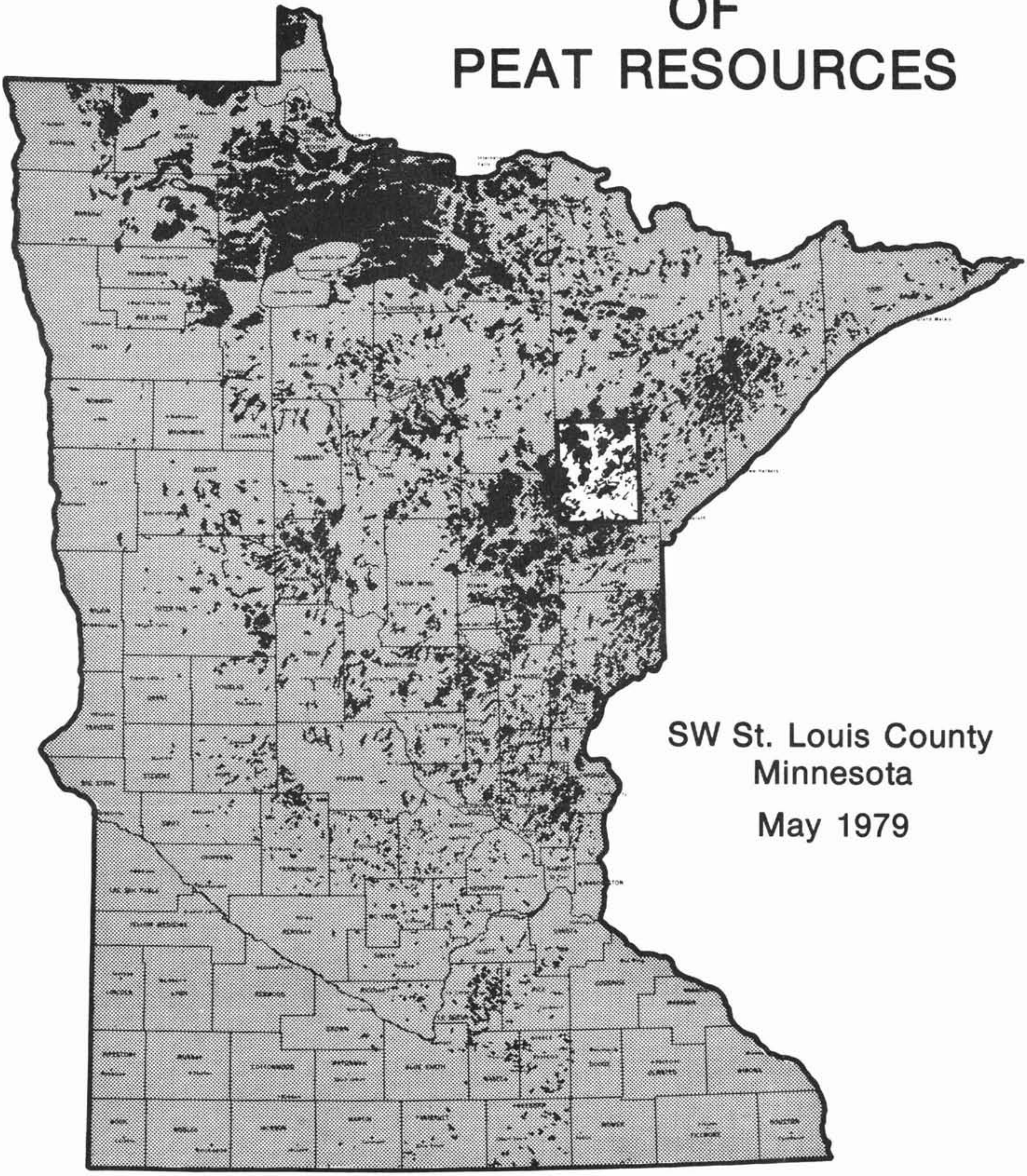
INVENTORY OF PEAT RESOURCES



SW St. Louis County
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INVENTORY OF PEAT RESOURCES IN SW ST. LOUIS COUNTY, MINNESOTA

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I. INTRODUCTION

Peatlands constitute one of Minnesota's many natural resources. They cover about 7.2 million acres of land which is about 14 percent of the State's total acreage. The majority of the 7.2 million acres occur on state-owned or state-administered land. Because most of these peatlands are presently in their natural state, Minnesota has an unique opportunity to develop sound management plans for the future of this resource.

The 1976 Minnesota State Legislature mandated that the Department of Natural Resources (DNR), Minerals Division, initiate a Peat Information Program. This program began to collect information on Minnesota peatlands and develop policy alternatives for the utilization of Minnesota's peatlands. Through this program the Minnesota Peat Inventory Project (MPIP) was initiated, with limited funding, to begin an inventory of large peatlands in Minnesota.

In 1977, the Minnesota State Legislature, through the Legislative Commission of Minnesota Resources (LCMR), provided the DNR, Minerals Division, with special funding to continue the MPIP. The purpose of the MPIP is to provide baseline information to the legislature to enable judicious management of this resource. The baseline information presented in this report pertains to the dimensions of major peat areas, to the determination of the quantity of peat, and to the recognition of the types of peat in southwestern St. Louis County.

A reconnaissance level survey of SW St. Louis County was completed by the MPIP. Peat types were delineated on a base map, and peat samples were collected and analyzed; the map delineations depict the areal and quantitative extent of peat types.

The focus of this report lies in SW St. Louis County. This is an area bordered on the south by Carlton County, on the west by Aitkin and Itasca Counties, on the north by Township 56 North, and on the east by Range 16 West (Figure 1). The area encompassed is approximately 276,200 ha (682,250 ac). Within this diversified region is one of the major peatland areas of the State. It contains the full spectrum of peat types existing in Minnesota and has a large concentration of Sphagnum peat.

Considerable research on peatlands in Minnesota is beginning to accumulate. Farnham reported on the application of northern European peatland classification criteria to a northern Minnesota peatland (Arlberg Bog — within SW St. Louis County) and presented a comparison of the United States organic soil classification system criteria to those used in Europe (6).

Heinselman presented two papers pertaining to peatlands in northern Minnesota: the first discussed forest sites, bog processes, and peatland types in the Glacial Lake Agassiz region (13); the second discussed the relationships of vegetation and peatland types of the Lake Agassiz Peatland Natural Area to topography, waterflow patterns, water chemistry, and the evolution of the landscape as recorded by peat stratigraphy (14).

Peatland inventory work has been carried out in Minnesota by E. K. Soper and the Iron Range Resources and Rehabilitation Board (IRRRB). In 1919, *Peat Deposits of Minnesota* was published (29). In this bulletin, Soper outlines and describes peat deposits in various locations throughout Minnesota. Soper's inventory data pertaining to SW St. Louis County was used in the compilation of the peat resources of SW St. Louis County map.

The IRRRB inventoried 46 individual bogs at a detailed level intermittently during a period of eleven years with the first report published in 1964. The IRRRB sampled 1,106 sites in 17 bogs within SW St. Louis County. At each site the peat depth was measured, the peat was described, and samples were taken at one-foot intervals to a depth of seven feet. Water content, mineral content, and pH were determined for each sample. This information was also used in the compilation of the peat resources of SW St. Louis County map (16, 17, 18).

Five major parts are presented in this report: 1) the geologic setting of the area; 2) an overview of

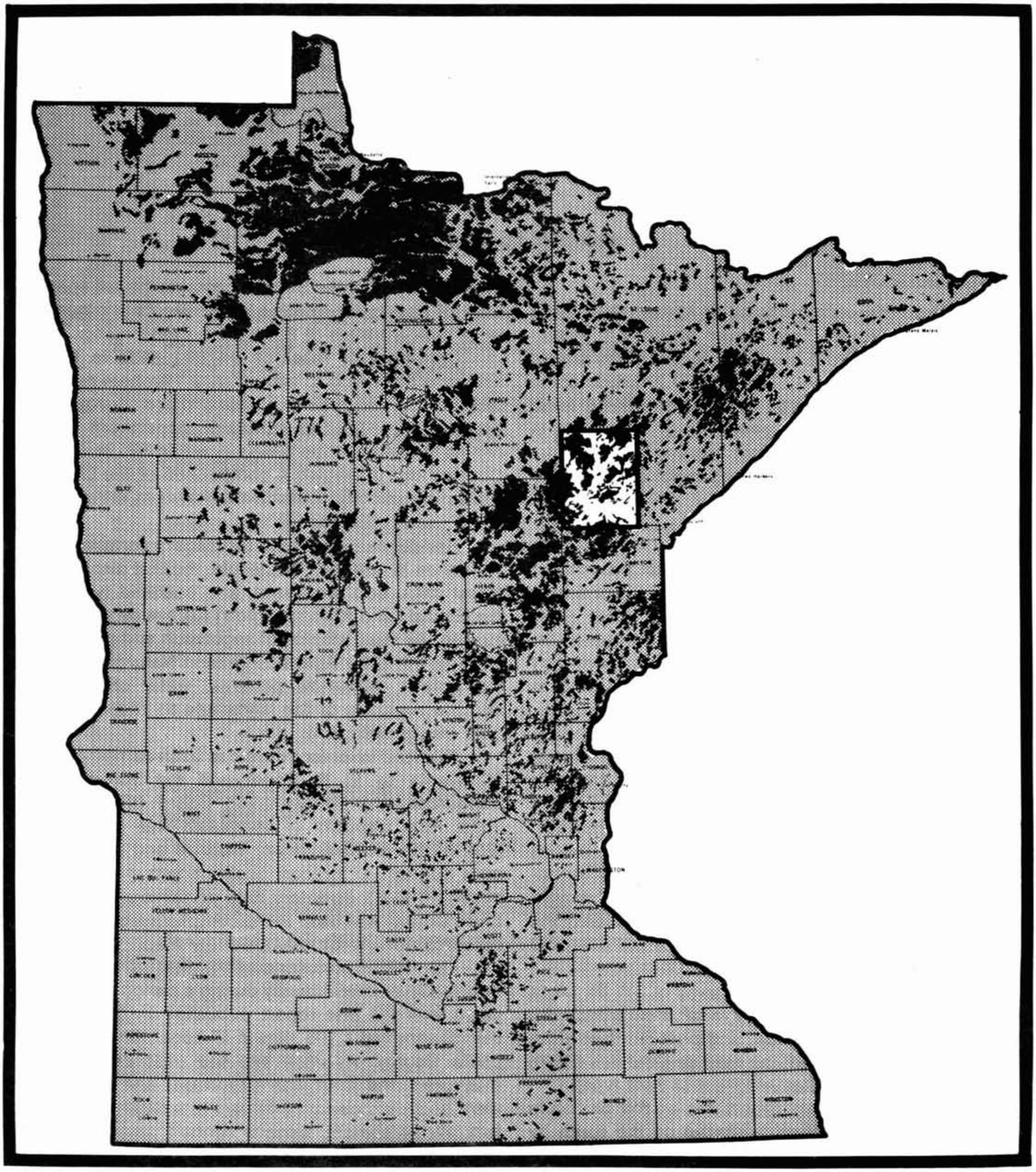


Figure 1. SW St. Louis County, Minnesota, in relation to state-wide peat distribution.

peat evolution; 3) the methods of investigation; 4) the SW St. Louis County peat map with a discussion of the classification system and mapping methodology; and 5) a discussion of the results.

II. GEOLOGIC SETTING

The landscapes of Minnesota reflect the effects of former, extensive glaciation. The time period spanned by glaciation to the present is referred to as the Quaternary Period. It is subdivided into the Pleistocene and Recent Epochs; the Pleistocene Epoch refers to the period of glaciation, and the Recent (Holocene) Epoch refers to the geologic strata deposited since the disappearance of the ice sheets.

Pleistocene Epoch

During the Pleistocene Epoch Minnesota was subjected to multiple periods of continental glaciation which were manifestations of significant climatic changes. Each glacial period was separated by long interglacial (interstadial) periods when the climate moderated and the ice thawed and retreated into the Arctic regions. Most of the surficial features in Minnesota are a result of the most recent glaciation, the Wisconsin Ice Stage, which spanned a period from > 55,000 to 10,000 years BP (10). Evidence of earlier glaciations was largely obscured by this ice stage.

The Wisconsin Ice Stage is divided into phases related to advances and retreats of individual ice lobes which entered northeastern Minnesota from the northwest and northeast (Figure 2). The glacial history of the area has been reconstructed by interpreting the stratigraphic and topographic relations of the glacial drifts; the drift of each ice lobe has a distinctive color, texture, and stone content depending on the area of its origin.

A simplified sequence of Wisconsin glaciation in the study area follows (33, 34, 35):

St. Croix Phase (Wisconsin Stage 20,000 years BP)

1. The Rainy lobe advanced from the north following a southwest course parallel to the Lake Superior coastline and adjacent to the contemporaneous Superior lobe (occupying the Lake Superior basin). Both lobes advanced south-southwestward and deposited the St. Croix moraine in the Twin Cities area and central Minnesota.
2. The end of the Phase is marked by:
   a) The retreat of the Rainy lobe to the north exposing the Toimi drumlin field that is composed of Rainy lobe till;
   b) The retreat of the Superior lobe and the flow of meltwater from both ice fronts south through the complex system of interdrumlin channels around the tongue of the retreating Superior lobe.

Automba Phase

1. The Superior lobe readvanced west and west-southwest from the head of the Lake Superior basin and built the Mille Lacs moraine. On the north flank of the Superior basin, it deposited the Highland moraine. This advance blocked normal southward drainage of the area and resulted in the formation of Glacial Lakes Upham I and Aitkin I north of the lobe. The Rainy lobe readvanced slightly to a position marked by the Vermilion moraine.
2. The end of the Phase is marked by the retreat of the Superior lobe into the Lake Superior basin.

Split Rock Phase

1. The Superior lobe again advanced and deposited the Cloquet moraine in Carlton and Aitkin Counties. Meltwater drained to the Mississippi River via the St. Louis River, Glacial Lake Upham I, and Glacial Lake Aitkin I.
2. The close of the Phase is marked by the ice retreating again and meltwater draining down the Kettle River to the St. Croix River.

Alborn Phase

1. The final major glaciation in the study area is marked by the advance of the St. Louis sublobe from the west. It crossed over Glacial Lakes Upham I and Aitkin I and covered the west edge of the Toimi drumlin field and the north side of the Highland moraine. Existing tills are a blend of St. Louis sublobe tills, older Superior lobe tills, and lacustrine materials.
2. As the St. Louis sublobe retreated westward, its meltwaters contributed to the formation of what is currently called Glacial Lakes Upham and Aitkin. The proglacial lakes were subsequently drained by multiple outlets in the south and southeast.

Recent (Holocene) Epoch

Postglacial changes in the landscape are minor in comparison to those that resulted from glacial processes. They include erosion and deposition by streams, formation of sand dunes, and the accumulation of peat. Alluvium occurs in most present-day streams as well as former glacial drainageways. Sand dunes developed in the northwest part of Lake Upham during a climatic dry period about 8,000 to 5,000 years BP (5, 12). Peat began to accumulate in northeastern Minnesota shortly after the retreat of the last ice sheet.

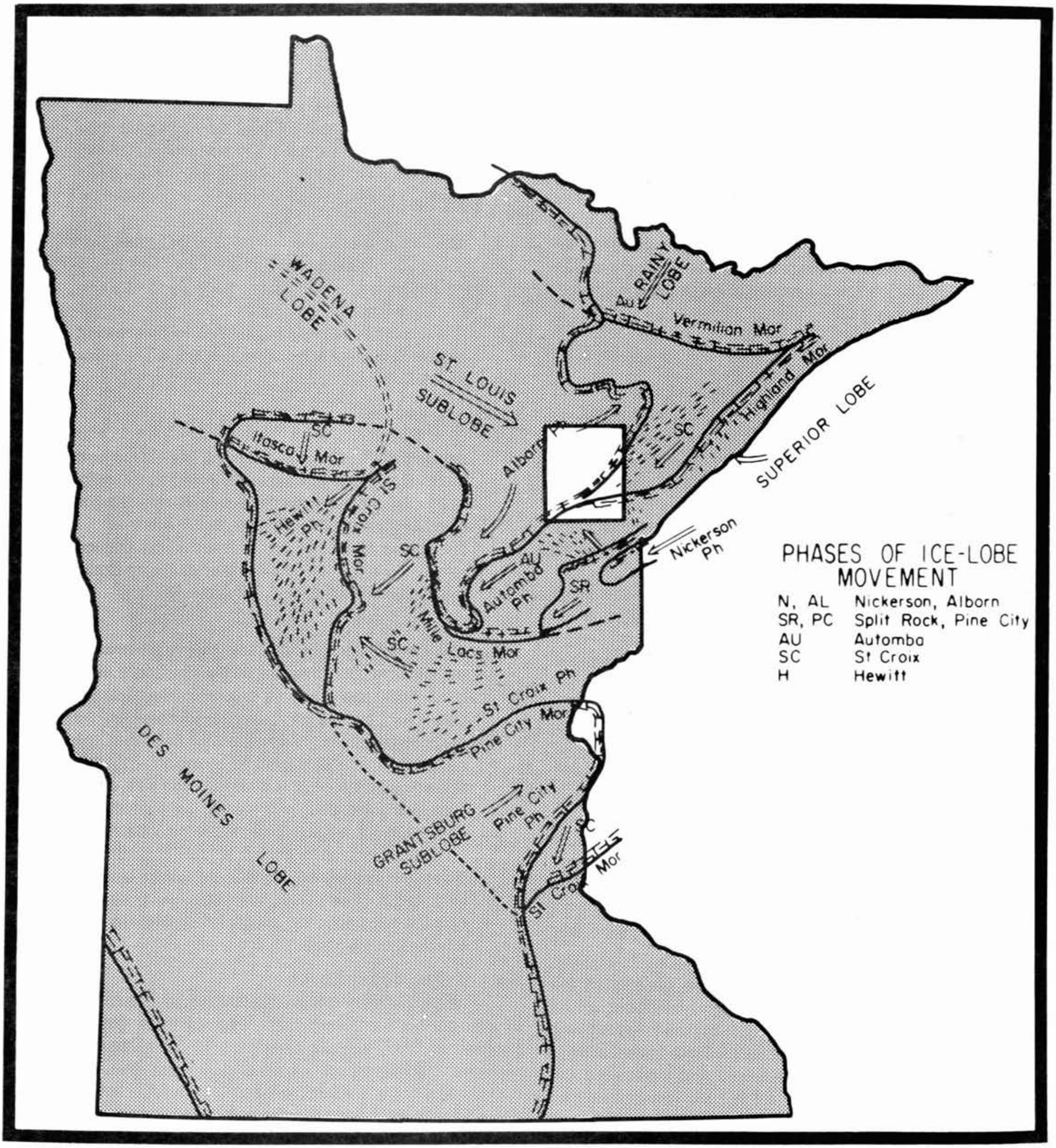


Figure 2. Phases of the Superior lobe, Rainy lobe, and St. Louis sublobe in relation to SW St. Louis County, Minnesota. Based on Wright (33).

Physiography

Glacial processes associated with Wisconsin glaciation produced a variety of landforms. These landforms were used as the primary basis for dividing Minnesota into physiographic areas (Figure 3). Most of SW St. Louis County lies within the four physiographic areas listed below (32).

Glacial Lakes Upham and Aitkin — This area consists of a lake plain and marginal sand plains, much of which is presently covered with peat. Sand dunes and till islands are scattered throughout portions of the northwestern part of Glacial Lake Upham. Beaches occur at the margins of the glacial lakes.

Aurora - Alborn Clay - Till Area — This area is represented by the undulating ground moraines and rolling end moraines composed of blended tills of the St. Louis sublobe and Superior lobe.

Sugar Hills - Mille Lacs Moraine Area — This rugged end moraine topography is composed of sandy tills deposited by the Superior lobe. Most of this area is covered by a cap of clay till deposited by the St. Louis sublobe; however, this cap does not occur within SW St. Louis County.

Toimi Drumlin Area — This drumlin field, oriented in a northeast-southwest pattern, occupies a position on the east side of the study area. It consists of a group of parallel, streamlined hills formed by moving ice. These half ellipsoid shaped hills are 1-2 miles long, 1/4 mile wide, and 30-50 feet high.

Surficial Geology of SW St. Louis County

The glacial features in SW St. Louis County have been delineated by Eng (5). His surficial geology map depicts glacial landforms, peat bogs, and peat bog patterns; his text outlines some of the hydrological events associated with the Glacial Lake Upham area.

The map specifically identifies lake bottom sediments, off-shore sand, end moraines, moraine overlap, ground moraines, ablation moraines, drumlins, eskers, kames, outwash, alluvium, terraces, beaches, and peat deposits.

Eng's mapping unit descriptions appear in Appendix A.

III. PEAT EVOLUTION

Peat, or organic soil, consists of dead and partly decomposed plant materials. It occurs in an unbalanced system where the rate of production of organic materials exceeds the rate of decomposition, usually under conditions of almost continuous saturation by water. The wet environment inhibits the exchange of gases that is necessary for microbial decomposers. When these anaerobic conditions develop, the rate of decomposition is greatly reduced and masses of partially decomposed material accumulate as peat.

Peat Formation

Contributing factors in the initiation and development of peatlands are topography, climate, and water. The rate of peat accumulation is dependent on the interaction of these factors.

Topography

In northern Minnesota, glacial depositional and erosional processes formed features that were particularly suited for peat accumulation. When geomorphic features slow water movement, they provide a base for peat accumulation (*e.g.* glacial lake basins, relatively flat ground moraines, outwash plains, and ice block depressions).

Large glacial lake basins were formed at ice sheet margins when meltwater became impounded between glacial ice and existing physical features. These ephemeral lakes are now marked by lacustrine soils (laminated silts and clays that were deposited by the sorting action of glacial lake waters). Impermeable soils and the low relief of the glacial lake basins inhibit good drainage.

Ground moraines are accumulations of till laid beneath glaciers. They tend to have low relief and relatively poor drainage; these areas provide conditions in which peat accumulates.

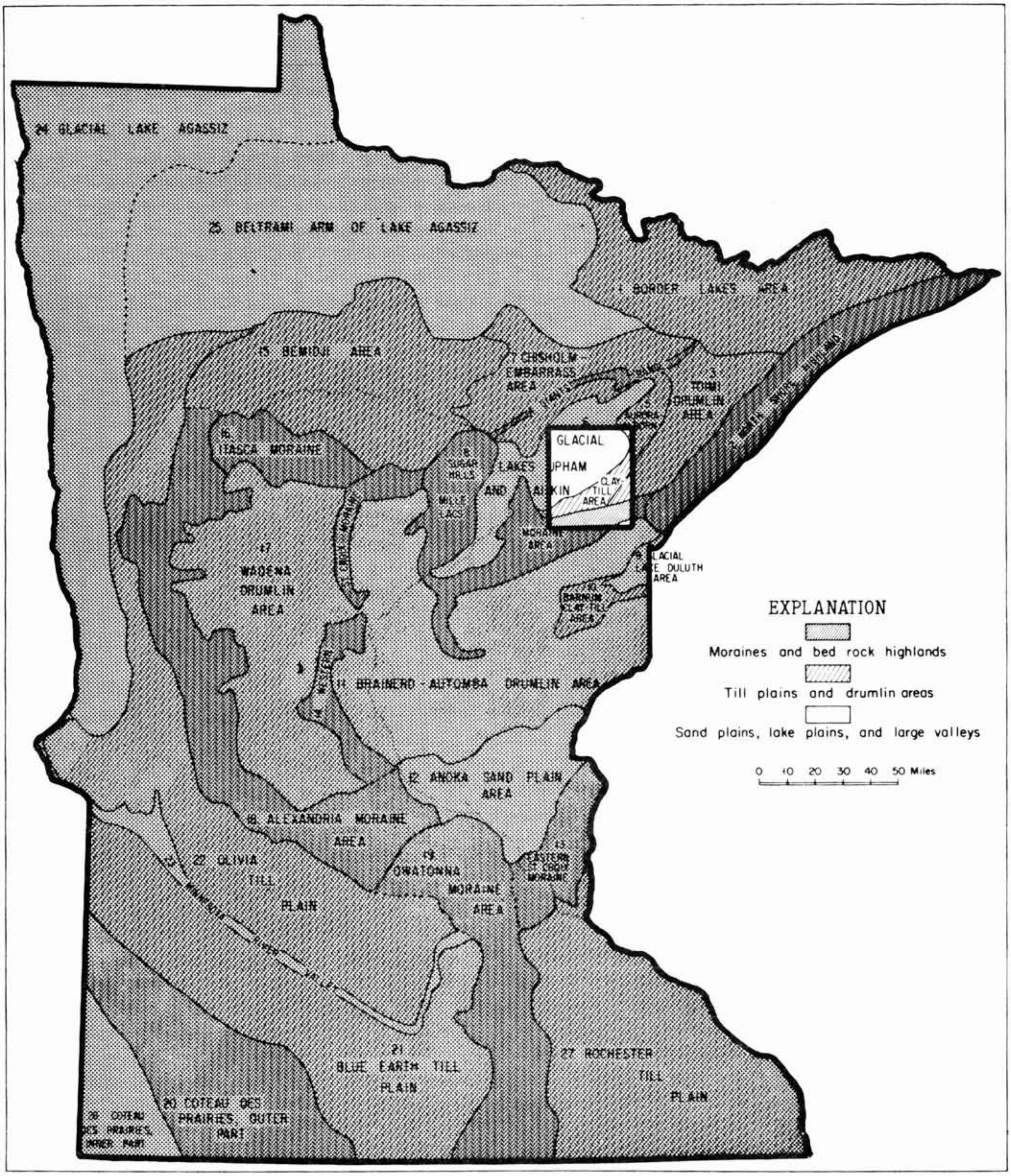
Outwash plains are formed by a series of merging outwash fans built by streams extending beyond an ice front. These stratified sands and gravels provide a base for peat accumulation when the water table is at or near the surface.

Outwash fans were often deposited over stagnant ice; when the ice melted, subsidence of the overlying material occurred and kettles resulted. Where outwash was deposited over stagnant ice of varying thickness, numerous kettles resulted; this type of topography is commonly referred to as a pitted outwash plain. These kettle lakes are suitable environments for peat accumulation when the water table level occurs within the kettles.

Kettle lakes are also formed in end moraine complexes. In areas of relatively impermeable till, these depressions filled with water and some eventually filled with peat.

Climate

Climate is an equally important influence in peat development. Peat most frequently occurs in cool, humid climates where precipitation exceeds evapotranspiration. Northern Minnesota is such an area; the sub-humid continental climate provides about 65 cm ($\sim$ 25 in) of annual precipitation, and the long, cold winters and short, warm summers greatly reduce the potential evapotranspiration. Generally, climatic factors have been conducive to peat formation in Minnesota for about 8,000 years; however, there have been significant climatic variations since that time.



Map of physiographic areas in Minnesota. 1, border lakes area; 2, North Shore Highland; 3, Toimi drumlin area; 4, Giants range; 5, Aurora-Alborn clay-till area; 6, Glacial Lakes Upham and Aitkin; 7, Chisholm-Embarrass area; 8, Sugar Hills-Mille Lacs area; 9, Glacial Lake Duluth area; 10, Barnum clay-till area; 11, Brainerd-Automba drumlin area; 12, Anoka sandplain area; 13, eastern St. Croix moraine; 14, western St. Croix moraine; 15, Bemidji area; 16, Itasca moraine; 17, Wadena drumlin area; 18, Alexandria moraine area; 19, Owatonna moraine area; 20, Coteau des Prairies, outer part; 21, Blue Earth till plain; 22, Olivia till plain; 23, Minnesota River Valley; 24, Glacial Lake Agassiz; 25, Beltrami arm of Lake Agassiz; 26, Coteau des Prairies, inner part; 27, Rochester till plain.

Figure 3. Physiographic areas of Minnesota in relation to SW St. Louis County. Based on Wright (32).

Water

A saturated environment must exist for most of the year for peat to accumulate. The amount, nutrient content, and acidity of peatland water determine the vegetation and; hence, peat present. Sphagnum moss growth occurs where there is a localized high water table; whereas, dense black spruce growth occurs in areas of greater slope ($>$1.6 m/km) or ($>$ 8 ft/mi) that allow sufficient aeration (2). Acidic water, low in available nutrients, favors the growth of Sphagnum moss but stunts the growth of black spruce. Less acidic water, with more available nutrients, is more favorable for the growth of black spruce, tamarack, and herbaceous material. Neutral water environments tend to enhance the growth of northern white cedar.

Peat Formation Processes

Peat formation generally occurs by two means — paludification and lakefill. Paludification (swamping) is a process of bog expansion caused by a gradual raising of the water table as peat accumulation impedes drainage (13) (Figure 4). This process begins with reed or sedge growth in areas of little or no relief; these herbaceous materials accumulate as peat. Due to the low relief and the blockage of drainage by the peat, the water table begins to rise leading to the growth of more herbaceous plants. As more peat accumulates, it begins to creep upslope and may gradually cover the divides. Thus, the elevations of peat-covered areas may actually be higher than the elevation of mineral soil along rivers flowing through the bogs.

Lakefill is defined as the filling in of lakes or ponds by vegetation (30) (Figure 5). It is initiated when limnic materials (organic or inorganic materials deposited in water by the action of aquatic organisms or derived from underwater and floating organisms) begin to accumulate on the lake bottom. This type of accumulation is sometimes referred to as aquatic peat. Simultaneously, sedge growth is initiated around the edges of the water-filled basin and gradually grows inward. The encroachment of the plant communities may actually occur as a floating mat. As the migration of plant communities continues to the center of the basin, dead plant matter eventually collects as peat. The more stable or outer portions of the peat allow other species of plants to migrate towards the center. Peat continues to accumulate inward, filling the basin, until the lake disappears (21).

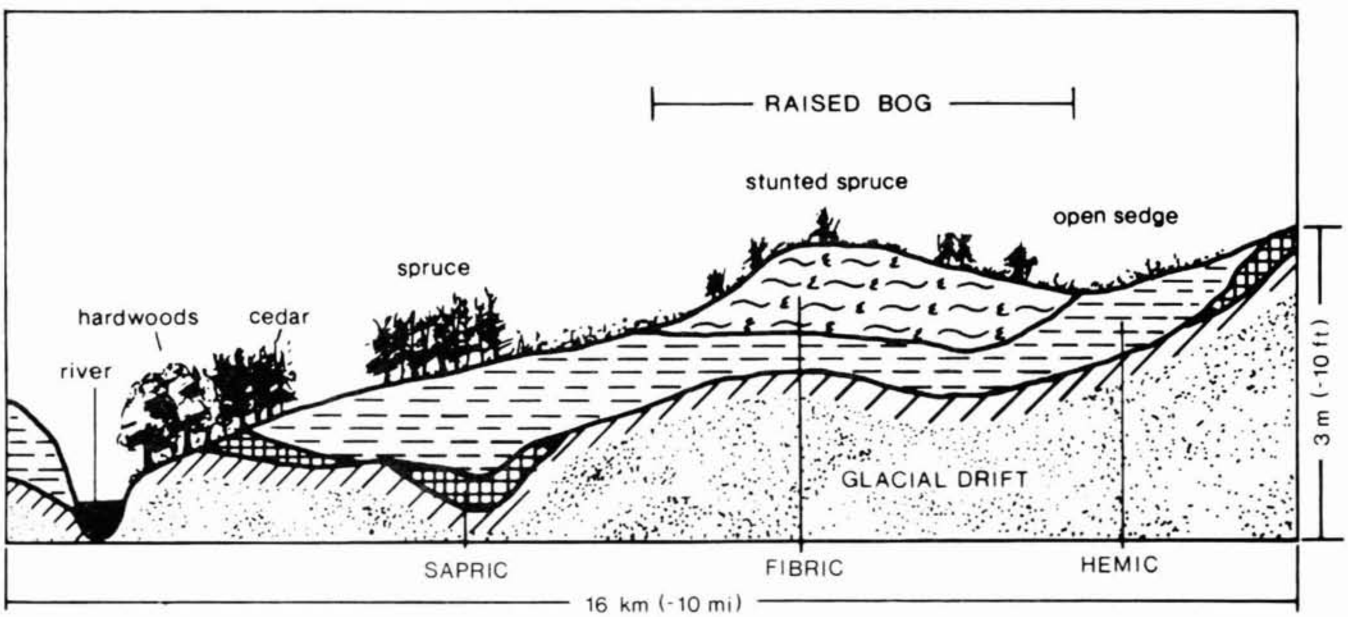


Figure 4. Paludification process.

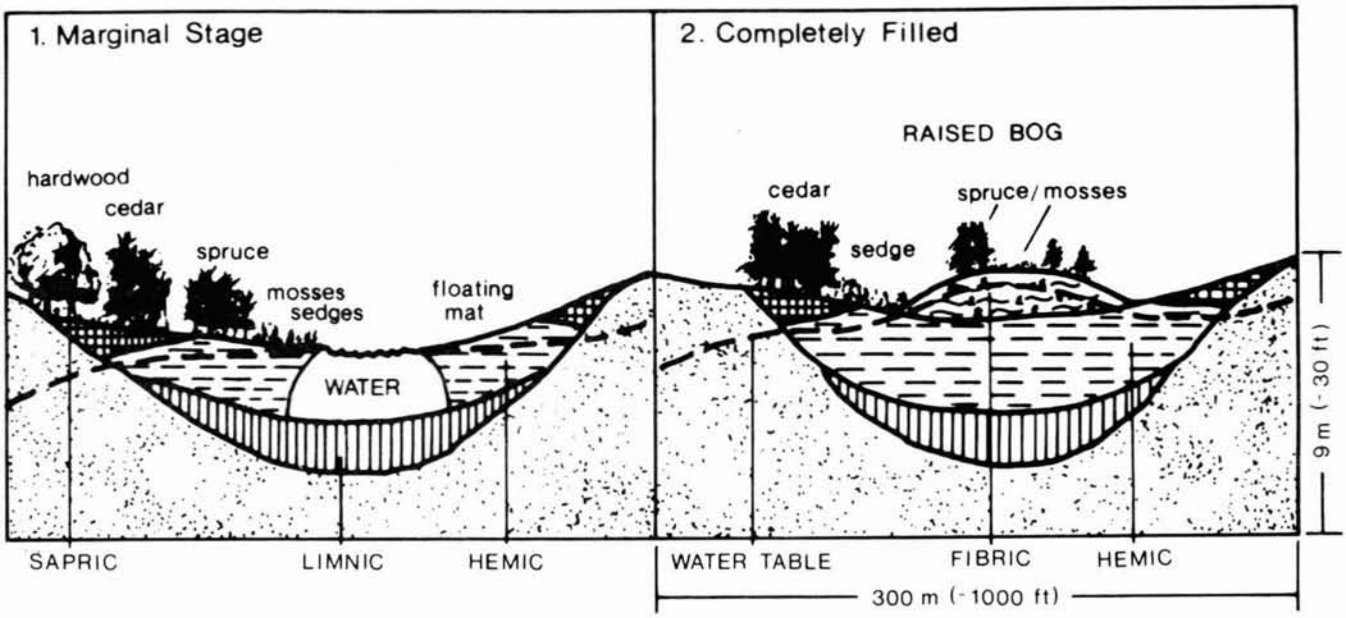


Figure 5. Lakefill process.

Sequence of Development

As the ice sheets retreated about 11,000 years ago, aquatic peat began to collect in lakes and ponds (2). About 8,000 years ago herbaceous peat, composed of reed, sedge, and cattail vegetation, began to accumulate as a result of the paludification and lakefill processes.

As herbaceous peat began to accumulate, forest vegetation advanced to bog areas where the nutrient content of the water was relatively greater, such as along beach margins, near mineral islands, and in areas of localized upwelling. Woody peat eventually accumulated from this forest vegetation.

About 3,000 years ago, raised bog development was initiated in Minnesota due to three circumstances: 1) a climate favorable to Sphagnum growth with an elevated water table; 2) the appropriate species of Sphagnum present; 3) a water table divide causing mineral depletion — either present in the original physiography, or developed by peat accumulation or by stream piracy (14).

Sphagnum selectively invades areas of low nutrient status and high acidity where it outcompetes less tolerant species. Sphagnum growth occurs in hummocks which may be 60 cm (~ 25 in) high and 100 cm (~ 40 in) across. This growth pattern tends to isolate it from the local water table. After Sphagnum growth is initiated, the pH level is further reduced by the high cation exchange capacity of the Sphagnum itself. The lower pH levels further limit the actions of decomposers which allow a more rapid accumulation of peat. A dome of Sphagnum moss may eventually form over herbaceous peat, hence, the term "raised bog" (Figure 4). As the dome of Sphagnum peat continues to accumulate, its nutrient supply comes exclusively from precipitation and aeolian dust (9).

The majority of peat in SW St. Louis County is herbaceous, formed by paludification on the Lake Upham plain. The lakefill process occurred in isolated areas within end moraines and pitted outwash plains. Sphagnum moss peat and woody peat exist in relatively few areas. Sphagnum moss peat, greater than 60 cm (~ 2 ft) deep, comprises about four percent of the peatland area in SW St. Louis County.

IV. METHODS OF INVESTIGATION

Field Procedures

The reconnaissance survey employed in the peat inventory of SW St. Louis County serves as a preliminary study to illuminate basic information. This level of mapping is extremely useful in relatively undeveloped, inaccessible regions and is generally used for broad-range planning.

The mapping of a specific bog area begins with a general inspection of the area in question using a regional, surficial geology map (*e.g.* Eng, 1979). It is essential for the surveyor to gain an appreciation of bog patterns and each bogs location in relation to landscape patterns within the geographic region. This overview of the physiography enables the surveyor to determine the best approach to surveying a specific bog.

Due to the nature of the survey and the inaccessibility of peatlands, the inventory was carried out by making selected traverses across specific bogs. Aerial photographs and U.S.G.S. quadrangle maps were used to determine traverse lines within a specific bog. Ideally, the surveyor aligns the primary survey line along the main axis of the bog; then, a number of secondary lines are selected perpendicular to the main line at various intervals. One of these traverses should run perpendicular to the grain or slope of the bog. If a distinct raised bog pattern appears on the aerial photo, one of the traverse lines should run through the center of it. Large or irregular shaped bogs that lack homogeneity may require several major axis lines. In the survey of a bog where previous inventory data exists, the traverse lines may be altered to prevent duplication of work.

The density of observation and sampling sites along the traverses was determined by the appearance of the bog on aerial photos, the surrounding geomorphic features, and drainage characteristics exhibited on the quadrangle map. For example, the depths of the peat/mineral interface of a specific bog may be as varied as the surrounding terrain. Thus, to obtain representative samples, the sample density in a bog within an end moraine has to be much greater than the sample density in a bog situated within a glacial lakebed. In areas of homogeneous peat where the peat was sampled less frequently, supplemental depth soundings were taken at selected intervals using a hand-held Davis peat sampler.

Peat profiles were observed at selected sites along traverse lines. Peat characteristics, subsurface soil texture, native vegetation, microrelief, and water table levels were recorded at each site. Samples were collected using a Macaulay peat auger mounted on a J-5 Bombardier. Twin samples were collected at constant intervals throughout the profile, and one sample of the mineral substratum was collected. One peat sample was used for laboratory analysis; the second, along with the mineral sample, was stored in a sample library for future reference.

Laboratory Procedures

There are a number of basic peat characteristics that can be measured which are manifestations of the varying genesis and pedological processes that occur in peat formation. The characteristics of bulk density, water content, pH, and mineral content were measured by the MPIP using standard laboratory procedures to facilitate comparison with other peat data. The degree of decomposition can be inferred from the above characteristics.

The results of sample analysis generally confirm the field classifications. Some discrepancies result due to the botanical origin of the peat; Sphagnum moss peat inherently has a lower bulk density and higher water-holding capacity than herbaceous peat of the same degree of decomposition.

A number of explicit and implicit relationships exist among the basic peat characteristics that can be interpreted to determine the potentiality of various peat deposits and predict possible implications involving their use.

Bulk Density

Bulk density is defined as the weight of a given volume of soil. It is usually expressed on a dry-volume basis. The core method of determining bulk density was used; a sampler of a known volume (Macaulay peat sampler) was inserted into the soil and a core was extracted. The oven-dry weight of the soil within the sampler was then determined.

There is a curvilinear relationship between bulk density values and water content values; as bulk density decreases, water content values increase (31).

Bulk density values increase with increased mineral content due to contamination of the peat and mineralization of plant materials.

Water Content

Water content is defined as the total moisture content of organic soil and is expressed as the weight of water per unit weight of oven-dry soil. It was determined by oven-drying a saturated organic soil sample and calculating the water loss by weight.

Higher water content values of relatively undecomposed peat are due to their greater pore size distribution (31). Water content values are also related to the botanical origin of the peat; Sphagnum moss peat has a larger water-holding capacity than herbaceous peat due to the cellular structure of the moss fibers.

pH

Hydrogen ion activity or pH is defined as the degree of acidity or alkalinity of a soil. The pH values were measured in a deionized water solution and in a 0.01$\underline{M}$ $CaCl_2$ solution. Organic soil is generally acidic, but has pH values ranging from 3.0 to 8.0. Low pH values indicate the presence of sulfides, whereas higher values are indicative of adsorbed calcium or sodium (31).

The range of pH values is related to peat vegetation and the degree of decomposition. Sphagnum moss peat acidity is higher than that of herbaceous peat; this can be attributed to the ion-exchange mechanism of the Sphagnum (13). Higher acidity also indicates lower levels of microorganism activity and a slower rate of decomposition; hence, a more rapid rate of peat accumulation.

Mineral Content

Mineral content is defined as the solids remaining after heating a sample of oven-dried peat to 500°C (932°F) for 30 minutes. These constituents, which are incombustible, are derived from the release of mineral components of organic matter through decomposition and from aeolian mineral contamination from surrounding areas.

Mineral content, as previously discussed, is directly related to bulk density; as mineral content increases, bulk density values increase. High mineral content is also an indication of highly decomposed peat.

Degree of Decomposition

Decomposition of peat is a pedological process which generally reflects a change in peatland environment. More decomposed peat is a result of a lower water table that allows accelerated oxidation or decomposition of plant remains to occur.

The characteristics of bulk density and water content are indirect measurements of the degree of decomposition (Table 1). These two characteristics are, perhaps, the most significant parameters for determining potential uses of peat.

A direct measurement of the degree of decomposition of peat is indicated by the percentage of original plant fibers not decomposed. However, this parameter (fiber content) is difficult to determine. A fiber is defined as a fragment or piece of plant tissue, excluding live roots, that is large enough to be retained on a 100-mesh sieve (0.15 mm openings) and that retains recognizable cellular structure of the plant from which it came (28).

Laboratory methods appear in Appendix B. Laboratory data and condensed field descriptions appear in Appendix C.

Table 1. Properties diagnostic for organic soils at the suborder level

DEGREE OF DECOMPOSITION	FIBER CONTENT UNRUBBED (percent)	FIBER CONTENT RUBBED (percent)	BULK DENSITY (g/cm^3)	BULK DENSITY (lb/ft^3)	WATER CONTENT AT SATURATION OR OVEN-DRY MATERIAL (percent)
Fibric	$>$ 66 2/3	$>$ 40	$<$ 0.10	$<$ 6.2	850 - 3000
Hemic	33 1/3 - 66 2/3	$>$ 10	0.07 - 0.18	4.4 - 11.2	450 - 850
Sapric	$<$ 33 1/3	$<$ 10	$>$ 0.20	$>$ 12.5	$<$ 450

Based on *Soil Taxonomy* (7th Approximation) (28).

V. SW ST. LOUIS COUNTY PEAT MAP

The procedures used in producing the peat map of SW St. Louis County involved classifying peat profiles, defining mapping units, and delineating the mapping units.

Two maps are included with this report: 1) "An Evaluation of the Surficial Geology and Peat Resources in SW St. Louis County, Minnesota — With Peat Resources Delineated"; and 2) "Distribution of Peat Observation Sites in SW St. Louis County, Minnesota."

Peat Classification

Peat, as all natural phenomenon, is classified to organize knowledge and determine the relationships among various peat types.

The MPIP uses the field classification system developed by the International Peat Society (IPS) (15). Of the many classification systems available for organic soil developed by investigators with diverse interests, this is perhaps the most versatile classification system available. It is extensively used in Europe where peat technology is more advanced than it is in the United States.

The IPS classifies peat according to its degree of decomposition and its botanical origin.

The three-grade scale of peat decomposition used by the IPS is: 1) weakly decomposed peat (R_1), fiber content > 70%; 2) medium decomposed peat (R_2), fiber content 70-40%; and 3) strongly decomposed peat (R_3), fiber content < 40% (Table 2).

Table 2. Three-grade scale of peat decomposition

Scale grade	Percent of fibers	Structure and look of the peat bulk	Presence and look of humus	Amount and look of water
Fibric (R_1) weakly decomposed peats	>70%	Spongy or fibrous, built of plant residues tied with one another. For separation tearing off the plant residues is required. Easily recognizable plant residues/well preserved. Elastic, compact.	Not visible or occurs in little amounts as a dispersed dark mass, saturating and coloring plant residues.	Great amount of water, which can be easily pressed out and pours as a streamlet. Almost totally pure or slightly brownish. May contain dark humus spots.
Hemic (R_2) medium decomposed peats	70-40%	Amorphous-fibrous; grass and moss peats contain numerous plant residues of various size; woody peats are more friable due to the presence of wood residues in amorphous humus. When pressed in fingers transforms into an amorphous, plastic mass.	Distinctly discernible against which plant residues are visible. Humus can be pressed out between fingers of the clenched fist, but not more than 1/3 of the taken sample.	Can be pressed out or flows by few drops; usually thick and of dark color/humus. In drained peat slightly colored with humus coagulated in consequence of a partial drying.
Sapric (R_3) strongly decomposed peats	<40%	Lumpy-amorphous, consisting in main part of humus. In lumpy-amorphous peat greater fragments of plant residues/wood, rhizomes, greater rootlets/occur. Friable, disintegrates under pressure. Amorphous peat strongly plastic, with sporadic greater plant residues.	Uniform mass, can be pressed out between fingers of the clenched fist in the amount of a half or the whole of the taken sample.	Cannot be pressed out, instead the humus mass is squeezed.

Based on International Peat Society (15).

The IPS classification system for the botanical composition of peat takes into account bog genesis. The nomenclature used is as follows: 1) moss peat — peat composed predominantly of remains of Sphagnum and other mosses (>75% moss and < 10% wood); 2) herbaceous peat — peat composed predominantly of remains of grasses, sedges, and related species (>75% herbaceous and < 10% wood); 3) wood peat — peat composed of at least 35% of remains of trees and woody shrubs. Other peat types are regarded as mixed types.

The IPS classification system is generally compatible with classification systems used by the USDA Soil Conservation Service (SCS) (27, 28) and the United States Bureau of Mines (USBM) (24,25). The USBM system classifies peat as moss, reed-sedge, or humus. In Minnesota, moss peat is generally R_1; reed-sedge is generally R_2; and humus is R_3. The SCS classifies organic soil according to the degree of decomposition or percent of fiber. The three types are: 1) fibric, > 66 ⅔ percent fiber; 2) hemic, 33 ⅓ to 66 ⅔ percent fiber; and 3) sapric, < 33 ⅓ percent fiber (Table 1). Although the SCS classification system does not incorporate the botanical origin of peat, it correlates easily with the IPS classification system.

In an effort to maximize communication of peat characteristics, the MPIP assumed that the SCS and IPS systems are similar enough to be equivalent. Throughout the rest of the report, the terms fibric, hemic, and sapric will be used in describing the peat.

Generally, it can be assumed that weakly decomposed (R_1) or fibric peat is comprised of Sphagnum mosses, and medium decomposed (R_2) or hemic peat is comprised of herbaceous or woody plant materials. The botanical origin of strongly decomposed (R_3) or sapric peat cannot be directly observed for the most part; it consists of almost completely decomposed plant remains (27).

Peat Stratigraphy

Peat stratigraphy is a record of bog genesis and evolution. It contains fossils of peat-forming vegetation and reflects the dynamic processes which occurred during the time the bog existed. Stratigraphy can be displayed by representative profiles and cross sections.

Representative Profiles

The field descriptions below illustrate the vertical sequence of layers that portray typical profiles of sapric, hemic, and fibric overlying hemic peat in SW St. Louis County.

1. Representative Profile: Sapric peat (Reference No. 188)

Location: SW1/4, NW1/4, NE1/4, SW1/4, Sec. 10, T.53N., R. 21W.

	cm	in	% fiber
Hemic peat:	0- 60	0- 24	40-50
Sapric peat:	60-154	24- 61	20-30
Fine sand:	154+	61+	

2. Representative Profile: Hemic peat (Reference No. 175)

Location: SW1/4, NE1/4, NW1/4, SE1/4, Sec. 3, T.53.N., R.20W.

	cm	in	% fiber
Fibric peat:	0- 42	0- 17	70-80
Hemic peat:	42-210	17- 83	50-60
Hemic peat:	210-288	83-113	60-70
Hemic peat:	288-310	113-122	50-60
Hemic peat:	310-325	122-128	40-50
Sapric peat:	325-338	128-133	20-30
Fine sand:	338+	133+	

3. Representative Profile: Fibric peat overlying hemic peat (Reference No. 31)

Location: SW1/4, SW1/4, SW1/4, SW1/4, Sec. 2, T.51N., R. 19W.

	cm	in	% fiber
Fibric peat:	0-265	0-104	70-80
Hemic peat:	265-525	104-207	60-70
Hemic peat:	525-540	207-213	50-60
Limnic:	540-550	213-217	
Silt:	550+	217+	

Peat Cross Sections

The cross sections below (Figures 6 and 7) illustrate vertical and horizontal zonation of peat deposits along traverses in the Arlberg bog (T.51/52N., R.18/19W.) and the Toivola bog (T.54/55N., R.20/21W.). Aerial photos and portions of Eng's map (5) pertaining to these areas are included to indicate the relationship of surficial patterns to peat types present.

Figure 6a. Aerial photograph (1:62,500) denoting traverses on Arlberg bog. Photography by Mark Hurd, 1969.

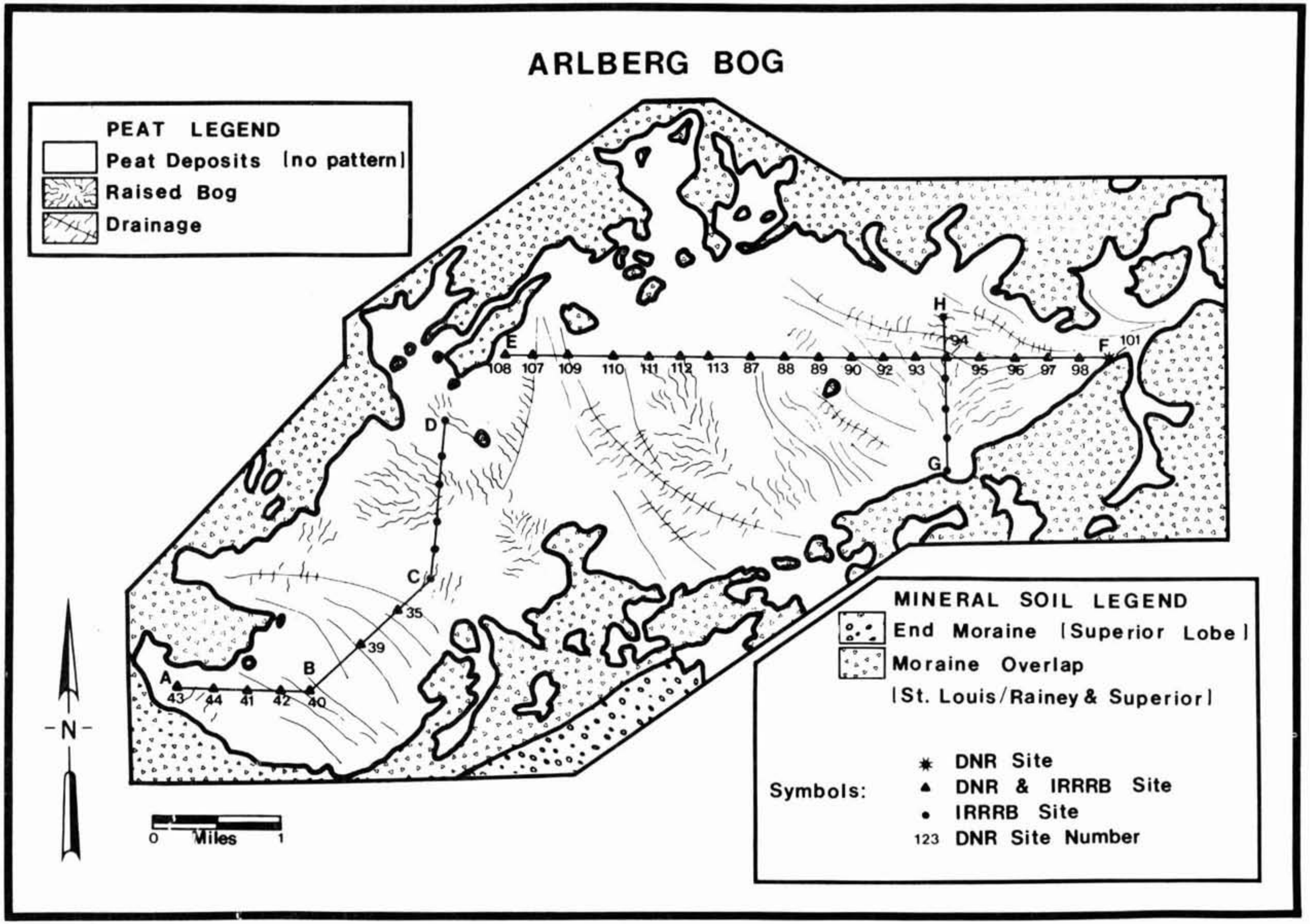


Figure 6b. Location map showing traverses and sampling site locations on Arlberg bog.

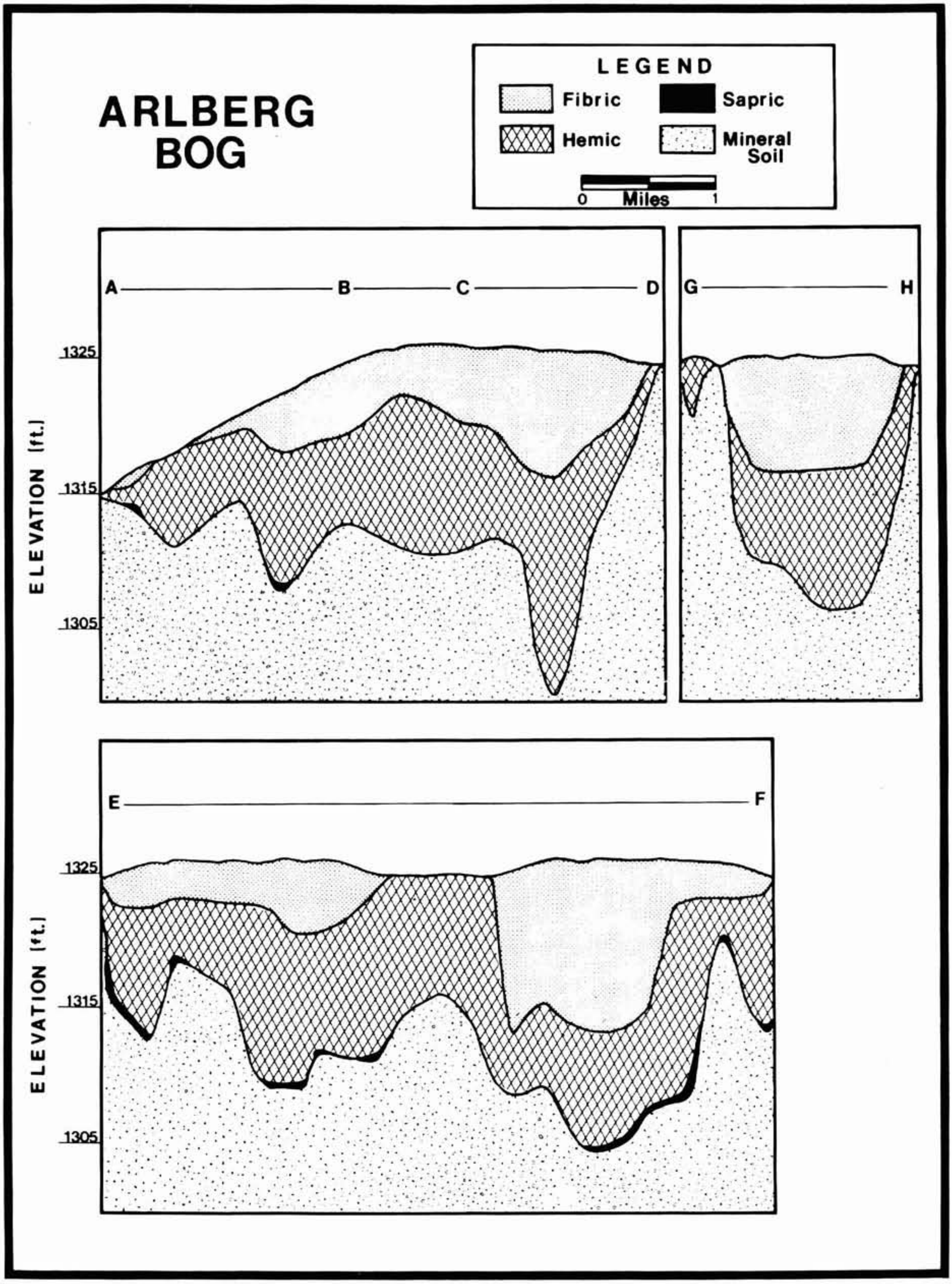


Figure 6c. Cross-sections of the Arlberg bog showing peat stratigraphy. (See Figures 6a and 6b for location of transect lines).

Figure 7a. Aerial photograph (1:62,500) denoting traverses on Toivola bog. Photography by Mark Hurd, 1977.

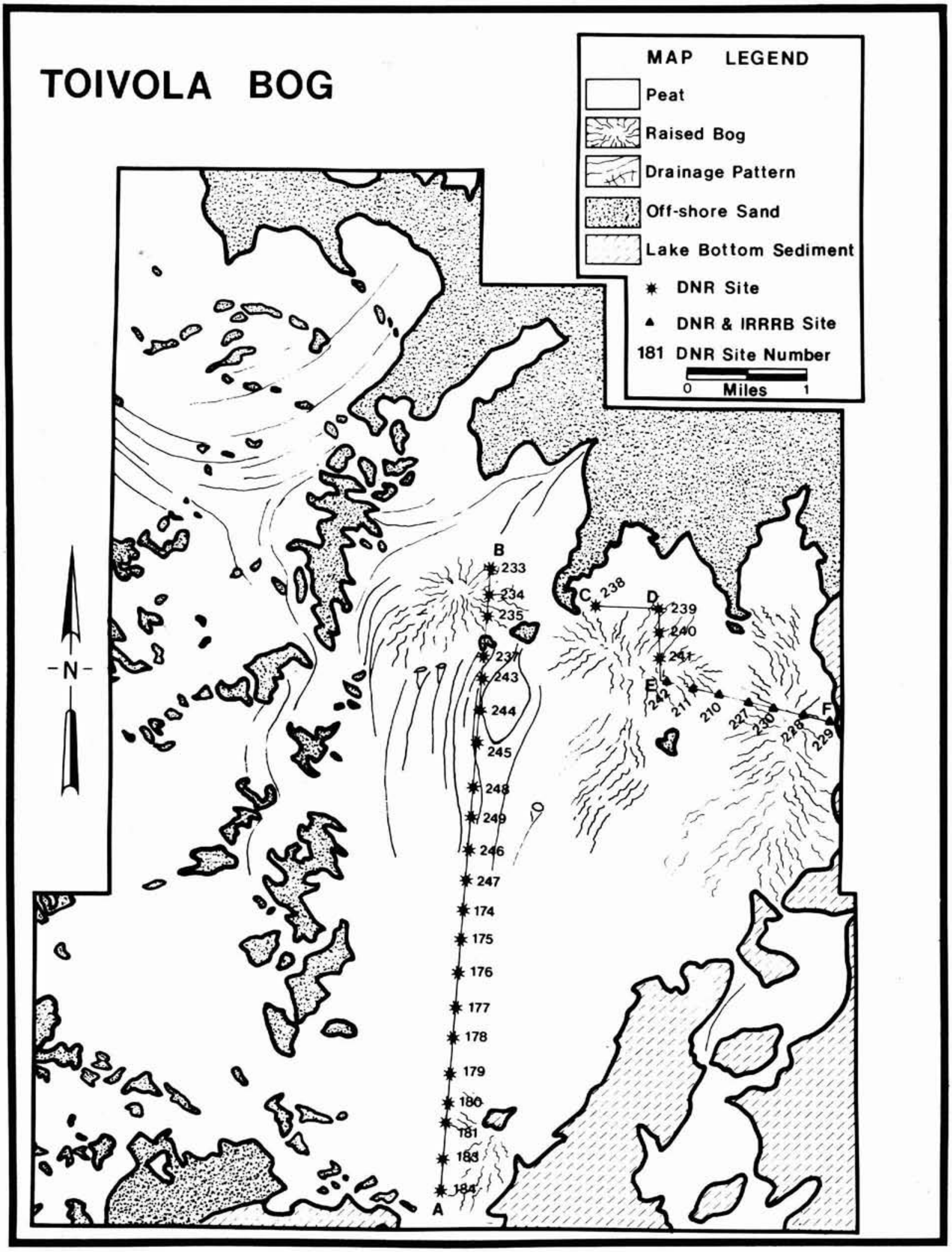


Figure 7b. Location map showing traverses and sampling site locations on Toivola bog.

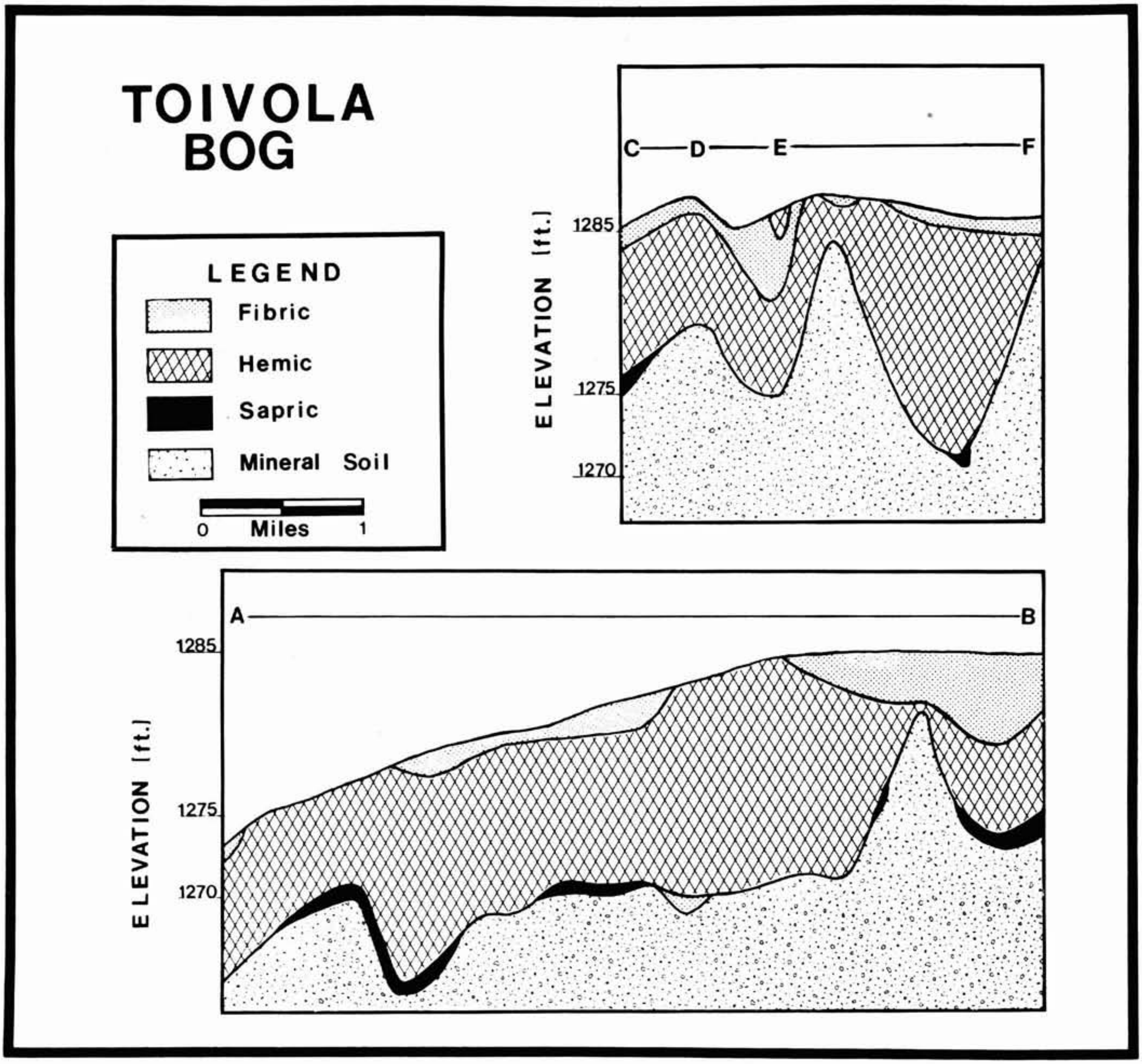


Figure 7c. Cross-sections of the Toivola bog showing peat stratigraphy. (See Figures 7a and 7b for locations of transect lines).

Mapping Units

Field data was used to categorize each profile into a specific mapping unit. A mapping unit can be defined as a composite of soils within any specific delineated area on a soil map.

In SW St. Louis County, the peat types are grouped into four major divisions. The divisions are: 1) sapric peat; 2) hemic peat that may have a fibric cap of up to 60 cm (~ 2 ft); 3) fibric peat overlying hemic peat with a fibric cap of 61-150 cm (~ 2-5 ft); and 4) fibric peat overlying hemic peat with a fibric cap of 151-300 cm (~ 5-10 ft).

These groups were further subdivided by depth to make up thirteen mapping units. The type of peat, depth of each mapping unit, and map symbol are listed in the peat legend (Table 3) and on the peat resources map.

Due to the complexity of peat types on the landscape, a mapping unit may contain inclusions of other peat types. Inclusions of other peat types may occupy as much as 30 percent of a particular mapping unit. Thus, at any specific spot within a delineation, another peat type may occur.

Table 3. Peat legend

Sapric:

Map Symbol	Depth
a	0-150 cm (~ 0- 5 ft)
b	151-300 cm (~ 5-10 ft)

Hemic: may contain fibric cap 0-60 cm (~ 0-2 ft)

Map Symbol	Depth
c	0-150 cm (~ 0- 5 ft)
d	151-300 cm (~ 5-10 ft)
e	301-450 cm (~ 10-15 ft)
f	451-600 cm (~ 15-20 ft)

Fibric overlying hemic: with fibric cap 61-150 cm (~ 2-5 ft)

Map Symbol	Depth
g	151-300 cm (~ 5-10 ft)
h	301-450 cm (~ 10-15 ft)
i	451-600 cm (~ 15-20 ft)
j	> 600 cm (> 20 ft)

Fibric overlying hemic: with fibric cap 151-300 cm (~ 5-10 ft)

Map Symbol	Depth
k	151-300 cm (~ 5-10 ft)
l	301-450 cm (~ 10-15 ft)
m	451-600 cm (~ 15-20 ft)

Mapping Procedures

Delineations differentiating mapping units along the traverse lines were drawn on U.S.G.S. 7.5 minute quadrangle maps. Specific data along the traverse was then extrapolated to areas of the bog not traversed. Blue line air photos, surficial geology maps, U.S.G.S. 7.5 minute quadrangle maps, and U.S.G.S. 7.5 minute orthophoto maps were used as an aid in extrapolating ground truth data. In conjunction with basic topographic data, these tools provide textural and tonal patterns that the surveyor interpreted to complete mapping unit delineations.

Compilation and cartographic work was done at a scale of 1:24,000. These maps were then reduced to a scale of 1:62,500 (1 inch = 1 mile) to use Eng's map (5) as a base map on which the peat delineations were drawn. The map was then reduced to a scale of 1:125,000 (1/2 inch = 1 mile) for publication.

VI. RESULTS

Peat Distribution

A brief overview of the map indicates that herbaceous hemic and sapric peat are relatively abundant; conversely, fibric Sphagnum peat is very limited and, thus, a very valuable resource.

Peat comprises about 41% (112,818 ha/278,660 ac) of SW St. Louis County while mineral soils comprise the remaining 59% (163,397 ha/403,590 ac) of the soil. Table 4 contains the areal and volumetric tabulations for each peat mapping unit; Appendix D contains the areal tabulations for mineral mapping units.

Of the peatland in SW St. Louis County, hemic peat with a fibric cap of 0-60 cm (~ 0-2 ft) comprises 80% of the total peat area while sapric peat and hemic peat with deeper fibric caps account for the remaining 20%.

Mapping Units *c, d, e,* and *f* (Hemic)

Hemic peat with a fibric cap of 0-60 cm (~ 0-2 ft) is divided into mapping units *c, d, e,* and *f*. The majority of this peat type occurs in the northeastern, northwestern, and west-central portions of SW St. Louis County. These large expanses of hemic peat lie within lake plain topography. The mapping units usually appear in conjunction with each other with deeper deposits near the center of the bog and the shallower deposits near the perimeter in a somewhat concentrical pattern. Scattered hemic deposits also occur in morainic areas in the southern regions of SW St. Louis County.

The acreage totals for these mapping units show that the deepest deposits occur infrequently; mapping unit *f* (451-600 cm/~ 15-20 ft) amounts to 1% (1,579 ha/3,900 ac) of the total peatland, and mapping unit *e* (301-450 cm/~ 10-15 ft) amounts to 8% (8,563 ha/21,150 ac) of the total peatland. The

Table 4. Areal and Volumetric distribution per mapping unit in SW St. Louis County, Minnesota

Mapping Unit		Percentage	Area ha	Area ac	Ave. Thickness cm	Ave. Thickness ft	Volume ha-cm	Volume ac-ft
a	Sapric	14.6	16,482	40,710	75	2.5	1,236,150	101,775
b	Sapric	1.1	1,215	3,000	225	7.5	273,375	22,500
c	Hemic	45.1	50,862	125,630	75	2.5	3,814,650	314,075
d	Hemic	26.1	29,486	72,830	225	7.5	6,634,350	546,225
e	Hemic	7.6	8,563	21,150	375	12.5	3,211,125	264,375
f	Hemic	1.4	1,579	3,900	525	17.5	828,975	68,250
g	Fibric		822	2,030	105	3.5	86,310	7,105
	Hemic				120	4.0	98,640	8,120
	Total	0.7			225	7.5	184,950	15,225
h	Fibric		1,745	4,310	105	3.5	183,225	15,085
	Hemic				270	9.0	471,150	38,790
	Total	1.5			375	12.5	654,375	53,875
i	Fibric		611	1,510	105	3.5	64,155	5,285
	Hemic				420	14.0	256,620	21,140
	Total	0.5			525	17.5	320,775	26,425
j	Fibric		190	470	105	3.5	19,950	1,645
	Hemic				> 495	> 16.5	> 94,050	> 7,755
	Total	0.2			> 600	> 20.0	> 114,000	> 9,400
k	Fibric	0.2	271	670	225	7.5	60,975	5,025
l	Fibric		498	1,230	225	7.5	112,050	9,225
	Hemic				150	5.0	74,700	6,150
	Total	0.4			375	12.5	186,750	15,375
m	Fibric		494	1,220	225	7.5	111,150	9,150
	Hemic				300	10.0	148,200	12,200
	Total	0.4			525	17.5	259,350	21,350
	TOTAL		**112,818**	**278,660**				

shallower deposits occur with increasing frequency; mapping unit *d* (151-300 cm/~ 5-10 ft) amounts to 26% (29,486 ha/72,830 ac) of the total peatland, and mapping unit *c* (0-150 cm/~ 0-5 ft) amounts to 45% (50,862 ha/125,630 ac) of the total peatland.

Mapping Units *g, h, i, j, k, l,* and *m* (Fibric overlying Hemic)

The most limited quantity of peat occurs within the mapping units that contain fibric peat over hemic peat, with a fibric cap of 61-300 cm (~2-10 ft). Fibric peat deposits are present in both lake plain and end moraine topography. In all but one case, these mapping units occur only in association with hemic peat (mapping units *d, e,* and *f*). The one exception is in T.53N., R.17W. where mapping units *g, h,* and *l* are surrounded by both hemic and sapric peat. Raised bog air photo patterns appear in conjunction with mapping units *g, h, i, j, k, l,* and *m*.

Fibric peat overlying hemic peat with a fibric cap of 61-150 cm (~ 2-5 ft) amounts to 3% (3,369 ha/8,320 ac) of the total peatlands (mapping units *g, h, i,* and *j*); whereas, fibric peat overlying hemic with a fibric cap of 151-300 cm (~5-10 ft) amounts to only 1% (1,263 ha/3,120 ac) of the total peatland.

Mapping Units *a* and *b* (Sapric)

Sapric peat comprises 16% (17,697 ha/43,710 ac) of the total peatland area in SW St. Louis County. It is primarily located in the north-central portion (T.53/54N., R.17/18W.) of SW St. Louis County. A smaller deposit lies on the west side of the Fens bog (T.55N., R.18W.).

Mapping unit *a* (0-150 cm/~ 0-5 ft) accounts for 15% (16,482 ha/40,710 ac) of the total peatland, and mapping unit *b* (151-300 cm/~ 5-10 ft) accounts for 1% (1,215 ha/3,000 ac) of the total peatland.

Peat Tonnages

The quantity of peat in each mapping unit illustrates the relative abundance and scarcity of each peat type. Volumetric tabulations have been converted to oven-dried and air-dried tonnage for economic consideration (Table 5).

Extracted peat is shipped at air-dried weight (approximately 35% moisture). Generally, peat that is used for direct burning has tonnages calculated at oven-dried weight. The two tonnages listed illustrate the negative characteristic of moisture content when peat is to be utilized for direct burning.

Table 5. Peat tonnage (air-dried and oven-dried) per mapping unit in SW St. Louis County, Minnesota

Mapping Unit		Metric Tons (oven-dried) @ 200 U.S. Tons/Acre-Ft.	U.S. Tons (oven-dried) @ 200 U.S. Tons/Acre-Ft	Metric Tons (air-dried: 35% moist.) @ 270 U.S. Tons/Acre-Ft	U.S. Tons (air-dried: 35% moist.) @ 270 U.S. Tons/Acre-Ft
a	Sapric	18,466,060	20,355,000	24,929,180	27,479,250
b	Sapric	4,082,400	4,500,000	5,511,240	6,075,000
c	Hemic	56,985,770	62,815,000	76,930,790	84,800,250
d	Hemic	99,107,060	109,245,000	133,794,530	147,480,750
e	Hemic	47,968,200	52,875,000	64,757,070	71,381,250
f	Hemic	12,383,280	13,650,000	16,717,430	18,427,500
g	Fibric	1,289,130	1,421,000	1,740,330	1,918,350
	Hemic	1,473,290	1,624,000	1,988,940	2,192,400
	Total	2,762,420	3,045,000	3,729,270	4,110,750
h	Fibric	2,737,020	3,017,000	3,694,980	4,072,950
	Hemic	7,038,060	7,758,000	9,501,380	10,473,300
	Total	9,775,080	10,775,000	13,196,360	14,546,250
i	Fibric	958,910	1,057,000	1,294,530	1,426,950
	Hemic	3,835,640	4,228,000	5,178,110	5,707,800
	Total	4,794,550	5,285,000	6,472,640	7,134,750
j	Fibric	298,470	329,000	402,930	444,150
	Hemic	> 1,407,070	> 1,551,000	> 1,899,540	> 2,093,850
	Total	> 1,705,540	> 1,880,000	> 2,302,480	> 2,538,000
k	Fibric	911,736	1,005,000	1,230,840	1,356,750
l	Fibric	1,673,780	1,845,000	2,259,600	2,490,750
	Hemic	1,115,860	1,230,000	1,506,410	1,660,500
	Total	2,789,640	3,075,000	3,766,010	4,151,250
m	Fibric	1,660,180	1,830,000	2,441,240	2,470,500
	Hemic	2,213,570	2,440,000	2,988,320	3,294,000
	Total	3,873,750	4,270,000	5,229,560	5,764,500
	TOTAL	**457,537,240**	**321,145,000**	**617,675,250**	**433,545,750**

Specific Bogs

SW St. Louis County contains a number of large bogs that are unique in their genesis and composition. These include the Arlberg, Toivola, South Toivola, Toivola East, Meadowlands, and Fens bog; with the exception of Arlberg, all were formed by paludification on the Glacial Lake Upham plain.

The Arlberg bog (T.51/52N., R.18/19W.) appears to be the most unique bog in SW St. Louis County. Its genesis is unlike any other in the area — it is speculated that it was formed by an ice thrust of the St. Louis sublobe which gouged out a depression in the Superior moraine (5). A reflection of this morainic topography is mirrored in the peat types that occur and shows a complexity that is absent in other bogs. It is only in this area that mapping units *f, g, h, i, j, k, l,* and *m* occur in such an intricate association. Arlberg has the most concentrated deposit of sphagnum peat in SW St. Louis County; approximately 35 percent of this bog has a fibric cap of 60 cm (~ 2 ft) or greater. It is also the deepest bog in the area; the deepest boring (Reference No. 20) revealed 810 cm (~ 27 ft) of peat overlying 334 cm (~ 11 ft) of limnic sediments, a total of 1,144 cm (~ 38 ft).

Toivola (T.54/55N., R.20/21W.), South Toivola (T.54N., R.20W.), and Toivola East (T.54N., R.19W.) are bogs located in the north-central portion of the map that are composed mainly of deposits of hemic peat (mapping units *c, d, e,* and *f*) with localized fibric caps deeper than 60 cm (~2 ft). Most of the underlying material is lacustrine soil with exceptions occurring near relic beaches and outwash areas. The crowns of numerous sand dunes, formed during a dry period 5,000-8,000 years BP, are exposed on the northwestern side of the lake plain.

The Meadowlands bog (T.53N., R.18/19W.), located east of the Village of Meadowlands, is comprised mostly of sapric and hemic peat. It contains the largest deposit of sapric peat in SW St. Louis County; this area has a relatively dense cover of northern white cedar, black spruce, and tamarack.

The Fens bog (T.55N., R.17/18W.) is located in the northwest corner of SW St. Louis County. This bog is the location of IRRRB's Wilderness Valley Farms which is the site of research involving horticulture, forestry, reclamation, and hydrological investigations.

Peat Utilization

The gamut of peat characteristics indicates a diversity of potential uses. Peat utilization has recently been expanded from traditional uses to include a number of new exotic uses. A variety of peat types can be utilized for specific uses although some are inherently more valuable for specific applications than others.

In northern Minnesota, the main use of peatlands is for forestry. Although some peatlands support only stunted black spruce and tamarack, others contain high quality stands of black spruce, tamarack, and northern white cedar. The relationship between environmental factors and optimum growth is not entirely understood, but the best stands usually appear on hemic or sapric peat.

In the natural state, peatlands have little agricultural value; however, when properly drained and fertilized, peatlands have proven to be very productive. While the climate of northern Minnesota severely limits production of certain crops, others proliferate. Potatoes, carrots, radishes, wild rice, cranberries, and turfgrass are among those that have known potential. Sapric and hemic peat are both managed for agriculture; however, sapric peat has the greatest potential because of its favorable structure, relatively high bulk density, and high humus content. Favorable structure and relatively high bulk density values relate to the physical management of the soil. High humus content is directly related to the soils ability to adsorb cations; high amounts of humus indicate a high cation exchange capacity.

The largest extractive use of peat in the United States is for the horticultural industry which uses peat as a soil amendment and a germinating and rooting medium.

The properties of peat that make it valuable as a soil amendment are: 1) it increases the water-holding capacity of coarse soils; 2) it increases the cation exchange capacity of soils (greater nutrient-holding capacity); and 3) it improves the physical structure or tilth of fine textured soils. The characteristics of fibric Sphagnum moss peat make it the most valuable peat for this use although hemic peat is also marketed as a soil amendment.

Peat has been used as an energy source in Europe for centuries. Today it is considered as a viable energy alternative in the USSR. As world economics continue to evolve, peat cannot be overlooked as an alternative energy source.

The plant material that comprises peat contains a relatively high percent of fixed carbon, hence, a relatively high energy value. Peat has an energy content that is approximately equal to lignite coal, with a caloric value of approximately 5,000 cal/g (9,000 BTU/lb) (oven-dried) and approximately 3,900 cal/g (7,000 BTU/lb) (air-dried, 30-40% water) (7).

Selected samples from SW St. Louis County were analyzed for percent volatiles, percent fixed carbon, percent total sulfur, and British Thermal Unit (BTU) per pound. These tests were originally developed to determine the quality of coal, but they also apply to the potential of peat for direct burning. The analyses were performed by a private laboratory using American Standard Testing Methods (1); results appear with the site descriptions and laboratory analysis of the basic peat characteristics in Appendix C (Reference Numbers 31, 88, 133, 163, 221, 235, and 249).

Many other uses of peat presently exist, too numerous to mention. They include the use of peatlands for the production of biomass, production of methane by gasification, production of coke, extraction of waxes, and as a filtration system for sewage.

VII. SUMMARY

Minnesota peatlands cover about 7.2 million acres of which the majority is state-owned or state-administered. The Minnesota Peat Inventory Project was generated by lease requests for the use of peatlands. The purpose of the MPIP is to gather baseline information concerning the distribution, quality, and quantity of peat in Minnesota; the inventory of peat distribution and characteristics is the foundation on which proper land management decisions will be based.

The glaciation of northern Minnesota laid the foundation of peatland formation in SW St. Louis County. Pulsations of the Rainy lobe, the Superior lobe, and the St. Louis sublobe, during the Wisconsin Ice Stage, resulted in many geomorphic features that were conducive to peat accumulation.

Peat is the accumulation of partially decayed plant material that occurs in a saturated environment; peat formation is a result of an unique interaction among topography, climate, and water. Topography that slows water movement provides a base for peat accumulation if the climate provides precipitation which exceeds evapotranspiration. The characteristics of water present in these areas play the dominant role in the type of vegetation that occurs. Peat formation generally occurs in two ways: paludification — bog expansion occurring as a result of a rising water table; and lakefill — the filling in of a lake by vegetation. The sequence of bog development generally goes from aquatic peat to herbaceous and woody peat to Sphagnum peat.

The reconnaissance survey of peat resources in SW St. Louis County was made by observing soils and soil boundaries along selected traverses and extrapolating the information to areas not traversed. Representative samples were collected and characterized; sample analysis included bulk density, water content, pH, and mineral content.

The resource map of SW St. Louis County depicts organic and mineral soils. The mapping units used in delineating peat resources are based on the classification system established by the International Peat Society; the nomenclature used is that of *Soil Taxonomy*.

Peat profile descriptions along with laboratory data are interpreted to predict the performance of specific peat for various uses. In SW St. Louis County, sapric and hemic peat is relatively abundant; however, fibric Sphagnum peat overlying hemic peat is relatively scarce. Hemic peat with a fibric cap of 0-60 cm (~0-2 ft) accounts for 80 percent of the total peatland, sapric peat accounts for 16 percent of the total, and fibric overlying hemic peat accounts for only 4 percent of the total.

The peatlands of Minnesota are an extensive and untapped resource of tremendous value — but, in essence, they are also an unrenewable resource!

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IX. GLOSSARY

This glossary was compiled from several sources, but primarily from:

(1) Soil Science Society of America. 1970. Glossary of Soil Science Terms. Madison.

(2) Soil Survey Staff. 1975. Soil Taxonomy. Agric. Handb. No. 436, USDA. U.S. Government Printing Office, Washington, D.C.

Acidity — See **pH.**

Bog - Permanently wet land having low bearing strength and containing organic soils (Histosols), synonymous with peatlands.

Bulk density - The mass of dry soil per unit bulk volume. The bulk volume is determined before drying to a constant weight at 105°C.

Cation exchange capacity - The total exchangeable cations a soil can adsorb. Expressed in milliequivalents per 100 grams of soil (or of other adsorbing material such as clay).

Clay - As a soil separate, the mineral soil particles less than 0.002 mm in diameter. As a soil textural class, soil material that is 40 percent or more clay, less than 45 percent sand, and less than 40 percent silt.

Coarse texture - Synonymous with sandy, see **sand.**

Crown cover - The amount of plant surface that covers the ground as viewed from above, expressed as a percentage of the total possible (100%) or of a particular group, *e.g.* black spruce crown cover of about 50 percent.

Decomposition - See **humification.**

Diagnostic horizons - Soil horizons or materials designated as differentiae in the higher categories of Soil Taxonomy.

Fibers - In defining organic soil materials, fibers are pieces or fragments of plant tissue, excluding live roots, that are large enough to be retained on a 100-mesh sieve (0.15 mm openings) and that retain recognizable cell structure.

Fibric - See **organic soil material.**

Fine texture - Consisting of or containing large quantities of the fine fractions, particularly silt and clay.

Hemic - See **organic soil materials.**

Herbaceous, peat - Deposits composed mostly of the residues of reeds, sedges, and grasses.

Histosols - See **organic soil.**

Horizon, soil - A layer of soil or soil material approximately parallel to the land surface and differing from adjacent, genetically related layers in physical, chemical, and biological properties or characteristics such as color, structure, texture, consistency, degree of acidity or alkalinity, etc.

Humification - The extent of decomposition or "huminosity" and a process by which organic matter decomposes to form humus.

Humus - That more or less stable fraction of the soil organic matter remaining after the major portion of added plant and animal residues have decomposed. Usually, it is dark in color.

Lacustrine deposit - Material deposited in lake water and later exposed, either by a lowered water level or by uplifted land. These sediments range in texture from sands to clays.

Layers, peat - Tiers of peat that formed in differing environments during the period of accumulation of the materials that now constitute the soil. Similar to horizon but not always meeting the criteria of a horizon.

Limnic material - Materials deposited in postglacial lakes. These materials are primarily chemical and biological precipitates or slightly to mostly decomposed aquatic organisms or both.

Loam - The textural class name for soil having a moderate amount of sand, silt, and clay. Loam soils contain 7 to 27 percent clay, 28 to 50 percent silt, and less than 52 percent sand.

Mineral soil - Soils that have a layer of organic soil material less than 40 cm in thickness or may be completely lacking an organic soil horizon.

Mineralization - The conversion of an element from an organic form to an inorganic state as a result of microbial decomposition.

Moraine - Unconsolidated rock and mineral debris deposited by glacial ice.

Organic soil (Synonymous with Histosols) - Soils having a layer of organic soil materials that extends from the surface to depths of at least 40 cm.

Organic soil materials - The major organic soil materials that formed primarily from rooted plants are:

Fibric soil materials - These are the least decomposed of all organic soil materials. They contain large amounts of fiber which is well preserved, and their botanical origin is readily identifiable. These materials commonly have bulk density values less than 0.1 g/cm^3; fiber content (unrubbed) exceeding two-thirds of the volume; and water content, when saturated, ranging from about 850 to over 3,000 percent of the oven-dry material.

Hemic soil materials - These materials are partly altered both physically and chemically. They are intermediate between the less decomposed fibric and the more decomposed sapric material. When rubbed, the fibers are largely destroyed. They have morphological features with intermediate values for fiber content, bulk density, and water content. Bulk density values are commonly between 0.1 and 0.2 g/cm^3; fiber content normally is between one-third and two-thirds of the volume before rubbing; and maximum water content, when saturated, ranges from about 450 to 850 percent or more.

Sapric soil materials - These are the most highly decomposed of the organic soil materials. They are relatively stable, *i.e.,* they change very little physically and chemically with time in comparison to others. They commonly occur on the surface of many areas of organic soils (Histosols) that have been drained and cultivated. In undrained bogs, they occur on areas rich in calcium, particularly if the water table fluctuates appreciably. Bulk density values for these materials commonly are 0.2 g/cm^3 or more; fiber content averages less than one-third of the volume before rubbing; and maximum water content, when saturated, normally is less than 450 percent on the oven-dry basis.

Peat - Organic soil of peatlands, exclusive of plant cover, consisting largely of organic residues accumulated as a result of incomplete decomposition of the dead plant constituents. It is generally synonymous with fibric, hemic, sapric, or any combination of these organic soil materials.

Peatland (Synonymous with bog) - Land covered with any kind of organic soil (Histosol).

pH - The negative logarithm of the hydrogen-ion activity of a soil. The degree of acidity or alkalinity of a soil, expressed in terms of the pH scale.

Profile, soil - A vertical section of the soil through all its horizons and extending into the parent material.

Sand - Individual rock or mineral fragments in soils having diameters ranging from 0.05 to 2 mm. The textural class name of any soil that contains 85 percent or more sand and not more than 10 percent clay.

Sapric - See **organic soil material.**

Silt - Individual mineral particles that range in diameter from the upper limit of clay (0.002 mm) to the lower limit of very fine sand (0.05 mm). Soil of the silt textural class is 80 percent or more silt and less than 12 percent clay.

Soil - A naturally occurring, unconsolidated material on the earth's surface that has been influenced by parent material, climate, microorganisms, and topography, all acting through time to produce soil that may differ from the material from which it derived in many physical, chemical, mineralogical, biological, and morphological properties.

Sphagnum, peat - Peat which is relatively undecomposed, raw, and composed of residues of Sphagnum mosses.

Substratum - In the case of peatlands, the mineral soil which underlies the peat.

Texture, soil - The relative proportions of sand, silt, and clay particles in a mass of soil. The basic textural classes, in order of increasing proportion of fine particles, are: sand; loamy sand; sandy loam; loam; silt loam; silt; sandy clay loam; clay loam; silty clay loam; sandy clay; silty clay; and clay.

Till - Unstratified and unsorted glacial drift deposited directly by the ice and consisting of clay, silt, sand, gravel, and boulders intermingled in any proportions.

APPENDIX A
DISCUSSION OF MAP UNITS

From: An Evaluation of the Surficial Geology and Peat Resources — Southwest St. Louis County, Minnesota (5)

D — DRUMLINS

The drumlins between Independence and Burnette are the oldest glacial deposits in the study area. They are part of the large Toimi Drumlin Field, deposited by the Rainy lobe, that forms a belt of drumlins about 35 miles long by five to fifteen miles wide oriented in a NE-SW direction along the Cloquet River Valley. The Toimi Drumlin Field contains hundreds of drumlins that are uniformly separated by a complex network of linear drainage channels. Individual drumlins typically are several miles long and 1/4 - 1/2 mile wide, are of uniform height (30-50 ft), and have a streamlined profile. They are constructed of a yellowish-brown to dark-reddish brown compacted sandy, bouldery till containing a high percent of gabbro rock. Farther west the drumlins are overlapped by the drift of the St. Louis sublobe; however, the strong NE-SW pattern of the underlying drumlins is still reflected through the overlying deposits as displayed by the orientation of the various units of the map.

EM-R - END MORAINES, and GM-R - GROUND MORAINES Constructed of RED TILL

Both units contain a reddish-brown sandy till deposited by the Automba Superior lobe in the rugged end moraine complex (EM-R) of the Highland Moraine and in the more level ground moraine (GM-R). The glacial drift may range up to 200 feet deep. Ice contact deposits of sand and gravel are abundant in this area.

GM-L - GROUND MORAINE - LAKEWASHED, and GM-G - GROUND MORAINE

GM-L consists of slightly undulating topography of ground moraine associated with the St. Louis sublobe that has been smoothed and modified by Glacial Lake Upham. The surface frequently is covered by large boulders and pebbles washed out of the glacial till by lake currents. Lakewashed ground moraine (GM-L) occupies the area principally located between the LBS and the shoreline of Lake Upham II. Conversely, GM-G is a more rolling ground moraine topography of the St. Louis sublobe showing little evidence of being washed. Both units are constructed of variable buff to brownish-red calcareous till representing a blend of the red Superior till that was overridden and incorporated by the St. Louis sublobe.

AM-L - ABLATION MORAINE - LAKEWASHED

Represents a lakewashed ablation moraine (elevation 1,290) containing stagnant ice features deposited by the waning St. Louis sublobe. Here, buff to light-brown calcareous till is deposited in a complex pattern of small oval landforms crossed by an intricate braided channel system.

LBS - LAKE BOTTOM SEDIMENTS

This unit is predominantly constructed of fine-grained sediments such as clay, silt, and fine sand that remained suspended in glacial streams for longer periods of time and were eventually deposited in the deep water basin of Glacial Lake Upham II.

Generally, the boundaries are transitional, but this unit forms a terrain that is smoother than the surrounding areas, contains less sand and fewer stones and boulders. Road cuts show varved lake deposits consisting of laminations of light gray-buff to brown calcareous clay and silt. The color and calcareous nature of the soils are indicators of St. Louis sublobe deposition by meltwater streams entering the area from the west and northwest.

A thriving farming community is expanding within this unit. It probably contains some of the best agricultural land in St. Louis County.

MO-G/R - MORAINE OVERLAP

The advance of the St. Louis sublobe from the west overrode the outlying rugged morainic topography deposited by earlier phases of the Superior lobe. It incorporated and blended with the red clays and silts and redeposited them as an end moraine of the St. Louis sublobe. The blended tills found within this unit are variably colored ranging from light buff to dark brownish-red depending upon the amount of blending that occurred locally. In certain areas the red color of the Superior till has overpowered the lighter colored St. Louis sublobe till. Gravel pits and road cuts in this unit show an increase in limestone and shale indicator rocks towards the inner side of the moraine. This tends to mark the position of the St. Louis sublobe.

OS-S - OFF-SHORE SAND

This unit represents a uniform fine sand that was deposited by meltwater streams discharging into the early stage of Glacial Lake Upham II about 13,000 years ago by the retreating St. Louis sublobe. Initially a major inflow of water-transported sediment came from the northwest, directly off the ice front marked by the moraine (MO-G/R) into the lake. This is reflected by the transition between various soils in the bed of Glacial Lake Upham, changing from sand and gravel in the West Swan River delta near Silica to the off-shore fine sand (OS-S) and then to deepwater deposits of calcareous silt and clay in the LBS unit.

Later, after deposition of the off-shore sands (OS-S), a period of sand dune development and vegetative change occurred in north-central Minnesota between 8,000-5,000 years ago. During this time Lake Upham withdrew, and the off-shore sand (OS-S) was reworked into dunes. Subsequently, the climate again changed, resulting in the accumulation of the peat bogs around numerous dune shaped islands, as evidenced by the Devils Islands in the Toivola Bog near Exnell Lake. One can expect to find off-shore sands (OS-S) beneath the peat bog in this area draped over the ground moraine of the St. Louis sublobe. Peat deposits around the islands are shallow and probably average under five feet in depth.

SAND AND GRAVEL - KAMES, ESKERS, CREVASSE FILLINGS, ICE-CONTACT SLOPES, GLACIAL OUTWASH, TERRACES, ALLUVIUM, and LAKE BEACHES

The formation and placement of sand and gravel in this area is directly related to glacial hydrology, resulting from hydraulic sorting of the glacial till by glacial lakes and streams. Melting of the glaciers produced a vigorous outflow of meltwater that formed many broad glacial streams, which reworked the till and transported the fine-grained particles downstream. Strong currents tumbled and rolled the larger heavy gravel size particles along the channel bottom, causing them to be rounded off and redeposited as gravel. Many streams were overloaded with sand and gravel, and they continuously shifted their channels, thereby changing the current flow, rate of deposition, and type of material being deposited. Each resurgence of meltwater upgraded the gravel quality. Consequently, the better gravel deposits are those that were reworked many times by strong currents and transported considerable distances beyond the ice front.

Gravel deposits are subdivided into Ice-Contact Deposits (those deposited within or under the ice) and Glaciofluvial Deposits (those deposited by rivers beyond the ice).

ICE-CONTACT DEPOSITS

Examples of ice-contact deposits are kames (K), eskers (E), and crevasse fillings (IC), consisting of sand and gravel deposited in holes and channels within the glacier.

K - KAMES

Kames are prominent cone-shaped hills of sand and gravel formed by water plunging into a hole in the ice. Kames frequently are found in clusters and characteristically are sandy near the top, grading to gravel near the bottom. All of the kames in the mapped area are located in the MO and EM-R units associated with the ice front of the St. Louis sublobe and Superior lobe.

E - ESKERS

Eskers are narrow sinuous ridges formed by subglacial streams flowing through tunnels within the glacier. The gravel deposited in eskers represents stream-bottom sediments. Gravel pits opened in eskers usually display a complex slump-bedded pattern of deposition, reflecting the subsidence of supporting ice walls. The quality of gravel in these deposits is very irregular because of the hydraulic effect of ice movement on streamflow. Nearly all of the eskers shown on the map are associated with the Superior lobe. The large esker trending north-south from Mirbat Station to Prairie Lake contains indicator rocks of both the St. Louis sublobe and Superior lobe and appears to mark the location where the two glaciers confronted one another. This esker is a major source of gravel for road construction in the study area.

IC - CREVASSE FILLINGS AND ICE-CONTACT SLOPES

These glacial phenomenon are included together under the ice-contact (IC) designation on the map. The term crevasse filling is generally applied to those ice-contact deposits (IC) that cannot be readily identified with other categories. They present irregular steeply sloping landforms within the MO-G/R and EM-R units, constructed of bouldery sand and gravel often mixed with inclusions of till. Several gravel pits are opened in the old bed of Lake Upham north and east of Toivola in the GM-L unit that probably represent ice-contact deposits of the Rainy lobe. All of the deposits are oriented in the northeast-southwest direction of the Toimi Drumlin Field. They contain a bouldery gravel rich in gabbro, granite, and iron formation rocks covered by a thin overburden of St. Louis sublobe till and lake sediments. Prominent ice-contact slopes are also designated IC on the map primarily to help in determining the position and relationship of local ice lobes.

GLACIOFLUVIAL DEPOSITS

Fluvial gravel deposits are deposited by streams beyond the ice front and are represented by Glacial Outwash (GO), Terraces (T), and the Alluvial (AL) units on the map. Lake Beaches (B) are also included in this category.

GO - GLACIAL OUTWASH

This unit presents a broad outwash plain of sand and gravel deposited by overloaded glacial streams. These streams often shifted their channels and merged to fill in large expanses with a plain of uniformly deposited sand and gravel. This type of deposit usually contains better quality gravel because it was subject to more intensive reworking, and transported longer distances by the streams. Outwash deposits are preferred for mining because they are very uniform as to depth and quality and cover large areas. Several large gravel-pit operations are located in the outwash deposits along the Cloquet River near Burnette at Sunset Lake. Other outwash deposits are found south of Schielin Lake and along Simian Creek.

T - TERRACES

Significant gravel deposits occur in the terraces along the lower St. Louis River from Brookston downstream to the White Pine River. Several large commercial gravel pits are opened in one of these terraces along Trunk Highway 33. This terrace is situated in a former channel of the St. Louis River now occupied by Johnson Creek and lower White Pine River. It was formed when increased flow from Lake Upham to the St. Louis River caused the river to start downcutting through its valley fill of sand and gravel. Originally the valley fill was deposited by glacial drainage systems (GO) discharging from the Superior end moraine (EM-R) near Burnette and Sunset Lake to the Cloquet River Valley.

AL - ALLUVIAL DEPOSITS

Alluvial soil of stream deposition is found along the St. Louis River Valley and it tributaries. Other postglacial alluvial deposits exist in the old glacial drainageways (DW) beneath a shallow cover of peat.

B - LAKE BEACHES

Sections of a weakly developed beach of Glacial Lake Upham are found scattered between Floodwood and Cotton along the inner side of the MO-G/R unit at elevation 1,300 feet. Gravel pits opened in the beach near Birch, Maple Lake, and Floodwood range between five to six feet in depth. The gravel pits contain considerable limestone and shale indicator rocks of St. Louis sublobe material.

APPENDIX B
LABORATORY METHODS

Bulk density (Db)

Bulk density is measured by taking a core of a known volume and oven-drying it to a constant weight (105°C for 24 hours). Calculations are carried out using the formula:

$$\text{Bulk density (g/cm}^3) = \frac{\text{oven-dry wt. core (g)}}{\text{vol. core (cm}^3)}$$

Water content

Water content is measured by taking approximately 100 g of a saturated peat sample and oven-drying it to a constant weight (105°C for 24 hours). The equation follows:

$$\text{Water content (\%)} = \frac{\text{weight of water (g)} \times 100}{\text{oven-dry wt. (g)}}$$

pH

The pH of a sample is determined in two solutions: 1) by mixing the organic soil material in a 0.01$\underline{M}$ $CaCl_2$ solution; and 2) by mixing the organic soil material in deionized water. Lightly pack 15 cc of a peat sample in a 100 cc plastic container. Add 15 ml of a 0.015$\underline{M}$ $CaCl_2$ solution (final concentration of approximately 0.01$\underline{M}$ $CaCl_2$). Mix and allow to equilibrate for one hour before measuring with a pH meter. Repeat the same process using deionized water.

Mineral content

The mineral content of a sample is determined by placing a pulverized sample of oven-dried peat (105°C for 24 hours) in a crucible and heating it at 500°C for thirty minutes. The sample is cooled and weighed. The weight of the ash equals the mineral content. Mineral content is calculated from the following equation:

$$\text{Mineral content (\%)} = \frac{\text{weight of ash (g)} \times 100}{\text{oven-dry wt. (g)}}$$

APPENDIX D

AREAL DISTRIBUTION PER MAPPING UNIT OF MINERAL SOIL AND WATER IN SW ST. LOUIS COUNTY, MINNESOTA

Mapping Unit	Hectares	Acres
D	2,798	6,910
EM-R	20,846	51,490
GM-R	7,640	18,870
GM-L	27,308	67,450
GM-G	5,194	12,830
AM-L	5,020	12,400
LBS	28,215	69,690
MO-G/R	32,490	80,250
OS-S	12,385	30,590
K,E,GO,T,B	9,915	24,490
AL	9,660	23,860
WATER	1,927	4,760