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Use of Drainage Patterns and Densities to Evaluate Large Scale Land Areas for Resource Management

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ABSTRACT

Objective large scale land capability evaluation techniques are needed if man is going to be able to properly plan where development should take place in the landscape. A 6,800 square mile watershed (St. Croix River, Minnesota) was studied using a new technique called "pattern analysis." By correlating drainage densities to soil textures and vegetation, inferences can be made as to the innate ecological diversity and management potential of a watershed. This information should assist the resource manager in recognizing the diversified nature of a major watershed along with which areas in it are best suited for such functions as road building, logging, recreation development, and wildlife management.

This paper describes a large scale land capability evaluation technique that utilizes natural land units (watersheds) as an objective inventory base. Since watersheds along with their inherent drainage patterns and drainage densities have been evolving for thousands of years they are probably the best expression of the earth's surficial material along with related biotic factors that is available to man.

Zernitz [1] studied drainage patterns and indicated their value in interpreting the landscape when she said:

"The location of every valley is initially determined by inequality of

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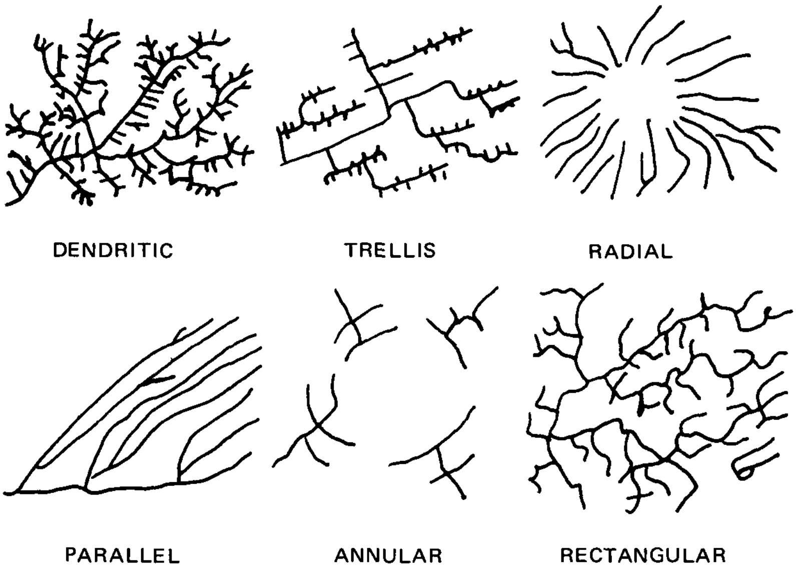

Figure 1. Six major types of drainage patterns. (Source: Parvis [2].)

> surface slope or inequality of rock resistance. Hence, drainage patterns reflect the original slope, the original structure, the present structure, and the successive episodes by which the surface has been modified; such as uplift, depression, tilting, warping, folding, faulting, and jointing and also the depositional features left by the sea, glaciers, volcanoes, winds and rivers. A single drainage pattern may be the result of one or of several of these factors."

The use of drainage patterns as a part of a land capability evaluation technique becomes somewhat simplified with the realization that drainage patterns tend to conform to six major types (Figure 1) thus providing the opportunity for investigations with a minimum number of variables [1, 2].

Drainage density, which is an integral part of a drainage pattern, reflects the amount of water that runs off a watershed and is related to several factors. Strahler [3] attributed the change in drainage density in different watersheds to rock type, ease of infiltration of precipitation into the ground surface and downward to the water table, and the presence or absence of vegetative cover. Thornbury [4] stated the factors that control drainage density are climate, geological age of the basin, relief of the topography, and infiltration capacity of the soil. Assuming all other variables are constant, Figure 2 illustrates the effect infiltration capacity alone can have on drainage density.

The two densities are different, however the basic drainage pattern

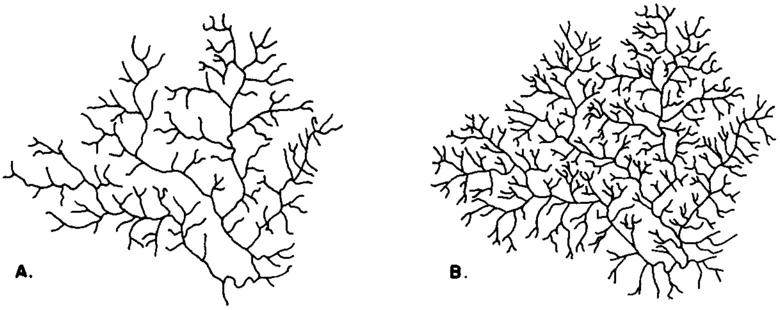

Figure 2. Differences in drainage density reflect different surficial material of the soil; "A" contains coarser material than "B".

(dendritic) is the same. Figure 2a represents a relatively low drainage density (water percolates into the ground thereby not creating many permanent overland drainage ways) whereas the opposite is true for the high drainage density pattern in Fig. 2b. In other words, it appears that soils comprised primarily of sand will have lower drainage densities than those with large amounts of silts and clays. The two geomorphic characteristics used (drainage pattern and density) reveal different quantitative information about drainage basins [5-8]. However, the data to date has not been used to describe the soil and its related vegetative potential in the drainage basin or to assemble this information into a large scale land capability evaluation technique.

Because drainage patterns and densities of large watersheds (6 to 10,000 square miles) can be determined in a relatively short time (approximately two weeks) and due to its inherent objectivity the application of this technique presents an attractive possibility for evaluating innate ecological capabilities of large land areas.

MATERIALS AND METHODS

Drainage patterns and densities of most of the 6,800 square mile St. Croix river drainage basin (Figure 3) were studied.[1]

This basin was selected because of its relatively natural character, its importance as a national scenic river, and its proximity to the University of Minnesota (base of research operations).

DRAINAGE PATTERNS

Drainage patterns were attained by overlaying United States Geological Survey maps (scale 1:62,500) with transparent vellum and tracing all

[1] United States Geological Survey maps were not available for the entire area.

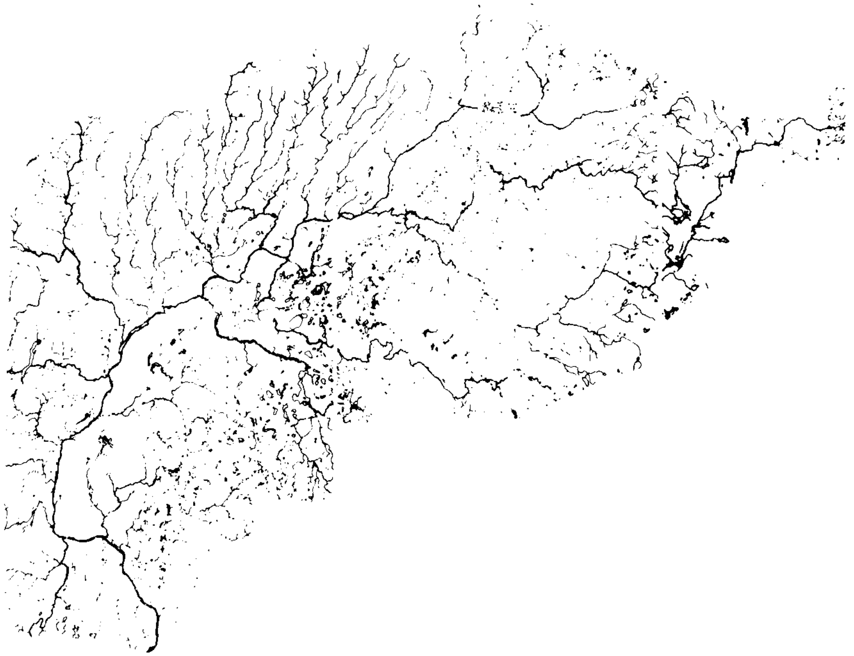

Figure 3. Drainage patterns and densities of St. Croix river drainage basin. (*Source*: U.S.G.S. maps.)

permanent and intermittent streams marked in blue on the maps. All lakes, regardless of whether they had inlets and/or outlets were also recorded on the overlay. The method of isolating homogenous drainage pattern types found in the basin was termed "pattern analysis" and involved an objective technique for labeling stream systems and determining the pattern types. Pattern analysis started with the St. Croix River (largest river in the basin) classified as the main stream, and all streams above a second order [5][2] that entered directly into the main stream were designated as primary streams. Watershed boundaries (using the topographic divide technique) were drawn around each primary drainage basin and the land area not within a primary basin, but inside the St. Croix River basin, was labeled as interprimary (Fig. 4).

The primary stream basins were then inspected to determine whether each had a homogenous drainage pattern type throughout. If so, the process (pattern analysis) was stopped, the drainage pattern identified, and the basin perimeter determined by topographic divide.

If more than one type of drainage pattern was found in a primary basin,

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[2] Streams below this order were small and therefore were not considered as significant data to record.

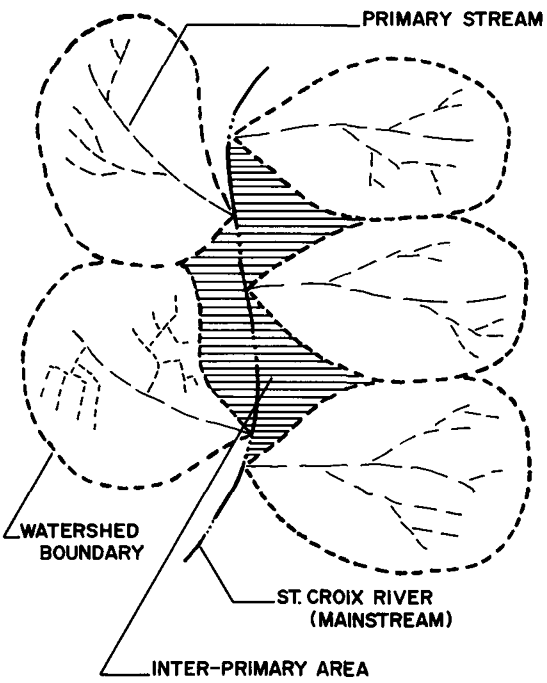


Figure 4. Hypothetical St. Croix River watershed showing the first step in pattern analysis.

that particular primary basin was classified as complex (Fig. 5). The complex primary basin was then subjected to additional pattern analysis.

All streams above a second order that flowed directly into primary streams were designated as secondary. Watershed boundaries were drawn around each secondary basin and the land area not within a secondary basin but within its respective primary watershed was labeled intersecondary (Fig. 5). Each secondary stream system was checked for a homogenous pattern throughout. If a homogenous pattern was found, it was identified and pattern analysis stopped. Secondary basins with more than one pattern was classified as complex, and the above procedure is continued until all stream basins (tertiary and quadrary) were categorically reduced to homogenous drainage patterns.

DRAINAGE DENSITY

Drainage density which can be defined as total length of stream miles divided by the total area of its drainage basin [5], was determined by using a rotating gauging wheel and recording the distance as registered on the gauge dial. Whenever a stream went through a lake it was assumed the stream ran in

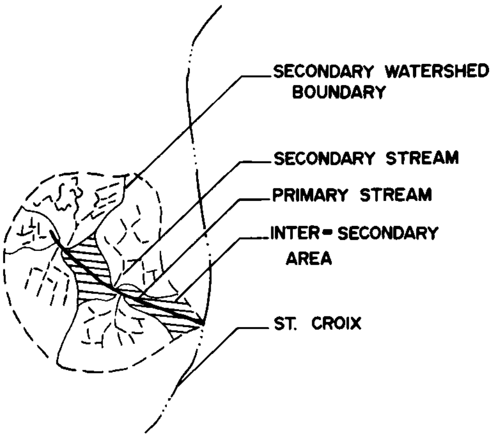


Figure 5. Blowup in scale and detail of a primary basin in Fig. 4 that was found to be complex. Note the different drainage patterns in this basin.

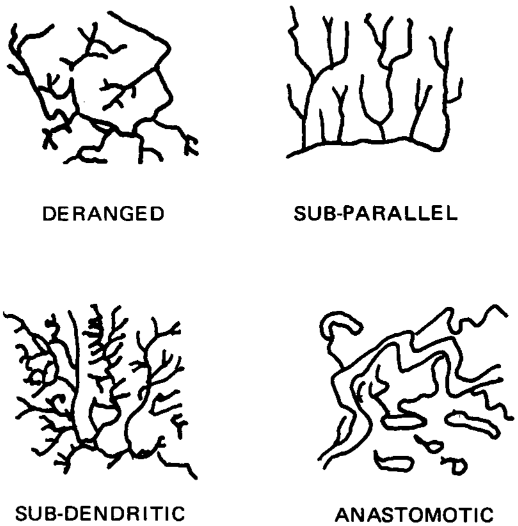
a relatively straight line from the lake inlet to its outlet. (If the lake was linear in shape and meandering the stream line was assumed to be centered between the shorelines, thus measurements reflected large meanders of a lake's shoreline.) The basin's total square miles was determined by a Bruning polar planimeter.

RESULTS

A total of 36 drainage basins and 28 interdrainage areas were categorized which produced six different types of drainage patterns, two (dendritic, parallel) of which were forms of the six commonly found patterns (Fig. 1). The remaining four (subparallel, subdendritic, deranged, anastomatic) were subpatterns of the two mentioned above (Fig. 6).

The results of "pattern analysis" is illustrated in Fig. 7 which shows the homogenous (A) primary; (B) secondary; (C) tertiary; and (D) quadrary stream basins found with their respective "inter" drainage areas. In the 36 drainage basins, the drainage densities ranged from .35 to 1.80 miles stream per square mile of land area while the 28 interbasin drainage densities varied between .00 to .75 miles/square mile. Table 1 shows the range of drainage densities found in the study area along with their corresponding soil textures.

Since soil texture is related to infiltration capacity of the soil, a correlation between drainage densities and soil textures was sought [9]. The dominant soil texture for each drainage basin and interbasin drainage was determined by overlaying the drainage pattern basins on available soil maps. The drainage basins and interbasins with .00-.59 miles/square mile had the majority of soil



DERANGED SUB-PARALLEL

SUB-DENDRITIC ANASTOMOTIC

Figure 6. Subpatterns of dendritic and parallel patterns.

textures ranging from sand to loamy sand. Basins and interbasins with densities from .59 to .96 miles/square mile had soil textures ranging between sandy loam to a loam. Soil texture classes ranging from loam to silts were found in drainage basins with densities of 1.05 to 1.20 miles/square mile. Basins with silts as the dominant soil texture had densities of 1.20 to 1.80.

The correlation coefficient between drainage density and soil texture (infiltration capacity) was computed using % sand for texture. The general relationship between textural classes and % sand is shown in Table 2.

The correlation coefficient between soil texture and drainage density was found to be -.85 which indicates that as % of sand in the soil increased, the drainage density decreased. Thus, it appears from again looking at Table 1 and the correlation coefficient (-.85) that drainage density and soil texture are directly related since the lower the drainage density, the coarser (more sand) the soil texture.

Discussion

Previous watershed-drainage density studies have been made in which the investigators determined what factors influence drainage density. In general these studies reveal that climate, geologic age of basin, topographic relief, infiltration capacity of the soil and vegetation were the dominent influencing factors [4]. Out of these five variables, the first three were found to be relatively constant in the St. Croix River watershed area.

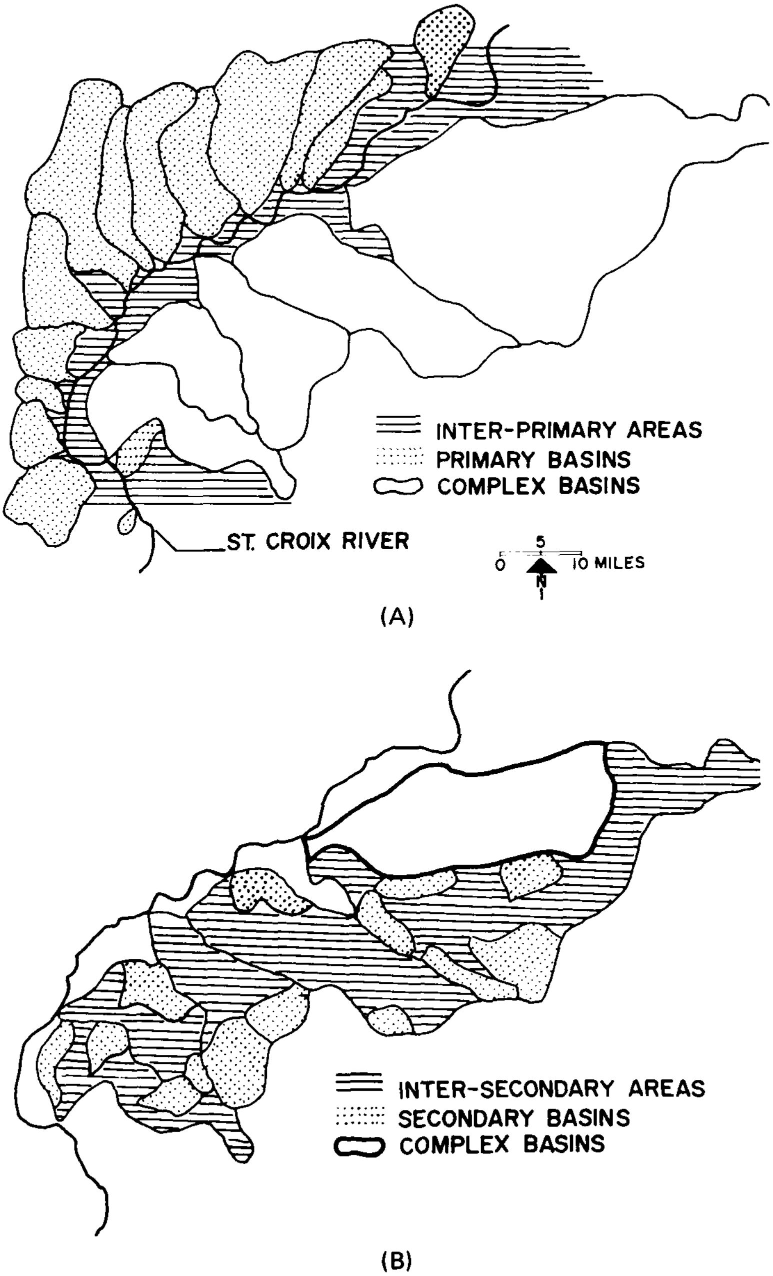
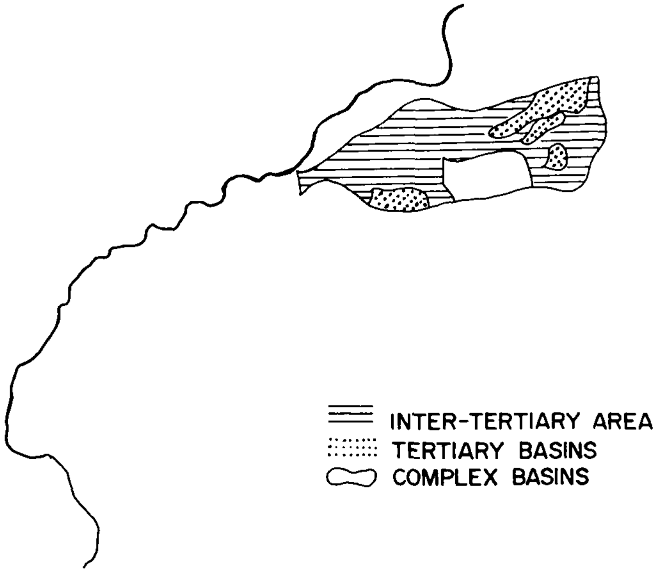
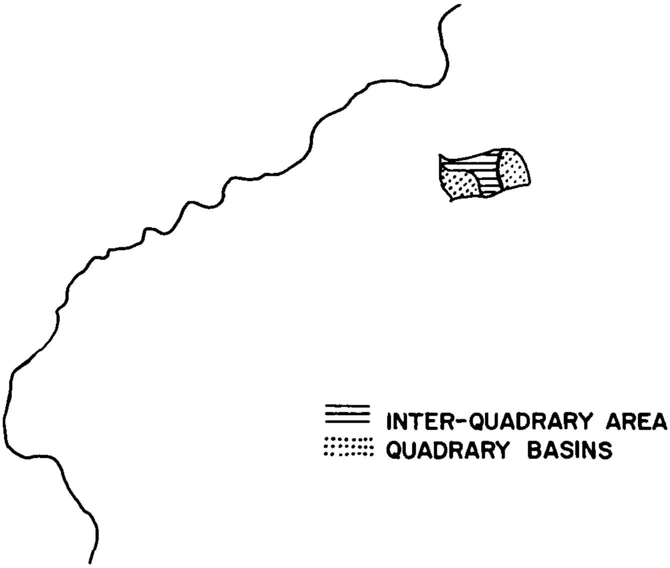


Figure 7. (A), (B), (C), and (D) show the result of pattern analysis of Fig. 3.



(C)



(D)

Note the different types of drainage patterns in the watershed.

Table 1. Range of Drainage Densities Found in the Study Area and Corresponding Soil Textures

Pattern number	*Drainage density*	*Soil texture*
56	.00	s
49	.00	s-ls
50	.00	s-ls
51	.14	s-ls
59	.15	s-ls
39b	.15	s-ls
46a	.19	s-ls
54	.20	s-ls
57	.20	s-ls
14b	.21	s-ls
31a	.24	s-ls
60	.25	s-ls
48	.26	ls
61	.29	l-ls
31b	.30	s-ls
46a	.30	sl
4	.35	s-ls
14a	.37	s-ls
7	.38	s-ls
11	.38	sl
58	.38	s-l
39a	.38	s-ls
29	.44	s-ls
55	.45	s-ls
8	.47	sl
41	.59	ls-sl
10	.60	sl-l
52	.61	sl-l
12	.64	ls-sl
22	.69	lfs-fsl
25	.71	fsl-l
24	.72	fsl-l
47	.72	fsl
36	.74	ls-sl
23	.75	ls-sl
28	.75	sl-l
53	.75	l
38	.76	ls-l
26	.78	sl-l

Table 1. (Continued)

Pattern number	*Drainage density*	*Soil texture*
20	.79	fsl
27	.85	sl-l
40	.86	fsl
45	.89	ls-sl
15	.93	sl-l
42	.96	sl
43	.96	sl
30	1.05	l-silt
3	1.08	l-silt
19	1.20	l-silt
35	1.21	silt
32	1.29	silt
6	1.29	l-silt
5	1.33	l-silt
33	1.47	silt
9	1.66	silt
37	1.80	silt

Soil Texture Key for Table 1.

s- sand
ls- loamy sand
lfs-fsl- loamy fine sand-fine sandy loam
sl- sandy loam
l- loam
silt- silt

Borchert-Yaeger [10] and Kittredge [11] state the differences in climate (rainfall-temperature) between parts of the study area are not of such magnitude as to cause major variations in tree growth, vegetation, or soils.

Table 2. Relationship Between Textural Classes and % Sand

Textural class	*% Sand*	*Average*
Sand	100-85	92%
Loamy sand	70-85	77%
Sand loam	50-70	60%
Loam	30-50	40%
Silt loam	20-30	25%
Silt	0-20	10%

(U.S.D.A.)

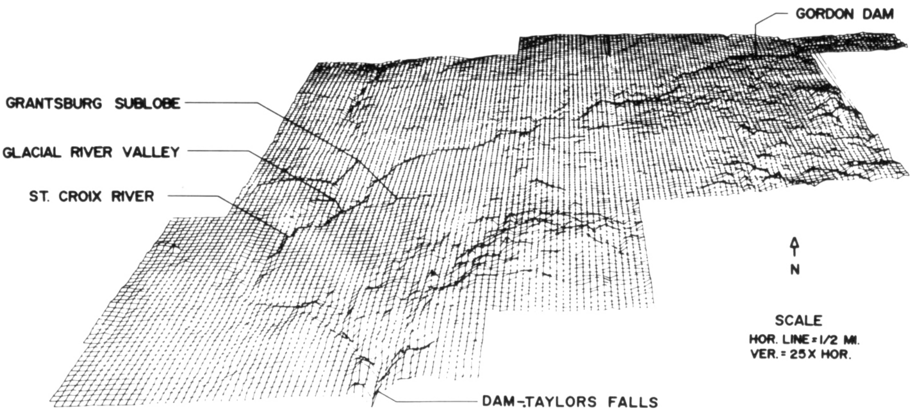


Figure 8. A computer relief map. (Kuska-Lamarra.)

Ruhe [12] studied the two different substages of the Wisconsin age of glaciation that deposited drift in the study area. He concluded the amount of stream dissection due to the time difference between the Cary and Mankato stages was not significant.

A computer relief map (Fig. 8) made by the authors showed little variation in large scale topographic relief. The data suggests the other two variables (infiltration capacity and vegetation type) have played a major role in producing the range of drainage densities found in the 36 basins studied. Infiltration capacity, which is related to soil texture and/or particle size influences infiltration directly. The work of Morgon [9] with soil texture classes and their relationship to infiltration capacity (Table 3) clearly implies that soils containing a high percentage of clay particles would tend to have more overland run off than soils composed primarily of sand.

The above phenomenon was substantiated by the data obtained from the study of the St. Croix drainage basin. Table 1 demonstrates that areas with low drainage densities (high infiltration) have high concentrations of sand. In

Table 3. Soil Texture Classes and Their Relationship to Infiltration Capacity [9]

Soil texture	*Infiltration capacity (in/hr)*
Clay loam	0.1-0.2
Silt loam	0.3-0.6
Loam	0.5-1.0
Sandy loam	1.0-2.0

areas where silt was the dominant soil texture there appeared to be a low infiltration rate (more run off) which produced higher drainage densities. Regarding the fifth variable (vegetation) that influences drainage density Eggler [13], Kittredge [11] and Wascher [14] have shown that soil texture is related to the aeration, concentration of nutrients, and moisture holding capacity of the soil, which in turn has a direct influence on the type of vegetation that will be able to successfully compete in a particular area.

Bakuzis, and Hansen [15], Daubermine [16], Eggler [13], Brown and Curtis [17], and Kittredge [11], have indicated that soil textures and vegetation are related. Our data supports their work as evidence by looking at Figure 9(A), (B), (C), and (D).

Conclusion

Pattern analysis coupled with drainage density data found in the St. Croix River watershed appear to provide the framework for predicting the innate ecological capabilities of relatively natural large scale land areas. By determining the total number, size and densities of drainage basins in the St. Croix watershed, inferences can be made as to the ecological diversity (texture of surficial material, potential vegetation) of the major watershed. It appears the

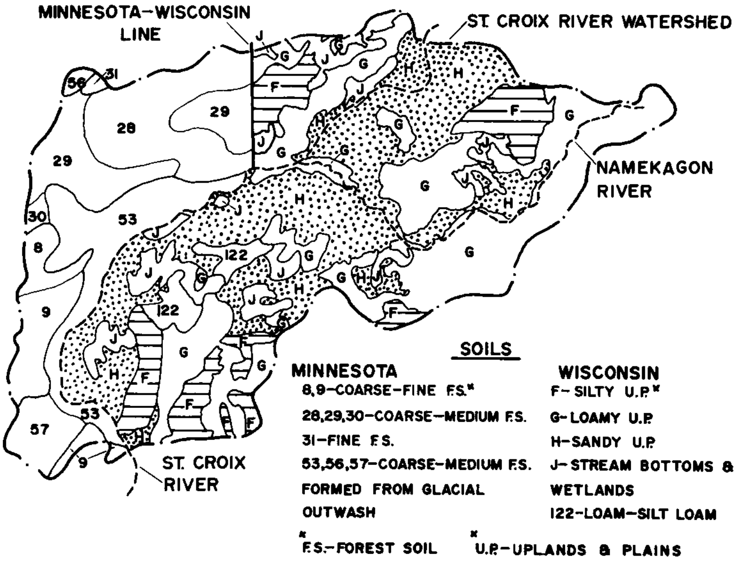


Figure 9(A). Existing generalized soil map showing soil units found in the St. Croix River watershed. (*Source*: Arneman [18], University of Wisconsin [19].)

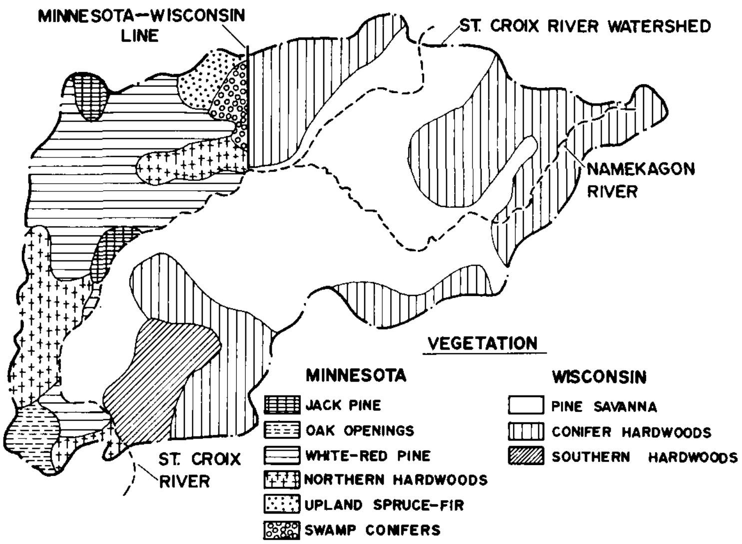


Figure 9(B). Existing generalized vegetation map of the study area. Note the correlation and discrepancies with Figure 9(A). (*Source*: S.C.S. [20], Curtis [21].)

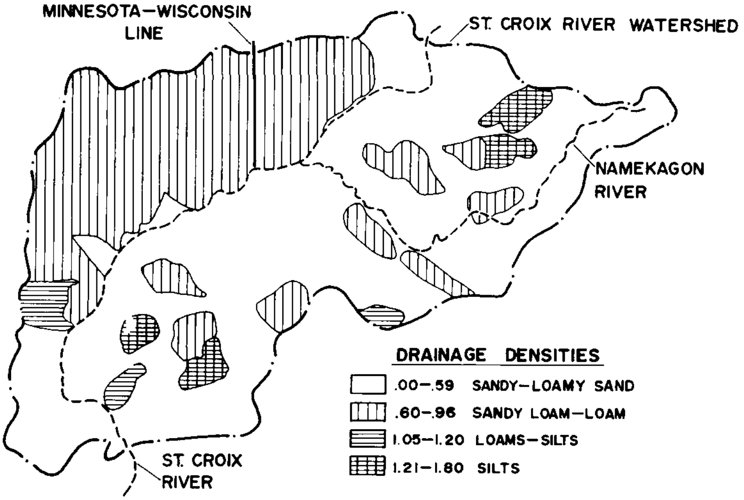


Figure 9(C). Result of Pattern Analysis Showing the Relationship of drainage densities to soil textures. Example—drainage densities between .00-.59 had soil textures ranging between sand—loamy sand.

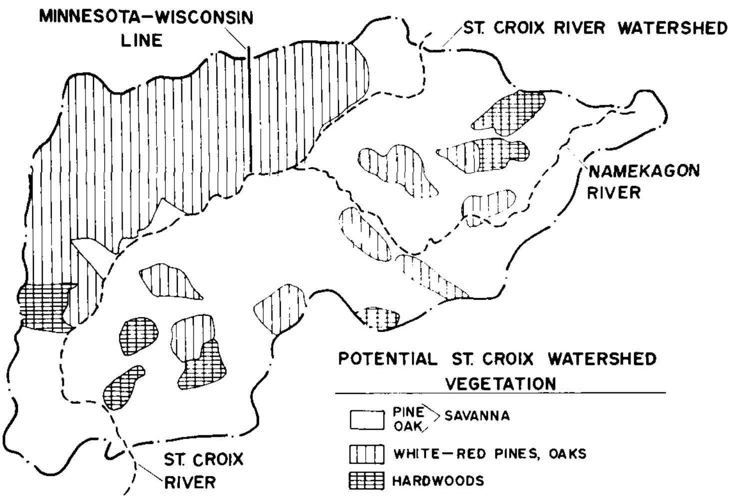


Figure 9(D). The authors' proposed vegetative cover determined by the use of drainage density–soil texture data correlated with synecological requirements for Minnesota forest. Note correlations and discrepancies with Figure 9(A), (B). (*Source*: Bakuzis-Hansen [15].)

more diverse the major watershed, the more administrative units one should set up to effectively plan and manage the total area. Since drainage densities reflect differences in soil textures which in turn influence the type of vegetation found in an area, the various sub-basins have to be managed differently to maintain the ecological diversity of the major basin. Hopefully, detailed applications and interpretations of pattern analysis will provide information that will indicate how many as well as which areas in a watershed can best support activities such as logging, horse trails, road construction, agricultural crops, game management areas, subdivision development, and related activities.

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