.A.T.E.R. programme utilized was only capable of handling the input from Forty Mile Creek. Bowmanville Creek and Duffin Creek, though mapped, exceeded the capacity of the programme.

From the drainage density analysis, the high densities may be seen as a function of the detail portrayed by the data source. While examples of drainage densitites quoted by standard texts and researchers range from 0.89 to 3.37 miles per square mile for humid regions (Langbein,1947), the densities derived from the high altitude data sources far exceeded these figures (Table VIII). The problem of any generalization concerning stream density measures derived from different data sources (eg. different topographic maps) may therefore be appreciated.

It follows that a standardized, efficient and comprehensive data source is required and the high altitude colour infrared photographic source appears to fulfill this need.

The variations in drainage densities within the same basin, and the similarities in drainage densities between basins in the same physiographic environment (Table VIII) tends to relate these drainage densities to their associated surficial environment. The drainage densities tend to increase with the more impermeable surfaces, as well as increasing in the region possessing a relatively higher topographic gradient. These relationships between the derived drainage densities and the surficial environment is significant enough to warrant further research into the utilization of these variations as an aid in identifying the nature of these surficial deposits by remote sensing techniques.

The transitional nature of the drainage pattern as it adjusts to its new environment when moving from one surficial deposit to another can account for the variation of drainage densities within the same physiographic units. The high and low sample densities associated with one surface material can be accounted for by this transition zone. The visual mapping of the variation in networks demonstrates the stream's attempt to adjust to a new environment, and how abruptly or slowly this can be achieved.

5.3 Future Studies

With the potential of the high altitude platform and colour infrared photography verified for drainage network studies, the realistic possibilities now exist for their utilization as data sources to facilitate a further understanding of the environmental controls involved in drainage network development. Through the employment of seasonal mapping, a composite drainage map might be developed which accounts for all seasonal variations; in turn, the seasonal variations themselves may be similarly analysed for the purpose of deriving evidence of the various environmental controls that exist. At the very least however, a standard now exists from which meaningful comparative studies may be undertaken.

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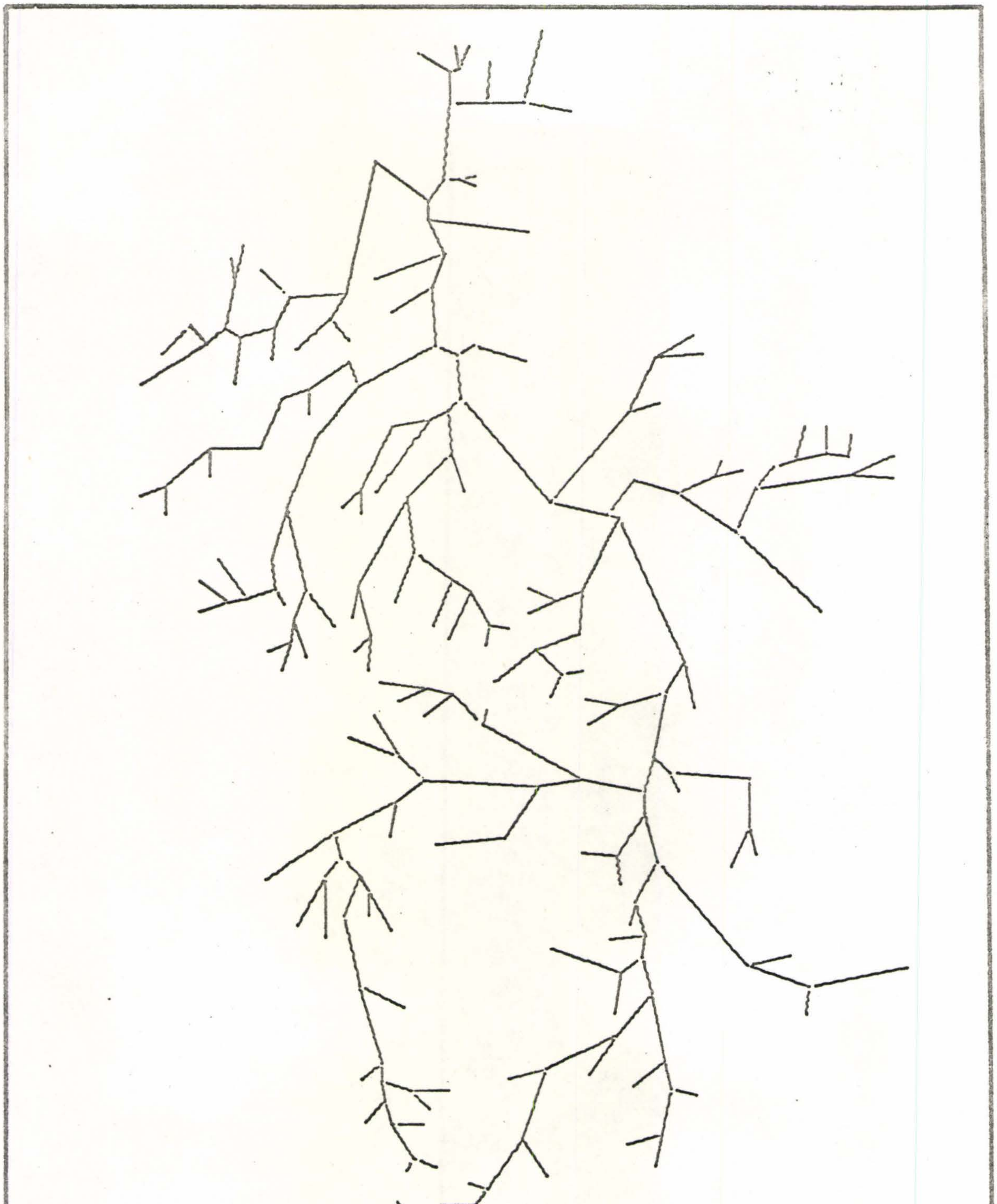

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FORTY MILE CREEK STUDY  SUB 1
1-120000 HIGH ALT PHOTO. MAY 71.
SCALE: 1 INCH =  25923 DATA UNITS.
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APPENDIX A: PRERUN OUTPUT FOR W.A.T.E.R. PROGRAMME