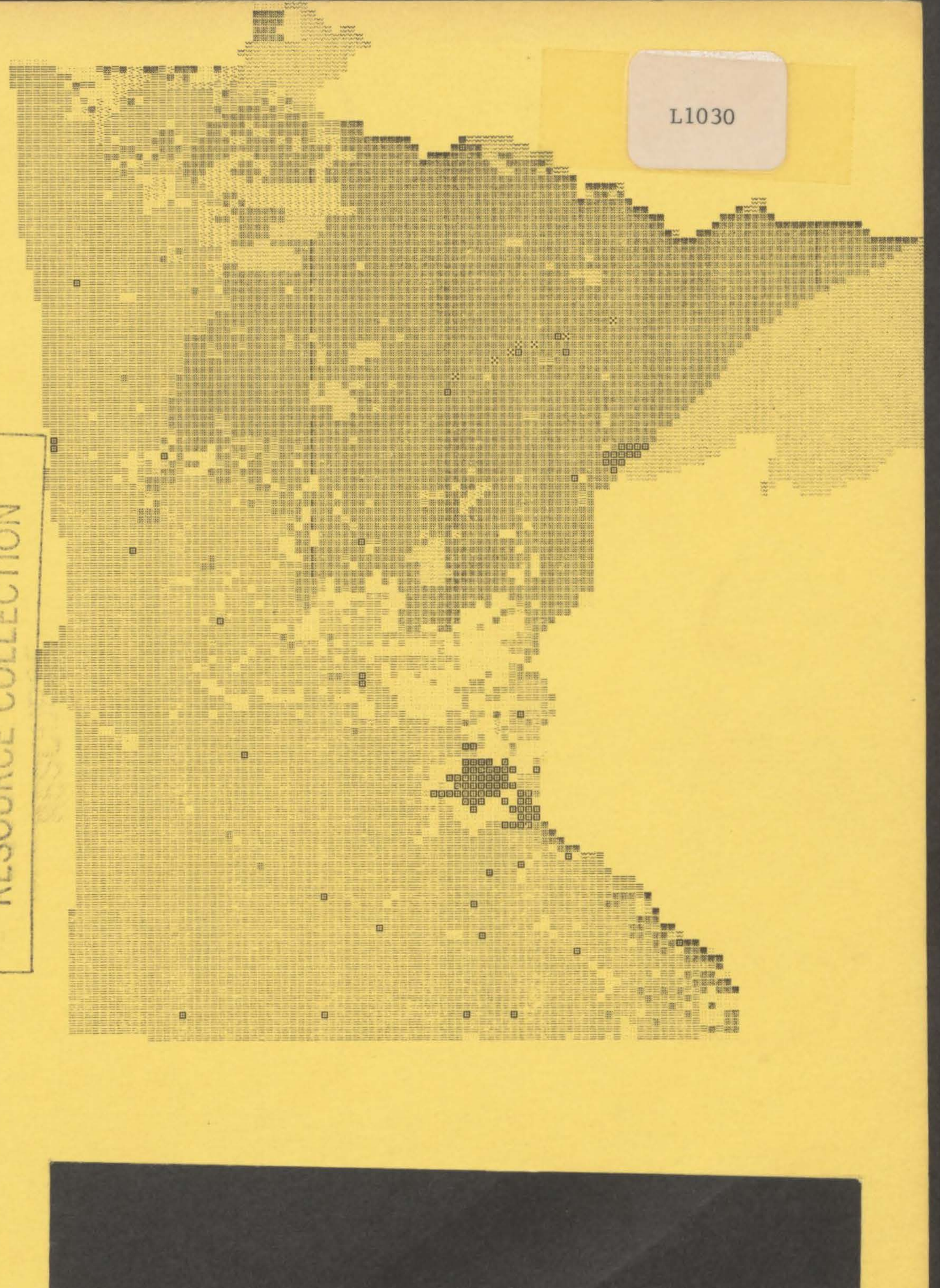
MLMIS



MINNESOTA LAND MANAGEMENT INFORMATION SYSTEM

WRITTEN BY: Robert Borchers

Barbara Deick

Bryan Higgins

Scott Nessa

SYSTEMATIC WATERSHED MAPPING IN MINNESOTA

ACKNOWLEDGEMENTS

This project has been a joint effort of the Minnesota Land Management Information System (MLMIS) Study and the Water Resource Research Center (WRRC) through funds made available from the Office of Water Research and Technology (OWRT), U.S. Department of the Interior, Project No. A-031-Minn. We wish to thank George Orning for his advice and support in planning and carrying out this project and Dennis Asmussen for his editorial assistance.

TABLE OF CONTENTS

For examples illustrating this text see:

1.) Map of Watershed Boundaries of the Arrowhead Region,

2.) Schematic Watershed Diagram of the Arrowhead Region,

Which are currently in press.

I: NEED FOR A COMPREHENSIVE WATERSHED MAP

The compilation of accurate water information, particularly watershed boundaries and stream flow characteristics, has lagged behind the documentation of land characteristics in Minnesota. This is unfortunate because of the contribution accurate watershed information can make to general planning tasks or the assessment of the environmental impacts of changes in land use.

Watersheds occur in a complex set of relationships with other natural systems including vegetation, soil, and slope. Through such processes as erosion, mass wasting, leaching and deposition, the chemistry of a watershed basin's runoff is determined. Thus, watersheds are connected to virtually all land and water based events such as construction activities or mining.[1]

Because of the importance of water information in planning and impact forecasting and the paucity of its documentation, the Minnesota Land Management Information System (MLMIS) began a search for comprehensive watershed maps. It was intended that such data, if available, would be added to the existing land and water information stored in MLMIS computer files. Watershed maps of northeastern Minnesota were sought first, since initial research at MLMIS focused on the Arrowhead Region (Region 3) in northeastern Minnesota.

The uses to which the data would be put require accurate and detailed watershed boundaries that are mapped for the entire state. As a result, maps lacking statewide coverage were rejected. Statewide maps were analyzed in depth for detail and accuracy.

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[1] See: "Relationships Between the Chemistry of Minnesota's Surface Waters and Wildlife Management," The Journal of Wildlife Management, Volume 20, Number 3, July, 1956.

A number of state and federal agencies have previously mapped all or part of the Arrowhead Region. The agencies in question include:

1) Department of Agriculture

   a. Forest Service - map of Superior National Forest watersheds.

   b. Soil Conservation Service (SCS) - entire state completed.

2) Department of the Interior - U.S. Geological Survey (USGS), Water Resources Division - about 20 percent of the quadrangles for the state at least partially completed.

3) Minnesota Department of Natural Resources (DNR), Division of Waters - about 75 percent of the state completed.

4) Pursuant to Public Law 566 and the Minnesota Watersheds Act, special purpose watersheds have been established for much of the state.

An analysis of the accuracy of the various watershed maps revealed significant variation in the location of watershed boundaries. Furthermore, procedures followed in the determination of watershed boundaries are undocumented, making it impossible to independently replicate the maps, or to expand existing maps into unmapped areas. A search for other sources of watershed delineation procedures was not successful. The literature treating watersheds and their graphic determination invariably uses as a model mature landscape types avoided by the last onset of continental glaciation.[2] The boundaries of mature stream watersheds are easily identified, while in recently glaciated landscapes they are not.

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[2] SEE:

Bloom, Arthur L., <u>The Surface of the Earth</u>, 1969, pp. 54-55, 90-99.
Chorley, R.J., "The Drainage Basin as the Fundamental Geomorphic Unit," <u>Water, Earth and Man</u>, 1969, pp. 77-98.
Leet, L. Don and Judson, Sheldon, <u>Physical Geology</u>, 2nd Ed., 1954, pp. 159-197.
Borchert, John R. and Yaeger, Donald P., <u>Atlas of Minnesota Resources and Settlement</u>, 1968, pp. 1-2, map on p. 5.

MAPPING WATERSHEDS IN GLACIAL TOPOGRAPHY

Northeastern Minnesota topography is difficult to divide into watershed regions. The terrain of the region is typically irregular moraine, ice scoured bedrock surfaces, and newer till plain. To the watershed mapper these physical features are ambiguous since two or more watershed boundaries may often be drawn in the same area. This ambiguity results from the indistinct heights-of-land and consequent helter-skelter runoff flow typical of glacial geomorphic features.

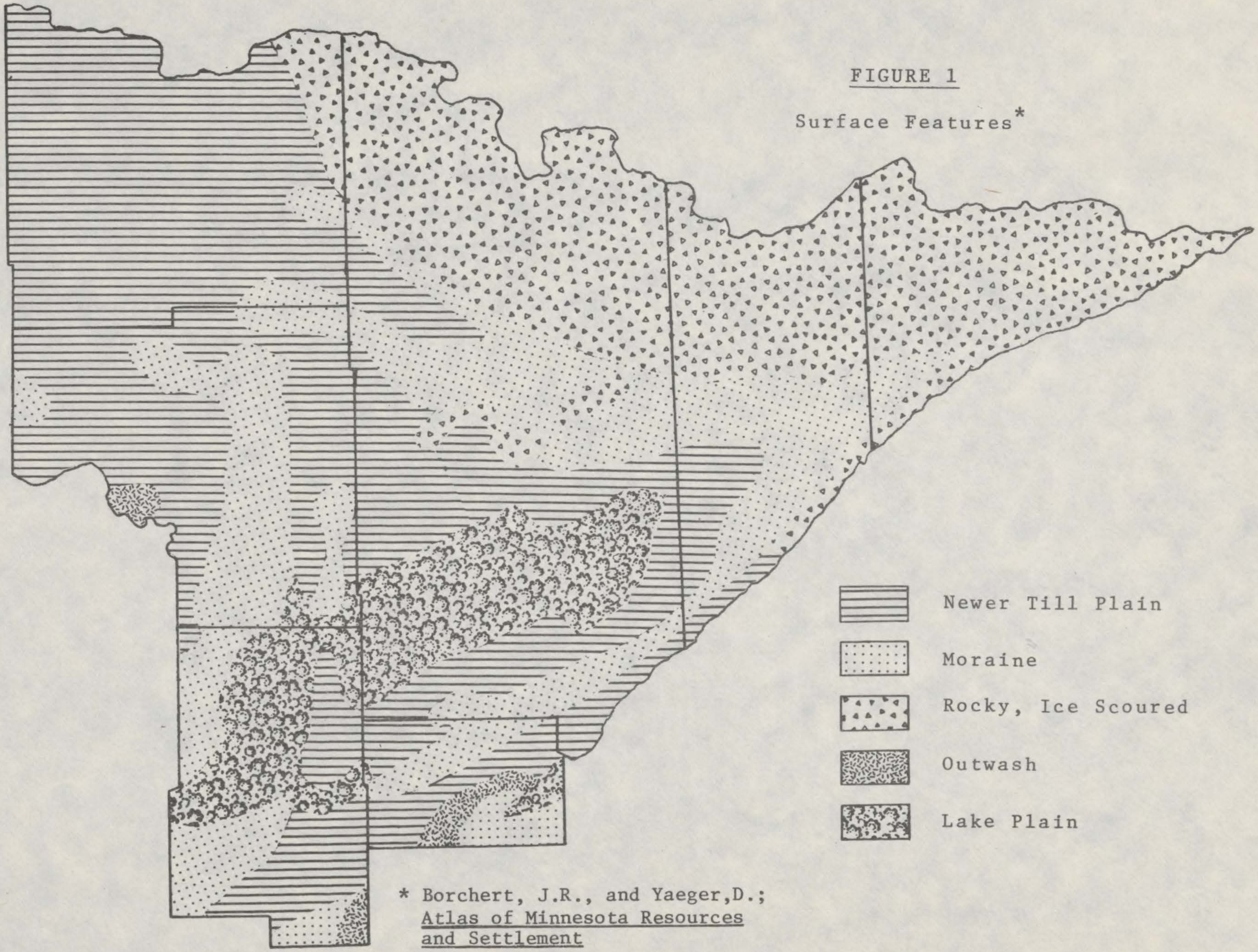
The rocky ice scoured regions in the northern parts of Cook, Lake, and St. Louis counties (Figure 1) consist largely of exposed bedrock laid bare when glacial ice transported the soil and subsoil. Subsequent weathering of the rock has created sufficient soil to support trees and brush, but not enough in most places to permit agricultural use. The impermeability of this landform coupled with precipitation surpluses results in large quantities of runoff flowing in sheets and streams across the landscape.

The southwestern portion of the study area, plus the area bordering the ice scoured region and extending down the coast of Lake Superior is identified on Figure 1 as outwash, moraine, till plain, and lake plain. The area is an intricate system of moraines with rolling to hilly surfaces, and level outwash plains of sand and gravel. GEntly undulating till plains separate the moraine areas. These features are due almost entirely to glacial deposition.

The moraines were formed at the stationary edge of the ice sheet at a time when the melting and deposition at the glacier's terminus equaled accumulation. They consist of sharp knolls and enclosed basins, and also of more or less parallel ridges which interlock in places. The moraines occur in roughly concentric systems that designate the successive positions of the terminus of each ice sheet as it melted. The outwash plains lie on the outer border of the moraines where sandy gravel was graded by dirt laden waters escaping from the ice. The till plains lie along the inner or iceward border of the moraines and signify areas over which the ice border advanced or retreated rapidly, forming relatively few knolls and ridges.

FIGURE 1

Surface Features*



* Borchert, J.R., and Yaeger, D.; *Atlas of Minnesota Resources and Settlement*

The northwestern part of the study area is shown as newer till plain in Figure 1 and is similar to the till plain areas which separate the moraines of the southwestern portion of the study area. The northwestern till plain area is more extensive than the inter-morainic till plains, offering less physical relief and more uniform drainage patterns than those created by the complex combinations of outwash, till plain, lake plain and moraine in the southwestern segment.

This large till plain area resulted when the last great ice sheet melted in the south long before it did in the north. The ice remaining in the north formed a dam which held back the north flowing drainage of the Red River basin and formed a large lake called Glacial Lake Agassiz, and several smaller lakes.

When the northern ice sheet finally retreated and the lake drained, there remained the lake's old beach ridges, extensive flat beds of lake sediment, and many depressions.[3]

The streams of the Mississippi headwaters, Rainy River, and St. Louis River drainage systems are interwoven in the southwestern part of the study area (see Figure 1), since no prominent dividing ridges separate them. In the northeastern part of the area there is less interweaving.

PROBLEMS WITH EXISTING WATERSHED MAPS

For glacial landscapes the lack of documented systematic watershed mapping criteria forces the independent mapper to establish his own guidelines. Thus, it is not surprising to find great variability in the determination of watershed boundaries by different map makers. Figure 2 shows this variability in the placement of watershed boundaries drawn from the same USGS topographic data by different agencies.

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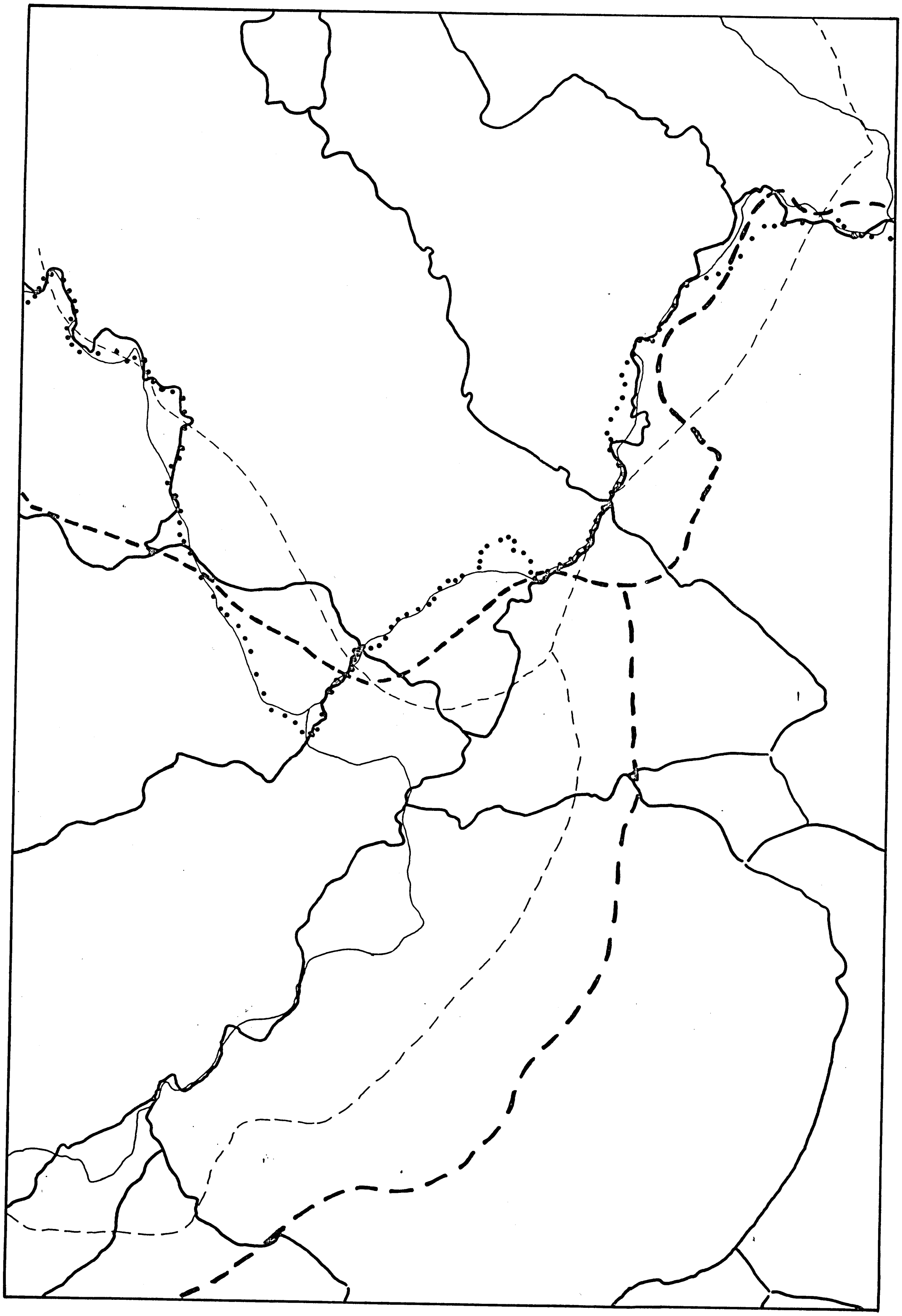
[3] For more information of glacial formations in this region see: Leverett, Frank and Sardeson, Frederick W., "Surface Formations and Agricultural Conditions of Northeastern Minnesota," University of Minnesota Geological Survey, Bulletin Number 13, 1917, pp. 2-10.



LEGEND

SYMBOL	AGENCY
• • • •	Army Lake Survey
▬ ▬ ▬	SCS
— — —	Forest Service
———	USGS
▬▬▬	MLMIS

0 — 1 MI

WATERSHEDS DRAWN BY FIVE AGENCIES ON THE BABBITT, S.E. QUADRANGLE

USGS BASE MAP SURVEYED IN 1952 - PHOTO REVISED IN 1969
SCALE: 1:24,000

FIGURE 2

Many of the problems encountered on available watershed maps are more serious than boundary variability. There are many discrepancies between maps drawn by different public agencies, and only the most serious are discussed here.

The watershed districts established pursuant to federal and state laws do not entirely coincide with natural basin units. For political convenience, these units have been designed with boundaries along municipal, township, or county lines. As a result, this source of comprehensive watershed boundaries was rejected.

Although comparatively accurate, the maps produced by the Forest Service (Superior National Forest) and the USGS will not be considered any further here due to the limited extent of completed maps. The more extensive mapping projects (DNR and SCS) will be discussed in some detail.

The only complete inventory of topographically determined watershed boundaries is that produced by SCS. Areas for which small scale topographic sheets were nonexistent were mapped by SCS according to the highly inaccurage hydrography displayed on Minnesota county highway maps. This creates problems of accuracy, but the format of the SCS map is of value. Data from topographic quadrangles has been transferred by SCS onto a set of county highway map bases. These maps have in turn been aggregated into a convenient set of eight small scale (8 1/2 X 11) regional sheets covering the entire state. All SCS mapped watersheds are numbered, placed in a hierarchically structured system, and areally measured.

The practical usefulness of the SCS watershed maps is questionable because:

1. Most of the watersheds are too large for site analysis. Information used in watershed studies, such as slope, soil types, or vegetation type, will vary considerably over large areas. The same data will tend to be

homogeneous if analyzed over small areas.[4] Site analysis data extrapolated from watersheds of less than seven square miles is more valuable than data from large areas, because it more precisely reflects an area's character.[5]

2. The maps are not sufficiently detailed. They display a generalized watershed boundary location that has straightened the actual zig-zag height-of-land watershed boundary. Figure 2 provides a comparison. Take special note of the difference between the SCS boundary and the MLMIS-DNR boundary. The SCS boundary is in the lowest region of the map. The MLMIS-DNR boundary closely follows the height-of-land. Greater precision than that provided by the generalized SCS watershed boundaries is needed when making many planning decisions.

3. The upper and lower basins of streams are often arbitrarily divided where no natural basin division exists.

4. The outlets of identified watersheds are periodically assigned to points along streams or lakeshore instead of to single points where two streams or a lake and a stream intersect.

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[4] The principle becomes clear if thought of in another way. Neighbors in a wealthy neighborhood tend to have similar incomes, a comparable number of years of education, as well as other measurable factors in common. Neighbors in poor neighborhoods will also have predictable similarities. It is not so easy to measure the similarities of individuals from a wealthy place combined with those from a poor place. Average income figures for an entire city tell nothing about specific neighborhoods. Likewise, average water purity says nothing about the cleanliness of water flowing past an industrial site compared to a residential site.

[5] Ward, R.C., Small Watershed Experiments: An Appraisal of Concepts and Research Developments, 1971, University of Hull, England.

5. Some watershed boundaries are drawn parallel to or coincident with running water, such as streams and drainage ditches.

6. The watershed boundaries are often shown as being coincident with political boundaries. This final problem is most frequent in the areas of greatest topographic ambiguity.

Such flaws can lead to the false impression that watersheds exist where, in actuality, they do not. Water would have to flow uphill to stay within the watersheds on many of these maps. They should not be used for research and planning purposes because conclusions drawn from a misplaced boundary can mislead.

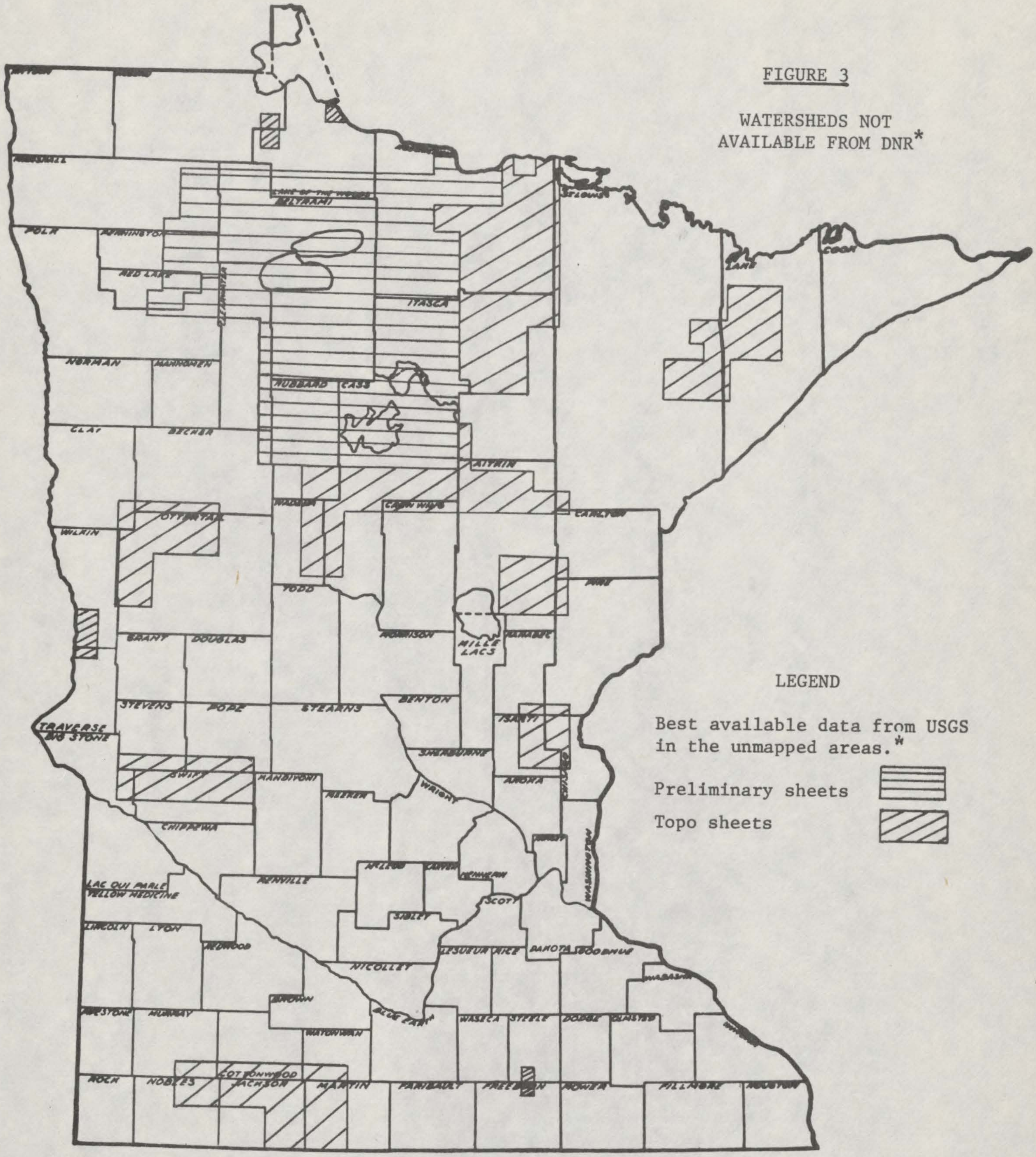
The most accurate and detailed small scale watershed map for Minnesota was produced by the DNR Division of Waters and embodies some of the same problems as the SCS maps. Though generally of high quality, the DNR maps are not without problems. Natural watershed basins on the DNR map are often arbitrarily divided into smaller units where no landscape features suggest such divisions, and they are not consistently detailed.

Figure 3 describes the areas not completed by the DNR mapping project. The DNR small scale maps generally display an amount of detail and effort not found in others. However, these maps are not consistently detailed throughout the state. In some parts of the state, such as the southeast and in the Lake Superior moraine, basins of less than one-fifth or one-tenth of a square mile in size are commonly mapped. In other areas, basins of equivalent size are neglected. No documentation exists to explain the inconsistencies.

DNR's Waters Division maps are available only in the form of the topographic sheets on which the watershed boundaries were originally drawn, with the exception of one pilot watershed study south of the Rochester gauge in the South Branch of the Zumbro River. To outline a complete watershed, even of the rather small size of 20-30 square miles, several 7 1/2 minute quadrangle sheets must be placed in a mosaic, making it cumbersome to use them.

FIGURE 3

WATERSHEDS NOT AVAILABLE FROM DNR*



* Compiled from DNR Waters Division inventories and USGS index maps.

In some cases, in spite of DNR's general accuracy with these boundaries, gross errors exist on the maps. The most obvious cases are those in which watershed boundaries have been drawn coincident with drainage ditches (a common problem for SCS as well) in the very flat Red River lake plain area, where elevation varies only slightly over great areas.

Our finding that existing watershed maps embody errors in boundary locations suggested the need for an accurate, detailed, and comprehensive watershed map of the Arrowhead Region. The DNR maps most nearly fit the needs of MLMIS. It was felt that the drawbacks of the maps could be rectified, given a consistent mapping methodology. This task required the specification of a set of mapping rules for determining boundaries and the creation of a numbering system to identify the relative and absolute location of drainage basins in a larger watershed system. The following two parts of this report discuss the decision rules and numbering scheme devised in the process of mapping the Arrowhead Region.

II: MATERIALS AND GENERAL PROCEDURES FOR WATERSHED MAPPING

Watersheds are the catchment areas of drainage systems. Their boundaries coincide with the line connecting the highest points of land, or the divide, separating one watershed system from adjoining watersheds.

When mapping the watersheds of mature stream dissected landscapes, the determination of watershed boundaries is a relatively simple matter. Elevation contours displayed on topographic maps identify geomorphological features and heights-of-land clearly for such landscapes. Except for the southeastern portion of the state, Minnesota's landscapes are typified by glacial erosional and depositional features. The stream basins in these glaciated landscapes are geologically immature and characterized by ill-defined watershed boundaries which require careful interpretive techniques and mapping methods.

MAPPING PROCEDURES

The creation of a regional watershed map involves two steps. In step one watershed boundaries are traced on topographic maps of the largest available scale, usually 1:24,000 or 1:62,500.[6] Large scale maps are used because of their accuracy and detailed display of heights-of-land. Watersheds drawn at this scale are useful when doing site analyses requiring hydrologic and land use data. In the second step, the large scale maps created in step one are photo-reduced and assembled to make a small scale map.[7] Such a map provides a regional picture of the interrelationships of watershed basins, their components, tributary

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[6] 1:24,000 approximately equals three inches to the mile, and 1:62,500 approximately equals one inch to the mile.

[7] In this case, 1:250,000 or one inch equals four miles.

watersheds, and the water that flows through them. When overlaid on other maps, such as the MLMIS land use map, a soils map, or a vegetation map, additional relationships can be observed between hydrology and physical and cultural features.

STEP 1: MAKING LARGE SCALE MAPS

Drafting Materials

The following materials are useful in drawing watershed maps:

A. Acetate, one side frosted, cut to allow for at least 1.5 inch overlap on each side.

B. Hard lead pencils and erasers.

C. Straight edge.

D. Rapidograph-type drafting pen.

E. 1:24,000 or 1:62,500 scale topographic quadrangles representing the area to be mapped.

F. Index of Topo-Watershed Maps (see Figure 4).[8]

Preparation

Watersheds are drawn on acetate overlays superimposed on USGS topographic sheets. The topographic sheets will provide the base source of topographic and hydrographic data required in the mapping process. The edges of the printed area of the maps should be clearly marked at the corners. Each acetate should be labeled according to its MLMIS index identifier.

Watersheds Mapped by the DNR Waters Division

When watershed-topographic sheets are available, they may be used, but with caution. The mapper should be alert to the potential problems cited in Part I of this paper, including omitted small watersheds and

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[8] The U.S. Geological Survey published an index of available topographic maps. It is printed on a Minnesota base map so that it not only shows the topo map names, but also their spatial relationship. An MLMIS index has been created (see Figure 4) which assigns a unique grid code to each topo sheet.

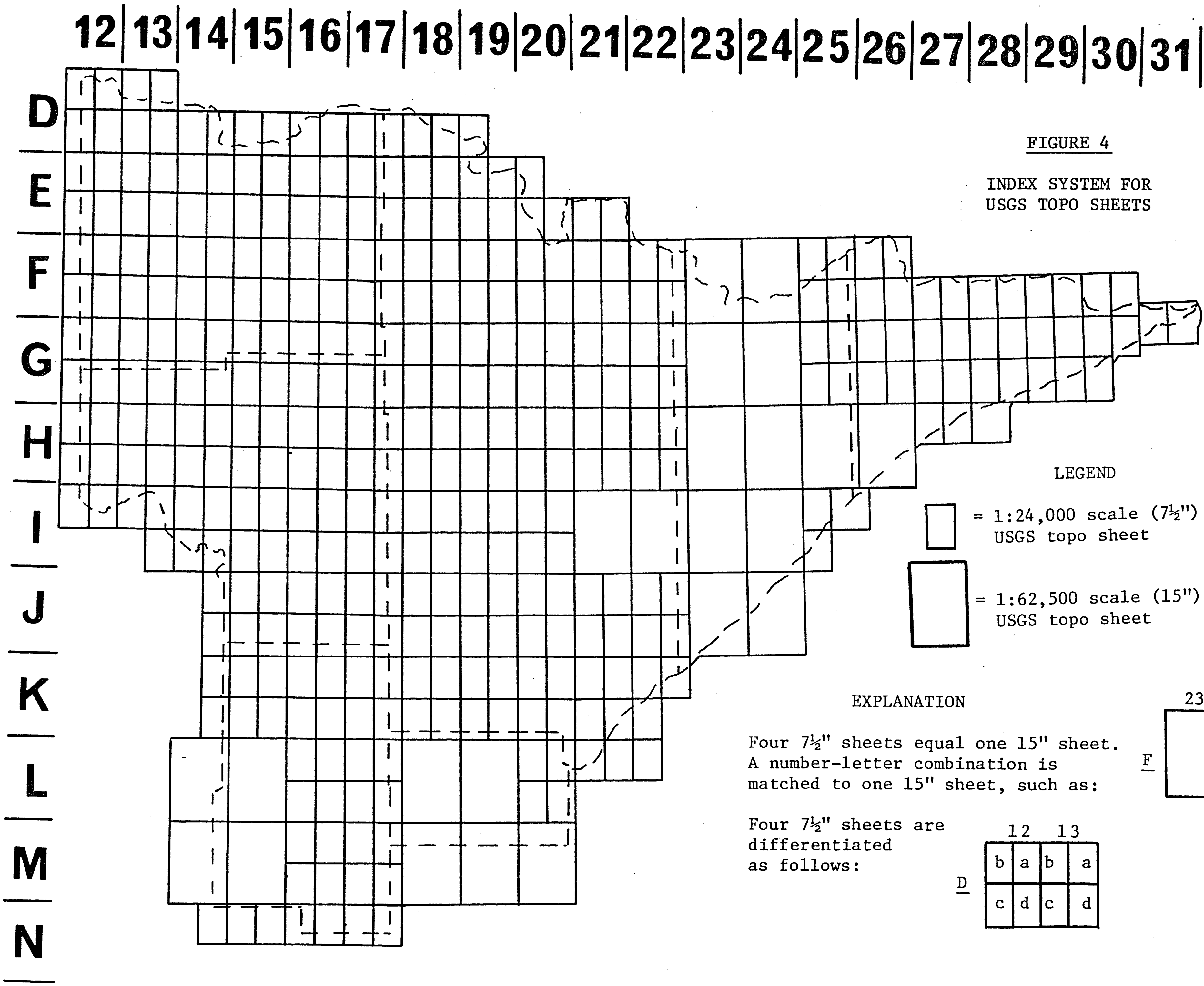

FIGURE 4

INDEX SYSTEM FOR
USGS TOPO SHEETS

LEGEND

= 1:24,000 scale (7½") USGS topo sheet

= 1:62,500 scale (15") USGS topo sheet

EXPLANATION

Four 7½" sheets equal one 15" sheet. A number-letter combination is matched to one 15" sheet, such as:

23

F

Four 7½" sheets are differentiated as follows:

	12		13	
D	b	a	b	a
	c	d	c	d

inaccurate boundaries. The watershed mapping rules which must be understood in order to correct these problems are listed in Part III of this paper. The same rules must be used to delineate watersheds in areas not mapped by DNR.

Mapping Process

Watersheds should be mapped from the most up-to-date USGS topographic sheets. These watersheds should be drawn on acetate overlays in a manner similar to the tracing process described above. The drawing of watershed boundaries should be done with a hard (e.g., 2H to 4H) lead pencil. Notes may be lightly made in pencil on the mapping surface for the aid of cartographers at this and later stages in the process. The notes should be erased when appropriate.

All final acetates should be done in ink. A number 2 1/2 rapidograph pen is best. At the places where watershed boundaries intersect with the confluence of streams, final acetates should note the direction of stream flow with pencil drawn (not inked) arrows.

STEP 2: MAKING A SMALL SCALE REGIONAL WATERSHED MAP

Drafting Materials

The following materials will be useful in making the regional map:

A. Acetate, one side frosted, cut so as to allow a 3 inch overlap on all sides of a 1:250,000 scale map.

B. 1:250,000 scale USGS map of the region.

C. Camera.

D. Tripod.

E. Slide projector.

F. Slide notebook.

G. Black and white film.

H. Hard (2H-4H) pencil.

Procedure

Tape the 7 1/2" or 15" watershed acetate on "clean white background." Slides of each acetate should be taken. In order to minimize distortion at the edge of the slides, move the tripod until the acetate as seen through the camera fills 70-85 percent of the area in the view finder. The exact distance at which this occurs will vary with the lens being used. Be sure the map index identification is clearly visible in the view finder and is large enough for easy labeling of the slide.

Slide Transfer Preparation After Development

Obtain a 1:250,000 scale USGS map of the study area. Find the black cross-hairs located at 15 minute intervals along the map. Overlay a piece of acetate on this map and reproduce the cross-hairs. Four 7 1/2 minute quads, or one of the 15 minute quads which you have just photographed will fit within the rectangle created by the cross-hairs. The map index identification number for each horizontal and vertical row of quadrangles should be placed on the margin of the acetate.

Transferring the Slides

Place the slide projector on a solid table, approximately three feet from the wall for a 7 1/2 minute slide, and five feet away for 15 minute slides. Project the slide image onto the wall so that the projection beam is level in order to minimize distortion. Manually adjust the 1:250,000 scale acetate until the four corners on the acetate corresponds to the vertices on the slide in the projector. Secure the acetate with masking tape. Make minor adjustments in the projector's location until the slide image exactly corresponds to the size ticked off for it on the acetate, and with the adjacent watershed boundaries. Trace the image on the acetate with a hard pencil. Repeat the process until the map is complete.

III: TOPOGRAPHICAL WATERSHED MAPPING RULES

The mapping rules set forth here are designed to systematize watershed delineation procedures in such a way that two independent mappers will produce the same results.[9]

RULES

1. Find the most up-to-date USGS topographic sheet.

2. Consult smaller scale map. A smaller scale map, preferably 1:250,000, will reveal regional details of hydrologic patterns not apparent on 7 1/2" or 15" topo sheets. Hydrographic patterns of uncertain destinations on a 7 1/2" or 15" topo sheet can be traced from inlet to outlet with surety on a smaller scale map.

3. Begin delineation at a stream confluence or the point of contact between a stream and a lake. These are the only places a watershed boundary will intersect with a watercourse, and are the logical starting points when delineating a watershed.

4. (a) At the confluence of two streams with drainage areas greater than two square miles, three watersheds always intersect (see Figure 5).

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[9] Borchert, John R., Perspectives on Minnesota Land Use - 1974, Minneapolis: University of Minnesota, Center for Urban and Regional Affairs, Minnesota State Planning Agency, October 1974, p. 51.

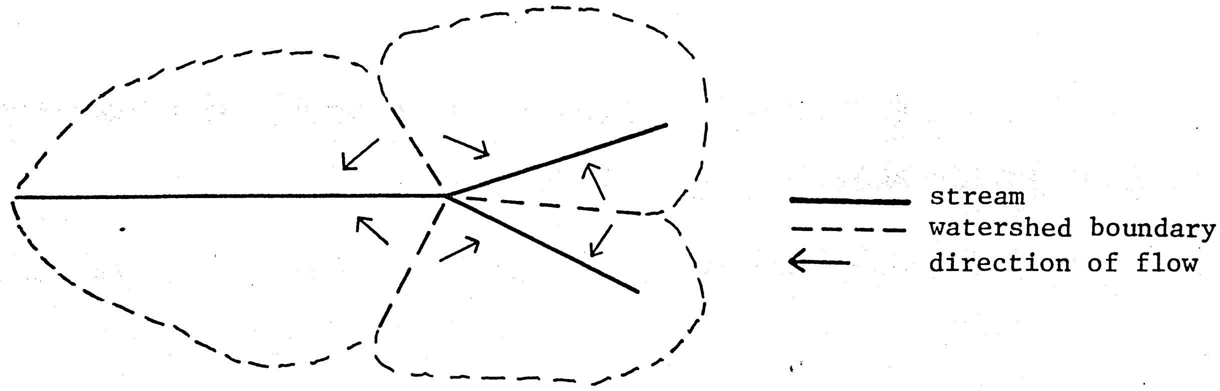


FIGURE 5

(b) At the point of contact between a lake and a stream, two watersheds may intersect (see Figure 6).

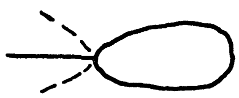


FIGURE 6

(c) If a lake is very large (greater than 2 square miles), it will merit its own watershed. The watershed boundary will connect the contact points between the lake and every major stream flowing into or out of the lake (see Figure 7).

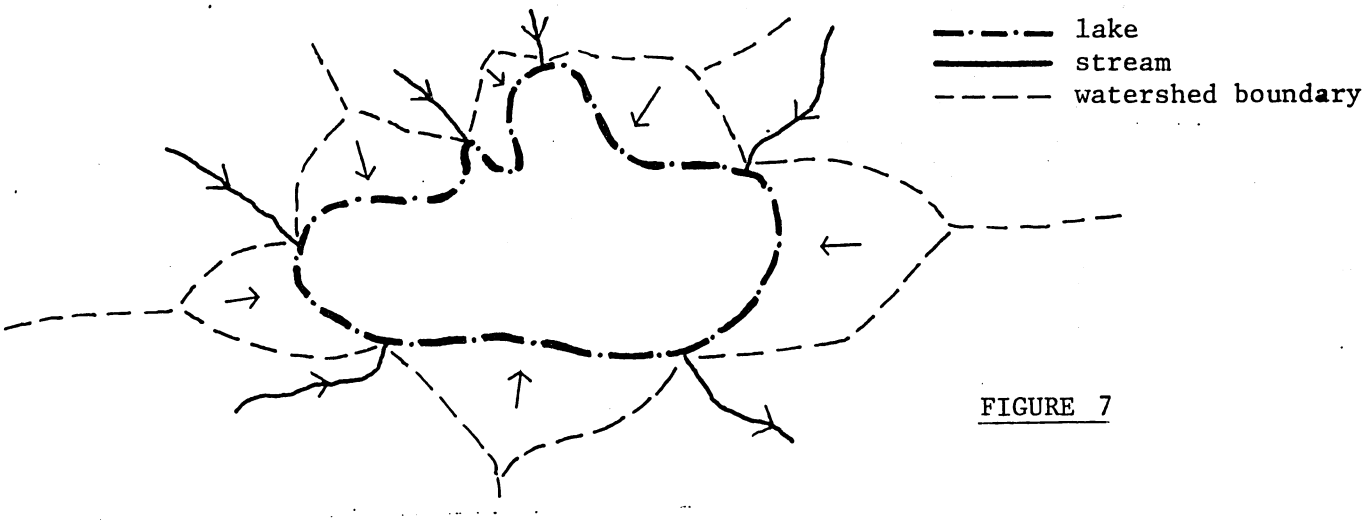


FIGURE 7

5. Heights-of-Land: From the starting point, extend the watershed boundary line to the contour line representing a level of greater altitude and thereafter circumscribe up and down around the divide returning to starting point.

6. Shortest Distance Rule: The path followed by the boundary should be the shortest distance between contours (see Figure 8).

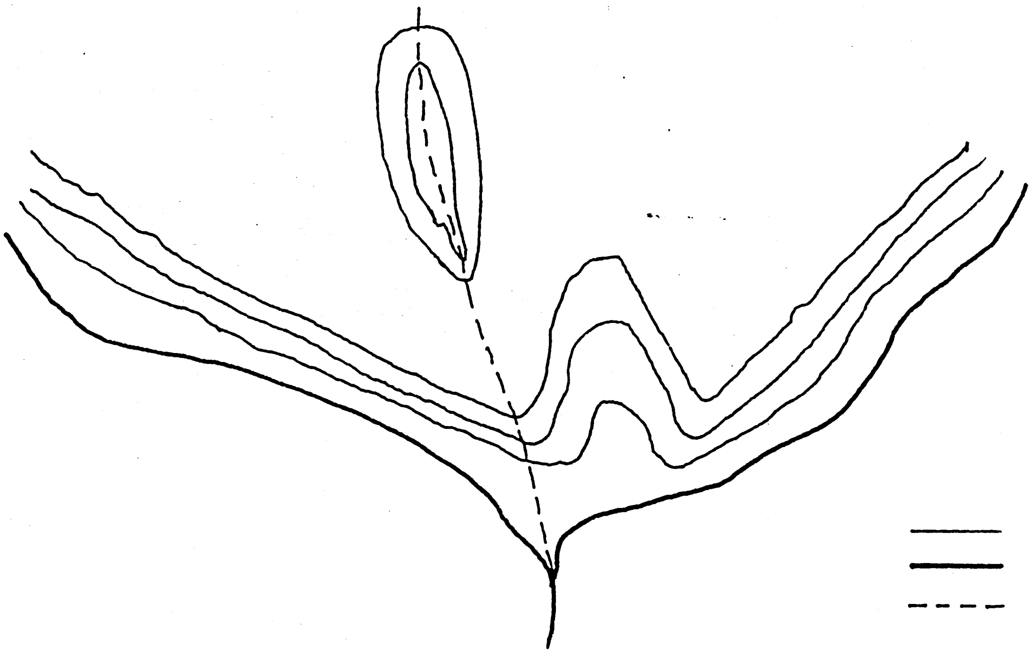


FIGURE 8

7. Minimum Size: All streams which have watersheds greater than two square miles in size should be mapped. With this rule small tributary streams may not merit a separate watershed boundary.

8. Stream Extensions and Direction: The blue lines designating perennial and intermittent streams on USGS topo sheets should be extended headward beyond the point where they end on the map to the last significant crenulations indicating the presence of occasionally flowing water. The

direction of stream flow should be noted with arrows. This is readily ascertained by noting elevation changes. This procedure helps to establish the outer limits of a watershed.

EXCEPTIONS TO THE RULES

1. In some cases the presence of isolated hills or depressions may alter the shortest distance rule, as in Figure 9 and 10.

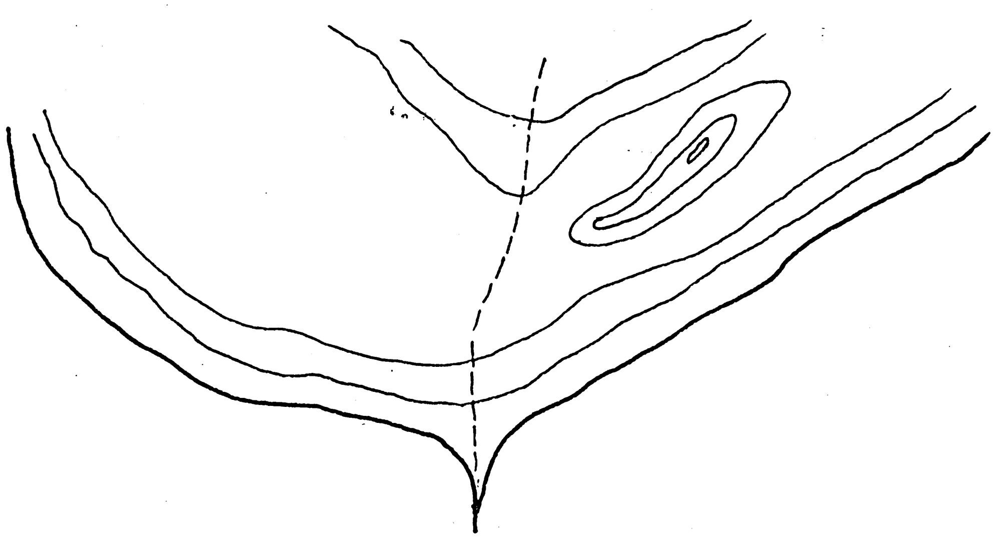
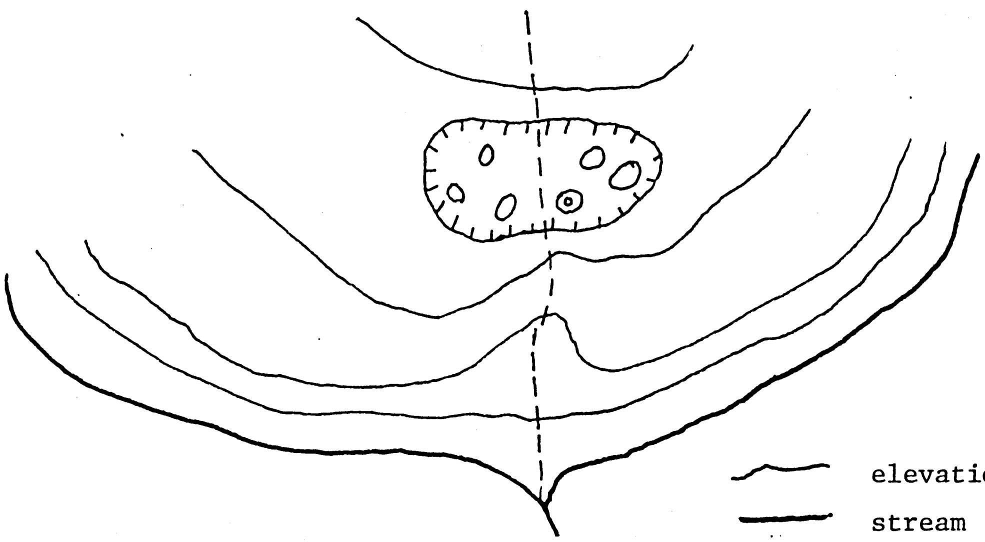


FIGURE 9



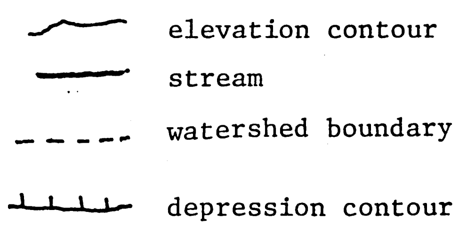


FIGURE 10

2. Although the purpose of the minimum size rule is to eliminate watersheds that would otherwise exist at every insignificant stream juncture, such as those within watershed A in Figure 11, watersheds smaller than two square miles will appear in situations like the following:

Watersheds A, C, and D in Figure 11 have an area of ten square miles or greater. They drain into the same river with outlets at extremely close intervals. The confluence rule requires that the watershed boundaries converge at these outlets. A consequence of this rule is that watershed B is created, and its area is less than two square miles.

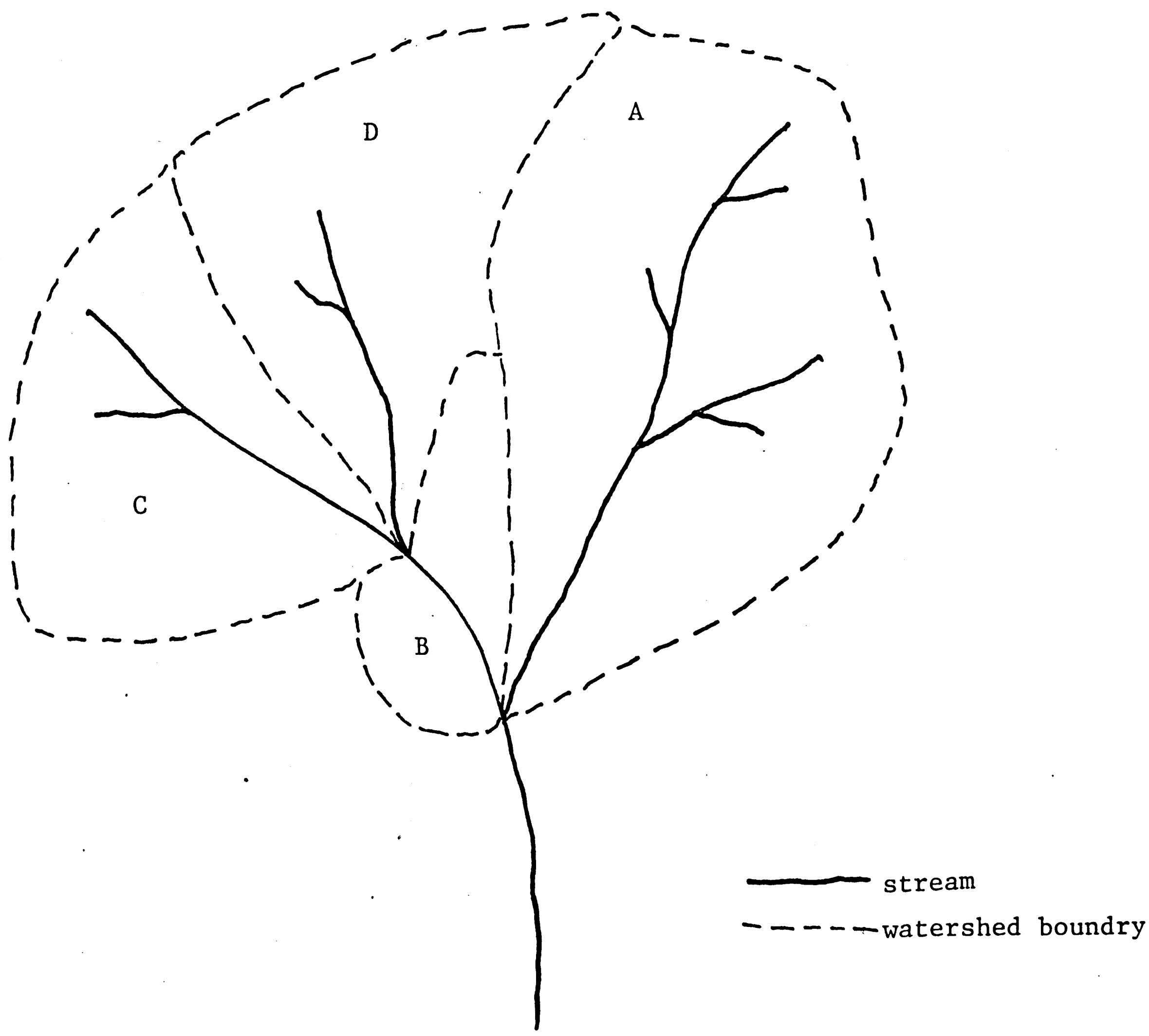


FIGURE 11

SPECIAL CASES

A. VERY FLAT LAND

1. In the undifferentiated marshland of the Arrowhead Region noncontinuous ridges in the natural terrain are less reliable indicators of the location of a watershed boundary than impermeable cultural features such as railroad or highway embankments. The mapper should be cautious of perennial and intermittent streams flowing through culverts and under bridges which belie this application.

2. Elevation changes in flat areas may occur at intervals of less than ten vertical feet and consequently may not be identified by the USGS elevation contour lines. Relative elevation can be inferred by the presence or absence of marsh. For example, the USGS symbol for marsh will appear if a portion is swampy and thus at lower elevation.

B. DITCHED LAND

1. Marshland in this study area often contains an intricate web of interlocking drainage ditches. These webs will require much patience to unscramble and determine the direction of flow.

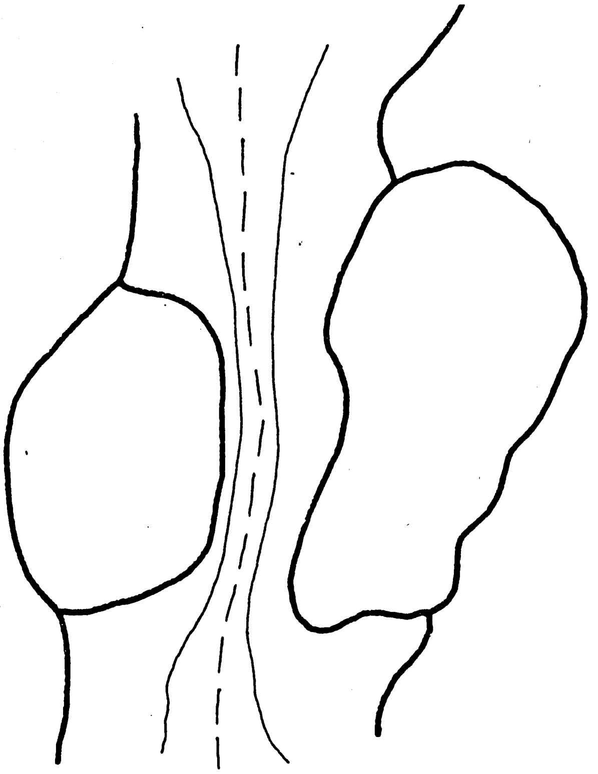
2. The watershed boundary of ditch patterns may be unraveled by consulting county highway maps which indicate the direction of flow in the ditches, although this should be done cautiously due to previously mentioned inaccuracies in county highway hydrography.

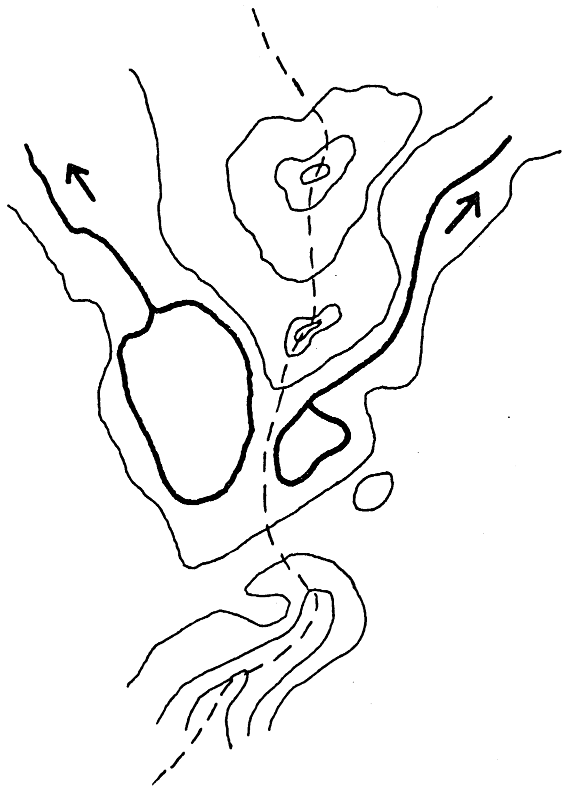
3. Ditches normally follow land division lines (i.e. section, quarter, sixteenths), frequently cutting through and negating the original height-of-land watershed boundaries. In these instances, pay close attention to the direction of ditch flow.

C. AMBIGUOUS TERRAIN

The ice scoured and moraine areas in the region pose a notable lack of physical regularity, and produce surprisingly recurrent problems.

1. The mapper should expect to find lakes in extremely close proximity, with a watershed boundary separating them, as in Figures 12 and 13.





——— elevation contours
– – – watershed boundary
▬▬▬ water

FIGURE 12

FIGURE 13

2. An unimpeded ridge of land possessing some but not all of the highest land is a search objective. By proceeding slowly and exploring avenues to and from every peak, the mapper will locate this watershed ridge.

HYPOTHETICAL APPLICATION

Figure 14 conceptualizes both the intent of the watershed mapping rules and some of the problems the rules are designed to avoid.

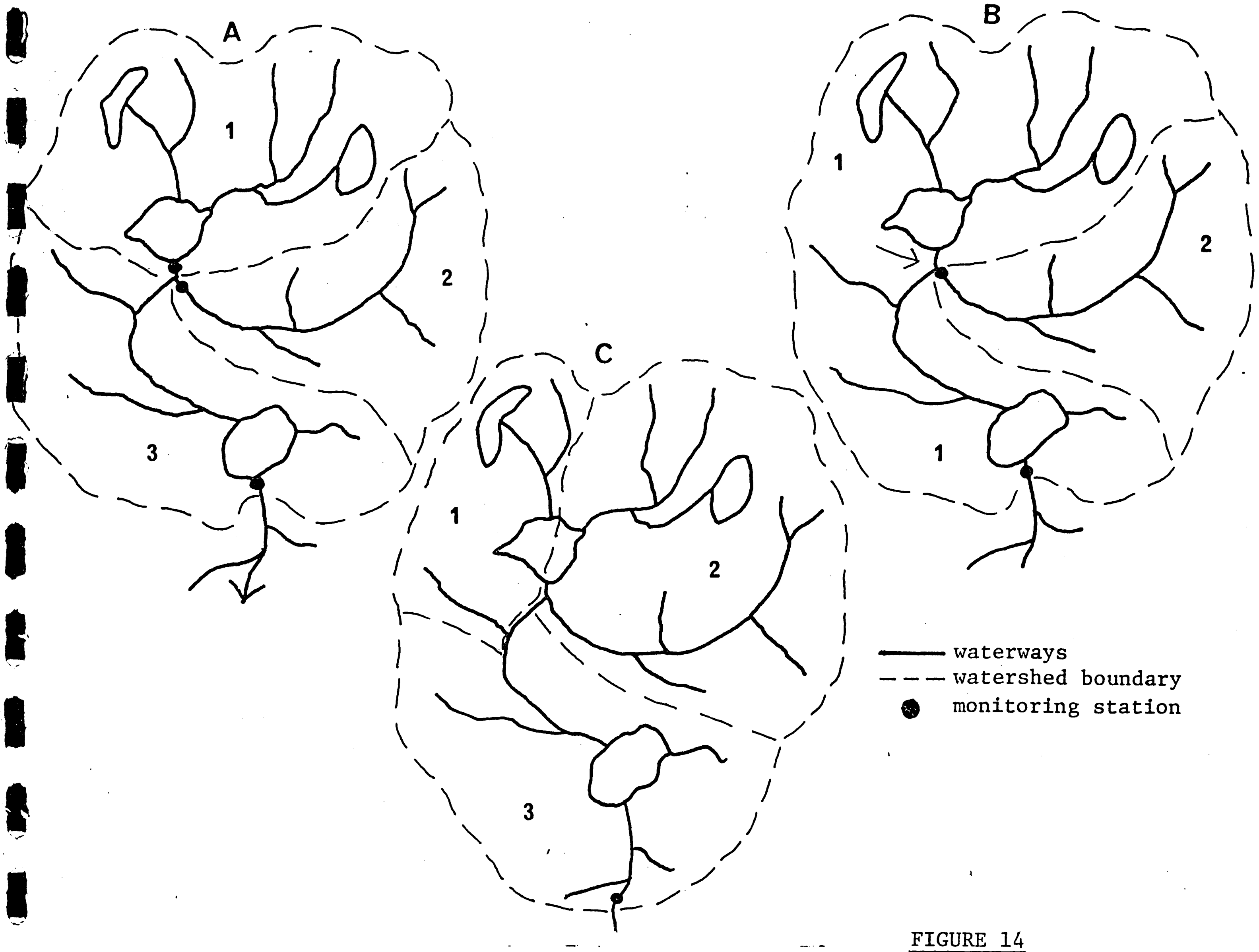


FIGURE 14

The schematic representation of alternative sub-basin delineations shown in Figure 14 is representative of the range of delineations drawn by different agencies on a single topo sheet (recall Figure 2). Delineation A in Figure 14 is reasonable, B is plausible but incomplete, and C is absurd.

Delineation C suggests that a height-of-land passes through a lake and terminates at a point on the river other than the confluence of two streams. These watershed boundaries do not make sense for two reasons.

1. A river or lake marks the place where water has collected from surrounding higher land and where it will subsequently flow to still lower elevations. A watershed boundary is called a height-of-land because it is the highest land between two stretches of flowing water, which means the watershed boundary cannot pass through the lake.
2. A height-of-land is often called a divide because it determines the destination of rainwater. Water falling on one side of the watershed boundary will flow into one river while water falling on the other side will flow into another river. If those two rivers were to meet, then it follows that a watershed boundary will divide the water between the two rivers right up to the confluence of the two rivers. The watershed must intersect with flowing water at the water's confluence.

Delineation B does not have the problems found in C, but it is not complete. It ignores the upper and lower separation of sub-basin 1. When the upper portion of sub-basin 1 intersects with sub-basin 2, it creates a unique river that flows through lower sub-basin 1. The river in the upper and lower portions of sub-basin 1 could have the same name, but they are still in different watersheds. Precipitation falling in the upper sub-basin can only enter the lower sub-basin at the basin's inlet, indicated by the arrow in delineation B.

Delineation A separates the major branches of the stream pattern at the point where the branches intersect and thus follows the basic topographical logic of height-of-land watershed mapping.

The watersheds in A have an advantage for land use planning that B and C lack. The water flowing through each sub-basin in A can be monitored from a single point at the sub-basin's outlet. The only reliable monitoring information obtainable from basin C would be data measured at the outlet to the entire basin, since the sub-basins are inaccurately mapped.

Sub-basin 1 in watershed B is too large for site analysis (recall footnotes 4 and 5). Futhermore, it is not similar in size to sub-basin 2, making it difficult to compare the waterborne impact of changes in the physical characteristics of the two sub-basins. If such a comparison were possible, a planner might recommend either that one sub-basin was better suited to future development, or perhaps that one sub-basin should be spared from certain forms of development because of an environmental sensitivity.

IV: WATERSHEDS AND RESOURCE MANAGEMENT

Resource management is dependent upon adequate and complete information relating to resource quantity, quality, and distribution. To date, resource management has treated water and land problems separately. As a consequence, information about these resources has been stored separately and catalogued in a variety of ways. Also, much of the information is incomplete. While sophisticated means of dealing with land and water information separately have been developed, there has been little work to integrate these two broad fields of resource management into one complementary system. As a part of this initial attempt at synthesis, we have developed a watershed numbering scheme to provide a relative geographical identifier for a combined land and water water resource management system.

There is a primary spatial distinction between land resource data and most water resource data. Land data exists in point and areal form while the water data is found in point and line form. In order to combine these two distinct information bases, it is necessary to identify land surface areas which provide surface runoff to corresponding linear stream segments. This connection can be made by mapping the height-of-land watershed boundaries which was previously discussed. Once the watersheds have been mapped, a given land area may be directly linked to a specific stream segment and at the same time its relation to the whole land and water network may be discerned.

The next step in an integrated system involves giving every land information point and every water information point an identifier which will place both types of information on the same spatial grid. To do this, a watershed numbering scheme is required to geocode all the resource information onto a computerized data base. While any arbitrary scheme of geocoding can accomplish this result, the relative scheme described here has the additional ability to incorporate information on the system's interrelations, a capability which will later facilitate data analysis programs.

WATERSHED NUMBERING SCHEME

The numbering scheme for watershed networks presented here has the following features: 1) a unique watershed identifier for each data parcel, 2) a relative position for each watershed in the network, 3) the flexibility to include new watersheds, 4) potential to be referenced to existing classification schemes, and 5) the capability to reference streams and lakes within the network. The following maps and text explain the watershed numbering scheme.

Figures 15 and 16 illustrate the Swan River Watershed of the Upper Mississippi River. Figure 15 represents the height-of-land watershed boundaries for this region drawn at the scale of 1:250,000. The dotted lines symbolize the year-round streams and rivers within each watershed. Figure 16 is also of the Swan River, but is a schematic representation in which the surface areas of each watershed boundary on Figure 15 have been converted to a linear measure by which the overall network of watersheds and their connections have been diagrammed. This topological generalization was constructed to show the ecological "tree" of watersheds which may then be numbered and used to study regional flows and interaction. The Swan River, Figure 16, also illustrates a systematic numbering scheme for network analysis. Given the arbitrary choice of the Swan River watershed as watershed number 1; the resulting line segments, which represent individual watersheds, are numbered correspondingly. In this system the far right alphabetic character denotes a tertiary watershed, or one which has no other watersheds flowing into it. The relative location of each shed is numbered in such a way to allow the programming of flows throughout the system with no additional (i.e., directional or contiguity) identifiers. On Figure 16 the first place of each numeral, far left, signifies the overall watershed which is being considered, in this case number (1). The second place designates the position with respect to nodes or intersections along the major axis (see Figure 17).

Swan River Watershed

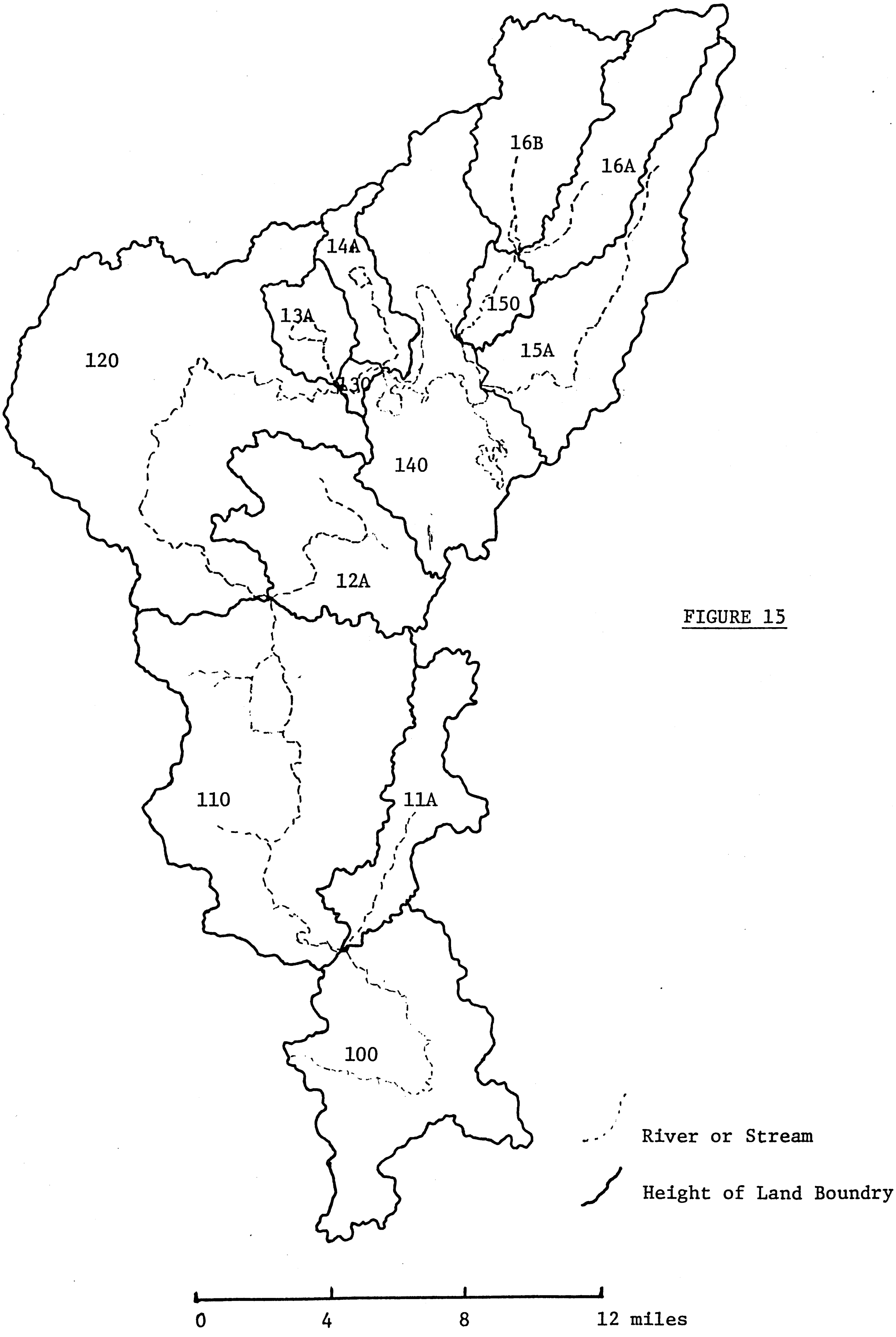
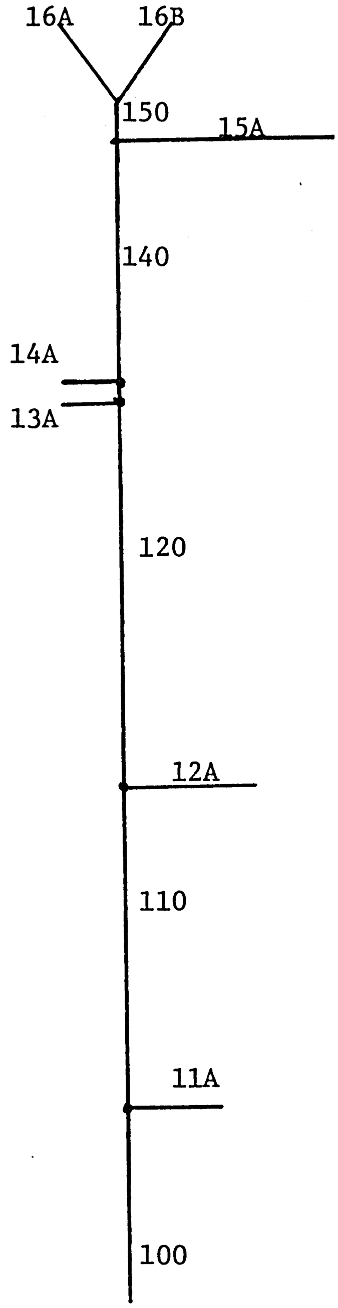


FIGURE 15

Swan River Watershed
Schematic Network Map



Watershed Number 1

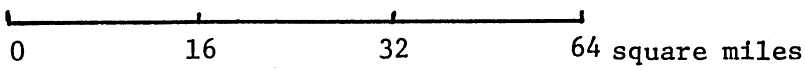


FIGURE 16

FIGURE 17

Any stream segment along this major axis receives the number of the node at its outlet point (Example: 12 for the second node on watershed number 1). Any secondary streams which enter at this lower node will also receive this number along with additional identifiers in the next place to the right (Example 12A). The watersheds on the major axis will have zeros in these additional places (Example 110). With the basic skeleton numbered, this watershed is now completely identified as there are no complex secondary tributaries. Reference to Figure 16 should answer further questions.

A second hypothetical example demonstrates the application of the numbering scheme to a more complex watershed network. Figure 18 is a topological representation of an imaginary watershed which includes many of the additional network complexities and watershed levels that will be encountered when watersheds are mapped statewide. The numbering scheme in Figure 18 is identical to that used in Figure 16. First, the nodes along the major axis are numbered (see Figure 19).

Imaginary Watershed

Schematic Network Map

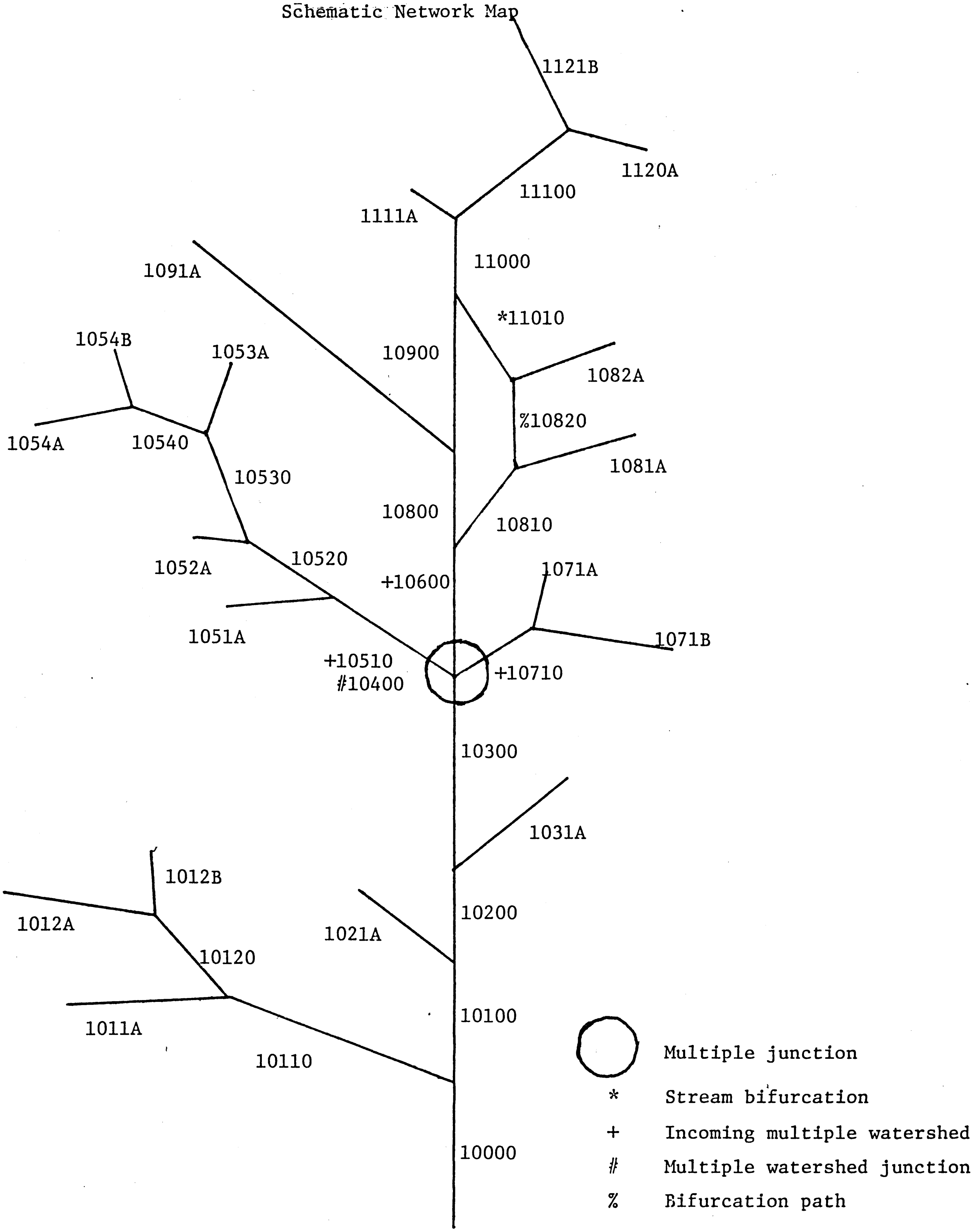


FIGURE 18

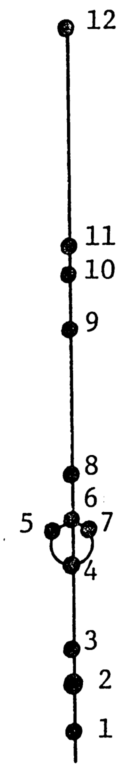


FIGURE 19

This imaginary shed has also been given the number 1 which occupies the far left place. The next two places code the position with respect to the major axis (Example 102: for the second node on the primary axis of watershed 1). Next, each of the tributary arms is treated as a secondary axis and the nodes along it numbered (see Figure 20).

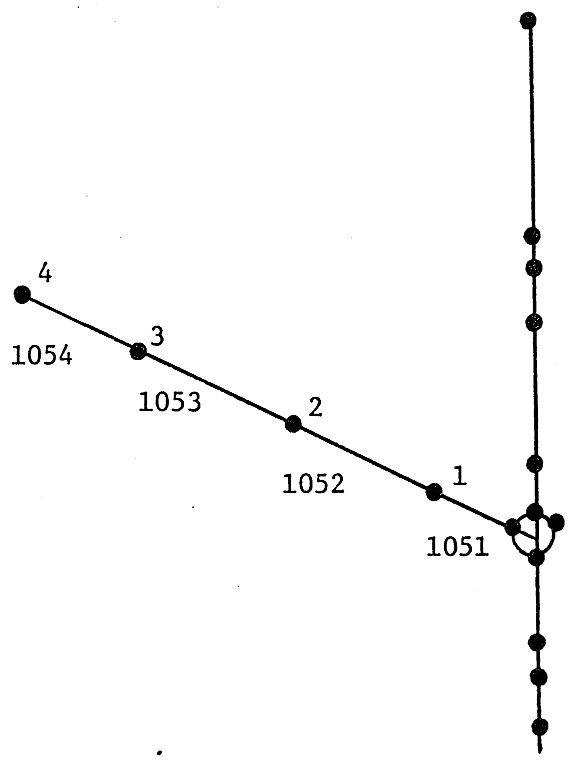


FIGURE 20

The secondary axis is numbered as the major axis, except that the first watershed (1051) receives the number one instead of 0 as on the major axis. All these secondary axis numbers occupy the 4th place of each identifier. Example 1052: the second segment on the secondary axis adjoining the fifth node on the major axis of watershed 1.

SPECIAL CASES

A brief note on two special cases which occur in this numbering example: First, the denotes a large lake into which more than one watershed flows. In this case, the lake and its height of land boundary constitutes its own watershed (Example +10400) and the inflowing sheds have been numbered in a clockwise sequence, starting from the outlet; node 4 (see Figure 21).

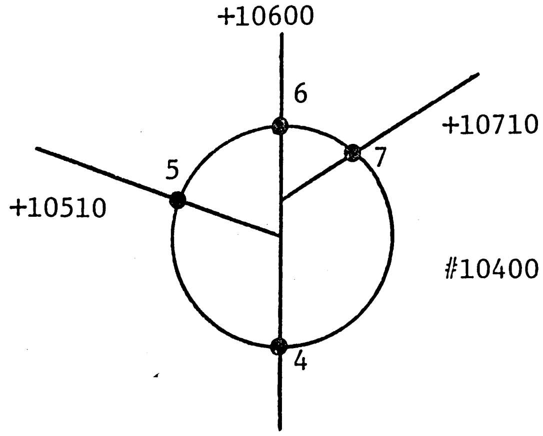


FIGURE 21

All the incoming watersheds will also have a plus (+) in column one and the junction itself a (#) symbol to designate their special nature. The other special feature within this scheme is marked with * and % to mark a bifurcation in the downstream flow (see Figure 22). Such a branching in the downstream flow is unusual but does occur in the glacial scour of the Arrowhead Region. In this case the first watershed has an * in the first column and is numbered as if it flowed into node number 10 on the major axis. The next watershed downstream is marked with a % in the first column and is numbered as a secondary axis of node 8 as are all the remaining bifurcation tributaries.

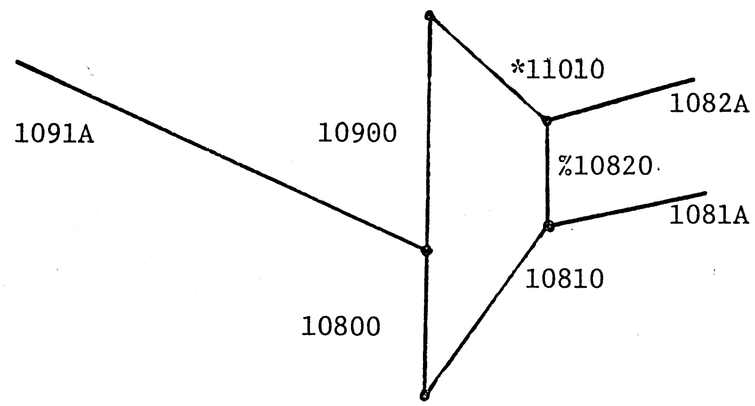


FIGURE 22

EXPANDING THE INITIAL WATERSHED SCHEME

Once a particular area has been chosen to be numbered by this watershed numbering scheme, a county for example, the scheme may also at a later date be easily expanded to include the surrounding counties' watersheds into a statewide system or the start of a more detailed watershed study within the region. For example, consider the Swan River watershed as one of the many tributaries of the Mississippi.

Within this broader regional context, additional watershed identification places will be required to identify each individual watershed. In this example the Swan River watershed forms the 8th node on the primary axis of the Mississippi River. Thus, all of the Swan River watersheds will have the number 8 in the far left place and the original numbers in the remaining places (Example 811A). The fact that the original identifiers remain intact for any area mapped provides flexibility for later shifts in study scale from the national level to a microscopic analysis (see Figure 23).

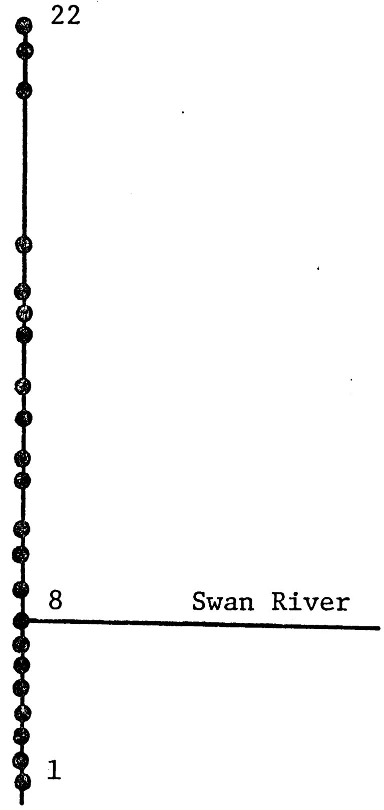


FIGURE 23

It should be noted that additions to the watershed numbering scheme in the form of inclusion into a larger geographic system will be dependent upon whether the primary axis is mapped to the end of the given river. For example, if the Swan River is given an identifier for its junction with the Mississippi River, it must be known how many intersections there are between the Swan River and the point where the Mississippi River leaves the state.

SUMMARY OF DIFFICULT ASPECTS OF WATERSHED NUMBERING

-- Bifurcation in downstream flow.

-- Expanding a watershed network.

-- Multiple junction intersection.

APPLICATIONS

This watershed numbering scheme is one part of the effort to create a land and water information system. This system, in order to succeed, must be based on a uniform set of definitions of stream and watershed location and identification. Such a system offers the potential to investigate many physical resource problems by combining these two forms of information.[10] For example, with this system it will be possible to create stream and lake modeling studies in which water quality and lakeshore development may be simulated and the effects of each studied. As another example, the process of erosion and its relation to land use or geomorphology may be studied with this integrated approach. The potential to investigate these physical problems may point to such social and political questions as zoning for watershed use and government policy for land and water use. Finally, a systematic computerized land/water data base will permit future data processing by more sophisticated resource interaction models and will, furthermore, make possible the inclusion of sound ecological and spatial information into future land and water studies.

The Arrowhead Region watershed map has been drafted at a scale of 1:250,000 and is on file in the MLMIS office. The Lake County portion of the watershed map is being published by the Arrowhead Regional Development Commission as part of an experimental county atlas program. Watersheds for Development Region 6E have also been mapped and will soon be part of a regional computer data base.

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WATERSHED MAPS

U.S. Department of Agriculture, Forest Experiment Station, Duluth, Minnesota.

U.S. Department of Agriculture, Soil Conservation Service, St. Paul, Minnesota.

U.S. Department of the Army, Corps of Engineers, St. Paul, Minnesota.

U.S. Department of the Interior, U.S. Geological Survey, St. Paul, Minnesota.

State of Minnesota Department of Natural Resources, Division of Game and Fish, Technical Services Section, St. Paul, Minnesota.

State of Minnesota Department of Natural Resources, Division of Waters, St. Paul, Minnesota.