PROJECT 208

MINNESOTA FOREST MANAGEMENT NON-POINT SOURCE POLLUTION ASSESSMENT

Submitted to the Minnesota Pollution Control Agency by the Division of Forestry, Minnesota Department of Natural Resources.

March 30, 1979

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(Consultant's report)

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INTRODUCTION

Federal legislation enacted PL-92500 in 1972. Section 208 of this law mandates that every state identify its non-point source pollution problems. The Pollution Control Agency was delegated the administrative authority to fulfill these laws in Minnesota. Some of the potential sources of non-point pollutants which are being examined by the PCA are the following: Drainage and Irrigation; Feedlots; Pasturing; Manure Application; Agricultural Fertilization; Pesticide Use; Road Construction; Construction Activities; Highway Chemicals; Urban Runoff; Residual Waste and Forest Management.

The Department of Natural Resources, Forestry Division entered into a cooperative work agreement with the MPCA. The DNR is to provide the PCA with technical data and its' analyses, of the current and/or potential non-point pollution problems related to forest management in Minnesota. Two forest hydrologists were hired to fulfill the terms of this agreement in January, 1978. The information contained in Segments I and II of this document is the technical data requested of the DNR, by the PCA.

Segment I is an overview of all the factors that are related to forest management and the associated potential to impact water quality. The types of activities normally asssociated with forest management are described in Section I. The activities described apply to forest management in general and do not quantify the current picture in Minnesota. The information is provided as background material and the basis for our methodology. Section II describes:

- the natural processes of the forest ecosystem;
- how forest management may disturb those natural forest processes;
- the transport processes which can carry non-point source pollutants from disturbed forest areas to a waterbody; and
- the resource and management factors which determine the amount and type

of non-point pollutants carried to a waterbody, by the transport processes.

Section III details various methodologies which can be used to estimate the probability of non-point source pollution.

Segment II outlines and discusses the methodology used by the DNR to assess the potential for forest management to affect water quality in Minnesota. The data gathering procedures and results are described in Section IV. These data relate current forest management in Minnesota. Activities identified and described in Section IV are then rated as to their potential for site disturbance (high, medium or low), in Section V. Section V is the analysis section of the report. The erosion potential associated with broad geographic regions is estimated on the basis of slope and soil erodibility characteristics. The regions with the highest probability for erosion are identified. Each identified 'high erosion potential' region is discussed in terms of resource characteristics and forest management activity within that region. Conclusions and recommendations are discussed in Sections VI and VII.

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I. FOREST MANAGEMENT

The data collected by the DNR, for the PCA, will eventually be reviewed and analyzed by the public. The people who review these data may have little knowledge or understanding of forest management and its associated benefits and practices. An understanding of forest management principles is essential to those people who must make important decisions about forest planning and policy. Forest land covers a large area and serves a wide range of benefits and products in the United States. Consequently, there are many activities associated with forest management. These activities vary nationwide as changes occur in population density, topography, climate, and forest type, etc.

The information presented in this section provides an overview of forest management activities as they apply to Minnesota. The discussion is general, and describes the various practices and programs currently in operation statewide.

Statistics on the actual acres and locations of the various practices will be covered in a later section.

The forested area of Minnesota amounts to 19,047,000 acres, or 37% of the total land area. Commercial forest area (excludes areas such as parks and recreational preserves) of the state is 17,062,000 acres (1971 DNR estimates). Approximately 45% of all commercial forest land in the state is owned by small landowners.

	ACRES	
Private-Farm	3,344,000	
Private-Industry	715,000	
Private-Other	3,464,000	
Total Private:	7,523,000	30%

Federal, state and county agencies manage the other 70%.

	ACRES	
Federal	2,819,000	
State of Minnesota	4,566,000	
County & Municipal	3,416,000	
Total Public:	10,801,000	70%
		100%

These forest lands constitute one of the most valuable renewable resources of Minnesota. Forest industry in Minnesota ranks third behind agriculture and mining in state income. Forestry provides jobs for thousands of Minnesotans, and also provides a wide range of use opportunities and products. Timber, wildlife, recreation, water, and forage are productsof multiple-use forest management. Forest products provide a variety of resources to our society. They fulfill a wide variety of everyday needs; ranging from lumber and construction materials to newspaper, boxes, and food packaging. Forest management and the resulting products (timber, wildlife, recreation, quality water, aesthetics, and forage) are very important to our quality of life. To insure that these resource uses and products will be maintained for the years to come requires that we manage the forest to provide protection to all of these resources. For these reasons, forest management is much more than just cutting trees.

Forest management is a science dedicated to the proper management of forest lands for the continued efficient production of harvestable trees, high quality water, and the other products previously mentioned. Foresters in Minnesota today are involved in all aspects of growing, managing, harvesting, and protecting trees. The major elements of forest management programs which are currently operating in Minnesota are listed below.

A. SILVICULTURE

1. Timber Harvest Systems
2. Transport & Hauling Systems
3. Establishment of new stands
4. Intermediate improvements and protection

B. RECREATION

C. WILDLIFE

D. MARKETING & UTILIZATION

E. GRAZING

F. PRIVATE LANDOWNERS ASSISTANCE PROGRAMS

G. DEMONSTRATION WOODLANDS & EXPERIMENTAL FORESTS

H. SCHOOL & COMMUNITY FORESTS

I. TREE FARMS & NURSERIES

J. SPECIAL USE PERMITS & LEASES

K. RESEARCH

The following sections will describe these programs as they occur in Minnesota. There is an explanation of the forest management practices associated with each program.

A. SILVICULTURE

Silviculture has been defined as:

1. the art of producing and tending a forest,
2. the application of the knowledge of silvics in the treatment of a forest,

3. the theory and practice of controlling forest establishment, composition and growth.

The silvicultural responsibilities of any forest manager are to analyze the natural and economic factors of each forest stand under his supervision. The forest manager then designs and conducts silvicultural treatments most appropriate to the management objective. There are many factors which determine the management objective and consequently the silvicultural treatment applied to a forest stand. A forest manager's job is to coordinate these factors in order to obtain the planned benefits for a given stand. A list of the factors which commonly affect the silvicultural treatment is shown below:

1. goals of the landowner (public or private):
   a. personal goals (private)
   b. resource value to be emphasized (i.e. water quality, timber, recreation, wildlife, etc.);
2. landowners' access to expert advice in the fields of soil science, hydrology, wildlife management, logging, engineering and other related disciplines;
3. size of the land area to be managed;
4. land characteristics (i.e. soil types; soil fertility, aspect, stability, steepness of slope, number and characteristics of streams);
5. techniques necessary to preserve site productivity;
6. Climatic characteristics (i.e. amounts, seasonal variation and form);
7. characteristics of timber to be managed (i.e. species, age, size, location, quality, volumes, presence of insects or disease, incidence of blowdown);

8. availability of markets for the timber (indicates value of the stand);
9. types of products to be removed (sawlogs, posts, shinglewood, pulpwood, etc.);
10. economics: long term vs. short term investments and returns;
11. availability to the landowner of various types of logging equipment (i.e. tracked vs. wheeled tractors; hauling and cabling systems; shearers vs. chainsaws)
12. fuels (slash) that will be created by the harvest operation and subsequent stand improvement activities;
13. species desired for next crop & regeneration requirements;
14. site preparation required for new crop;
15. possible need for fertilizers, herbicides or insecticides during the development of the new crop; and
16. timber stand improvement needs.

When the new crop is mature and harvested, a rotation has occurred and the cycle begins again. Silviculture is a continuous process, composed of logically ordered steps for any given stand, which are dependent upon many interrelated and sometimes conflicting factors.

The overall objective of any silvicultural system is to provide the landowner with a sustained, annual yield of forest products without causing irreparable damage to the natural resources. The system should fit into the overall management plan for the forest. Components of the silviculture system are listed below and discussed in the following section.

1. Harvesting Systems & Methods
2. Logging Methods
3. Transport & Hauling Systems

4. Regeneration & Site Preparation Systems

5. Intermediate Stand Improvement & Protection Systems

1. Harvesting Systems & Methods:

Harvesting (or cutting) is the last step in the silvicultural process and sets the biological stage for the next crop. The harvest systems most widely recognized and used are the clearcut, seed-tree, shelterwood and selection systems.

a. clearcut:

In the clearcutting system all or nearly all of the trees are removed or felled from a specified stand or collection of stands. The main purpose is to clear the area to establish a new, even-aged stand usually composed of valuable and fast-growing species which will not reproduce satisfactorily under competition from other trees. The clearcutting method is commonly used when one or more of the following conditions exist:

1. when the residuals (remaining trees after harvest) are not worth keeping because they will not:
   a. increase in market value
   b. serve as a seed source to the new crop
   c. protect the new crop;
2. when the desired regeneration is intolerant of partial or total shade or competition with other trees;
3. when entire stands are mature or overmature;

4. when stands are in danger of loss due to disease, insects, or blowdown;
5. when converting stands to another species; and
6. when partial cuts would be uneconomical;

The area may be clearcut in patches (3-5 acres), strips, or large blocks (40-1000 acres). If regeneration is desired, it may be obtained through a number of methods:

1. vegetative reproduction: trees which naturally reproduce by vegetative suckering from existing roots or stumps;
2. natural seeding: seeds are dropped on the ground by standing trees, scattered on the ground during felling of trees, or blown into cut area from trees surrounding the cut area;
3. artificial seeding: seed is scattered on ground by hand or machine after cutting operation is over; and
4. planting: seedlings are planted by machine or by hand after cutting operation is over (seedlings are grown from seeds in a nursery).

b. <u>seed-tree method</u>:

In using this method, an area is clearcut with the exception of certain trees, called seed trees. These trees may be left standing singly or in groups. The purpose of these remaining trees is to furnish enough seed to restock the cut area naturally. After a new crop has been established the seed trees may be removed or left standing indefinitely. Use of this method results in the production of an even-aged stand. However, planting or direct seeding may be necessary where natural restocking has proved inadequate.

This method is only used when the desired species can be reproduced by natural seeding. This would not be used when converting to another species. It would not be used where regeneration will be natural suckering, or where planting is the anticipated method of regeneration. Due to the liability of windthrow, the seed tree method should not be used with characteristically shallow-rooted species, such as spruces, or with species that have wood of low strength, such as eastern white pine. The method is also not applicable to any species growing on moist or thin soils where rooting stratum is shallow.

The usual number of seed trees varies from two to ten per acre. If more than ten are left, the remaining trees cover a large part of the area and begin to resemble a shelterwood cut. An attempt should be made to distribute the trees uniformly over the cut area. However, it is more important to select the proper trees than to attain an absolutely even spacing.

c. <u>shelterwood method</u>:

The shelterwood method involves the gradual removal of the entire stand in a series of partial cuttings. These partial cuttings occur at intervals over part of the rotation. The whole process is usually accomplished within a relatively short time. In the shelterwood method, as its name implies, reproduction is achieved under the shelter of a portion of the old stand. The first cutting creates vacancies in the growing spaces of the stand in which the new crop can become established. Besides furnishing seed, the old stand affords protection to the young seedlings. A time arrives when the overstory shelter is not needed any longer. It is then necessary to remove the remainder of the old stand, giving the new stand possession of the area and opportunity to develop in even-aged form. Normally, the shelterwood method requires a minimum of two cuttings. Regardless of the number of cuttings, the largest, most vigorous, and best formed individuals of desirable species are retained until the final cutting. In this way, the best trees of the stand are left to provide seed for the new crop. Meanwhile, they also continue to produce wood of high quality at a good rate, thereby, increasing the value of the crop. The main difference between the shelterwood method and the two previously discussed methods is that establishment of a new crop is accomplished <u>before</u> the final harvest.

Again, this method is only desirable when the desired species is tolerant of partial shade and natural regeneration would not occur using other methods.

d. <u>selection</u>:

This term can be applied to any silvicultural program which has as its purpose the creation or maintenance of <u>uneven</u>-aged stands. An uneven-aged stand contains at least <u>three</u> well-defined age classes.

In the selection method, the mature timber is removed either as single scattered trees or in small groups at relatively short intervals. Any one harvest would normally remove less then one-third of the total stand. The selection system is adapted to tree species that are tolerant and will reproduce under dense shade and competition for soil moisture, nutrients and light.

2. <u>Logging Methods</u>:

Once the appropriate harvest system has been chosen, a method of actually harvesting (cutting) the trees must be picked. Years ago it was simple to decide. A man would cut each tree by hand with a crosscut saw or a chainsaw. This was slow, hard work. Modern technology has changed the picture of harvesting today. Fully mechanized methods of harvesting have been developed in the last 20 years, resulting in quicker and more efficient harvesting. Common methods of harvesting used today combine conventional hand labor with mechanization. Three methods are most common in Minnesota:

a. shortwood,

b. tree length, and

c. full tree.

(In actual practice most operations use modified systems which may include elements from all three methods).

a. <u>shortwood</u>:

This is the conventional system. In this method, the tree is felled, limbed, bucked into log lengths and stacked, all in close proximity to the stump. Few fully mechanized operations use this system. Most of the shortwood operations are partially mechanized. A piece cutter fells each tree with a chainsaw; then limbs and bucks it. The logs may then be dragged on a dray by a skidder or tractor to the landing.

b. tree length:

Using this method the trees are felled, topped and limbed at the stump. The full length of the tree is then skidded to a landing. This is the most widely used method in northern Minnesota. In these operations, the felling and limbing is done with chain saws. The use of mechanized shearers (feller bunchers) capable of both felling and limbing, however, has been increasing in the state.

c. full tree:

In this method, the trees are felled and hauled to the landing with the limbs still on. Most full-tree operations are fully mechanized and use feller bunchers and grapple skidders. With the recent introduction of whole tree chippers, it is expected that use of the full-tree method will increase. The full-tree works well in winter logging of conifers. During cold weather, most of the branches will be snapped off while being skidded to the landing.

3. Transport Systems

a. equipment

In Minnesota, the major system used for skidding, (the movement of logs from the stump or point of felling to a landing or point of concentration is the tractor. Tractor skidding is accomplished with either crawler or wheel type units. Animal, cable and aerial logging are methods not used to any extent in Minnesota.

Agricultural (farm) tractors were the first wheel-type units to be used for logging. During the 1950's, however, several manufacturers developed a rubber-tired wheel skidder, designed especially for logging.

Crawler tractors used for logging are normally equipped with a winch and wire rope. When on steep, swampy, rocky or otherwise difficult terrain, the tractor can be located on stable terrain and the winch used to skid logs a short distance to the tractor.

Wheel skidders have the advantage of greater speed, but have limited traction. They can be equipped with a light bulldozer blade useful for clearing obstacles from skid roads and moving logs at the landing. Wheel skidders can be equipped with an articulated hydraulically operated grapple which lifts the leading end of the log free of the ground and reduces soil disturbance during skidding. Inaccessible logs can be winched short distances into position to be grappled and skidded to the landing.

b. skid trails

The path of a skidder on its route from the stump to the landing is termed a "skid trail". Skid trails vary widely in frequency of use.

This is dependent upon the layout of harvest operation and the topography of the cutting area. Some harvest operations are designed with main skid trails. These main trails lead back to the landing. These main skid trails, therefore, receive heavy use for the duration of the logging operation. Optimum design and efficient use of main skid trails reduces the need for skidding off of them.

Some areas are cut with no planned design for removal. In these areas there are no main skid trails to receive a higher intensity of use. Logs may be skidded over the entire harvest area.

Skid trails are mainly used for timber access and transport to landings. They are not designed for permanent access and in most cases are revegetated naturally or artificially. These trails may be brushed out and used in future harvesting operations, or they may be used by forest visitors as hunting or hiking trails (etc.).

c. hauling

Once the logs reach the landing, a variety of actions may occur. If the shortwood or the tree length system of harvest is used, the logs will be loaded onto a truck ready to be taken to market. If the full tree method was used for harvest, the trees may be prepared for market in one of the following ways:

1) loaded directly onto the truck;
2) limbed prior to loading;
3) limbed and bucked prior to loading; or
4) whole tree chipped.

There are two main types of roads associated with timber transport to a market: permanent and temporary.

i. temporary:

Temporary roads are those forest access roads which lead from a permanent road to the timber sale area. Temporary roads are maintained only for the life of their use and have no permanent surfacing. Except when kept open by public use, these temporary roads will usually revegetate naturally. In some cases, artificial revegetation of these roads may be desired. In these cases, the roads are barred from public access.

Temporary Forest access roads may be constructed by two primary methods: 1) bulldozing, and 2) brush out a previously constructed road. Forest access roads are often used by the public after the cutting operation has ended for various recreational activities (i.e. hunting, cross-country skiing, ORV driving, hiking, etc.).

ii. <u>permanent</u>:

Permanent roads are those which are:

1. maintained on a regular basis;
2. built according to established specifications
3. sometimes have permanent surface of gravel, limestone, or other material; and
4. are part of a recognized system of roads connecting places of interest or importance to the user.

Permanent roads serve many functions, depending on their location.

iii. <u>watercourse crossings</u>:

Temporary and permanent roads must sometimes cross a watercourse in order to take advantage of the land form, to minimize construction and related difficulties, or to shorten length of transport to markets. Bridges, culverts, snow bridges and earthern bridges are all used to cross watercourses. The type of crossing constructed will vary according to the following factors:

1. type of road & degree of development;
2. anticipated future use of the road;
3. fundings available for construction;
4. time of year of harvest activity; and
5. width & depth of watercourse;

Permanent roads, built to a standardized set of specifications, will generally have permanent bridges or culverts constructed. As projected road use decreases, funds and energy spent on construction of crossings also decreases. If the road will only be used during months when the watercourse is frozen (i.e. swamp harvest operations) the crossing may consist of compacted snow, bulldozed dirt or compacted snow corduroyed with logs. Fording of a watercourse may also occur on a limited basis, where width and depth of a watercourse permit.

4. Regeneration

The chief objective after the final harvest is the early establishment of a new crop of trees. The decision of which species to grow is based on soil, site productivity, and other growth related conditions. If the selected species is one which will grow back naturally, nothing needs to be done to the stand. This is called natural regeneration. If the desired species will not grow back under natural conditions or, if conversion to a new species is desired, then steps must be taken to artificially regenerate the stand by planting or seeding. No single form of reproduction is adapted to all conditions. Many variables enter into the final decision on type and method of reproduction. Economics is the final determining factor.

a. natural regeneration

Natural regeneration is best accomplished when forest management practices provide favorable conditions for natural seeding or sprouting, and growth of the desired species. The method of harvest is an important factor in establishing the required conditions. Site preparation or release treatments may be necessary to control competing vegetation. Harvesting, site preparation, and release methods relating to natural regeneration of Minnesota species will be discussed later (See Silvicultural Guides).

b. artificial regeneration

When the species that will reproduce naturally on a given site is not the desired species, steps must be taken to artificially regenerate the desired species. The most important decision made in artificial regeneration is the selection of the species used in each new stand. The species chosen must be well adjusted to the climatic and biotic conditions of the site. If there are several species which could be grown, a decision must then be made favoring the species that offers the best prospects to meet the objectives of the owner.

Some of the factors considered are:

1. costs of establishment & management;
2. susceptibility of species to losses from insects and disease;
3. rate of growth of species; and
4. usefulness and value of the products generated by the species.

Some of the advantages of artificial regeneration are:

1. the forest manager has an opportunity to select a species more suitable to site conditions;
2. it enables the forest manager to develop a more definite plan for management; and
3. it can provide a well-stocked stand usually within a year or two.

The main disadvantage is the high cost of stand establishment.

Artificial regeneration is obtained by planting young trees or by direct seeding.

i. <u>planting</u>:

Conifer stock is usually three years old when it is lifted from the seed bed and distributed for planting. Hardwood stock is one to two years old, depending on the species. A small amount of stock is transplanted (less than 5%), and used for special purposes, such as windbreak plantings.

"Spacing" determines the number of trees planted per acre. The optimum spacing is that which will produce the greatest volume of product in the size, form and quality of trees required. Stands which are too highly stocked or are understocked do not produce high quality trees. This results in inefficient use of growing space. Choice of spacing varies with site, growth habit of species, expected survival, product objectives, future silvicultural treatment, and kinds of logging equipment to be used in future operations. Seedings must be planted when they are dormant and when soil moisture conditions are favorable. Soil moisture conditions are usually best in the spring, but occasionally fall lanting can be accomplished. Spring planting normally results in better survival of the planted trees.

Forest planting is accomplished by either machine methods or by hand. Various types of planting machines can plant from 5,000 -10,000 trees per day, depending on site conditions, and they provide the most economical method of planting large accessible areas. On site where machine access is a problem, such as rocky or brushy areas, hand planting is normally used. A typical site for hand planting would be in lowland areas where it is too wet for machines.

Successful planting often depends on such measures as the reduction of competing vegetation, the removal of physical obstacles to planting, and the drainage of water toward or away from the planted trees. The control of competing vegetation is especially important because many planting sites are crowded with undesirable plants. Even a cover of grass offers serious competition. Competing vegetation can be controlled through the use of herbicide; hand tools, or mechanical operations.

ii. <u>direct seeding</u>:

Direct seeding is the application of the seed of the desired species to any area which has been prepared for seeding. Seeds are subject to a high rate of mortality and have more exacting requirements for seed-bed conditions than planted seedlings. This means that more intensive site preparation is usually necessary to reduce the cover over the soil. Seeds should usually be placed in direct contact with mineral soil. Moisture must be almost continuously available at/or close to the surface of the mineral soil until the seedling roots have penetrated to a stable moisture supply.

Seeds are also subject to predation by seed-eating birds and animals. Approved chamical treatment of seeds helps to prevent the loss by predators. However, the use of highly toxic chemicals is no longer permitted and seed loss by predation can be a serious problem in certain areas.

Seeds may be applied to the prepared seedbed by aircraft, snowmobile, or hand.

5. Site Preparation

Treatment of a site for artificial regeneration is imperative for most species. Some species can be regenerated by several methods of cutting, but by only one method of site preparation. The major categories of site prepation are listed and described below.

a. slash disposal:

"Slash" is the logging residue or tree debris which is left after the removal of the merchantable logs. The amount, distribution and the type of slash left varies with the logging system, the proportion of the canopy removed and the extent to which felled trees are utilized. For example a clearcut operation which is fully mechanized, including a chipper, generates little slash; and this is usually in the form of small chips . Slash is a potential fire hazard if not disposed of properly. Slash can also hinder establishment of reproduction. This is due to the heavy shade and physical obstruction to growth that is imposed by the slash.

There are three common methods of slash disposal: 1) burning, 2) chopping and scattering the slash, or 3) windrowing. Burning of slash usually kills competing vegetation, and expose bare mineral soil. These conditions are favorable seed-bed conditions. Chopping and scattering breaks up the slash into smaller pieces and redistributes it. Seedling growth is hindered less when the shade and bulk of the slash is removed by this method. Windrowing concentrates the slash in long rows, leaving most of the area free of slash. This is usually accomplished through use of bulldozers. Each of these methods are discussed in greater detail.

i. <u>burning</u>

1. broadcast burning: slash on clearcut areas is burned as it lies, within prepared fire line boundaries;
2. spot burning: a modification of broadcast burning in which slash is burned in patches containing high concentrations of slash; only employed where there is little risk of fire spreading; and
3. burning of piled slash: slash is bulldozed into piles with bulldozers or similiar equipment; use of these machines has the important, incidental advantage of reducing competing vegetation and exposing mineral soil on the treated areas.

ii. chopping and scattering of slash:

The fire hazard and/or physical obstructions to regeneration survival caused by slash can sometimes be avoided without burning. In this method, the logging debris is cut up so that branches lie closer to the ground. Chopped slash is advantageous in cases where burning would destroy much of the advance reproduction. It also provides a method for seed dispersal on species such as jack pine.

iii. windrowing

This method reduces physical obstructions to tree growth on the cleared areas. However, the area of the windrows may constitute as much as 15% of the site. The slash is bulldozed into long rows, leaving the area between rows free for planting. Use of bulldozers reduces competing vegetation and exposes mineral soil. The area covered by windrows is lost from timber production. Windrows may be considered an eyesore but may provide wildlife habitat.

b. treatment of the forest floor and competing vegetation:

Regeneration from seed is dependent on the seed-bed requirements. These requirements cannot always be fulfilled by regulating the method of cut, the amount of soil disturbance in logging, or by treating undesirable vegetation after it's already established.

Preparation of seedbeds involves treatment of the forest floor. The forest floor is composed of fallen leaves, twigs, plant remains, and other organic matter which has not yet decomposed (also called litter). This matter is not good seedbed material for most species. Bare mineral soil is generally much more favorable for regeneration. However, some hardwood seed germinates better when buried beneath the litter and black spruce seed germinates well in sphagnum moss.

There are two general methods of eliminating or reducing the amount of litter on the forest floor: prescribed burning and mechanical site treatment.

i. prescribed burning:

A method employing regulated fires to reduce forest litter or low, undesirable vegetation.

ii. mechanical site treatment:

The purpose of mechanical treatment is to prepare a good seedbed by reducing competing vegetation and exposing mineral soil. Mechanical site preparation is generally used in areas where prescribed burning is ineffective or unsafe and where herbicides have not proven to be very effective. Mechanical reduction of undesirable vegetation can be accomplished by:

1. uprooting woody plants
2. chopping up smaller plants
3. plowing under grasses & other herbs
4. cutting, shearing off stems of woody plants which are incapable of stump sprouting. Once stems are cut off, they may be left, chopped or plowed into rows, depending on their size. Most mechanical site preparation

involves some sort of soil disturbance, no matter what the management objective. Exposure of mineral soil is the usual desired result when preparing a seed bed. The desired amount of exposed mineral soil varies by species and their associated seed bed requirements.

c. Treatment of the Mineral Soil

Ordinarily, exposure of mineral soil is the most important factor needed for seedbed preparation. Fertilization, drainage and irrigation are intensive treatments of mineral soil aimed more at improvement of site quality than at site preparation for regeneration.

i. fertilization

Fertilization is still a relatively new concept in forestry. Not all forest soils provide an optimum supply of the nutrient elements essential for the growth of trees. Marked deficiencies may exist due to low natural fertility of the site or improper land management in the past. These deficiencies may limit normal plant growth. Fertilizers add some of these nutrients to the soil, thereby optimizing plant growing conditions. There is a long history of experimentation with fertilizers in agriculture. This means that there is still much to be learned about the effects and/or feasibility of forest fertilization.

Fertilization is not widely used in Minnesota.

ii. drainage & irrigation:

Trees will not grow at an optimum rate if soils are too dry or too moist. The objectives of drainage & irrigation practices are to correct extremes of soil moisture. Irrigation is not used as a method of soil treatment for forest crops in Minnesota. Application of drainage techniques in Minnesota forest management has been limited to a few drainage experiments.

6. Intermediate Stand Improvement & Protection Systems:

During a rotation, the period of tree growth between the establishment of a stand and harvest, the crop may require additional cultural treatment. The crop may become too dense and trees may compete with each other for light, nutrients, and water. In this case, the crop would require thinning. Or, the crop may be understocked and require spot planting or seeding. Depending on the species present and the location, some stands may be subject to insect, disease, weather or nutrient problems. In these and other cases, practices to improve the stand conditions and protect the growing trees must be implemented. The practices which will be discussed are listed below:

a. thinning,

b. pruning,

c. fertilization,

d. pest control,

e. wild fire & control,

f. salvage cuts,

a. thinning:

Thinnings are cuts made in a stand before it matures. The two main purposes of thinnings are to stimulate the growth of the remaining trees and to increase the total yield of useful material from the stand. The objective is to create growing space for the healthy and vigorous trees, not to create areas for establishment of a new crop.

Young stands are typically crowded with many seedling or saplings. As they mature, competition increases. Trees decrease in number, rapidly at first, then slowly with time. This continual decrease in number is primarily the result of natural selection, a fundamental biological law of nature. Thinning is man's way of expressing this biological law by helping the healthiest trees attain optimum growth under managed competition.

Advantages which are gained from thinning are:

1. salvage of anticipated losses of merchantable volume (those trees which die and decay before rotation age, or those damaged by insects or disease);
2. increase in value due to enhanced growth in tree diameter;
3. increased income from growing stock during the rotation;
4. improvement of product quality (less knots, better form); and
5. opportunity to change stand composition and prepare for establishment of new crops.

There are two major types of thinning: precommercial and commercial. Precommercial thinnings occur when the trees in the stand are so young and small that they cannot be marketed. These thinnings occur for the sole purpose of improving stand conditions. Precommercial thinnings may be done with chain saws.

Commercial thinnings may occur several times throughout the rotation of the stand. The purpose is the same (to improve stand condition), but the trees that are harvested can be marketed and usually are machinery harvested.

b. <u>pruning</u>:

Pruning is a forest management tool whose purpose is prevention or control of knots, which are defects in the wood located at the junctions of branches and trunks. Pruning is carried out by cutting selected branches.

Pruning may occur naturally or artificially. Natural pruning occurs slowly during the life of the forest crop, typically from the ground upward. The rate of dying of the lower branches increases with stand density and tree vigor. Once these dying branches are shed by the tree, the new wood growth on the tree will be free of knots in those areas. If a branch dies and remains on the tree, the new wood will grow around the branch, creating a loose knot. Loose knots in lumber eventually fall and leave holes in the lumber. The knots formed by living branches are far less damaging than those left by dead branches, but knot size should be controlled.

Artificial pruning can remove dead or live branches from trees that do not prune well naturally. The purpose of artificial pruning is to produce high quality clear lumber. If properly done, it is not harmful to the tree. There are, however, certain species which do not adapt well to pruning.

Pruning is almost always necessary in plantations where the spacing is not dense enough to promote natural pruning and solid wood products are desired from the trees. Pruning is also used in Christmas tree plantations to shape the tree. Pruning can be done with a chainsaw, handsaw, shears or a machine with a rotating cutting head.

c. <u>fertilization</u>:

Fertilization of forest crops which are already established is a management practice which does not occur to any appreciable extent in Minnesota.

d. <u>pest and disease control</u>:

There are many agents which are harmful to the growth of trees in the forest environment. Animals, insects, bacteria, viruses and fungi all have the potential to harm a crop of trees. The type of pest or disease which may injure trees varies with species or location. Thousands of acres of valuable timber are lost to these agents each year. If not controlled, these agents continue to attack large numbers of healthy crops. Control methods used vary with the type of pest or disease.

Methods of control which are commonly used in Minnesota:

1. various harvesting techniques
2. burning
3. chemical use

The 1977 DNR Forest Pest Report describes occurrence of the following most common pest and diseases of Minnesota trees:

INSECTS:

Jack Pine Budworm

Spruce Budworm

Aspen Defoliators

White Pine Weevil

Yellow Headed Spruce Sawfly

DISEASES:

White Pine Blister Rust

Oak Diseases

Dwarf Mistletoe

Dutch Elm Disease

Diplodia Tip Blight

Scleroderris Canker

The specific diseases of commercial Minnesota species and how they are controlled will be discussed in a later section (See SILVICULTURAL GUIDES).

e. fire and fire retardants:

Prescribed burning can be a beneficial tool in forest management. Stands may need release from dense shrubs, weeds, insects or disease. Fire, when correctly planned, is an efficient method of release.

Wildfire on the other hand, is unplanned and often causes major damage. New concepts in forest management allow certain wildfires to burn under predetermined weather conditions. This policy only applies when the wildfire occurs in an area which has been previously scheduled to be burned. The fire is then contained within these prescheduled boundaries.

Uncontrollable wildfires or escaped prescribed fires are damaging and must be controlled. Loss of timber is not the only consideration here. Human lives, homes, crops, and wildlife may all be endangered. Firebreaks water, and fire retardants are common methods of fire control today. Crawler tractors plow or doze firebreaks to expose top soil, and remove fuels to prevent the spread of fire. Firebreaks must be wide enough to keep the fire from jumping the line. Fire retardants are mostly dropped from the air, especially in cases when large acreages must be covered in a short time. Fire retardants are designed to slow or stop the fire by creating chemical fire lines. Water may also be used to extinguish or slow the spread of the fire.

f. <u>salvage cuts</u>

Insects, fire, weather or careless logging all have the potential to reduce the amount of wood gained from any crop. Often these losses can be partially overcome by salvage cutting.

Stands which are infested with insects or disease and are threatening other healthy stands, may be removed by cutting or prescribed burning. This removes the pest plus its habitat, and salvages timber which may be merchantable.

Tornadoes, wind, drought and fire are all common occurrences in nature. All are unpredictable and, in most cases, unpreventable. Vast acreages of trees may be uprooted by tornadoes or high winds. Severe ice storms may snap off branches. Standing trees may be killed by severe fires or drought. In most cases, these trees which are damaged or killed by natural causes contain merchantable wood. Despite considerable loss due to breakage or scarring and the possibility of limited access, these stands can still be salvaged in many cases.

Salvage cuts are also essential to remove the trees and prepare the damaged site for a new crop. Stands of this nature are usually clearcut. The size of the cut is dictated by the size of the area damaged and the availability of a market for the timber. If there is no market for the timber, the wood will probably not be harvested.

Summary:

Silviculture is an integrated system of logically ordered steps. Harvesting of a crop is the most usual culmination. Site preparation, regeneration, stand improvement, stand protection, and economics, are as much a part of silviculture as harvesting. All contribute to the overall management objectives.

Silviculture is one part of a larger system forest management. Wise use of the forest resources for all benefits is the current philosophy. Recreation and wildlife are two major benefits of the forest resources. In some cases, management practices to provide optimum benefits for timber production, recreation and wildlife are in conflict with each other. Where the concerns of each area are compatible, these benefits occur together. However, there are areas where recreation is the main objective and those where wildlife or wood production is the main objective. National, state, or county and municipal parks are managed primarily for recreation. Harvesting of timber in the parks is not usually part of a normal park management plan. The philosophy is to preserve the natural or present composition of the forest land. Harvest here occurs mainly for insect or disease control.

B. RECREATION AND FOREST MANAGEMENT

There are many types of recreational activities which are possible in today's society. The types of activities, or provisions for these activities, with which this report is concerned are those which:

1. occur in a forest area
2. involve manipulation of forest vegetation

The kinds of activities which meet these requirements are: camping; picnicking; trail use for cross-country skiing, hiking, snowshoeing, snowmobiling, horseback riding, hunting, and biking; ORV use; historic, scenic and wayside rest areas; etc.

Outdoor recreation is rapidly winning its place as an important form of land use. Technological progress has accelerated the drift away from the simple life and direct contact with nature. This has resulted in the concentration of large numbers of people into crowded urban centers. In the cities, active outdoor recreation is limited. The reservation and development of recreational areas is, therefore, important to the well being of our urban society. Also, the steady rise in the American standard of living, characterized by higher per capita incomes and greater leisure time, has been accompanied by an urge to re-establish contacts with nature. Not only is recreation a distinct social benefit, but it is also important economically. It has fostered the development of an industry which ranks fourth in Minnesota.

Further recreation expansion is inevitable and in most cases desirable. But, if it is to be an orderly development bringing the maximum benefit to the recreationist, the recreation industries, and the state, it should be managed in harmony with other land uses.

Silvicultural activities are concerned with the growth, protection and use of harvestable trees. Recreational activities, with respect to forest management, are concerned with the removal of forest vegetation to create spaces for recreation to occur, and the preservation of residual trees for an aesthetic recreational environment, as well as maintenance of a unique vegetation type.

Heavy use, compaction and impermeable surfaces all restrict the regrowth of vegetation in recreational areas. The trees left standing are left for aesthetic purposes. These residuals are not cut unless irreparable damage occurs to the tree from disease, fire, wind, insects or old age.

C. WILDLIFE

Wildlife is another important benefit derived from the forest. Minnesota's thriving recreation industry is supported, in part, by an abundant and permanent supply of fish and game. Therefore, it is important that wildlife be cultivated and managed in such a way as to sustain the yield.

As man has colonized Minnesota, he has utilized the forests to partially fulfill his needs for food, heat, and shelter. As the forests change in structure, through man's manipulation, the habitat of the animals which live there also changes or disappears. Increased competition for food and protection may reduce natural levels of wildlife to low levels. Fortunately, forest management practices generally complement wildlife requirements to provide required food and cover for various species.

In recent years, more and more attention has been given to the preservation or development of the conditions or habitat necessary for each species of wildlife.

The practice of creating small openings in the forest where low shrubs and herbaceous vegetation can grow promotes food for deer and other species. Wildlife openings and browse cuts can sometimes be coordinated with silvicultural activities.

Minnesota has many programs which deal with wildlife habitat improvement. There are 812 wildlife management areas covering 1,080,110 acres in Minnesota. The objective of forest management on these lands is the maintenance and perpetuation of wildlife habitat. In these areas, foresters work cooperatively where possible, with wildlife managers to coordinate harvests of mature timber with wildlife needs.

Far more people engage in fishing than in the taking of game. Species of fish taken vary with the type of water fished. Some species of fish are very sensitive to temperature changes in their habitat as well as water quality alterations. These limitations must be considered in any timber harvest operation which occurs in close proximity to a watercourse.

D. MARKETING & UTILIZATION

Trees felled, whether for wood supply, recreation or wildlife concerns, are marketed whenever possible. The forest products industry is the 3rd largest in Minnesota. There are paper mills, saw mills, pulp and chip mills, and other related companies. The forests of Minnesota contain many species of trees which are used in the wood and paper products industry. Each species exhibits different structural characteristics and is used for different products accordingly: (i.e. oak is used for furniture because of its strength. The long fibers in pine and spruce are necessary for paper production. Cedar is used for fence posts because of its resistance to decay under moist conditions.)

New methods of logging and new techniques in manufacturing result in more complete utilization of a tree. Chippers which chip up previously unmerchantable portions of a tree, now provide forest industries with material for chipboard and hardboard.

E. GRAZING

Practices to promote grazing of livestock may involve the removal of forest trees or the compaction of soil around existing trees. Compacted soil hinders the growth of trees, sometimes killing them, and also reduces natural regeneration. Forest land is used as pasture in Minnesota where suitable pasture does not exist.

F. PRIVATE FOREST MANAGEMENT

Analysts predict that the demand for timber will increase about 80% by the year 2000. The land managed by federal, state, county, and private forest industry may not be able to fulfill these demands. In Minnesota, approximately seven million acres of forest land is in small private ownership. These lands are potentially among the most productive and most accessible of all lands, though many are in need of improvement.

Programs have been established in Minnesota which give assistance to landowners who wish to manage their land. The State legislature passed an act in 1947 which provides that foresters be employed for the purpose of furnishing owners of less than 1000 acres of forest land with forest management services. The State government has an agreement with the U.S. Forest Service whereby matching funds for state Private Forest Management programs are available under the federal Cooperative Forest Management Act.

Wherever possible, foresters integrate woodland management with crop or other management to achieve total management of the land. After applying for assistance, owners are contacted and their objectives determined. Management plans are then prepared which are specific to the intent and capabilities of the owner. Finally, the forester guides the owner in carrying out these plans. These services are free to the landowner. At present, approximately 4,000 landowners are receiving these services in Minnesota.

G. DEMONSTRATION WOODLANDS

Demonstration woodlands have been established in Minnesota forests for public education. The purpose is to show the public how to manage land for desired benefits. All of these woodlands have had some kind of treatment or development. Timber has been harvested and stands have been improved. Some areas are being managed for the production of maple syrup. Nature trails have been constructed to provide self-guided tours. Picnic areas and other recreational facilities have been developed. Wildlife habitat improvement and water protection structures have been implemented. Scenic developments will be made to improve appearance. Annual field trips are undertaken to demonstrate the various benefits that can be obtained from these lands.

H. TREE FARMS

A tree farm is an area of privately owned, tax-paying forest land dedicated to the growing of repeated forest crops for commercial purposes. The minimum area is five woodland acres.

The tree farm system is designed to give service to the private woodland owner and public recognition to those doing a good job.

Minnesota tree farms have been sponsored since 1949 by Keep Minnesota Green, Inc. in cooperation with the American Forest Institute. The program has the cooperation of the Minnesota Forest Industries, the Minnesota Department of Natural Resources, the University of Minnesota Agricultural Extension Service, and other organizations interested in the fullest development of Minnesota's forest resources.

A management plan is written by a forester for the tree farm. Inspections are made frequently to ensure that the plan is being followed. Approved and certified tree farm owners obtain a plaque at a public meeting.

I. AGRICULTURAL CONSERVATION PROGRAM

The Agricultural Conservation program is a federally sponsored program that cost shares conservation practices on small private woodlands and agricultural lands. The program pays a share of the cost of certain forest practices, such as tree planting, site preparation, thinning, pruning, and release.

Foresters inspect the woodlands to determine the need for these practices and to provide forestry advice and assistance. After the practice has been completed by the owner, the foresters check to ensure that the work was completed satisfactorily. If the work is satisfactory, the woodland owner will be reimbursed for a portion of the costs.

J. SCHOOL FORESTS

In 1949, The Minnesota State Legislature passed an act providing that any school district or any public educational institution may establish and maintain a forest. This program aids schools that wish to develop a forest or to manage their present forest. Foresters with the state or federal government help the schools to select suitable forest sites and prepare management plans.

In the development and management of a school forest, students can become acquainted with seed production, planting and plantation maintenance, inventory and management, growth studies and predictions, and harvesting and marketing. Recreational development and wildlife habitat improvement are also studied. The soil-protective and water retentive properties inherent in well-managed woodlands can be demonstrated in these forests.

The school forest can be considered a living laboratory. Constant observation of natural phenomena is possible and may be blended with classroom activities. These close associations with nature help provide adults with an appreciation of the wise use of our resources.

K. TREE NURSERIES

When a desired species cannot be satisfactorily regenerated naturally then young trees must be planted. The purpose of tree nurseries is to provide sufficient, healthy seedlings to landowners wishing to artificially regenerate their land.

Trees in a nursery are grown from seed under carefully supervised conditions for a period of 1-4 years. The trees are then sold at the cost of production to landowners wishing to plant.

Presently 3 state nurseries are in Minnesota (one is inactive). They are owned and operated by the State government. The present production from the state nurseries consists of predominantly conifer stock (approximately 90 percent). The other 10 percent is hardwood stock. The distribution of tree stock has been approximately 45% to public lands and 55% to private lands.

L. LEASES

Public forested land in Minnesota is leased for various causes: (i.e. lakeshore cabins, rights of way for utility lines, agriculture, commercial industry, gravel pits and peat).

M. RESEARCH

Research is an extremely vital part of forest management. As demand for forest products increases, and available land space decreases there is an increasing need for more efficient production and utilization of forest materials. Research has made possible the use of aspen and jack pine for a wide variety of wood fiber products, such as insulation materials, hardboards, and paper products, thereby increasing utilization of two major Minnesota forest species. Expansion of research is urgently needed in all fields of forestry and forest products. Listed below are some areas where research is continuing.

1. improvement in production methods
2. growth rates and quality of planting stock;
3. determination of the most productive planting sites on a species by species basis;
4. control of brush in replanting;
5. control of forest insects & diseases;
6. utilization of all tree by-products and utilization of large amounts of excess, low-quality aspen of pulpwood size
7. fire protection; and
8. watershed protection.

II. FOREST MANAGEMENT AND WATER QUALITY

Forest management for water quality requires knowledge of terrestrial and aquatic ecosystems and the hydrologic cycle. These systems are dynamic, constantly undergoing change due to natural processes and man's influence. To assure that these complex systems are maintained, it is necessary to regulate the limits to which they can be altered. To carry out effective resource management, an understanding of the processes operating within the ecosystem and an ability to predict the consequences of various forest management activities is required.

A. THE FOREST ECOSYSTEM

A forest ecosystem is viewed as a forest community and its environment which interact as a functional unit. Within each forest ecosystem there are three major processes; these are the flow and transfer systems of energy, water, and nutrients.

1. Energy Flow and Transfer

Solar energy enters the ecosystem through the atmosphere and is captured by the photosynthetic process in green plants. Some of this captured energy is utilized to form various plant materials (i.e. cellulose, amino acids and proteins). The chemical building blocks of these materials are transferred among all of the organisms in the ecosystem (trees and other plants; herbivores and insects; and carnivores, which are ultimately decomposed, releasing heat in the process). Some of the engery captured by green plants, therefore, is utilized by other organisms, and some is used for the plant's own growth and development.

2. Water Flow and Transfer

The upland ecosystem is the major source of water for lowland ecosystems, both terrestrial and aquatic (Fralish, 1977). Precipitation is typically the principle source of water to an upland area.

Precipitation entering the forest ecosystem through the canopy as unhindered rainfall or crown drip is termed throughfall. Water that evaporates prior to reaching the forest floor represents the loss due to interception. Thus, precipitation onto a forest ecosystem can be accounted for by the two following processes:

1. interception by the canopy; and
2. entry into the forest floor as either throughfall or stem flow

Water reaching the forest floor may be retained temporarily in the organic surface layer. Conifer stands tend to have more litter than hardwood stands. Litter in hardwood stands is readily broken down by fungi and earthworms and mixed with mineral soil.

As water reaches unsaturated mineral soil, it infiltrates the surface. If rainfall is heavy, infiltration rates may be exceeded and surface runoff can occur. This problem tends to be more prevalent in finer textured and compacted soils. Water entering the soil is stored in pores between soil particles.

Once these pores are filled, subsurface flow and deep seepage begin. Infiltration rates at this time are very slow, and if precipitation continues surface runoff may occur. Water stored in the soil may be absorbed by plant roots, transported to the crown and lost through transpiration (evaporation through the pores of the leaf surfaces) or evaporated directly from the soil surface.

As evapo-transpiration occurs, soil moisture space becomes available, infiltration rates increase and the amount of surface runoff is slowed and reduced. As a general rule, the slower the runoff, the higher the quality of water reaching the stream. This is because the water will percolate through the soil rather than run off from the surface where it can pick up and carry mineral and organic particulates.

The amount of water and the time it takes for that water to appear in streams varies. This variation is dependent upon:

1. intensity and duration of precipitation
2. characteristics of the soil
3. moisture content and storage capacity of the soil
4. slope gradient to stream or watercourse

3. <u>Nutrient Flow and Transfer</u>

Nutrients may enter the ecosystem in a number of ways:

1. atmospheric input
2. bedrock weathering
3. surface and subsurface lateral flow of water
4. additions by man (i.e. fertilizers). (These are covered in the processes section).

The soil is one of the primary storage areas for nutrients. This storage supplies the bulk of the minerals necessary for tree growth. Nutrients are retained in the storage sites until absorbed by root hairs of forest plants, carried away by surface or subsurface flow of water, or converted to minerals.

Once absorbed by the plant's roots, the nutrients flow in a water solution to the stem and leaves. Consequently, leaves and young twigs have a high concentration of nutrients. As nutrients are lost by the ecosystem, they are also added to it by being incorporated into plant tissue, which may in turn be ingested by animals as another step in the cycling process. Decomposition of plant matter and animal wastes returns nutrients in available forms to the forest floor. As decay occurs, the nutrients move into the soil where they may be absorbed by plant roots again.

B. HOW FOREST MANAGEMENT DISTURBS THE ECOSYSTEM

Climate, soil type, soil development processes and forest community types combine in various ways to create a forest ecosystem.

The upland terrestrial ecosystem which includes forest ecosystems, is a potential non-point source of minerals and particulates to streams, lakes and other water bodies (Fralish, 1977). The forest ecosystem is variable in its effect on water quality depending on the forest type, site environment, and type of disturbance. Disturbances to the forest ecosystem come from nature as well as from man.

Disease, insects, windstorms, droughts and fires are natural disturbances which can affect the quality of water flowing in a forest ecosystem. Forest management activities (those discussed in Section I) are disturbances by man which can also affect the quality of water in the forest ecosystem. The types of disturbances associated with forest management activities and the resulting effects on the forest ecosystem are discussed in the following sections.

1. <u>On-Site Disturbances</u>:

   a. <u>reduction of growing material</u>:

      Most forest management practices involve the harvesting of timber or the removal of competing vegetation for the growth of new stands. Removal of trees and other herbaceous cover may result in the following disturbances to the forest ecosystem:

      i. Removal of the forest canopy permits precipitation inputs to fall directly to the forest floor. Precipitation which was previously caught on leaves and branches and evaporated now adds to the total precipitation received by the forest floor. Thus, for any given rainfall, precipitation reaches the forest floor in greater amounts and with greater impact energy. Under these conditions, exceedance of the infiltration rate causing increased surface runoff is favored.

ii. The stems of plants and trees plus litter on the forest floor not only catch falling precipitation, but also impede the downhill flow of water. When these obstacles are removed, the velocity of surface runoff in a given slope is increased. The faster the water moves over the surface, the less chance there is of infiltration, which favors surface runoff.

iii. As the velocity and amount of runoff increases, there is an increase in runoff energy. This increased energy added to the runoff enables it to pick up and carry increased amounts of particles and other movable materials from the forest floor. These may then be deposited in the water. These particles may consist of nutrients, soil, and organic matter.

b. <u>exposure of mineral soil</u>:

Processes and methods to remove stands of timber or regenerate new stands sometimes result in or require exposure of bare mineral soil. The amount of mineral soil exposed by an activity is variable, being dependent upon the time of year, cover type, machinery used, and purpose.

Weathering of bedrock and decomposition of organic matter are important components of the soil development and nutrient flow process in the forest ecosystem. Moisture and soil micro-organisms are necessary for these processes to occur. Bare soil which is allowed to dry out provides an unfavorable environment for micro-organisms. They require the temperate conditions which a forest canopy and litter layer can provide.

Thus, when the soil dries out, there is a limited release of nutrients into the ecosystem. If the loss of nutrients and soil particles to surface runoff is increased, serious loss of site productivity can occur.

The layer of organic matter over the mineral soil also acts as a buffer in extreme conditions. The litter catches and stores precipitation and thereby reduces the potential for surface runoff. It also provides shade to the soil from the sun.

Dry soil is usually hard and less receptive to infiltration of falling precipitation (dry sponge-vs-wet sponge effect). Again, a decrease in the infiltration rate can result in increased surface runoff. The rate of removal of nutrients and soil particles is a function of the following factors:

1. velocity of runoff;
2. intensity and duration of precipitation;
3. soil moisture storage capacity;

4. soil porosity and structure;
5. soil aggregation;
6. nutrient characteristics;
7. root density; and
8. amount of soil exposed.

c. compaction of soil:

Machinery used in the felling and removal of trees can compact the soil. The degree of compaction is dependent upon:

1. soil structure;
2. time of year of activity;
3. number of times of use/given area;
4. amount of litter on soil surface; and
5. type of equipment used.

Compaction of the soil reduces available pore space for moisture storage. Consequently, infiltration rates are reduced and surface runoff may be increased. Compaction of the soil can occur whether mineral soil is exposed or not. If soil is compacted where mineral soil is exposed, there is a greater chance of nutrient and particle flow in surface runoff.

Soil compaction also inhibits seedling and root development. Soil compaction combined with loss in soil productivity slows the rate of revegetation, thereby leaving soil with a higher potential for erosion for a longer period of time.

2. Off-Site Disturbances to the Aquatic Ecosystem

The forest ecosystem is composed of many smaller, compartment ecosystems. On-site disturbances (those previously discussed) can potentially affect the quality and quantity of surface runoff to the aquatic ecosystems, which are part of the larger forest ecosystem. These disturbances are considered off-site.

A water pollutant is defined as that material found in the aquatic ecosystem in significantly higher levels than they naturally occur. The major types of water pollutants generated from forest management disturbances to the forest ecosystem are:

a. nutrients,

b. sediment,

c. pesticides,

d. organic matter,

e. thermal, and

f. pathogens.

a. nutrients:

Plants are composed of mostly carbon, hydrogen, and oxygen. These three elements account for about 95% of the total weight of most plants (USFS HB2509.15, 1961.) The sources of these elements are the atmosphere and soil water.

Other elements required by plants are nitrogen, phosporus, potassium, calcium, magnesium, sulfur, iron, manganese, copper, zinc, boron, molybdenum, and chlorine. (USFS HB2509.15, 1961.) All of these elements are considered essential to plants, and life could not occur without any one of them. The supply of these elements (all those named excluding carbon, hydrogen, and oxygen) depends primarily on soil factors. The elements furnished by the soil are considered to be plant nutrients.

The nutrient cycling process within a forest ecosystem consists of inputs, outputs, and intrasystem circulation. Nutrients are found in four basic compartments (Bormann and Likens, 1970.):

1) an organic compartment consisting of living organisms and their debris
2) the available nutrient compartment which is comprised of those nutrients held by soil particles in the clay-humus fraction
3) the soil and rock compartment
4) the gaseous compartment

Nutrients can move among these compartments through an array of natural processes.

Available nutrients are incorporated into plant matter and eventually re-enter the available nutrient compartment through leaching and decomposition of the plant materials. Minerals in soil and rock are decomposed by weathering, thus making them available for subsequent biological uptake or transformation back into unavailable forms by conversion into new minerals. Nutrients tend to cycle between the organic, available nutrient and soil plus rock compartments, forming a pattern of circulation within the system (Bormann and Likens, 1970). The processes of photosynthesis, respiration and the fixation and volatilization of nitrogen account for a large part of the intrasystem nutrient cycling from gaseous forms to other compartments. (Bormann and Likens, 1970).

A forest ecosystem is connected to surrounding and larger ecosystems by a range of input and output channels. Nutrients enter and leave the forest ecosystem in the form of gases, dissolved chemicals in runoff or precipitation, and/or components of living matter in the tissues of animals that move across ecosystem boundaries (Bormann and Likens, 1970.) Inputs and outputs can be transported by meteorological forces such as precipitation and wind, and geological forces such as running water and gravity.

The entry of nutrients and other naturally occurring chemicals into the aquatic ecosystem can be affected by forest management activities in several ways. Fertilizers and fire retardants contain nutrients, such as phosphorus and nitrogen, and their application on forest lands can lead to abnormally high loading rates (EPA, 430/9-73-010, 1973). Increased rates of delivery through leaching, erosion, and direct deposition account for these effects. Interruptions in the nutrient cycling process caused by harvesting and burning operations can also alter the natural rates of loading. Removal of vegetation for instance may significantly reduce nutrient uptake by plants and stimulate decomposition of organic matter on the forest floor, thus making more nutrients available for export from the ecosystem (EPA, 430/9-73-010, 1973).

The types of nutrients and other ions generated from lands where management activities take place include monovalent cations (Na^+, K^+, etc.), heavy metals (Mg^{++}, Ca^{++}, etc.), various anions (CL^-, HCO_3^-, PO_4^-, SO_4^-), and the oxidized and reduced forms of nitrogen (NO_3^- and NH_4^+, respectively). The two elements that have received the most attention as water pollutants are nitrogen and phosporus.

Nitrogen is water soluble in both the reduced and oxidized forms, and therefore, susceptible to transport in either the surface or subsurface flow. Both ammonia (NH_4^+) and nitrate (NO_3^-) exhibit toxic properties above certain concentrations (the former on fish and the latter on humans) (EPA 430/9-73-010, 1973).

Phosphate is the most common inorganic form of phosphorus. This compound binds itself to soil particles, and the typical means of its entry into surface waters is transport by eroded soil particles. Phosphorus is an important indicator of water quality because it is known to stimulate eutrophication (EPA, 430/9-73-014, 1973).

b. sediment:

Sediment is solid soil material, consisting of organic and/or inorganic components, that is light enough to be suspended in stream flow (Brown, 1978). The source of this material may be outside the stream channel, in which case the processes of upland erosion and mass wasting account for delivery to receiving waters. The material may also originate from within the channel itself, in which case the amount generated may increase with the rate of discharge (Linsley, 1975).

Suspended sediment concentration is usually expressed in mg/L, and when combined with discharge data over a given time period, sediment yields in weight per unit of drainage area (kg/ha/yr) can be computed (EPA, 600/3-77-036, 1977).

Soil sediment is the most significant pollutant generated from forest management activities (EPA, 600/3-77-036, 1977). In general, sediment is the most widespread type of pollutant, and its effects on water quality are known to result in both physical and chemical degradation. In addition, sediment acts as a carrier of pesticide residues and nutrients.

c. <u>pesticides</u>:

Pesticides being used in silviculture include insecticides, fungicides, and herbicides. These chemicals can enter surface waters through a variety of processes. Direct deposition onto surface waters following aerial application is the most significant source for short term, high level contamination of streams (Brown, 1978.) The use of proper application procedures, however, precludes or significantly reduces direct deposition.

Pesticides may also enter the aquatic environment through transport in the surface runoff and leaching through the subsurface flow. In both cases, the pesticide residues may be either dissolved in solution or absorbed on suspended matter. The most favorable conditions for pesticide wash-off occur after the first storms that take place following pesticide applications. Leaching of pesticides is a slow process and only accounts for small inputs to receiving water bodies (Brown, 1978). In general, however, these processes only account for very small loadings to surface waters. Overland flow seldom occurs in forest environments, and pesticide leaching is a very slow process (Norris, 1968).

Pesticides are manmade chemicals with no naturally occurring counterparts. These substances are toxic by design, and their presence in aquatic ecosystems can significantly degrade the environment. The evaluation of water pollution from pesticide contamination is quite complex since many factors affect overall hazard. Analysis of potential impact on aquatic ecosystems must include consideration of the following factors: 1) persistence or rate of degradation of the pesticide, 2) mechanisms of transport through the environment to nontarget areas, and 3) knowledge of toxicity to nontarget species (EPA, 430/9-73-010).

d. organic matter:

Organic matter of vegetative and animal origin is delivered to surface water primarily through transport in runoff. The material may range from freshly fallen leaves to well-decomposed humus. Direct deposition of plant materials by man sometimes occurs where management activities take place (e.g. slash disposal into streams, constructions of stream crossings with felled timber, etc.).

This type of pollutant can potentially affect aquatic ecosystems in a variety of ways - such as creation of nuisances from floating debris, interference with the natural aquatic ecology, and disturbance of the oxygen balance as a result of increased organic matter decomposition (EPA 430/9-73-010, 1973). In some cases, the depletion of oxygen caused by the increased entry of organic matter into lakes can kill fish (Brown, 1978).

e. thermal pollution:

Thermal pollution is normally thought of as an increase in stream water temperature that results from increased exposure to solar radiation (Brown, 1978). This is caused by removal of protective shoreline vegetation. Water temperature is important to the aquatic ecology of a stream for several reasons. The potential availability of oxygen for fish decreases as the water temperature increases because the amount of gas a liquid can hold is inversely proportional to temperature. Warm water is conducive to the growth of many kinds of micoorganisms, some of which are pathogenic to fish (Brown, 1978).

f. pathogenic organisms:

Pathogenic organisms represent a type of water pollutant generated from forest lands, but the magnitude of the associated water quality problems is generally quite low (EPA 600/3-77-036, 1977). Waste disposal is the most significant cause of pathogen loading from forest lands.

Most types of disposal (eg. sanitary land fills, application of municipal treated waste water, eg.) are not associated with forest management. However, on-site sanitary facilities for recreationists are exceptions. Grazing, recreation, and lowhead impoundments can potentially lead to increased loading but their significance as causes of nonpoint pathogen pollution is less than that of waste disposal.

C. PROCESSES THAT DELIVER POLLUTANTS TO THE AQUATIC ECOSYSTEM IN RESPONSE TO FOREST ECOSYSTEM DISTURBANCES

1. Overland Flow:

The surface runoff comprises the water that travels over the land surface as sheet or channel flow to main courses. (Harrold, Schwab, and Bondurant, 1974). Generally, in undisturbed forest environments the infiltration rates of the soils are very high. Consequently, most of the water added to the soil surface as precipitation, snowmelt, or lateral flow enters into the soil rather than becoming surface runoff. (Anderson, Hoover, and Reinhart, 1976).

In a study conducted in a small watershed in northern Minnesota, the water loss due to the surface runoff component was significant (Timmons, Verry, Burwell and Holt, 1977). Annual surface runoff over a three year period ranged from 5.10 to 12.52 cm., and interflow losses (see glossary) ranged from 5.66 to 5.82 cm. The reason for these findings is related to the hydrological characteristics of the area. Practically all the surface runoff comes from snowmelt during the spring thaw. The annual amount of water in the snow accumulation prior to spring melting ranged 9.52 cm. to 20.90 cm. (approximately 12 to 25% of the annual total precipitation) during the three year study period. Spring snowmelt, therefore, represents the addition of up to one fourth of the annual precipitation in liquid form to the soil surface within a short time span.

Overland flow is related to nonpoint pollution of surface waters because it directly affects the transport of several important pollutants to aquatic ecosystems. Surface erosion is directly influenced by overland flow, and it accounts for the movement of soil particles as well as adsorbed nutrients and pesticide materials into receiving waters. Transport of dissolved nutrients and pesticides also depends on overland flow. Each of these delivery mechanisms are discussed in terms of their relationship to overland flow in this subsection.

a. surface erosion:

Surface erosion is the movement of a fairly uniform layer of soil from the land surface by some agent, such as water, wind, or ice. Detachment and transport of soil particles are the component processes of surface erosion. In humid and temperate regions, surface water flow is the primary agent of detachment and transport (USFSHB 2509.15, 1961).

The amount of energy required for detachment is generally greater than for transport. Both the impact of raindrop splash and the movement of water over the soil surface provide this energy. Transport of eroded material by moving water only occurs when the force of the flow exceeds the resistance of the material on the land surface to be moved. Based on theoretical relationships between suspended particle weight and flow rate, a doubling of flow velocity increases the weight of particles that can be carried by a factor of 64. A linear increase in flow velocity of moving water, therefore, results in an exponential increase in the capacity for transport (USFSHB 2509.15, 1961).

b. nutrient transport:

Nutrients transported by overland flow are either dissolved or adsorbed onto eroded soil particles. Generalizations about the proportion of nutrients in each form cannot be made, although some specific information has been reported in certain studies. The relative importance of nutrient transport through subsurface flow is also poorly understood. Research conducted at the North Central Experiment Station, however, does provide some information for these relationships.

Nutrient losses from an aspen-birch forested watershed have been studied in northern Minnesota (Timmons, Verry, Burwell and Holt, 1977). The extent of annual losses for each of the nutrients analyzed (N, P, K, Ca, Mg, Na) through the surface runoff ranged from 54 to 92% of the total loss from the watershed, except for sodium, which was only 29%. Interflow accounted for the remainder of the losses.

The distribution of nutrient transport within the overland flow phases has been investigated under undisturbed conditions in the Coweeta watershed in North Carolina (Johnson and Swank, 1973). The export of cations was measured in the discharge at the outlet of the watershed, and the fraction transported via sediments only comprised 1% of the total annual loss. (The total loss was considered to be the dissolved nutrients plus those adsorbed onto sediment particles less than 2 mm. in diameter).

Plant nutrient losses from forested lands in two separate study areas have been investigated on both treated and untreated sites in western Montana (DeByle and Packer, 1972). The treated sites were clearcut and broadcast burned one year after harvesting. Collector troughs set flush with the ground surface were installed on hillsides in the study areas. Runoff and eroded soil particles drained into them followed by conveyance to holding tanks, where samples were collected. Average loss rates (expressed on a per acres basis) of the nutrients analyzed (P, K, Ca, Mg, Na) were measured in both the dissolved fraction and the sediments.

In the untreated control areas, nutrient losses in the solid phase were nonexistent because erosion was negligible. This finding is quite similar to the results reported for the Coweeta watershed study. In the treated areas, however, nutrient losses in the sediment fraction over a four year period following the burning were 58 and 80% of the total losses, respectively, for the two study areas. Total nutrient losses from the treated areas were only increased slightly above the control levels during the denuded period. However, revegetation returned the rates to approximately the control values within five years. Increased runoff and erosion caused by the harvesting and burning account for the elevated nutrient loss rates as well as the higher contribution of sediment losses.

c. pesticide transport:

Pesticides can be transported to receiving waters through surface runoff. According to most studies on pesticide movement in forest environments, surface runoff events associated with severe rainstorms can be an important cause of pesticide entry into aquatic environments. However, direct deposition is the single most important source (Brown, 1978). As stated previously, observance of proper precautions precludes direct deposition from occurring.

2. Subsurface Flow:

Subsurface flow represents the portion of precipitation that infiltrates into the soil and moves to stream courses as either interflow or ground water runoff. Interflow is the component that infiltrates to a relatively shallow depth in the soil and after reaching an impermeable layer, begins to move in a lateral plane (Harrold, Schwab, and Bondurant, 1974). Eventually, this water either returns to the ground surface on a hillside and runs to a stream course or else flows directly into a stream.

Groundwater flow is the water that percolates through the soil and reaches the groundwater reservoir, eventually reaching stream channels as base flow. The outflow of groundwater into streams is uniform in rate, responding to precipitation events in only a very indirect fashion. The changes in groundwater runoff caused by precipitation events exhibit lag times of weeks or even months. This component is the long term source of stream flow that supplies runoff during periods of drought. In general, the transport of nutrients and pesticides into receiving waters through subsurface flow is not significant (Brown, 1978).

Nitrate nitrogen (NO_3) is the most notable inorganic anion that can be delivered to receiving waters through the subsurface flow. In a study conducted by Verry et. al., nutrient losses through interflow were less than those in the surface runoff except for sodium (Timmons, Verry, Burwell and Holt, 1977). According to an EPA literature review on nonpoint pollution, leachng or subsurface flow of pesticides is a slow process, only capable of moving small amounts of these materials short distances, and therefore, not considered to be significant (EPA 430/9-73-010, 1973).

3. Mass Soil Movement:

Mass soil movement is a general term that refers to the instantaneous downslope movement of large volumes of soil and rock material. The two primary forms are 1) deep, rotational types of soil movement, such as slumps and earthflows, and 2) shallow debris movements, including landslides and avalanches (EPA 910/0-75-007, 1975). Slumps and earth flows are the most common forms of mass movements associated with forest management activities. The effects of logging road construction on soil stability appear to be the principle cause of mass soil movements in managed forest environments. This type of erosion may predominate in areas with steep slopes, high rainfall rates, and soils of low strength or stability.

4. Channel Erosion:

The bank and bed of a stream may be important sources of sediment depending on their stability and resistance to scour during periods of high flow (Brown, 1978). The importance of channel erosion to the total sediment yields of watersheds is highly variable since many different factors exert an influence.

5. Wind Movement:

Wind is an agent that can blow aerially applied pesticides from the point of application to nontarget areas over surface waters. This process is commonly called drift, and is generally considered the most significant cause of pesticide nonpoint pollution (EPA 430/9-73-010, 1973).

6. Solar Radiation:

The exposure of streams to solar radiation brought about by harvesting of shade cover vegetation along the banks is considered to be thermal pollution if stream water temperatures rise above normal levels, causing significant changes in the aquatic ecosystem. Temperature effects can be particularly damaging in small streams during low flow periods (EPA 430/9-73-010, 1973).

D. FACTORS THAT REGULATE THE DELIVERY OF POLLUTANTS FROM THE FOREST ECOSYSTEM TO THE AQUATIC ECOSYSTEM

"The surface of upland forests where minimal soil is fully protected by a cover of litter and humus, contributes little or no sediment to the streams. In these forests, erosion occurs almost entirely within the major and minor stream channels.

"Where areas of the forest floor have been disturbed by logging, grazing, or burning, infiltration is reduced by the compactive effect of moving equipment, trampling animals or beating raindrops and overland flow; soil erosion can result. Loss of soil then becomes a function of soil erodibility, length and steepness of slope, and the intensity of storm rainfall" (Anderson, Hoover, Reinhart, 1976).

When the forest ecosystem is disturbed by forest management practices, pollutants may be generated and delivered to the aquatic ecosystem by several processes. Overland flow and surface erosion are two of the key processes, and mass wasting is another in certain regions.

Many factors affect these processes, and the following sections summarize the relationships of these factors to the poocesses.

1. <u>Overland Flow or Surface Runoff</u>:

Water moving over the soil surface has the ability to pick up and carry pollutants to the aquatic ecosystem. The energy required to carry the pollutants increases with the amount and speed of the moving water. Factors which affect the amount and rate of runoff and the amount and type of materials to be carried by runoff are explained below.

a. <u>climatic factors</u>:

In order for surface runoff to occur, precipitation must exceed the infiltration rate of the soil. This may happen when rainfall occurs under the following conditions:

i. the soil is saturated;

ii. the intensity of rainfall is higher than the infiltration rate;

iii. the soil surface becomes sealed by raindrop impact; or

iv. the soil surface is frozen (early spring).

Precipitation in the form of rain has the most immediate impact on infiltration rates. Short, heavy rainfalls often exceed infiltration rates, even when the soil is not previously saturated. Most of the precipitation occurring during these intense storms is lost to surface runoff (i.e. except where the ground is flat, in which case pooling may occur and water is then slowly infiltrated or evaporated).

Heavy rainfall on bare soil may seal the soil surface, blocking entry of precipitation into soil pores. Little or no infiltration can occur, resulting in either surface runoff or pooling. For this reason, areas receiving low annual amounts of rainfall in high intensity storms can still have runoff problems.

Long rainfalls of light intensity, for a given soil type and soil moisture content, will generate less surface runoff or pooling effects, than short, high intensity storms delivering the same amount of precipitation. If the duration of a rain storm is long, infiltration may cease as the soil becomes saturated, favoring surface runoff or pooling. Previous soil moisture content and soil storage capacity are important factors in this case.

Precipitation which falls as snow generally has no immediate impact on surface runoff. All effects occur when the snow melts. If the snow melts at a slow rate, allowing the melt water to be infiltrated into the ground, little or no runoff occurs. However, if the snow melt occurs when the ground is still frozen, or when the soil is saturated from fall rains, surface runoff or pooling does occur.

Given a set of climatic conditions, the inherent susceptibility of surface soil to erode (inherent erosion hazard) is dependent upon a variety of physiographic and soil development factors.

b. <u>physiographic factors</u>:

Physiographic features such as slope gradient, slope length, slope dissection and slope shape affect the amount and rate of runoff. The steeper the slope, the more rapidly the water will run off. The quantity of soil detached and moved by rapidly flowing water, is greater than that moved by slowly flowing water. Long slopes expose more surface area to the erosive force of rapidly flowing water than short slopes. Consequently, more soil can be displaced.

Slopes which are highly dissected can retard the flow of water by catching it in depressions. Flat areas, (swamps, marshes, bogs, etc.) exhibit little runoff. Most water movement in this area is through groundwater seepage. When considering surface runoff, exposure of mineral soil is less critical in these flat areas.

c. <u>soil development factors</u>:

Factors which influence soil development, in turn, determine the stability of the surface aggregates and how well they resist detachment by rain and surface runoff. As soil development proceeds, a larger portion of surface soil particles are combined into water-stable aggregates. Therefore, those factors which influence soil development also influence inherent soil erodibility. Factors which influence soil development are parent material, climate, vegetation, biologic activity, time and topography.

i. parent material:

The end product of the chemical and physical weathering of parent material is soil. Soil characteristics affected by variations in parent material are texture of surface soil, inherent structure and consistency, depth of soil (especially to restrictive layers), porosity and the percolation rate of subsurface horizons (Youngberg, 1963). Collectively these factors determine the receptiveness of the soil surface to water and the capacity of the soil to infiltrate and store precipitation.

Bulk density and fertility of the soil are also a function of parent material. As bulk density increases, there is a corresponding decrease in porosity. This causes a reduction in rate of infiltration and an increase in overland flow. Certain parent materials weather to form soils low in fertility. If the soil is infertile, the regrowth of vegetation to a disturbed area will be slow, thereby leaving exposed mineral soil with no roots to bind the soil particles together.

Willen (1965), Wallus and Willen (1963), and Andre and Anderson (1961), demonstrated that soils derived from acid igneous rocks tend to be considerably more erodible than soils derived from other parent materials. As a result of a study of soils at 258 locations, Wallis and Willen ranked parent materials in the following manner.

Erodible parent materials - granite, quartz, diorite, granodiorite, Cenozoic nonmarine sediments, schist.

Intermediate - diorite, a variety of metamorphic rocks.

Nonerodible - Cenozoic marine, basalt and gabbro, pre-Cenozoic marine sediments, peridotite and serpentinite and andesite.

ii. climate:

The role of climate in soil development and inherent erosion hazard is extremely variable and important. Climate determines to a large extent the type of vegetation in a given area.

This, in turn, determines the quality, quantity and distribution of organic matter. Organic matter releases nutrients to the soil, has a high water-holding capacity and reduces the kinetic energy of raindrop impact.

Climate, particularly moisture and temperature, strongly influence the rate and extent of soil development. Temperate, moist sites favor rapid breakdown of parent materials and consequent soil development. Wetting and drying cycles, as well as freezing and thawing, influence aggregate development by accentuating lines of shear within the soil and by mixing soil particles (Brown, 1978).

iii. biologic activity:

Biologic activity favors soil development and resistance to erosion. Earthworms and plant roots increase porosity and promote infiltration with their mixing actions. Acidic by-products of microbial decomposition and leachate from plant litter help decompose plant materials. (Brown 1978).

iv. vegetation:

Vegetation, which is a function of soil fertility and climate, aids in soil development. It binds the soil, promotes infiltration, dissipates raindrop energy, and develops greater porosity through root development and enriches the surface soil (Copeland, 1963). Without the stability afforded by vegetation, most soils could not have developed. They would have been displaced by gravity or would have been blown or washed away.

The nature of the vegetation also strongly affects the quantity of organic matter present in the soil. Vegetation also serves as an obstruction to downward flow of water, and will slow or stop the loss of soil by erosive water forces. Rapid revegetation of exposed mineral soil is desirable since soil loss to the aquatic ecosystem becomes less likely.

v. <u>topography</u>:

Elevation and slope aspect are physiographic factors which affect soil erodibility through their influence on soil development. Soils at high elevations develop at a slower rate than soils at lower elevations, (Willen, 1965).

The elevation or position of a site on the landscape also determines the amount of water available for soil development and/or surface runoff. Further down the slope, more water is available which has collected from runoff from at higher elevations. Deters (1940) found that site index, density and species were strongly influenced by physiographic location (elevation and aspect) in southeastern Minnesota.

Soils on aspects with a southerly or western exposure are generally drier. Dry soils produce less vegetation and less organic matter. Consequently, soil development proceeds slowly, resulting in a reduction in site index.

vi. time:

Time is required for soils to develop from parent materials. The rate of development is a function of all the above factors, parent material, climate, vegetation, living organisms and topography. For a given set of factors, however, the degree of development is a function of length of time over which the soil forming process has occurred (i.e. soils forming on newly deposited pumice or lava would probably be less well developed than soils developing on ancient lava flows).

d. management factors:

The factors which characterize a forest ecosystem: (climate, vegetation, topography, biologic activity, and soil movement), also describe the stability of that ecosystem to natural or man-induced disturbance (i.e. inherent erosion hazard). Forest management activities which change the structure of the ecosystem, may also change the stability of the system. In some cases where natural factors have weakened the stability of the system, man may act as a stabilizing force.

Conversely, some forest management activities may weaken the system's ability to withstand the potentially destructive forces of nature (sun, wind and water). In these cases a disturbed forest ecosystem, depending on its inherent stability factor, has the potential to disturb the aquatic ecosystem by generating the pollutants discussed earlier (sediment, nutrients, chemicals, organic matter and heat). Not all forest management activities create disturbances which significantly alter a forest ecosystem to a polluting condition. Types of forest management disturbances which contribute to the instability of a forest ecosystem are listed below:

a. exposure of mineral soil;

b. compaction of mineral soil;

c. reduction in productivity; and

d. reduction of growing material;

These disturbances were described in an earlier section. The effects that these management disturbances have on the aquatic ecosystem are regulated by management factors, as well as inherent stability factors. The management factors which regulate the effects on the aquatic ecosystem are:

i. proximity to water;

ii. location of slash & waste disposal;

iii. time of year of activity;

iv. purpose of activity;

v. extent of activity; and

vi. frequency of activity.

i. proximity to water:

Forest management operations which occur directly adjacent to the edge of a watercourse are more likely to generate pollutants to the watercourse than those activities located farther away. Soil particles and organic materials which must travel long distances to a watercourse are more likely to be caught behind surface obstructions or in surface depressions. Those materials generated close to watercourses have less distance to go and may have less chance of obstruction.

ii. location of slash & waste disposal:

Slash is defined as "the residue left on the ground after timber cutting and/or accumulating there as a result of storm, fire or other damage." It includes unutilized logs, uprooted stumps, broken or uprooted stems, branches, twigs, leaves, bark and chips (Ford-Robertson, 1971). Heavy logging slash which is well distributed will retard the flow of surface runoff. When the velocity of runoff is slowed, less soil particles and organic matter can be picked up and carried. This results in higher quality runoff. Timber cutting activities which utilize most of the tree generate little slash, except for twigs, leaves, bark and chips. If there is a rapid flow of surface runoff, these light materials may be picked up and carried to the aquatic ecosystem.

Waste is any material which has been discarded by man in the forest ecosystem. All forest management activities have the potential to contribute a wide range of waste materials to the system. All forest visitors may contribute ashes, food remains and food packaging. Oil, grease, and/or gas may be left or spilled on the ground during harvest or road-building operations. Slash and waste materials may enter the aquatic ecosystem in several ways:

1. direct deposition;
2. accidental deposition; and
3. transport through surface runoff.

iii. purpose of activity:

Management practices vary widely in purpose. As purposes vary, so do the resulting disturbances to the forest and aquatic ecosystems. Some practices (i.e. road-building operations and site preparation for seedbeds) necessitate exposure of mineral soil. Other activities such as pruning and tree-felling, rarely involve exposure of mineral soil. Management activities involving high intensity visitor use or requiring use of heavy machines may cause soil compaction. Compacted soil is undesirable when regenerating new stands since compacted soil inhibits root growth and slow regeneration.

The amount of mineral soil exposed, the type of slash and waste material generated and the degree of compaction of the soil are all affected by the purpose of an activity.

iv. time of year of activity:

Forest management activities occur year-round. Potential disturbance to the forest ecosystem vary according to time-of-year of disturbance. Snow-covered frozen soil has more protection from activities which might otherwise expose mineral soil. Frozen soil is also somewhat less susceptible to compaction by heavy machinery (Mace, Williams, Tappeiner, 1971). Therefore, activities which occur in the winter months may cause less disturbance to the ecosystem. Soils with high moisture contents tend to lose their cohesiveness and are easily disturbed.

v. extent of activity:

As forest management activities impact larger acreages, the scale of the potential impacts on the aquatic ecosystem is increased as well.

vi. frequency of activity:

The more times an area is disturbed during a given period, the greater the potential for disturbance to the aquatic ecosystem. Some forest management activities, such as clearcutting, may occur only once every 30-100 years, allowing ample time for recovery. However, if forest management activities occur frequently in an area resulting in a constant state of disturbance, the degree of disruption to natural conditions may result in significant damage to the aquatic ecosystem.

2. Mass Soil Movements

Mass soil movement occurs when the angle of repose or the shear strength of a mass of soil is exceeded by gravitation and other stresses. Mass soil movement is usually associated with the steep slopes in the western States.

A number of different factors are related to the occurrence of mass soil movements, including geologic substrate, soil type, aspect, elevation, and steepness of slope (Brown, 1978). The interaction of several of these factors often leads to mass failures. Studies conducted on the H.J. Andrews Experimental Forest in Oregon have shown that 63.8

percent of all the mass movement events occurred on a substrate of greenish tuffs or breccias even though these materials underlie only 8 percent of the total area (Dryness, 1967). An additional 29.8 percent of events occurred on reddish tuffs and breccias which underlie 29.2 percent of the study area. Tuffs and breccias accounted for nearly 95 percent of all the mass movement events even though they underlie less than 40 percent of the watershed area.

Soil slip is a form of shallow soil movement. It occurs because of frictional failure along a surface essentially parallel to the topographic surface. The factors or conditions most favorable to this type of failure are cohesionless soils, intense rainfall, steep slopes and insufficient vegetative protection. Slope is the most important causative factor of soil slip, according to research carried out in the Sierra Mountains of Southern California (Rice, et. al, 1969). Rotational slumps and earthflows, on the other hand, are most often associated with deep, saturated, fine textured soils on moderate slopes (Burroughs, 1973).

In the case of mass soil movements along logging roads, the most important single influence is human activity. The specific factors include undercutting of unstable or marginally stable slopes, oversteepening of cut and fill slopes, sidecasting of excavated materials on steep slopes, improper enbankment construction, and drainage system failure (EPA, 1975).

III. METHODOLOGIES AND MODELS TO PREDICT THE ACTUAL AND POTENTIAL DELIVERY OF POLLUTANTS

Various approaches are possible in the prediction of pollutant loadings into receiving waters in both disturbed and undisturbed forest conditions. In any area where forest management occurs, the generation and delivery of a given type of pollutant to the aquatic ecosystem is dependent on the type of activity and site factors. This section describes the types of information that must be collected about forest management practices and resource features for purposes of pollution potential evaluation.

Forest resource managers and planners need to know the consequences of proposed management programs and plans. They may be faced with questions that involve the amount and type of pollutant loadings, and the duration and extent of these loading effects.

Forest lands can be evaluated in terms of their potential for generation and delivery of pollutants at various scales of intensity. Three levels of intensity provide the framework for organizing the discussion of the methodologies and models.

A broad scale approach implies evaluation of a large area, on the order of an entire state. The resource data is very general and the sources of it are usualy aids, such as maps, surveys, and aerial photographs. The objective of this type of analysis is typically descriptive of the study area on the basis of broad similarity in resource parameters. The objectives of a broad scale evaluation may also include assessment of the amount and extent of the forest management activities. This type of information was collected by a written survey in conjunction with random sampling of study sites in a project conducted by the state of Maine (more detailed disussion of this project follows).

Medium intensity analysis may involve an area of only several square miles, or a much larger area such as a region within a state. The level of detail in the resource data may be highly specific, depending on the source. The data may be collected from either field inventories or aids. A medium intensity evaluation can provide the capability for estimation of erosion or the erosion potential from a watershed among various land uses. Medium intensity analysis of an area or watershed is likely to be an appropriate approach for staff level specialists and planners.

Site specific evaluations normally depend on data collected on-site. Reliable estimates of erosion potential and accurate measurements of erosion are possible in this approach. Field level specialists (forest hydrologists) are most likely to be faced with assessment of the potential impacts resulting from management activities on a site specific basis. Methodologies designed for on-site evaluation of potential hazards that are simple and practical would be most useful to them.

A. BROAD SCALE APPROACHES

1. State-wide Assessment Of Forest Management Activities And Water Quality Impacts In The State Of Maine

The Land Use Regulation Commission in the State of Maine devised a methodology for assessment of the occurrence and extent of nonpoint pollution problems resulting from forest harvesting and logging operations. A forest practices survey was performed by field inspection of recently cut over sites.

Data was collected to determine the frequency of occurrence of water quality problems caused by forest management activities, and if possible, to identify patterns of association of site characteristics and operational practices to observed problems.

The data collected about operational practices included size of area cut over, volume of timber harvested, season of operation, skidding methods, type of disturbance area, and water management techniques. Site characteristics data pertained to topography, drainage conditions, soil depth, and type of surface water. The occurrence of any nonpoint pollution problems was also noted, and evaluations made of any observed erosion, sedimentation, or slash disposal into surface waters.

If a problem was detected, a control site was chosen and sampled. Control sites were selected on the basis of similarity to problem sites in terms of structures, site characteristics, and disturbances. The main advantage of this approach is the high cost. A team of trained personnel must make field visits to each sample site and collect an extensive amount of data. A considerable amount of time may be necessary to locate sample sites, since only recent-cutover areas above a minimum size are suitable for sampling.

2. <u>State-wide Assessment of Forest Management Activities and Water Quality Impacts in the State of Minnesota</u> (Summary of MDNR approach used in the "208" Project)

The state is described on the basis of resource variables associated most closely with the potential for surface erosion. Slope and soil erodibility provide the basis for the determination erosion hazard indicator classes throughout the forested land of the state. The resource data were manually entered into the computerized data banks maintained by the Minnesota Land Management Information System (MLMIS).

In conjunction with the resource analysis, data regarding forest management activities has been collected from a written survey sent to 1,500 private landowners and 200 different organizational units responsible for forest management operations (federal, state, county, and private industry). This data has been analyzed to determine the relative intensities of various types of practices, and also their potential to cause site disturbances. Since the survey did not represent a complete census, only estimates of the impact and extent of various practices are possible. A general picture is provided, however, of the locations where high site disturbance potential practices occur. A detailed discussion of this methodology will be presented in the analysis section of the report.

B. MEDIUM SCALE APPROACHES

1. Medium Intensity Analysis With Computer Mapping

The description of this approach is based on the modeling and mapping work performed in the DNR directed MINESITE project (MINESITE Data Manual, 1976). The purpose of this project is an evaluation of an area in Northeastern Minnesota covering approximately 560 square miles, for development of copper-nickel mining. The MINESITE study defines many of the natural resources features of the area in a descriptive and quantitive manner, providing a basis for land use planning and assessment of environmental resource values.

Twenty-four data variables associated with natural and cultural resources have been coded into a mapping grid system made up of cells approximately 2.5 acres in size. Data related to slope, cover type, soil associations, and other specialized variables, have been entered into a computer system and used to determine values of the variables in the Wischmeier soil loss equation. Estimates of soil loss have been computed for each grid cell, and the values grouped into range classes and displayed on maps through symbols and color tones.

The Universal Soil Loss Equation, originally intended for application only on agricultural lands, has recently been modified for use in forest environments as well (Proceedings "208" Symposium, 1977). The equation A=RKLSCP has been developed to measure soil loss. (A=average annual soil loss in tons per acre, R=rainfall index, K=soil erodibility, L=length of slope, S=steepness of slope, C=cover management factor which is assumed to 1.0 in forest environments).

The value of R can be obtained from maps prepared by the ARS and Weather Bureau stations. Several sources of information may be used to estimate K values.

Soil survey maps of some counties have been prepared by the SCS for most of the agricultural areas in the state. Areas not surveyed will eventually be mapped on soil atlases. These maps are being produced by the SCS in cooperation with the Soil Science Department of the University of Minnesota and the U. S. Department of Agriculture at a scale of 1:250,000.

The soils are delineated into soil landscape units with representative soil series named for most of these units. Estimates of K values can be assigned to soil landscape units on the basis of the representative soil series. Soil maps prepared by the U. S. Forest Service can also be used as a source to determine K values on national forest lands, and these values were used in the MINESITE model.

Slope grade and length can be determined from U.S.G.S. topographical maps. "Effective" slope length was estimated for use in the MINESITE project model on the basis of land form. Effective slope length is dependent on the amount and extent of topographical features, such as hummocks or depressions, that would trap or contain eroded material. The more of these features present, the more effective slope length is reduced. In the MINESITE project study, the effective slope length was 60 feet for each 100 feet of actual length. Following determination of values for grade and length (or effective length) of slope, a slope-length factor read from a graph can be used in the soil loss equation.

Criteria for estimation of cover factor values in forest environments have been formulated by the MINESITE project team. Vegetation type and density were the factors used as the basis for estimation. Another reference on forest cover factor estimation is a table prepared by the SCS in cooperation with the U.S.D.A. in Illinois. The following variables provide the criteria for estimation: 1) stand condition, 2) percent canopy cover, 3) percent litter cover, 4) type of understory management (amount of control on grazing and fires).

The computer modeling techniques developed by the MINESITE project team have been used to display quantitative estimates of erosion potential for individual cells 2.5 acres in size throughout the study area. Maps produced by a computerized printer show erosion potential values for each cell with different color tones and symbols.

The advantage of this approach is that assessments can be made of potential erosion for broad areas at a medium scale of intensity. Forest management planning on a region wide basis is enhanced because the areas with the highest erosion rates can be identified with greater reliability. The erosion potential maps do not, however, eliminate the need for on-site evaluations involving decisions about the use of specific management practices.

The disadvantages of this approach are the relatively large requirements of money and time. The data needed for application of the Wischmeier model are very detailed, requiring intensive sampling and analysis of an area. The data must also be coded and entered into a computer system. This involves labor costs as well as expenditures for computer time. This approach does not assess sediment loading potential, but the information generated from it could be used for this purpose if sediment delivery ratios could be determined.

2. <u>Evaluation of the Impact of Individual Forest Management Practices on Suspended Sediment Yield</u>

This approach determines the contributions of individual forest management activities to the total sediment load within the upland watershed area above the point of sediment yield measurement (see appendix). The data required for this method is extensive, requiring stratification of the study area on the basis of resource features and land use, followed by field sampling. The following steps must be taken:

1. The study area is stratified on the basis of soil types, slope ranges, land uses, vegetation, and disturbances. One stratified map is produced, and the area of each stratum is determined.
2. The various strata are sampled using fixed area plots located on a transect. Erosion and sedimentation are computed for each type of land use or disturbance within each stratum. Erosion is computed using the Universal Soil Loss Equation. Sediment yield is estimated by tracing the movement of eroded material on slopes leading to water bodies.

3. Gross erosion and sedimentation are computed for the watershed, and the percentage distribution of erosion and sedimentation contributed from each type of land use and disturbance is then used as a basis to compute the percentage distribution of the measured sediment yield.

The advantages of this approach are that individual management activities within a watershed can be evaluated in terms of their projected sediment load generation. In addition, benefits of sediment control programs can be established by using data from well managed areas. The relative impacts of different management alternatives can be assessed in terms of their sediment loading potential, providing a meaningful basis for land managers to make decisions.

The disadvantages are that large amounts of time and manpower are necessary to collect the data for the watershed analysis. Annual sediment yields must be known for the watershed under study, or the procedure cannot be applied. In many watersheds, estimates or measurements of the annual sediment yield are not available.

3. Compartment Examination Process in the Chippewa National Forest

The management of the Chippewa National Forest incorporates a compartment examination program that provides basic resource information (timber stand characteristics, soils, water, wildlife, etc.) to staff level specialists for assessment of potential impacts resulting from proposed management activities. Compartments about 1500 acres in size, are assigned to a particular watershed. Each compartment is normally inventoried every ten years assuming adequate manpower is available. The inventory involves plot sampling within each stand to measure timber stand volume, species composition, density, etc. Special environmental considerations may also be made if a specific type of problem is anticipated.

At the time of the inventory an environmental document is prepared (Environmental Assessment Report), and the potential impacts of any proposed management operations on the forest resources are addressed. This document is completed by district level foresters, and then submitted to the forest headquarters for staff review.

Any potential water quality problems identified by the field personnel are reviewed by the forest hydrologist. If an impact of some kind is expected for a specific body of water or stream, the hydrologist may make some recommendations about the proposed activity on the basis of the sensitivity or trophic level of the water.

A management program of this type guarantees that each land unit within the jurisdiction of a management organization will be evaluated periodically in terms of potential impacts likely to result from proposed activities. It assures that on-site inspections will be made that utilize the experience and judgement of professionally trained personnel, plus review of any special problems by a team of resource specialists.

C. SITE SPECIFIC APPROACHES

1. Surface erosion

A methodology by the USFS for on-site evaluation of soil erodibility is described in the Forest Service Handbook 55.25 (See appendix). The handbook states that total erosion hazard is a function of the following variables - precipitation, topography, effectiveness of erosion retardants (such as vegetation, litter mulches, etc.), and the inherent soil erodibility. This procedure only accounts for physical soil properties in the evaluation; the effects of other variables, such as precipitation and topography, are excluded from consideration. Instructions for application are given in the appendix.

The cost of this methodology is negligible and the amount of time necessary for its application is very small. Elaborate testing of soil samples and expensive equipment are not required. Adequately trained personnel are necessary for performance of soil testing and interpretation of results.

2. Mass soil movement

The probability for the occurrence of mass soil movements is difficult to predict with a high level of confidence. Understanding of soil mechanics as it relates to mass failures is poorly developed (Brown, 1978). Some conceptual models have been developed to described these processes, but none of them accurately and reliably predicts when a particular slope will undergo some type of failure (EPA-600/377-036, 1977). Precise and universal rules that relate the main causative factors of mass movements, such as slope steepness, soil strength, etc., to the probability of occurrence are unavailable. Predictive methodologies have been developed for local use, but they are based on empirical or semiempirical factors that require modifications for application elsewhere (EPA-910/9-75-007).

Certain measures can and should be taken in the planning and placement of forest roads to avoid the occurrence of mass failures despite the absence of predictive methodologies. One step is to determine if failures have previously occurred along a proposed route. Indicators of mass wasting include downslope and U-shaped depressions, streambank overhang, tension cracks in the ground surface, and curved trees.

Other considerations that may be helpful in the assessment of soil stability are inherent soil strength, amount of overburden to bedrock, and natural bedding planes within bedrock (EPA 910-9-75-007). The depth to the water table along the alignment should also be investigated since soil moisture is an important factor. Consideration of all these factors provides a basis for assessment of the potential for mass wasting.

3. <u>Channel erosion</u>

The processes of gully and channel erosion have not received as much research as surface erosion. Methodologies have not been developed which predict the magnitude of channel erosion or the effects associated with forest management activities. In a nationwide study of water quality models developed for application in wildland environments, none were reviewed that estimated the contribution of eroded channel material to total sediment yield (EPA-600/3-77-036, 1977).

4. <u>Nutrient loading</u>

Most models that attempt to predict or estimate loadings and concentrations of chemicals such as nutrients are not capable of quantifying the effects of specific management activities (EPA-600/3-77-036, 1977). Regression models have been developed for specific areas that relate nutrient concentrations to flow volumes, but none of them appear to be broadly applicable outside of their regions of development.

5. <u>Pesticide loading</u>

The same conclusions drawn about predictive modeling of nutrients applies to pesticides.

6. <u>Thermal effects</u>

Several models have been developed that predict temperatures changes of stream water as a result of increased exposure to direct solar radiation following removal of shoreline vegetation. Most of these models are based on relationships of energy balance components, water properties, flow rates, depth, and area of water exposed.

A model developed by Brown uses energy budget analysis to predict water temperature changes following manipulations of streamside vegetation (Brown, 1970). Brown's model was developed in the Pacific Northwest, but when this model was tested in the Southern Appalachians, the results revealed that temperatures were significantly overestimated (EPA-600/3-77-036, 1977). The validity of a temperture model cannot be assumed to extend to areas outside of where it was developed. Existing models developed for specific areas, therefore, need to be tested in a variety of wildland situations to determine their potential for general application.

7. Pathogen transport

Presently very little information is known about the relationship between forest management activities and pathogen loading on surface waters (EPA-600/3-77-036, 1977). Models that predict the movement of pathogens in a wildland environment have not demonstrated the capability to predict the effects of forest management activities. Until further testing and evaluation is carried out on these models, conclusions cannot be made about their potential utility for such purposes.

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IV. FOREST MANAGEMENT ACTIVITIES IN MINNESOTA

Two separate surveys designed to elicit information about ongoing and projected forest management activities provide the data base for analysis of activities and practices. One survey was distributed to public agencies, units of government, and private industries, which have some role or responsibilities in forest management. The second survey was sent to individual woodlot owners believed to be actively involved in forest management of their lands (names and addresses of these landowners were obtained from Department of Natural Resources files of cutting reports and management plans). The first survey hereafter will be referred to as the "public landowner's survey" (despite the fact large private companies are included as respondents), and the second as the "private landowner's survey". The raw data collected from the surveys were manually entered into data banks within the computer system of the Minnesota Land Management Information System (MLMIS). Computer analysis has been used for display and presentation of the data in both tabular and map form.

The nature of some of the questions in the surveys required respondents to estimate information rather than measure or determine it in some precise manner. Interpretation and analyses of the survey data is limited, therefore, by the following factors: 1) personal bias of the respondent toward the significance and meaning of certain questions, 2) interpretation and understanding of certain questions by respondents, and 3) knowledge of the respondent about the information requested. Another limitation is that the surveys fail to provide actual totals of data for any type of activity (in terms of acreages, numbers of operations, etc.) because they only represent a sample, and not a census of the total population of operations. The information developed from the surveys, therefore, is inferential in nature, showing trends related to the major types of activities, the extent of their occurrence, and a comparative picture of regional differences in terms of type and extent of management activities.

A. RESULTS OF "THE PUBLIC LANDOWNER'S SURVEY"

Approximately 200 surveys were sent out for distribution. Of these, 168 completed surveys were received, representing a return rate of 84%. Data were requested for up to 30 forest management operations per survey, and information pertaining to forty variables was requested for each operation. Summary data for certain types of activities were also requested (total acres harvested, prescribed burned, site prepared, etc.). All the information (except for the questions regarding projected activities) pertaining to operations is for the fiscal year 1977. The following table lists the agencies and organizations that completed and returned surveys, and the number of surveys returned.

The agencies and organizations represented in the list account for approximately 55% of the total forest land ownership in the state. Data were received for 2,201 individual operations. Approximately 575 of these were missing responses to the line entry questions, leaving about 1,625 operations with valid data. The data analysis is based on the information provided for these operations. (Not all questions were answered for every line entry item associated with an operation, causing the number of valid operations to fluctuate.) The following subjects are discussed in this section: 1) site characteristics, 2) timber harvesting, 3) regeneration, 6) timber stand improvement, 7) thinning, 8) firebreaks, and 9) rights-of-way.

	ORGANIZATION	NUMBER OF SURVEYS RETURNED PER ORGANIZATION
1.	Department of Natural Resources - Forestry Division	22
2.	Department of Natural Resources - Parks and Recreation	38
3.	Department of Natural Resources - Fish & Wildlife	22
4.	United States Forest Service	2
5.	Bureau of Indian Affairs	2
6.	United States Corps of Engineers	1
7.	Bureau of Land Management	1
8.	United States Fish & Wildlife Service	5
9.	Voyageurs National Park	1
10.	County Land Commissioners	8
11.	Private Forest Industry	3
12.	Northern States Power	1
13.	Burlington Northern	1
14.	Mining Companies	10
	Total	168

1. SITE CHARACTERISTICS

A slope percentage of 4% was reported for approximately 70% of the total sites described in our survey. Sand and peat were the soil material descriptions given most often for these sites. The number of operations associated with a given slope range decreased markedly as the slope range values increased. Approximately 92% of the total reported operations occurred on slopes estimated to be less than 12%. The most common soil type descriptions were loam and sand on sites with slopes greater than 12%. On extreme sites with mineral soil exposure in the 61-100% range, the soils were reported to be predominantly sand, clay and rock and gravel (see Fig. A & B).

2. TIMBER HARVESTING

Timber harvesting was listed most often as the main purpose of an operation. Timber harvesting includes harvests made for mature timber, disease control, insect control, salvage purposes, and for conversion to another species.

According to the summary data 5774 timber harvest operations occurred during a 12 month period in fiscal year 1977 (Table 1). These operations covered 62,238 acres, or .3% of the commercial forest land in Minnesota. This is an average of approximately 11 acres per operation. We received data for 1067 timber harvest operations, or 18.4% of the total as reported in our summary data.

Methods of cutting trees were grouped into clearcut, shelterwood, selective and commercial thinning. Clearcutting is the most often used method. This type of harvest can be done in the following ways: clearcut in patches, clearcut in alternate strips, clearcut in progressive strips, seed tree cut, and conversion to another species. Clearcutting occurred on 85.3% of the timber harvest operations. Many species and combinations of species were cut on these operations. These species were grouped into major forest cover types. A listing of these species groups and the number of harvest operations for each is given in the following table.

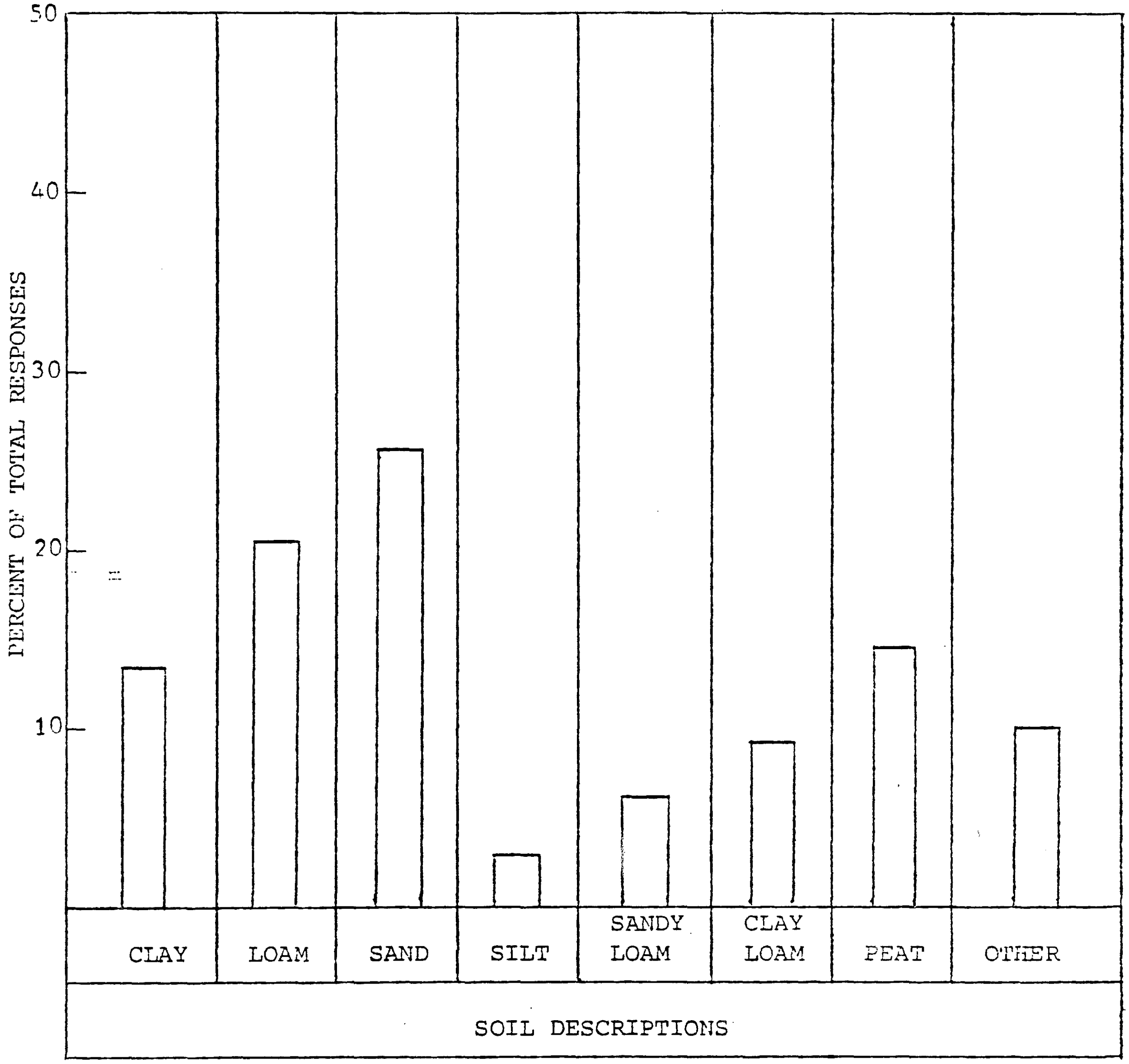


Fig.A . Frequency distribution of soil type responses given for site locations of operations reported in the public landowner's survey. (Based on a total of 1612 responses.)

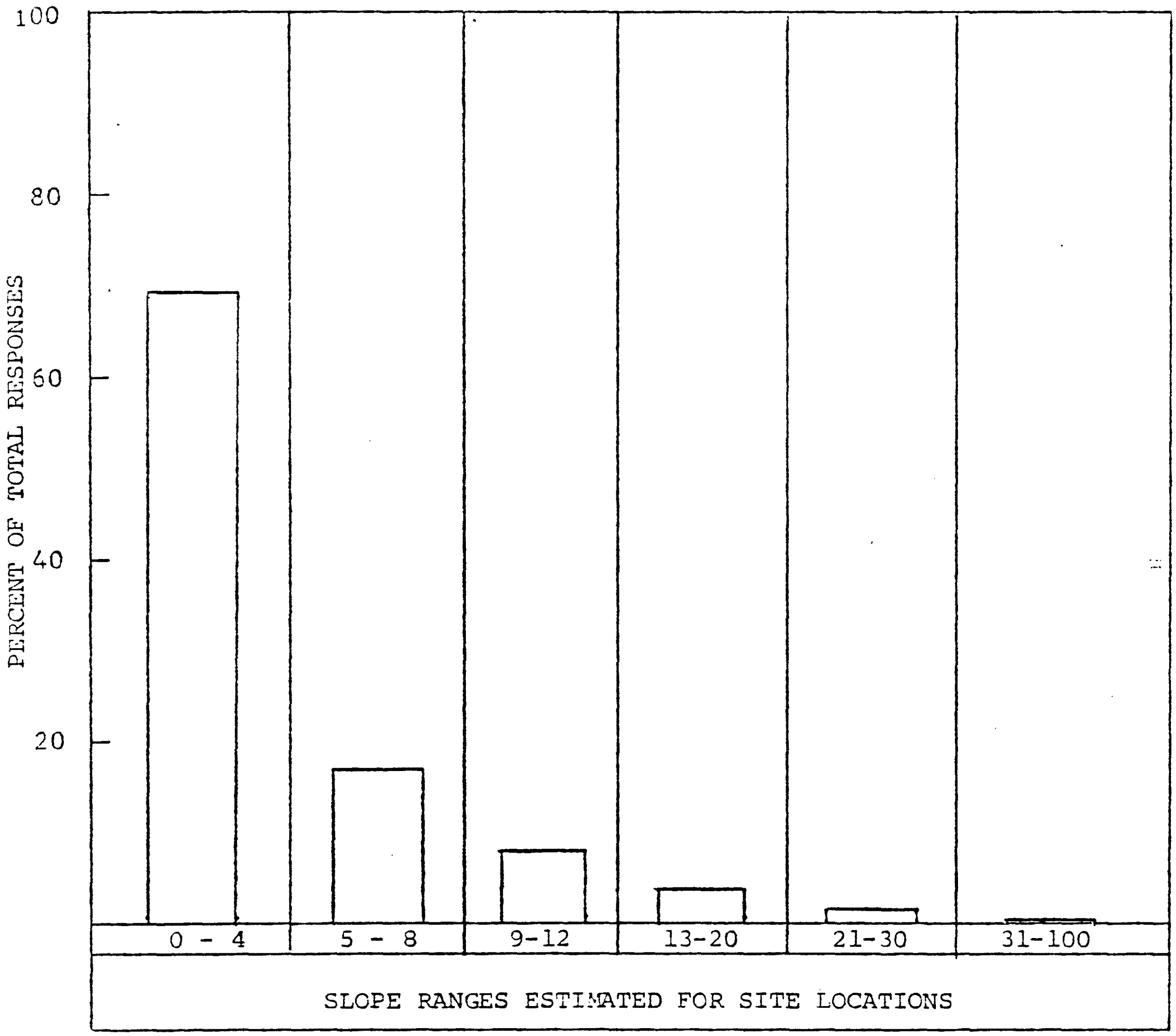


Fig. 8. Frequency distribution of slope range responses given for site locations of operations reported in the public landowner's survey. (Based on a total of 1601 responses.)

	NUMBER OF OPERATIONS
Pine Mixtures	115
Pine and Spruce Fir Mixtures	54
Lowland Mixtures	150
Pine and Upland Hardwoods	8
Mixed Hardwoods	22
Brush	2

Aspen-birch was harvested extensively, in terms of both number of operations and acres cut. Approximately 30% of the total valid responses indicated harvesting of aspen-birch and 88% of these operations were done by clearcutting.

Jack pine was the next species most frequently cut, but the operations involved much fewer acres. Most (95%) of the jack pine operations involved clearcutting. The remaining jack pine operations were thinning and selective cuts. Black spruce was the third most frequently cut major species. These operations were almost exclusively done by clearcutting.

Red pine operations usually involved selective cuts or thinning. Red pine was cut on 72.7% of the thinning operations. Oak operations split almost evenly between clearcutting and selective cutting.

Acres cut per operation ranged from one acre to over 1000 acres. About half of the operations were less than 10 acres in size. Most of the larger sized cuts were associated with aspen-birch and lowland mixture operations. Approximately 45% of harvest operations occurred during the winter months (December-March), and a small percentage in the spring.

TABLE 1

ANNUAL NUMBER OF HARVEST OPERATIONS BY FOREST MANAGEMENT ORGANIZATION BASED ON PUBLIC LANDOWNER'S SURVEY

Organization	Number of Harvest Operations
DNR - Forestry	3,195
DNR - Parks & Recreation	20
DNR - Fish & Wildlife	30
U.S. Forest Service	300
Bureau Indian Affairs	15
U.S. Army Corps Engineers	0
Bureau Land Management	0
U.S. Fish & Wildlife Service	7
Voyageurs National Park	0
Counties	2,007
Forest Industries	160
Private Companies	40

Total Number of Operations	5,774
Annual Average (Last 5 Years)	4,017

3. SKIDDING

	NUMBER OF OPERATIONS	PERCENT OF THE OPERATIONS
Equipment		
Four-wheel drive articulating skidder	829	59.4
farm tractor	221	15.8
crawler tractor	142	10.2
Animal, truck, snowmobile & other	23	1.7

The four-wheel drive articulating skidder is the most commonly used machine in Minnesota operations. It is used on 59.4% of reported skidding operations. The farm tractor is second and crawler tractor third. Other methods of skidding include animal, truck, cable, and snowmobile, but these methods are negligible in Minnesota.

The most common type of logging operation involved clearcutting trees into tree lengths and hauling them to the landing with a four-wheel drive articulating skidder (414 operations). The following table shows the combinations of cutting method, logging technique and skidding equipment, used in harvesting operations, and their frequency distribution.

	COMBINATIONS	NUMBER OF OPERATIONS
1.	Clearcut X Tree Length X Articulating Skidder	414
2.	Clearcut X Shortwood X Wheeled Farm Tractor	115
3.	Clearcut X Full Tree X Articulating Skidder	111
4.	Selective X Tree Length X Articulating Skidder	67
5.	Clearcut X Shortwood X Crawler Tractor	62

The number of skid trails per operation ranged from 0 to 75. Many operations (256 or 21.1%) involved only one skid trail, and 61.4% involved 5 or less.

When more than one skid trail was involved, the most frequently reported distance between them ranged from 100-400 feet, with 200 feet occurring most often. Approximately 19.8% of the operations utilized skid trails closer than 100 feet. The more trails used, the less the distance between trails. Generally, the steeper the slope, the less skid trails used.

Several types of skid trails were used in harvest operations, and are listed as follows:

- two way skid trails extending from the top to the bottom of the hills
- a one way downhill skid trail with a hill road constructed for uphill travel; and
- two way skid trails on lower portion of a hill with remaining trees on upper portion cabled to the top.

The two way skid trail was the most commonly used type of trail. Most of these trails were revegetated artificially. About all 12% of the trails were planted, seeded or provided with erosion control structures. A few skid trails were left for future use.

In order to obtain access to the timber, the logger must either build a new forest road, brush-out a previously used forest road, or use existing forest roads. Sixteen percent of the operations included a road-building operation; of these 78% involved harvesting. The number of miles of road built per operation ranged in length from 1/8 to 25 miles. The total length of roads built was approximately 400 miles. Less than 1% of the total number of roads built were greater than 5 miles long. Twelve percent of the operations involved brushing out a forest road.

A total of three hundred sixty miles were brushed out, and on 76% of these roads the length was less than one mile. Another 2,484 miles of existing forest road were used in 75% of the operations.

The types of forest roads built on these operations were either temporary or permanent with a gravel surface. Temporary roads were built most often. These roads were usually built in the winter or summer, and were built to established standards about 15% of the time. When the operation was over, the temporary roads were managed in one of the following ways:

1) closed permanently, with a physical barrier to motorized access;

2) revegetated artificially with no barrier installed;

3) left to revegetate naturally with no barrier to motorized access;

4) left to revegetate naturally with erosion control structures installed; or

5) closed permanently and revegetated artificially.

Approximately forty percent of the temporary forest roads were left to revegetate naturally with no barrier to motorized access.

4. SITE PREPARATION

After a site has been harvested, preparation normally begins for a new crop of trees. Site preparation methods vary depending on the desired species. Some species require no site preparation. According to the summary data there were 473 site preparation operations in fiscal year 1977. Sixty-nine operations were expressly for site preparation as the main purpose. Eighteen percent of the total operations include site preparation in their plans for the future, and 8.4% exclude

TABLE 2

ANNUAL NUMBER OF SITE PREPARATION OPERATIONS BY FOREST MANAGEMENT ORGANIZATION BASED ON PUBLIC LANDOWNER'S SURVEY

Organization	Number of Site Preparation Operations
DNR - Forestry	90
DNR - Parks & Recreation	51
DNR - Fish & Wildlife	7
U.S. Forest Service	241
Bureau Indian Affairs	10
U.S. Army Corps Engineers	0
Bureau Land Management	0
U.S. Fish & Wildlife Service	0
Voyageurs National Park	0
Counties	8
Forest Industries	66
Private Companies	0
Total Number	473
Annual Average (Last 5 Years)	585

TABLE 3

ANNUAL NUMBER OF ACRES SITE PREPARED BY CHEMICAL MEANS BASED ON PUBLIC LANDOWNER'S SURVEY

Organization	Acres Chemically Site-Prepared
DNR - Forestry	245
DNR - Parks & Recreation	50
DNR - Fish & Wildlife	0
U.S. Forest Service	150
Bureau Indian Affairs	0
U.S. Army Corps Engineers	0
Bureau Land Management	0
U.S. Fish & Wildlife Service	0
Voyageurs National Park	0
Counties	25
Forest Industries	1
Private Companies	0
Total Acres	471
Annaul Average (Last 5 Years)	828

TABLE 4

ANNUAL NUMBER OF ACRES PRESCRIBE
BURNED BASED ON PUBLIC LANDOWNER'S SURVEY

Organization	Acres Prescribe Burned
DNR - Forestry	445
DNR - Parks & Recreation	825
DNR - Fish & Wildlife	294
U.S. Forest Service	590
Bureau Indian Affairs	180
U.S. Army Corps Engineers	0
Bureau Land Management	0
U.S. Fish & Wildlife Service	60
Voyageurs National Park	0
Counties	0
Forest Industries	0
Private Companies	0
Total Acres	2,394
Annual Average (Last 5 Years)	3,842

TABLE 5

ANNUAL NUMBER OF ACRES SITE PREPARED BY MECHANICAL MEANS BASED ON PUBLIC LANDOWNER'S SURVEY

Organization	Acres Mechanically Site Prepared
DNR - Forestry	2,121
DNR - Parks & Recreation	40
DNR - Fish & Wildlife	100
U.S. Forest Service	4,150
Bureau Indian Affairs	40
U.S. Army Corps Engineers	0
Bureau Land Management	0
U.S. Fish & Wildlife Service	100
Voyageurs National Park	0
Counties	235
Forest Industries	3,098
Private Companies	0

Total Acres	9,884
Annual Average (Last 5 Years)	7,934

site preparation entirely. Of the operations which did employ site preparation methods, prescribed burning was the most common. Windrowing and shearing, felling, and brush-clearing were close seconds. Chemicals were the least commonly used method. Site preparation operations occurred evenly throughout the year. The following table shows total acreages by site preparation method.

	TYPE OF SITE PREPARATION	TOTAL ACRES
1.	Chemical Site-Preparation	471
2.	Prescribed Burning	2394
3.	Mechanical Site Preparation (includes all types of site preparation which involve machines)	9884

These figures are based on Tables 2 through 5.

5. REGENERATION

Aspen-birch was regenerated on one-third of the operations involving reforestation. This is the most frequently regenerated species and requires no site preparation (see Silvicultural Guides in Appendix D). Red pine is second on the regeneration list, with spruce-fir, black spruce and upland hardwoods close behind. Oak and cedar were regenerated the least among major species types. Below is a list of the major types of species, their most common method of site preparation, and their most common type of regeneration.

MAJOR SPECIES TYPE	METHOD OF SITE PREPARATION	TYPE OF REGENERATION
Aspen-Birch	None	Natural
Red Pine	None or Burning	Planting
Black Spruce	None	Natural
Spruce-Fire	None	Natural
Upland Hardwoods	None	Natural
Jack Pine	Burning or None	Seeding
Tamarack	None	Natural
Lowland Hardwoods	None	Natural
Cedar	None	Natural

6. TIMBER STAND IMPROVEMENT

During the growth of a new crop, forest managers may have to make several improvements to ensure the best possible management of the stand. A small percentage of operations reported in the survey involved timber stand improvement (TSI). Only 24 or 1.5% of the operations indicated TSI as the main purpose.

7. THINNING

Commercial thinning is also a form of timber stand improvement, but the by-products are merchantable. Only 8.4% (136) of the total operations indicated commercial thinning was the main purpose.

8. FIREBREAKS

Firebreaks are built as a means of forest protection. They are designed to help slow the spread of wildfire. Firebreaks were the main purpose on only 14 operations.

9. RIGHTS-OF-WAY

This category includes road rights-of-way, powerline rights-of-way, etc.

B. RESULTS OF THE PRIVATE LANDOWNER'S SURVEY

1. OVERVIEW OF SURVEY SAMPLE

Approximately 1,500 surveys were mailed to individuals believed to be actively involved in the management of their privately owned woodlots. Names and addresses were obtained from records of DNR district forest management plans and cutting reports. Of the 462 surveys completed and returned (constituting a return rate of about 31%), 418 were from landowners who currently hold some forested land. The amount of land owned by the respondents of these surveys is 40,698 acres, or .2% of the commercial forest land in Minnesota, and .5% of the total land under private woodlot ownership. (Private landowners have approximately 40% of the state's commercial forest land.)

2. SUMMARY OF RESPONSES

The information was collected state-wide, but much of it pertains to southeastern Minnesota since a disproportionately large amount of woodlot owners hold land in that region. Summary data pertaining to land holdings (total acres, acres forest, etc.) and data about specific forest management operations were requested for any activities within the last five years.

Respondents were asked if a stream or lake is present in their property. If the response was negative, the data from the survey was not included in the analysis. Surveys from 128 respondents fit this category. Of the remaining 290 respondents, 83 did not manage their land during the last five years. This leaves 107 surveys, and the data from this group provides the basis for analysis of management activities.

Approximately 39% of the respondents indicated the contour of their land was hilly to steep. Forty-four percent stated their land was gently rolling to rolling, and another 9.2% reported their land to be flat.

Data were received for 476 forest management operations. The number of operations per respondent ranged from 1 to 9, and the average was 2.2. Approximately 65% of them occurred in the period 1976-1978, which is about the same time frame as the public landowner's survey. About one-fifth of the operations occurred in the winter, and the rest were evenly distributed throughout the year. These operations directly affected 14,480 acres.

The types of activities were grouped into eight major categories: 1) harvesting, 2) burning, 3) chemical spraying, 4) grazing, 5) mechanical site preparation, 6) planting, 7) timber stand improvement, and 8) a combination of harvesting and site preparation. Harvesting was by far the most common activity and accounted for 52% of the operations. Harvesting in combination with site preparation accounted for another 15%, and burning was the least common of all.

The purposes of these various activities were numerous. They have been broadly grouped into the following categories shown in the following bar graph (Fig.). Most of the operations associated with these purposes involved harvesting. Operations carried out for timber production, firewood cuts, and salvage of timber accounted for 68% of the total. Selective cutting was used as a cutting method more often than clearcutting since harvesting on private woodlots usually involves felling of scattered trees or scattered clumps of trees.

Chainsaws were used for the felling in 272 operations, which is considerably more times than any other type of equipment (i.e., for instance mechanical shearers were used on only 8 operations). A farm tractor - either used by itself or in combination with a truck or trailer - was used in about half the operations involving skidding. Cables, animals, crawler tractors, and skidders were also used, but only on a small percentage of operations.

On over 50% of the operations the landowner actually did the harvesting. Almost 70% of the operations involved the landowner in cooperation with neighbors and friends. A small independent logger was involved on 82 operations, and a large company

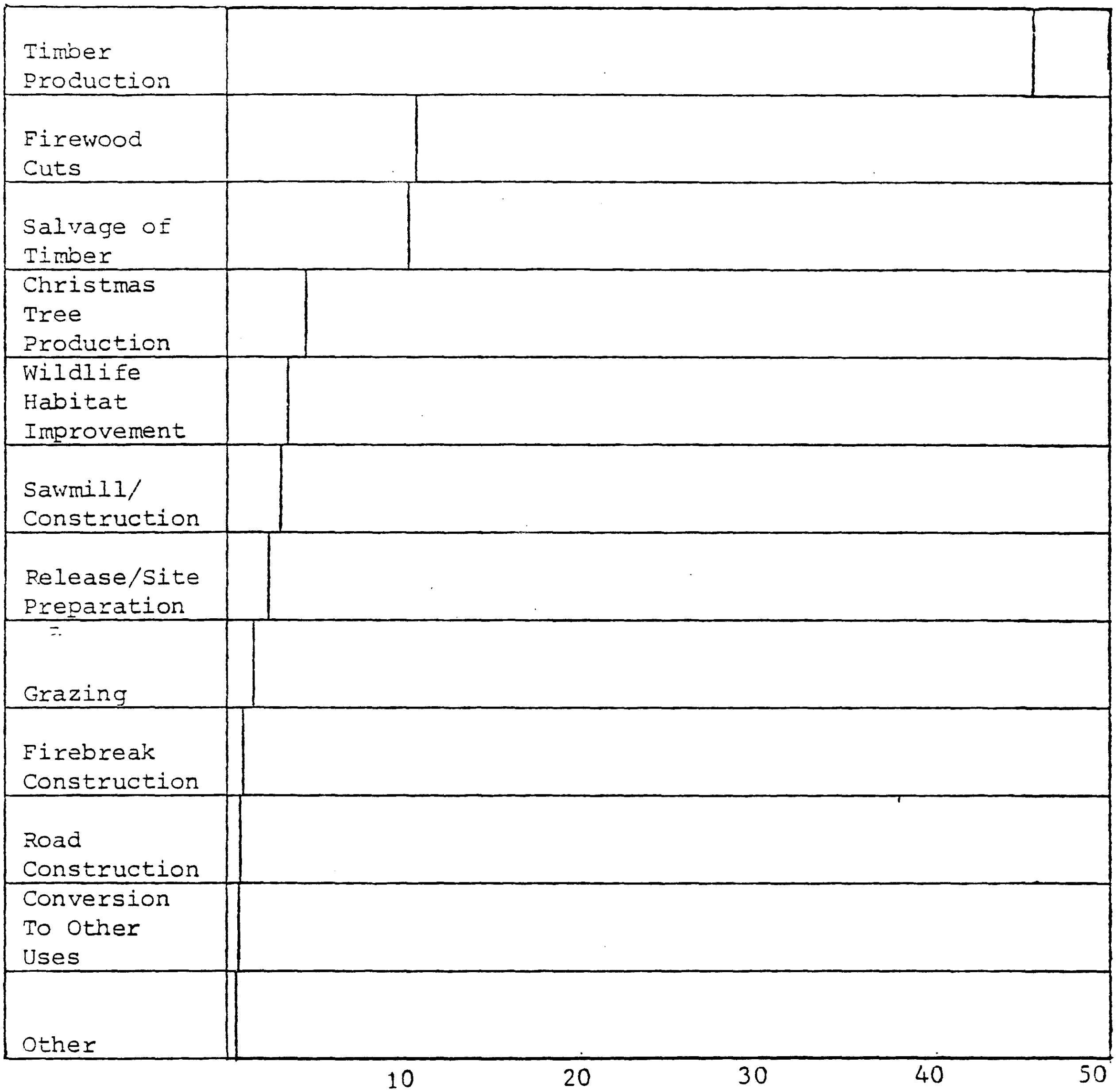


Fig. C. Percentage distribution of purposes of forest management operations conducted on private woodlots (based on data pertaining to 433 operations collected from the private landowner's survey).

did the work on about 25 operations.

The landowners were asked to describe any road-building operations on their land during the last five years. Only 39 of the respondents indicated that road-building was done. Various degrees of road development were reported, and are listed as follows:

1. limited clearing of trees,
2. road bulldozed in,
3. construction of unsurfaced road,
4. construction of gravel surface road, and
5. construction of sand and gravel surface road.

Most road building was done in summer. Of the 39 road building operations, 27 involved construction of a road less than one-half mile in length. Half the roads were built in connection with forest management operations, and the others mainly for driving or access to the landowner's home or property.

C. TIMBER SALE PROCEDURES

Timber sale procedures vary according to the policies of the agency or company that owns the stumpage. Procedures also vary from district to district within an agency such as the DNR or the Forest Service. Procedures are dependent on such variables as timber type, extent of land ownership, available manpower, and experience of the land managers. Wide differences may exist among timber sale procedures of forest industries.

This section describes in general terms the timber sale procedures employed by the U.S. Forest Service, Department of Natural Resources, counties, and a typical forest industry. Information regarding timber sales was obtained from forest management personnel from these agencies and organizations. The reader is cautioned that not all the generalizations made about these procedures apply to a specific district or firm. Timber sale procedures of non-industrial private forests will be described in another section.

The basic steps in a timber sale consist of the following actions:

1) determination of how much timber to harvest and where harvests should occur;
2) timber cruise and appraisal;
3) writing of the timber sale contract; and
4) advertisement and awarding of contracts.

1. U.S. FOREST SERVICE

a) Determination of Volume and Location of Harvest:

A ten year management plan is written for each district of a National Forest. (A forest may have 5 or more districts, each headed by a ranger.) The ten year management plans include the allowable cut for the period.

The allowable cut is based on sustained yield management and area regulation. Sustained yield management means that as quickly as practical, the forest will be regulated so harvests equal wood production. Area regulation means the forest will be regulated for sustained yield by harvesting a prescribed amount of area each period (as opposed to volume regulation, which means a prescribed volume is harvested each period).

Following the calculation of allowable cut, the next step is the performance of field compartment inventories. Compartments comprise 600 to 1000 acres, and several may be contained in a district. Ten percent of the compartments are inventoried each year. In the inventory, prescriptions are made for treatments needed by each stand.

An Environmental Analysis Report (EAR) is written for each stand that is designated for a harvest operation. An EAR contains information about the stand regarding potential problems and restrictions that may be necessary to prevent such problems.

The sale is then written by the forester. In the sale write-up are included such specifications as road design requirements, rights-of-way, and type of stream crossings. Most sales are integrated; that is, a variety of species and products are sold in the same sale.

b) Timber Cruise and Appraisal:

The sale area is cruised to either delineate sale boundaries or mark trees for cutting, followed by assessment of the timber value. Assessment is based on "transaction evidence", which is an average of what has been bid for stumpage over a 4-quarter period.

c) Writing of the Timber Sale Contract:

Contracts are written for a maximum of 6 years; 4 to 5 years are the average. Contracts may be extended for 1 year if roads have been built and contract requirements have been met. The stumpage rates for the remaining stumpage are re-evaluated at the time an extension is granted.

The authority to make timber sales rests with either the district ranger, the forest supervisor, or the Chief of the Forest Service, depending on the volume or value of the sale and/or the experience of the ranger. Most sales are made by the ranger.

d) Advertisement and Awarding of Contracts:

Regulations require any sale valued at $10,000 or more to be advertised. However, a policy of the Forest Service is to advertise any sale for which competition is likely to exist. Sales are advertised for 30 days in local (usually weekly) newspapers. Sale descriptions are also sent to those people who have made bids on previous sales.

Most timber sales are made through the use of sealed bids. Oral auctions are used occasionally. Informal (over-the-counter) sales are made for timber sales for which no one bid on and also for those involving products which have poor markets.

Payment of the bid price is required before cutting may begin on a cutting unit. Perhaps 7 or 8 cutting units may exist in one timber sale. Thus, stumpage payments may be made 7 or 8 times during one logging operation.

Scaling is not done on Forest Service timber sales. Rather, the logger is allowed to cut whatever timber is marked, or in the absence of marking, whatever timber is in the sale area. If he cuts more than what was indicated by the cruise, he has an over-run and comes out ahead. The logger pays only for the volume indicated by the cruise.

If a timber sale does not receive any bids, it can be sold over-the-counter for its appraised value or else be split up and included in other sales. If a contract is awarded, but the timber is not cut, either an extension is granted or the sale is closed and damages assessed.

Loggers working on National Forest timber sales include company crews and contract loggers. Company crews are employed by a timber or paper company. Contract loggers work under a contract with a timber or paper company. This contract assures the logger of a certain amount of stumpage per year that is purchased by the company. Loggers may also purchase stumpage on their own.

Supervision of logging operations on National Forests is intensive. The use of cutting units allows for control of the logger's performance since a harvested cutting unit can be inspected before logging is permitted to start on the next.

2. MINNESOTA DEPARTMENT OF NATURAL RESOURCES

a) Determination of Volume and Location of Harvest:

An inventory is conducted to assess the timber resources, to determine the allowable cut, and to make stand prescriptions. The allowable cut is determined for each forest type for the next 15 years, based on area regulation and sustained yield.

Stands are selected for harvesting on the basis of the prescriptions made in the inventory. Factors considered in the prescriptions include volume, age, growth rate, risk, and log size.

In some cases, a current inventory may not exist for a district. In this case, the same factors used in making a stand prescription are used to determine which stands should be cut. However, an allowable cut cannot be determined, and stands that are in need of treatment may be overlooked.

b) Timber Cruise and Appraisal:

The sale area is cruised to determine volume and sale boundaries, or trees to be cut are marked if obvious type boundaries cannot be used as sale boundaries.

Stumpage values are determined by multiplying a base stumpage price by a price factor. Price factors are based on such criteria as:

1) amount of timber per acre

2) number of 16' logs per tree

3) terrain

4) quality of timber

5) distance to mill

6) condition of roads

c) <u>Writing of the Timber Sale Contract:</u>

Contracts for auction sales are written for 2 year periods. Extensions for 1 year can be granted a maximum of 3 times. A penalty of 6 percent of the remaining stumpage value is assessed at the time of contract extension.

The authority to make timber sales is shared by different levels in the organization. If a district cutting plan is approved by the area forester and the regional forester, then informal sales may be appraised by the district forester and awarded upon the approval of the area forester. If no district cutting plan exists, informal sales must always be approved and issued by the Office of the Director of Forestry. The value of an informal sale must not exceed $1,500.

The timber sale contract may include such specifications as buffer strips along watercourses, maximum stump height, road construction, and slash treatment.

d) <u>Advertisement and Awarding of Contracts:</u>

Informal sales are unadvertised. Contracts are awarded for the appraised value of the sale. Payment is made in full at the time the contract is awarded. Informal sale contracts last 1 year with a possible 1 year extension. No penalty is assessed for extensions on informal sale contracts. Informal sales are made more often than auction.

Auction sales must be advertised at least 3 times in 3 weeks beginning 30 days prior to the auction. Advertisements are usually placed in the county seat newspaper and in newspapers of other important logging communities. Twenty-five percent of the appraised value is paid upon being awarded the sale. A surety bond for the remainder of the bid price is required within 90 days and prior to the commencement of logging. The use of sealed bids is not practiced.

Scaling may be done by the forester (ground scale) or by the consumer (consumer scale). Consumer scaling is less costly and time consuming since it is generally done by the consumer. The logger is charged for the actual amount of timber contained in the sale. He must pay for the additional stumpage if an over-run occurs.

Loggers working on DNR timber sales include mostly contract loggers and independent loggers. Independent logging operations usually involve 2 or 3 men, often a family operation. Some independent loggers have only a pick-up truck and a chainsaw. These loggers buy most of their stumpage through informal sales.

Supervision of DNR timber sales varies according to the length of time that a logging operation is in progress and the past performance of the logger. When timber ground is scaled, 2 to 6 visits are commonly made during a logging operation.

3. MINNESOTA COUNTIES

a) Determination of Volume and Location of Harvest:

Many counties have inventories which are incomplete or out of date. Consequently, the allowable cut is unknown. County timber sales consist of both planned and unplanned sales.

Planned sales are initiated by the forester. The forester examines tracts to determine silvicultural needs, makes a prescription, and prepares the sale.

Unplanned sales are initiated by the logger. The logger may come to the forester with a particular tract in mind or with a request for a particular product. The forester then examines the tract or tracts in question, determines if a harvest prescription is warranted, and if the products available on the tract will satisfy the logger.

b) Timber Cruise and Appraisal:

The timber is cruised to determine volume, sale boundaries are flagged (providing sale boundaries are not made along forest type boundaries), and an appraisal is made. Appraisals involve the same considerations that are involved in DNR appraisals, but the calculations may be less exact.

c) Writing of the Timber Sale Contract:

Informal sale contracts can be written for sales in which stumpage values do not exceed $750. Time limits on permits vary depending on the county and the value of the sale. Extensions are sometimes granted with the assessment of a flat-rate penalty.

Auction sales occur infrequently on county forests. Some counties have never had one; others average 2 per year. Sealed bid sales are not made.

Authority for making sales rests with the county forester or, in some cases, with the county land commissioner. In either of these cases, an annual review is conducted by the DNR. In some counties, sales are actually authorized by the DNR area forester.

Contract provisions may include slash treatment, stream crossing restrictions and buffer strips along water bodies.

d) Advertisement and Awarding of Contracts:

Informal sales are unadvertised and contracts are awarded for the appraised value. Payment for stumpage is required before commencement of logging.

In the past, roads were laid out almost entirely at the discretion of the logger. Roads in county forests are now commonly flagged out or at least discussed between the logger and the forester.

Scaling is done by several methods on the ground by the forester, at the mill by the consumer, or by a broker. The logger pays for the stumpage he cuts whether or not that volume agrees with the volume indicated by the cruise.

Loggers that operate on county timber sales are mostly independent. Crews consist of 2 or 3 men, possibly 4 if a trucker is included (otherwise the transport of the timber is contracted out). Contract logging crews may work on auction sales. Supervision of logging operations is similar to the DNR.

4. PRIVATE INDUSTRIES

a) Determination of Volume and Location of Harvest:

In the past, the amount of timber harvested on industry lands was determined by the industry's procurement needs. Currently, forest industries are turning more to sustained yield management and volume regulation.

The allowable cut is determined by an inventory, during which silvicultural prescriptions are also made. Stands with harvest operations prescribed are earmarked for cruise and appraisal.

b) Timber Cruise and Appraisal:

The sale area is cruised and boundaries are marked. Appraisal is based on standard stumpage prices.

c) Writing of the Timber Sale Contract:

Most forest industries use company crews or contract loggers. Company crews have salaried positions and use company-owned equipment. Contract loggers have a contract with the company whereby the company supplies them with a specified amount of stumpage per year. Scaling is done only at the mill. Loggers are paid for the volume that is actually cut. Road building may be done by the logger or by the company. Road layout is determined by the company. Supervision of logging operations is performed on the basis of field visits. Operations usually are inspected once or twice a week.

V. ESTIMATION OF THE POTENTIAL FOR FOREST MANAGEMENT TO IMPACT WATER QUALITY IN MINNESOTA: BASED ON RESOURCE CHARACTERISTICS AND FOREST MANAGEMENT ACTIVITIES

Section IV has described forest management in Minnesota. Section V is an analysis of the potential impact that forest management could have on water quality. The focus of the analysis is on surface erosion potential as determined by resource characteristics and the nature of site disturbance effects associated with various forest management activities.

Sediment is the primary type of water pollutant associated with erosion. Our study assumes a greater surface erosion potential is an indicator of an increased sedimentation potential, even though the two processes are not necessarily correlated. Other types of pollutant loadings, such as organic matter, nutrients, pathogens, thermal effects, etc., are not addressed in this section on account of the lack of information, plus time and budgetary restraints.

Part A discusses the methodology and data used to identify and describe resource characteristics which play a key role in inherent erosion potential. Part B describes the methodology and data used to determine the potential for Minnesota forest management activities to cause the following effects:

(1) disturb a given site and

(2) create conditions under which surface erosion could occur.

Part C is an analysis of surface erosion potential on the basis of combined information from Parts A and B. Practices identified on the basis of high site disturbance potential are matched in terms of location with geomorphic regions containing a high surface erosion potential.

A. FOREST RESOURCE CHARACTERISTICS

1. INTRODUCTION

The State of Minnesota is described in terms of resource characteristics for purposes of subdivision and land classification. The intent is to provide a general description of the state as a whole, and identify regions within it which are similar in terms of broad ranges of environmental parameters. The Minnesota Land Management Information System (MLMIS) has displayed and tabulated slope grade, K-factor, and woodland suitability data for both the project area and geomorphic regions. These variables have been analyzed as indicators of surface erosion potential.

Surface erosion is a function of many factors (see section II. D of segment I). Among all the factors discussed in this report that influence erosion potential, slope grade and soil K-factor are emphasized the most for purposes of project area assessment. These two variables are known to be key factors that determine the susceptibility to erosion of any given site with exposed soil.

The Universal Soil Loss Equation is a mathematical model that estimates erosion on the basis of five quantified variables (see section III. B 1 of segment I). Slope grade and soil K-factor are two of these parameters (Soil K-factor is a measure of inherent erodibility). Among the three remaining variables, statewide data is only available for the rainfall erosion index factor. This factor does not account for very much of the variability in erosion rates within the forested areas of the state. The highest mean annual value occurs in the southeast part of the study area and only exceeds the smallest value (which occurs along the northern rim of the state) by a factor of two (see Appendix A). The two remaining variables in the model - slope length and cover factor - are impossible to evaluate on a statewide basis because the necessary data is lacking. Thus, the application of the Universal Soil Loss Equation (to estimate erosion) throughout all of the project area is unfeasible. The attempt has been made in this report to use slope grade and soil K-factor as indicators of erosion potential because of the importance and availability of data associated with these factors.

2. METHODOLOGY

a) Minnesota Land Management Information System (MLMIS)

The principle function of the MLMIS is centralization and presentation of data pertaining to Minnesota's resources. The data is related to cultural, resource, and land unit boundary information. The data is stored in computer files by both 40 acre and 5 kilometer square parcels. A package of computer programs is available to retrieve data in tabular, map, statistical and computer file form.

Approximately fifteen different variables are entered into the MLMIS. A "data level" is associated with each variable, and this value is recorded for each parcel (40 acre and 5 kilometer square) in the state. The variables most relevant to the needs of this project are soil landscape units, geomorphic regions, soil K-factors, slope grades, and woodland suitability ratings.

Geomorphic regions are areas with similar surface features which are often associated with glacial deposition, erosional processes and/or bedrock conditions. Contour (relief) and soil parent material data contained in Minnesota Soil Atlases

(University of Minnesota, 1969 et sequence) were used to locate about 100 of these regions throughout the state. A map of all the geomorphic regions in the state is shown in Fig. 1.

Soil landscape units are defined on the basis of four factors: 1) texture of soil material below five feet, 2) texture of soil material above five feet, 3) drainage characteristics, and 4) surface soil color. The landscape unit designations were made from soil surveys produced by the USDA - Soil Conservation Service, and also from field collected data.

Woodland suitability ratings have been matched with soil series by the USDA Soil Conservation Service. These ratings represent an assessment of soil productivity, species adaptability, and potential problems related to soil features. Erosion hazard is one type of problem associated with some of the ratings (see appendix B).

Supplemental data may also be entered into the system in several ways. Manual coding is the most common method, even though it is typically a tedious process requiring considerable time if large amounts are involved. In this project soil K-factor and slope grade data associated with soil landscape units, plus woodland suitability groupings (also associated with landscape units), have been manually entered into the MLMIS.

b) Data Manipulation

The project study area consists of those geomorphic regions in the state with at least 10% of their areas classified as forest cover. Each 40 acre cell is coded by a land use variable, and forest cover is one data level within this variable. A cell with at least 50% of its area classified as forest is coded as forest. The project area consists of geomorphic regions with at least 10% of their cells classified as forest and it comprises approximately 55% of the state.

Geomorphic regions provide the basis for subdivision of the state into land units for purposes of description and analysis. Statewide descriptions have been made using slope and soil K-factor data, and wherever possible, geomorphic regions that exhibit a high correlation to either of these variables are identified and described.

Estimates of the minima, maxima, and mean values of slope grades have been made by soil scientists affiliated with the Soil Atlas Program for all soil landscape units in the state. The mean and maximum values of these ranges have been entered into the MLMIS and assigned to each five kilometer square data cell in the project area. (The estimates of maximum slope do not represent the most severe slopes of a region because steep bluffs and escarpments were excluded from consideration).

The K-factor values derived for the soil landscape units are the means of the K-factors assigned to the representative series. Soil interpretation sheets produced for the soil Atlases cover approximately half the project area. The published Atlases list the names of representative series within their respective areas of coverage. Preliminary drafts of Soil Atlas manuscripts are the source of representative series names for those areas not covered in the published editions.

The reliability of the named series being truly representative of the soil landscape units within a given county is a function of the amount of field-conducted soil inventory work. In the southeast part of the project area, intensive county surveys have been performed throughout most of the region. Consequently, the representative series named for the landscape units in those counties are much more likely to be accurate than named series in the northeast part of the study area where very little soil inventory data has been collected.

Woodland suitability ratings have been assigned to soil landscape units based on the ratings associated with representative soil series. In most cases only one suitability rating corresponded to all the representative series for a given landscape unit. When more than one did correspond, the rating with a description most closely matched to the soil landscape unit was selected for coding.

The combined effects of slope and K-factor are analyzed as indicators of erosion potential. Ratings related to erosion hazard have been assigned to each data cell throughout the project area. These ratings are functions of slope and K-factor, and represent the occurrence of sites with certain slope and soil K-factor characteristics.

The ranges of the slope and K-factor data entered into the MLMIS were divided into class intervals on the basis of their frequency distributions. Weighted means were calculated for each interval, and these values served as <u>class marks</u> for the intervals. Slope-length factors used in the Wischmeier soil loss equation were determined for each class mark associated with the slope intervals. Each combination of class mark values representing K-factor and slope-length factor were multiplied times each other as if they were in the Universal Soil Loss Equation, with all the other variables held constant.

The values of the products were then arranged in ascending order and divided into classes, each one representing a group of slope and K-factor combinations indicative of relative erosion potential. The class representing the highest erosion potential contains those combinations with the highest slope-length and K-factors. Each succeeding class of decreasing erosion hazard is associated with decreasing slope-length and K-factor values. The MLMIS read the values of these variables for every five kilometer square data cell in the project area, and assigned the combinations to one of the erosion potential indicator classes. The classes are displayed on maps of the project area.

Woodland suitability ratings have been assigned to each soil landscape unit on the basis of both average and maximum slope ratings. The ratings associated with potential erosion hazard problems are displayed on maps of the project area.

3. RESULTS

a) K-Factor Data

Fig. 2 is a map of the project area that shows K-factor ranges associated with soil landscape unit and geomorphic region combinations. The maximum range is 0.31 to 0.43. The southeast region is clearly the most extensive area of homogeneous maximum K-factor range. This area corresponds very closely to the Red Wing - La Crescent uplands (this geomorphic region is shown in Fig. 9 of Appendix C). Maximum K-factor ranges are also present in the central, north central, and north shore regions of the project area. The total amount of area in this class of K-factor range accounts for about 12% of the project area.

The next lowest K-factor range extends from 0.21 to 0.30. The amount of area in this class represents approximately 40% of the project area. It is distributed fairly evenly throughout the study area except in the northeast section, where it is almost completely absent.

Approximately 28% of the study area exhibits a K-factor range of 0.15 to 0.20. This class is distributed throughout the project area; however, the Tower - Ely glacial drift geomorphic region (Appendix C) in the northeast is homogeneous in this class.

The mean values of K for each geomorphic region in the project area have been calculated using the values of K-factor assigned to each data cell in the geomorphic region of interest. Geomorphic regions with mean values greater than 0.30 are listed in descending order along with their values: 1) Red Wing - La Crescent uplands (0.36), Northome moraine (0.32), Nashwauk - Warba moraine (0.32), and Aurora till plain (0.31) (Appendix C).

b) Slope Data

A map of range classes representing estimates of average slope assigned to soil landscape unit/geomorphic region combinations is given in Fig. 3. All the area in the highest class range is localized in the southeast portion of the project area. The amount of area in this slope class (20% grade) comprises less than 2% of the study area, and it is located in the Red Wing - La Crescent uplands. The next lowest class (7 to 12%) is present on about 30% of the project area. This class is distributed among the following geomorphic regions: 1) Tower - Ely glacial drift, 2) Alexandria moraine, 3) Itasca moraine, 4) Mesabi range, and 5) Highland moraine (Appendix C).

A map of maximum slope estimates for soil landscape unit/geomorphic region combinations is shown in Fig. 4. The highest class (25%) is present in about 15% of the project area, and is located in three distinct areas: 1) the northeast corner which corresponds to the Tower - Ely glacial drift, 2) a west central zone that is mostly contained in the Itasca moraine, and 3) a southeast section of the study area within the Red Wing - La Crescent uplands (Appendix C).

c) Erosion Potential Indicator Data

Maps of the project area representing the combined effects of slope and K-factor on erosion potential are shown in Fig. 5 and 6. The first is based on average and the second on maximum slope estimates of the soil landscape unit/geomorphic region combinations.

The amount of area shown in Fig. 5 which belongs to the highest erosion potential indicator class is less than 2% of the project area, all of which is located in the Red Wing - La Crescent uplands. The next highest class appearing on the map (level 3) constitutes approximately 15% of the study area. (No cells belong to the class corresponding to level 4 since the combinations of slope and K-factor values associated with this class do not exist). Roughly 40% of the area in the level 3 class is located in the Highland moraine, Itàsca moraine, and St. Croix moraine geomorphic regions (Appendix C). The remainder of this class is distributed throughout the study area without any clear pattern of association with geomorphic regions.

Fig. 6 shows erosion potential indicator classes based on estimated maximum slope. Approximately 7% of the project area is in the highest class, most of which is in the Red Wing - La Crescent uplands, Itasca moraine, and Aurora till plain. The next highest class comprises nearly 40% of the project area. The following geomorphic regions all exhibit large proportions of their areas in this class: Tower - Ely glacial drift, Highland moraine, Vermillion range (moraine), Nemadji - Duluth lacustrine plaine, Erskine moraine, Fosston till plain, Northome moraine, Wahlston moraine, Big Rice moraine, Thomson - Cloquet moraine, Clearbrook moraine, Bagley outwash plain, Swatara plain, Falk till plain, Sugar Hills moraine, St. Croix moraine, Henning till plain, Alexandria moraine and Brainerd - Pierz drumlin area.

d) <u>Woodland Suitability Data</u>

Fig. 7 is a map of woodland suitability ratings associated with potential erosion hazard problems. These ratings have been assigned to soil landscape unit/geomorphic region combinations on the basis of their estimated average slope. The 4 d 1 rating (Appendix B) is most prevalent among the ones displayed. Most of the area assigned this rating is located in the Tower - Ely glacial drift. Less than 2% of the project area exhibits a 2 r 1 rating, all of which is present in the Red Wing - La Crescent uplands. The third rating displayed is not localized in any one region, and it constitutes about 2% of the study area.

The map in Fig. 8 shows woodland suitability ratings associated with erosion hazard problems that are based on estimated maximum slope values. Most of the 2 r 1 (Appendix B) rating is located in the St. Croix moraine, Itasca moraine, Highland moraine, and Red Wing - La Crescent geomorphic regions, and it comprises roughly 12% of the project area.

The 4 d 1 rating is present on about 10% of the study area, most of which is contained in the Tower - Ely glacial drift geomorphic region. The remaining three ratings only account for about 4% of the study area, and do not exhibit any pattern of association with geomorphic regions.

4. DISCUSSION

a) Erosion Potential Indicator Classes

i. average slope - indicator classes

All of the highest erosion potential indicator class based on average slope is localized in the southeast part of the project area (Fig. 5). High values of slope and K-factor are present throughout much of this area, which corresponds very closely to the Red Wing - La Crescent uplands.

A considerable amount of relief is characteristic of the topography in the Red Wing - La Crescent uplands (Minnesota Soil Atlas, St. Paul sheet). Steep bluffs and valley hillsides are present throughout much of the region, accounting for the maximum average slope estimates.

Silt loam is the dominant textural description given for soil landscape units in the Red Wing - La Crescent uplands (Minnesota Soil Atlas, St. Paul sheet). Since fine textured soils high in silts and clays are the most erodible on the basis of particle size distribution (Wischmeier, Johnson, and Cross, 1971), the extensive occurrence of high K-factor ratings throughout this region is to be expected.

The next highest indicator class (level 3) that appears on the map in Fig. 5 reflects a lower erosion potential than expected because the class defined for level 4 is nonexistent in the project area. The dominant geomorphic regions in the level 3 class are Itasca, Highland, and St. Croix moraines. Both the Highland and St. Croix moraines have rolling to hilly landforms, and each have soils of mostly sandy loam texture (Minnesota Soil Atlases, Duluth and Brainerd Sheets). The Itasca moraine is described in the next subsection.

ii. maximum slope - indicator classes

An important difference in the meanings of maximum slope and average slope erosion potential indicator classes needs to be understood for correct interpretation of the data. The erosion potential indicator classes based on maximum slope only indicate the occurrence of a site with the K-factor and slope grade characteristics associated with the class. The extent of the occurrence is not indicated. Erosion potential indicator classes based on average slope estimates, on the other hand, reflect the influence of slope and K-factor characteristics which are the most representative or extensive throughout the soil landscape unit.

The slope characteristics associated with the highest erosion potential indicator class using maximum slope as the basis are more severe than those for the highest average slope class. The erosion potential hazard indicated by the highest maximum slope indicator class, therefore, is assumed to be higher than the highest average slope indicator class.

The areal extent of the highest erosion potential indicator class based on maximum slope exhibits a wider distribution than the highest class based on average slope (7% vs. 2% of the project area). This is related to the areal extent of the highest maximum slope class in comparison to the highest average slope class (15%

vs. 2% of the project area, respectively). Three geomorphic regions account for most of the area assigned to the highest erosion potential indicator class: 1) the Red Wing - La Crescent uplands, 2) the Itasca moraine, and 3) the Aurora till plain.

The Itasca moraine consists of soil landscape units with mostly rolling to steep topography and sandy loam texture (Minnesota Soil Atlas, Brainerd Sheet). The Aurora till plain is mostly hilly with short, irregular slopes. The till material is calcareous silty clay, with a thin layer of silt loam over much of the region. The slope features of the Itasca moraine and soil erodibility characteristics of the Aurora till plain are the most critical factors of these regions with respect to erosion potential.

The next highest indicator class (level 3) is widely distributed throughout the project area, extending into more than 20 geomorphic regions. The distribution of this class correlates very closely with the second highest maximum slope class, except for the Tower - Ely glacial drift, which is in the highest.

b) Woodland Suitability Ratings

Woodland suitability ratings reflect an assessment of soil productivity, species adaptability, and potential types of problems associated with a given soil series. Ratings that include erosion hazard problems are displayed in Figs. 7 & 8.

Erosion hazard is evaluated in terms of three factors for the purposes of these ratings: 1) soil textural properties, 2) slope grade, and 3) rooting depth. The third factor provides a basis for evaluation of the impact of surface erosion on site productivity. Shallow soils are unable to withstand as much soil loss as deeper ones without a reduction in productivity. Consequently, ratings associated with erosion hazard problems represent the potential for the combined problems of soil loss and reduction in site productivity. For this reason the distribution of erosion hazard ratings associated with woodland suitability groupings may not necessarily correspond to the distribution for the ratings developed on the basis of slope and K-factor characteristics.

i. ratings based on average slope

Two geomorphic regions account for most of the area that exhibits woodland suitability groupings displayed in Fig. 7: 1) the Tower - Ely glacial drift and 2) the Red Wing - La Crescent uplands. The rating assigned to the Tower - Ely drift (4 d1) is associated with course textured, well drained soils, underlain by shallow bedrock (see appendix A). This description is consistent with the resource characteristics listed for the Tower - Ely geomorphic region given in the Hibbing Sheet Soil Atlas. The relatively thin layer of topsoil is a key factor that accounts for the moderate to severe erosion hazard associated with the rating.

The woodland suitability rating assigned to the area within the Red Wing - La Crescent uplands applies to well drained sites, with moderately coarse to moderately fine textured soils, and slopes that range from 12 to 40 percent. The erosion hazard that corresponds to this rating is moderate to severe.

ii. ratings based on maximum slope

The woodland suitability ratings shown in Fig. 8 are based on maximum slope estimates. Some similarities between the distributions of suitability ratings between the maps in Figs. 7 & 8 are apparent. The Tower - Ely glacial drift and Red Wing - La Crescent uplands still exhibit the same ratings, except for the presence of some relatively small areas in the 3 rl grouping in the extreme southeast corner of the Red Wing - La Crescent uplands. The 2 rl rating is distributed among three additional geomorphic regions besides the Red Wing - La Crescent uplands. They are the Itasca, Highland and St. Croix moraines. Each of them have drainage features and soil textural properties consistent with the 2 rl suitability rating (well drained and medium textured).

c) <u>Comparison of Erosion Potential Indicator Classes and Woodland Suitability Ratings</u>

Despite the different criteria in erosion hazard assessment using slope and K-factor data vs. woodland suitability ratings, similarities between the two approaches are evident. The Red Wing - La Crescent uplands and Itasca moraine both correlate with the 2 rl woodland suitability rating and the highest erosion potential indicator class based on maximum slope. The other two geomorphic regions that comprise the majority of area with a 2 r1 rating are the St. Croix and Highland moraines, and they correspond to the second highest erosion potential indicator class (based on maximum slope).

The 4 d1 woodland suitability rating is assigned to practically all of the Tower - Ely glacial drift, which is also in the second highest erosion potential indicator class based on maximum slope. The occurrence of sites in the Tower - Ely region with a high potential for surface erosion is very unlikely to be widespread, however, because this region is almost entirely in the next to the lowest erosion potential indicator class using average slope as the basis. The sensitivity of this region to erosion is largely a function of the shallowness of its soil rather than inherent soil erodibility and steep topography.

d) Nemadji River Basin

The "red clay area" within the Nemadji River Basin is known for the high erosion hazard of its soils. A wide range of land uses, such as farming, construction, and forestry have all encountered problems related to the soil stability. The red clay erosion problem, particularly as it affected agriculture, began to receive attention from soil and water conservation districts in the 1930's and 1940's.

Mounting concern about the special problems of the region culminated in the Red Clay Project in 1974. A multi-disciplinary team of resource specialists studied the area and its erosion related problems. The project study area includes several counties in northwestern Wisconsin and Carlton County in northeastern Minnesota.

The soils of the area were derived from glacial clay, sand, and other debris. The red clays were deposited from glacial melt waters which eventually became glacial Lake Duluth. Most of the bedrock formations consist of shale and sandstone. These rocks are deep in the soil, and consequently, do not affect topography. The relief in the region is the result of rock debris deposition in the ground, lateral, and terminal moraines (EPA - 905/9-76-002,1976).

Despite the known erosion hazard problems in the Red Clay Project area, the erosion potential indicator classes shown in Fig. 5 (average slope) are mostly in the next to the lowest level. The average slope classes shown in Fig. 3 are generally quite low for the region (1 to 6%), reflecting the absence of widespread relief. This accounts in large part for the relatively low erosion potential.

Most of the soils in the Red Clay area are in the next to the highest K-factor class (Fig. 2). The nearly complete absence of the maximum K-factor class, despite the documented severity of erosion problems, can be accounted for by the nature of these problems.

The principle type of soil loss problem in the Red Clay area is channel and bank erosion. Steep stream banks of red clay soil material are highly prone to mass wasting directly into the channels (Steve Andrews, Project Director of Red Clay Study, in a personal communication). Surface erosion on the upland areas is not believed to be the most significant cause of sedimentation compared to the channel and bank erosion. Since K-factor is a measure of inherent soil erodibility and not an indicator of mass wasting potential, the levels of the K-factor classes in the Red Clay region are not necessarily inconsistent with the levels to be expected.

5. SUMMARY

The susceptibility of exposed soil in forested lands to surface erosion is a key determinant of an area's sensitivity to disturbance. Surface erosion on forested lands is a function of many different factors. Two of the most important - if not the two most important - are slope grade and soil erodibility, as measured by K-factor. These two variables have been analyzed throughout the study area in terms of their combined effects on erosion potential, providing the basis for an assessment of erosion hazard throughout the forested areas in the state.

The southeast section of the state is clearly the most hazardous region on the basis of slope grade and soil erodibility characteristics. The estimated average slope is 20% and the K-factor range is in the highest class (.31 to .43). These conditions are present within an area that is known as the Red Wing - La Crescent uplands geomorphic region. The next highest class in the project area (based on average slope) represents a considerably lower level of hazard, and it is found in the west central, north central, and north shore regions of the project area, plus portions of the Red Wing - La Crescent uplands.

Estimates of maximum slope grades have been made for the project area, and used as a basis for determination of erosion potential indicator classes. These indicator classes represent the most severe conditions of slope and K-factor, but not their distribution, which may be very limited. The highest erosion potential indicator class (based on maximum slope) is distributed throughout the southeast portion of the project area. The second highest class is distributed throughout the project area, covering nearly 40% of it.

The erosion potential indicator classes are <u>relative</u> ratings among soil landscape unit/geomorphic region combinations within the project area. They are not absolute ratings based on quantified estimates of actual or potential erosion computed with some mathematical model, such as Universal Soil Loss Equation. These ratings do not mean that a certain amount of erosion has occurred or will occur on areas designated with a certain indicator class. The indicator classes can be thought of as representing probabilities for the occurrence of sites with given slope grade and soil erodibility characteristics. The highest class designates areas that have the highest probability for sites with the steepest slopes and most erodible soils within the project area. Each succeeding indicator class is associated with progressively lower ranges of slope and soil erodibility, with the lowest one designating areas with the highest probability for sites with the least slope and least erodible soils.

The indicator classes do offer a statewide assessment of forested lands. Areas of similarity in slope and soil erodibility characteristics are identified, providing a basis for regional comparisons and evaluation of surface erosion susceptibility, given the previously discussed limitations. The highest indicator classes may also be used as a guide to designate areas for more intensive analysis in the event more thorough studies are conducted in the future.

B. ESTIMATION OF THE SITE DISTURBANCE POTENTIAL ASSOCIATED WITH VARIOUS MINNESOTA FOREST MANAGEMENT PRACTICES

In this section, forest management activities occurring in Minnesota are grouped into types of practices which exhibit similar site disturbance characteristics. The water quality implications of these characteristics are discussed for each group of practices and a rating is estimated of their potential (high, medium or low) to disturb a site. Those practices identified as having a high potential to disturb a site are located on maps for further analysis in Part C.

1. LISTING OF MINNESOTA FOREST MANAGEMENT ACTIVITIES

The following is a list of those forest management activities which occur in Minnesota. This list is compiled from activities identified and described in Sections I and IV.

a) FELLING

Clearcut in Patches

Clearcut in Progressive Strips

Clearcut in Alternate Strips

Harvest for Disease Control

Harvest for Insect Control

Harvest for Salvage

Harvest of Overmature Timber

Conversion to Another Species

Water Yield Improvements

Rim Cut

Seed Tree Cut

Wildlife Openings

Selection Cuttings

Diameter Limit Cut

High Grading

Commercial Thinning

Shelterwood Cut

Firewood Cut

Firebreaks

b) SKIDDING

A tree may be skidded in one of three forms: 1) shortwood, 2) tree length, or 3) full tree. Any one of the following devices may be used to skid the trees to the landing.

1) Four-Wheel Drive Articulating Skidder

2) Crawler Tractor

3) Wheeled Farm Tractor

4) Cable

5) Animal

6) Truck

7) Feller Buncher and Grapple Skidder

8) Payloader

9) Snowmobile

c) TRANSPORT

Once the trees reach the landing, they must be hauled to market via roads. The different types of forest road are listed below:

1) Permanent with Gravel Surface

2) Temporary

3) Existing Permanent Roads

d) RIGHT-OF-WAYS

The construction of roads or power lines may involve clearing the existing vegetation for a certain distance on either side. This is called a right-of-way. Regrowth of trees and tall shrubs is suppressed. This practice occurs in the following situations:

1) Road Right-Of-Ways (only for permanent roads)

2) Trail Corridors

3) Power Line Right-Of-Ways

e) WATERCOURSE CROSSINGS:

Sometimes the routes to market involve crossing streams, rivers, etc. When this occurs, the following methods of crossing the watercourse are employed:

1) Bridges

2) Culverts

3) Snowbridges

4) Earthern Bridges

5) Driving through the Watercourse

f) SITE PREPARATION

After the timber has been harvested from an area, the site must be prepared for the growth of a new crop. One or more of the following methods may be used:

1) Prescribed Burning

2) Chemical Spraying

3) Scalping

4) Furrowing

5) Scarification

6) Shearing

7) Felling Residuals

8) Brush Saw Clearing

9) Cull Felling

10) Plowing

11) Bulldozing

12) Windrowing

13) Piling Slash

14) Crushing & Scattering Slash

15) Roller Chopping

16) Root Raking

17) Rock Raking

18) Chemical & Mechanical Combinations

g) REGENERATION

Once the site is ready for a new crop, it will be regenerated in one of the following ways:

1) Natural Regeneration

2) Artificial Regeneration by Planting (machine or hand)

3) Artificial Regeneration by Seeding

h) TIMBER STAND IMPROVEMENT

During the growth of a new crop, the stand may require certain improvements in order to promote efficient and quality growth. Improvements which may be used are:

1) Non-Commercial Thinning

2) Pruning

3) Shearing

4) Release

5) Girdling

6) Bough Cuts

7) Fertilization

i) RECREATION

In order to facilitate recreational activity within the forest, removal of some vegetation may be necessary. The following types of development and uses each entailing some clearing of vegetation and disturbance to the land surface:

1) Campgrounds

2) Picnic Grounds

3) Trails (hunting, skiing, snowmobile, hiking, biking and horse)

4) Off-The-Road Vehicle Use

j) GRAZING

This category applies only to those situations where forested land is used as pasture for farm animals.

2. GROUPING OF ACTIVITIES

The preceding list of forest management practices is cumbersome to work with. Many of the practices, by nature of their purpose, exhibit similar site disturbance characteristics. The practices were grouped by these site disturbance characteristics into the categories which follow. The practices included in each category are listed, along with a brief explanation of why they were included.

a) FELLING SYSTEMS

CATEGORY 1: CLEARCUTTING

INCLUDES FOLLOWING PRACTICES	EXPLANATION
1. Clearcut in patches 2. Clearcut in progressive strips 3. Clearcut in alternate strips	The objective of each of these is to remove all or most of the trees within a given area.

4.	Harvest for disease control	When harvesting for disease, insect, salvage purposes, the entire stand is usually removed.
5.	Harvest for insect control	
6.	Harvest for salvage purposes	
7.	Harvest of over-mature timber	Over-mature timber is often clear-cut to salvage timber which may not be merchantable if left standing for a longer period of time.
8.	Conversion to another species	When the desired species is other than the present growing species, the present species must be clear-cut in order to establish the desired in most cases.
9.	Water yield improvements	When greater water yield is desired from a given unit of forest land, a harvest operation is usually required to achieve this result.
10.	Rim cut	A rim cut is comparable to a progressive strip cut, only the cut occurs around the rim (edges) of the entire stand, rather than cutting in straight, cross-sectional strips.
11.	Seed tree	A seed tree cut removes virtually all of the stand with the exception of a few

	residuals whose purpose is to provide seed for regeneration.
12. Wildlife openings	Wildlife openings are typically created in the forest by clearcuts. These openings may be maintained by the use of chemical or mechanical treatments, or allowed to grow back naturally.

CATEGORY 2: SELECTION CUTTING

INCLUDES FOLLOWING PRACTICES	EXPLANATION
1. Diameter limit	Trees up to a certain diameter limit are cut and all other trees are left. This method varies in terms of volume removed from the stand, depending on the distribution of tree diameters within the stand and the diameter limit at which the cutting is set.
2. High grading	By this method, trees are selected for harvest by one of two methods: 1) The forester cruises a stand and marks only a desirable species and the logger is not required to cut anything else.

2) A logger cuts only the best of a certain allowable species.

Either of these methods involve selection cutting. The trees remaining are usually undesirable and the stand is left in poor shape.

CATEGORY 3: SHELTERWOOD - contains no other practices

CATEGORY 4: COMMERCIAL THINNING - contains no other practices

CATEGORY 5: FIREBREAKS - contains no other practices

b) SKIDDING SYSTEMS:

CATEGORY 1: FOUR-WHEEL DRIVE ARTICULATING SKIDDER

CATEGORY 2: CRAWLER TRACTOR

CATEGORY 3: WHEELED FARM TRACTOR

Other methods of skidding listed in Part 1 of this section are seldom used. Therefore, they have been excluded from further analysis.

c) TRANSPORT (ROAD) SYSTEMS:

CATEGORY 1: PERMANENT WITH GRAVEL SURFACE

CATEGORY 2: TEMPORARY

CATEGORY 3: USE OF EXISTING ROAD SYSTEMS

CATEGORY 4: RIGHT-OF-WAYS

d) WATERCOURSE CROSSINGS:

The construction of watercourse crossings is an activity which pertains more closely to stream channel erosion than surface erosion. For this reason, watercourse crossings are not evaluated in this methodology.

e) SITE PREPARATION SYSTEMS:

CATEGORY 1: PRESCRIBED BURNING

This includes all operations where prescribed burning occurred alone or in combination with other site preparation practices.

CATEGORY 2: SCARIFICATION

INCLUDES FOLLOWING PRACTICES	EXPLANATION
1. Scalping	Scalping is also termed 'spot' scarification.

2. Furrowing	Furrowing consists of scarifying in lines.

CATEGORY 3: CLEARING

INCLUDES FOLLOWING PRACTICES	EXPLANATION
1. Shearing	This refers to shearing trees remaining after a harvest from the stump with the blade of a machine.
2. Felling residuals	This means cutting trees remaining after a harvest by a chainsaw or machine.
3. Brush saw	This involves removal of shrubs and small trees left after a harvest with a small saw.
4. Cull felling	This consists of cutting down diseased, decayed, insect-ridden or mis-shaped trees which are remaining after a harvest.

CATEGORY 4: PLOWING

No other practices are grouped with plowing.

CATEGORY 5: WINDROWING

'Piling of slash' is grouped with windrowing.

CATEGORY 6: CRUISING AND CHOPPING

No other practices are grouped with cruising and chopping.

CATEGORY 7: ROOT RAKE AND ROCK RAKE

These are very similar practices.

CATEGORY 8: CHEMICAL AND MECHANICAL SITE PREPARATION

This includes operations where chemical spraying was combined with mechanical site preparation. Chemical spraying alone has been dropped from further analysis since it does not relate to surface erosion.

f) TIMBER STAND IMPROVEMENT SYSTEMS:

INCLUDES FOLLOWING PRACTICES	EXPLANATION
1. Non-commercial thinning	Young, dense stands are thinned, usually by chainsaw, to obtain more growing room for remaining trees. The trees are not merchantable and are left on-site. Heavy machinery is seldom used.
2. Pruning	Lower branches are removed from the stem of the tree with clipper or chainsaws. Branches are left on-site. The practice promotes knot-free lumber.
3. Girdling	Girdling is a means of killing undesirable

		or diseased trees. The trees are left standing. No machinery is involved. The tree is killed by removing bark all around the tree.
4.	Shearing	This practice involves cutting the tips of branches off from the trees and promotes development of fuller, branchier trees. Shearing is usually practiced in Christmas tree plantations. No machinery is involved, and little slash is generated.
5.	Release	Release is accomplished by spraying the undesirable (competition) species with toxic chemicals or by cutting out brush (usually done with a chainsaw). No heavy machinery is involved. Little slash is generated with chemical release.
6.	Bough cut	This practice involves the removal of the green part of the lower branches by clippers, snippers, or chainsaws. These boughs are used to make wreaths, etc. It is not a stand improvement technique, per se, but is has the same types of disturbance associated with

it. Little slash is generated.

3. ESTIMATION OF SITE DISTURBANCE POTENTIAL OF GROUPED ACTIVITIES

The practices listed and described in the previous section are evaluated now on the basis of the following criteria:

1. Assessment of key types of disturbances most likely to cause surface erosion for each of the practices, and

2. Estimation of the degree or magnitude of these types of disturbances.

The three types of on-site disturbances which were discussed in Section II serve as the main basis for our analysis here. These three site disturbances are listed as follows:

1. EXPOSURE OF MINERAL SOIL,
2. COMPACTION OF MINERAL SOIL,
3. REMOVAL OF GROWING MATERIAL.

The impact of forest management on the water resource depends upon the severity of the changes in vegetal cover, the exposure and compaction of the mineral soil, and the proportion of the watershed affected (Anderson, Hoover & Reinhart, 1976).

In order for surface erosion to occur, mineral soil must be bared. For this reason, the degree of mineral soil exposure is assumed to be a primary factor in the surface erosion process.

Soil compaction is a compounding factor. Under normal circumstances not all eroded particles carried in overland flow reach forest streams. The filtering action of the forest floor traps most of the sediment. If soil infiltration rates remain high, the chances of accelerated sedimentation are minimal (Darrach, 1972). Soil compaction reduces infiltration rates, and when it accompanies bare mineral soil, the chance of surface erosion is greatly increased.

The more growing material removed in an area the greater the possibility of mineral soil exposure. A high degree of mineral soil exposed per given area, of course, indicates a high volume of growing material removed. However, the reverse is not always true. Soil compaction and volume of growing material removed are secondary factors.

Each of these three factors have been broken down into 3 qualitative classes: high, medium, and low. The following tables show the breakdowns for each factor.

(1) DEGREE OF MINERAL SOIL EXPOSED - PRIMARY FACTOR

HIGH	=	61 - 100 percent exposed (heavy rutting, root layer severed)
MEDIUM	=	41 - 60 percent exposed (root mat maintained)
LOW	=	0 - 41 percent exposed (little to no mineral soil exposed)

The percentage breaks were made where logical breaks occurred in the data received on our survey. A question was asked on the degree of mineral soil exposed by the harvest operation and the site preparation operation. These data are the primary source on which the practices were rated. The comments in parentheses are those site characteristics that would be associated with each category.

(2) DEGREE OF MINERAL SOIL COMPACTED - SECONDARY FACTOR

HIGH = deep mineral soil compaction in the form of ruts; machines use one trail as main travel route for long distances

MEDIUM = wheels or logs break through litter layer; mineral soil exposed and compacted shrubs broken down; machines may travel on same trail several times

LOW = wheel marks of machine visible but no mineral soil exposed; litter layer packed; machines usually travel on same area once.

Once the above categories were developed, literature review and analysis of our data gave us information on the relative soil compaction differences in equipment and yarding systems (Zasada and Trappeiner, 1969). We then rated the practices on this basis.

(3) DEGREE OF GROWING MATERIAL REMOVED - SECONDARY FACTOR

HIGH = all shrubs and trees felled or removed; herb layer heavily disturbed;

MEDIUM = most trees and shrubs felled or removed; herb layer mostly intact;

LOW = most trees and some shrubs felled or removed; herbs and some shrubs intact.

Only the practices which involved actual felling or removal of vegetation as their primary purpose were rated on degree of growing material removed.

SUBJECTIVE RELATIVE RATING:
BASED ON SITE DISTURBANCE POTENTIALS
AS INDICATED BELOW

	MAJOR ENVIRONMENTAL FACTORS		
a) FELLING & LOGGING SYSTEMS	SECONDARY	SECONDARY	PRIMARY
	DEGREE OF GROWING MATERIAL REMOVED	DEGREE OF SOIL COMPACTION	DEGREE OF MINERAL SOIL EXPOSED
Clearcut & Tree Length & Skidder	H	M	L
Clearcut & Shortwood & Wheel	H	L	L
Clearcut & Full Tree & Skidder	H	H	L
Selective & Tree Length & Skidder	M	H	L
Clearcut & Shortwood & Crawler	H	L	L
Clearcut & Shortwood & Skidder	H	M	L
Clearcut & Tree Length & Wheel	H	M	L
Thinning & Full Tree & Wheel	L	M	L
Selective & Shortwood & Wheel	M	L	L
Selective & Shortwood & Crawler	M	L	L
Selective & Tree Length & Crawler	M	M	L
Selective & Full Tree & Skidder	M	H	L
Clearcut & Tree Length & Crawler	H	L	L

<u>DISCUSSION</u>: "FELLING & LOGGING SYSTEMS"

The variables used for skidding equipment are listed:

1. Four-wheel drive articulating skidder
2. Crawler tractor
3. Farm tractor

For a given size and weight the articulating skidder will compact the soil to a greater degree than either the crawler or farm tractor. The articulating skidders have wheels which exert more pounds per square inch than the crawler tractor. The farm tractor also has wheels, but does not have the maneuverability of the skidder, and will not disturb as much mineral soil.

The combination of all of the above factors were used to rate the soil compaction potential for each of the thirteen felling and logging systems listed. The degree of mineral soil exposed for each of these operations was taken directly from our data. For all thirteen systems, over 90% of the operations exposed less than 40% of the mineral soil. For this reason all of these systems are rated 'low' in terms of their potential to cause mineral soil exposure.

b) MISCELLANEOUS SYSTEMS	SECONDARY	SECONDARY	PRIMARY
	DEGREE OF GROWING MATERIAL REMOVED	DEGREE OF SOIL COMPACTION	DEGREE OF MINERAL SOIL EXPOSED
TSI	L	L	L
Clearing for Firebreaks	H	H	H
Clearing for Rights-of-Way	M	H	L

DISCUSSION: "MISCELLANEOUS SYSTEMS"

TIMBER STAND IMPROVEMENT: The purpose of TSI is to maximize the volume of growing material in a stand. The operations usually remove only parts of trees or a few small trees. These operations ordinarily do not involve heavy machinery or removal of materials. For these reasons, soil compaction and exposure is minimal on most TSI operations.

CLEARING FOR FIREBREAKS: A firebreak is constructed during a fire to help prevent its spread. A firebreak line is usually bulldozed along the whole length of the fire front. The firebreak should be wide enough to keep the fire from jumping the line. The purpose of the firebreak, therefore, is to remove all burnable material from the fire's path. This exposes mineral soil and removes growing material. The action of the bulldozer is restricted to the firebreak line and will tend to cause heavy compaction in this area.

CLEARING FOR RIGHT-OF-WAY: The purpose of a right-of-way clearing is to suppress the growth of tall, woody trees and shrubs. These areas are harvested and then sprayed to keep this type of vegetation from returning. Growth of small shrubs and herbs is encouraged. Soil compaction is estimated as high, although localized, and mineral soil exposure is rated as low.

c) HAULING & TRANSPORT SYSTEMS	SECONDARY	SECONDARY	PRIMARY
	DEGREE OF GROWING MATERIAL REMOVED	DEGREE OF SOIL COMPACTION	DEGREE OF MINERAL SOIL EXPOSED
Permanent Access Roads	H	H	H
Temporary Access Roads	H	H	H

DISCUSSION: "HAULING & TRANSPORT SYSTEMS"

A purpose of any road is vehicular travel. In order to build a typical forest road, all growing material and obstructions must be removed, and the road surface must be hardened in some way. Mineral soil is exposed in the construction and repeated travel over the road leads to soil compaction. For these reasons, both permanent and temporary roads have received a high rating for each factor.

d) SITE PREPARATION METHODS	SECONDARY	SECONDARY	PRIMARY
	DEGREE OF GROWING MATERIAL REMOVED	DEGREE OF SOIL COMPACTION	DEGREE OF MINERAL SOIL EXPOSED
Prescribed Burning	M	L	L
Chopping & Scattering	H	M	L
Scarification	M	M	H
Windrowing	H	H	L
Root & Rock Raking	H	H	H
Clearing	H	M	L
Plowing	H	H	H
Chemical & Mechanical Combination	H	H	L

DISCUSSION: "SITE PREPARATION"

The main purpose of any site preparation operation is to manipulate the site into the environmental conditions best suited to the desired species. The degree of growing material removed depends, to a large extent, upon the cutting practice used in the harvest; and to a lesser degree upon the site requirements of the species. A species which requires bare mineral soil for regeneration necessitates removal of all or most of the growing material and the exposure of a high degree of mineral soil. Plowing and root and rock raking are the site preparation practices which exposed the highest amount of topsoil on the most number of operations. Scarification also involves exposure of mineral soil, but covers less of the area. Operations which only require the removal of existing vegetation or the crushing and scattering of harvest residues do not expose much mineral soil on the basis of the survey data.

e) ARTIFICIAL REGENERATION METHODS	SECONDARY	SECONDARY	PRIMARY
	DEGREE OF GROWING MATERIAL REMOVED	DEGREE OF SOIL COMPACTION	DEGREE OF MINERAL SOIL EXPOSED
Machine Planting	L	M	L
Hand Planting	L	L	L
Seeding	L	L	L

DISCUSSION: "ARTIFICIAL REGENERATION SYSTEMS"

The actual regeneration operations, where seeds are spread or trees are planted do not involve any further disturbance to the site. Any mineral soil exposure occurs during the site preparation operation. Seeding is usually done by plants or by hand and involves no further compaction of the soil. Artificial regeneration is necessary in order to ensure the reproduction of certain Minnesota species (see Silvicultural Guides in Appendix D).

f) RECREATION	SECONDARY	SECONDARY	PRIMARY
	DEGREE OF GROWING MATERIAL REMOVED	DEGREE OF SOIL COMPACTION	DEGREE OF MINERAL SOIL EXPOSED
Campgrounds	M	H	H
Picnic Grounds	M	H	H
Trail Construction & Use	H	H	H
Hunting Trails	H	H	H
Orv Trails	H	H	H

DISCUSSION: "RECREATION"

The use of the forest for recreation often involves the manipulation of the vegetation and is therefore a type of forest management. Recreation differs greatly from silviculture in one major respect -- frequency of disturbance. Silviculture, by its very nature involves application of stand treatments on an infrequent basis -- perhaps once in 50 years. Recreation involves the entry of people and their mode of transportation into the same areas year after year. There is little time, if any, for a site to recover between visits. Recreationists are often restricted to certain areas (trails, campgrounds, etc.). Constant use of these areas compacts the mineral soil and over time exposes the mineral soil. These localized areas can serve as channels for surface runoff and increase the potential for erosion. The ratings given above assume a high use area where no rotation of use is practiced.

g) GRAZING	SECONDARY	SECONDARY	PRIMARY
	DEGREE OF GROWING MATERIAL REMOVED	DEGREE OF SOIL COMPACTION	DEGREE OF MINERAL SOIL EXPOSED
Grazing	H	H	M-H

DISCUSSION: "GRAZING"

Grazing is not a forest management practice, per se (i.e. it does not involve the removal or manipulation of the trees). However, grazing does disturb a forested site. Grazing, like recreation, involves constant and repeated use of a given area. The presence of many heavy, hoofed animals compacts the soil and with time exposes bare mineral soil. Any herbaceous vegetation is either eaten or trampled. Bare and compacted forested pastures have lost the water purifying characteristics normally associated with a forest. All or most of the precipitation which falls onto such areas is lost to surface runoff. This runoff not only carries sediments, but pathogens and nutrients contained in the wastes of the grazing animals as well. Growth of the trees in the pasture slows because the soil becomes dry and compacted.

4. ANALYSIS OF THOSE PRACTICES WITH THE MOST POTENTIAL FOR SITE DISTURBANCE

Those practices with the most potential for site disturbance are now assessed in greater detail. The ones singled out for further analysis received a 'High' rating for each of the three disturbance factors. These practices are given below:

1. Clearing for firebreaks
2. Permanent access roads

3. Temporary access roads

4. Root and rock raking (site preparation)

5. Plowing (site preparation)

6. Grazing

7. Recreation

Figure 10 displays forest management practice data received on the public landowners survey. The practices shown on this map include those rated as 'high' in terms of site disturbance potential (firebreaks, permanent and temporary access roads, plowing and root and rock raking). The number of operations per cell ranged from 1 to 13, and only two cells in the whole state had more than four.

Figure 11 displays practices for data received on the private landowners survey. High site disturbance practices shown on this map are grazing, mechanical site preparation, and a combination of harvest and site preparation. These categories are a little different from those associated with public landowner survey data. This is due to differences in the questions and the nature of the responses between the two surveys. The major differences are as follows: 1) harvest and site preparation plus mechanical site preparation have not been broken down into component practices, and 2) roads have not been subdivided into permanent and temporary categories. Harvest and site preparation are not discussed further since no conclusions can be made as to which activity most contributed to site disturbance. They are not considered together since the practices associated with each activity differ in purpose and level of disturbance.

The map (Fig. 11) indicates the number of times the above mentioned, high site disturbance potential activities occurred within each five kilometer square cell. The numbers ranged from 0 to 6, with 42 cells exhibiting only a single occurrence. The total number of operations among these activities is 122.

The following maps display each of the high site disturbance practices separately.

FIGURE 13: TEMPORARY FOREST ROADS BUILT IN 1977 - PUBLIC LANDOWNERS SURVEY

The number of roads built per 5k all ranged from 0-13. There were no road building activities in the southeast. The bulk of these roads were built in the east-central and northeast portion of the state. The map represents a total of 191 operations and of these, 104 occurred only once per 5k cell.

FIGURE 16: PERMANENT FOREST ROADS BUILT IN 1977 - PUBLIC LANDOWNERS SURVEY

The number of these roads built per 5k cell ranged from zero to 3. A total of 40 operations are represented, and 29 of these occurred only once per 5k cell. This type of road building occurred almost exclusively in the northeast portion of the state.

FIGURE 18: FOREST ROADS BUILT ON PRIVATE LAND - PRIVATE LANDOWNERS SURVEY

The maximum number of roads built per 5k cell was one. The data represents a total of 31 operations, all of which were fairly evenly distributed throughout the state.

FIGURE 12: FIREBREAKS - PUBLIC LANDOWNERS SURVEY

A relatively low occurrence of firebreak operations were reported. A total of 14 operations are shown, none of which occurred more than one time per 5k cell.

FIGURE 15: PLOWING FOR SITE PREPARATION - PUBLIC LANDOWNER SURVEY

Only 18 operations in our data used plowing as a method of site preparation. The maximum number of operations per 5k cell was two, which occurred in two 5k cells. The plowing operations were most common in the west central and central portions of the state.

FIGURE 14: ROOT AND ROCK RAKING FOR SITE PREPARATION - PUBLIC LANDOWNERS SURVEY

Data were received for 25 root and rock raking operations. The number per 5k cell ranged from 0-3, and most of these occurred in the central portion of the state.

FIGURE 17: MECHANICAL SITE PREPARATION - PRIVATE LANDOWNERS SURVEY

This map represents all reported operations which were site preparation only. Only 10 operations were reported. A maximum of 2 operations were observed per 5k cell. Other site preparation operations occurred on private land, but they were included with harvesting.

C. ANALYSIS OF THE POTENTIAL FOR WATER QUALITY PROBLEMS IN MINNESOTA BASED ON THE INTENSITY OF FOREST MANAGEMENT ACTIVITIES WITH HIGH SITE DISTURBANCE POTENTIAL IN HIGH EROSION POTENTIAL GEOMORPHIC REGIONS.

In the previous two sections, the relationship of forestry in Minnesota to potential impacts on water quality were discussed in the context of the following approaches:

1) erosion potential indicator classes, and
2) potentially site disturbing forest management activities.

Both approaches are combined in this section. The potential is assessed for those activities with a high site disturbance potential to occur on high erosion potential sites.

Those geomorphic regions which contain some area in the highest erosion potential indicator class (based on maximum slope) are used in this analysis. Nine geomorphic regions fit this description, and they represent those areas that have the highest probability for sites with the steepest slopes and most erodible soils within the project area. The higher the percentage of this class contained within a geomorphic region, the higher the proportion of steep slopes and erodible of soils in the region (see Table 6).

All forest management activity data were entered by location into the MLMIS system. These data can also be portrayed by geomorphic region. Total activity per geomorphic region and the percentage of those activities which are potentially site disturbing can be displayed (Table 7). Figures 19 and 20 show the total number of forest management activities, per selected geomorphic region, for the public and private landowners surveys respectively. Figures 21 and 22 show the number of potentially high site disturbing activities which occur within each geomorphic region, on the public and private landowners surveys respectively.

TABLE 6

PERCENTAGE DISTRIBUTIONS OF HIGHEST MAXIMUM SLOPE EROSION POTENTIAL INDICATOR CLASS BY GEOMORPHIC REGION

	GEOMORPHIC REGION	PERCENT OF GEOMORPHIC REGION IN HIGHEST EROSION POTENTIAL CLASS	PERCENT OF HIGHEST CLASS IN THE GEOMORPHIC
1.	Red Wing - La Crescent Uplands	92%	41.5%
2.	Itasca Moraine	79%	31.5%
3.	Aurora Till Plain	55%	10.5%
4.	Nashwaukwarba Moraine	29%	5.0%
5.	Marcell Moraine	33%	4.0%
6.	Mille-Lacs Moraine	15%	3.5%
7.	Mesabi Range	14%	2.0%
8.	Nickerson Moraine	38%	1.5%
9.	Thomson-Cloquet Moraine	10%	.5%

These nine regions represent all of the geomorphics which contain some portion of the highest erosion potential class within their boundaries.

The discussion which follows describes each of the nine selected geomorphic regions on the basis of erosion potential indicator classes and occurrence of high site disturbance potential activities. The reader is referred to Minnesota Soil Atlases (University of Minnesota, 1969 et. sequence) for more detailed descriptions of the regions. In addition Table 8 contains a tabulation of K-factor, slope range, and erosion class data for each of the nine regions.

1. RED WING-LA CRESCENT REGION:

TABLE 7

NUMBER OF ALL OPERATIONS AND HIGH SITE DISTURBANCE POTENTIAL OPERATIONS FOR GEOMORPHIC REGIONS WITH THE HIGHEST EROSION POTENTIAL INDICATOR CLASS

GEOMORPHIC REGION	PUBLIC LANDOWNER'S SURVEY			PRIVATE LANDOWNER'S SURVEY			COMBINED RESULTS OF BOTH SURVEYS		
	NUMBER OF ALL OPERATIONS	NUMBER OF SITE DISTURBING OPERATIONS	PERCENT OF OPERATIONS WHICH ARE SITE DISTURBING	NUMBER OF ALL OPERATIONS	NUMBER OF SITE DISTURBING OPERATIONS	PERCENT OF OPERATIONS WHICH ARE SITE DISTURBING	NUMBER OF ALL OPERATIONS	NUMBER OF SITE DISTURBING OPERATIONS	PERCENT OF OPERATIONS WHICH ARE SITE DISTURBING
1. Red Wing-LaCrescent Uplands	42	1	2.3	57	25	43.8	105	27	24.7
2. Itasca Moraine	85	19	22.3	0	0	0	85	19	22.3
3. Aurora Till Plain	19	7	36.8	11	0	0	30	7	23.3
4. Nashwauk-warba Moraine	23	9	43.4	2	1	50.0	25	10	40.0
5. Marcell Moraine	16	4	25.0	20	1	5.0	21	5	23.8
6. Mille-Lacs Moraine	27	10	37.0	13	4	30.7	40	14	35.0
7. Mesabi Range	21	7	33.3	0	0	0	21	7	33.3
8. Nickerson Moraine	12	4	33.3	1	1	100	13	5	38.4
9. Thomson Cloquet Moraine	3	1	33.3	2	1	50.0	5	2	40.0

TABLE 8

PERCENTAGE DISTRIBUTION OF K-FACTOR, MAXIMUM SLOPE, AND EROSION POTENTIAL INDICATOR CLASSES IN THE NINE SELECTED GEOMORPHIC REGIONS

PERCENTAGE DISTRIBUTIONS

	K-FACTOR RANGE		MAXIMUM SLOPE RANGE			EROSION POTENTIAL INDICATOR CLASS			
	0 - .30	.31 - .43	0-12%	13-20%	> 25%	4	3	2	1
1. Red Wing-LaCrescent Uplands	1	99	8	--	92	92	--	--	8
2. Itasca Moraine	99	1	8	11	81	78	11	1	10
3. Aurora Till Plain	19	81	11	13	76	55	22	6	17
4. Nashwaukwarba Moraine	46	54	62	38	--	38	31	31	--
5. Marcell Moraine	40	60	45	55	--	34	47	--	19
6. Mille-Lacs Moraine	21	79	71	29	--	29	58	2	11
7. Mesabi Range	95	5	85	--	15	16	48	6	30
8. Nickerson Moraine	85	15	37	18	45	14	57	--	29
9. Thomson Cloquet Moraine	53	47	47	42	11	11	89	--	--

"The Red Wing-La Crescent Uplands consists of the coulees, bluffs, and associated ridges and alleys adjoining the Mississippi River and its minor tributaries. Topography is largely bedrock controlled. Sloping to steeply sloping ridges are bordered by steep bluffs and steeply sloping valleys" (Minnesota Soil Atlas, St. Paul Sheet).

The Red Wing-La Crescent Region contains 41.5% of the highest erosion potential indicator class. This class is distributed over 92% of the region.

This region also contained the highest number of forest management activities. Forty-two public operations and 57 private operations (99 total), were reported. Of these total operations, 1 public operation (permanent road) and 25 private operations were identified as having a high potential for site disturbance, for a total of 26 or 24.7 percent of the total within the region. This is the highest number of operations with a high site disturbance potential recorded for any of the nine geomorphic regions.

2. ITASCA MORAINE

"The prominent Itasca Moraine Complex has rolling to steep knob and kettle topography. There are 38 lakes, each over 160 acres in size located in this geomorphic region. The moraine consists of limy sandy loam glacial till. Pockets of sand and gravel are intermixed with the till in about 60 percent of the region. The region also includes a few small gravelly outwash areas" (Minnesota Soil Atlas, Brainerd Sheet).

The Itasca Moraine contains 31.5% of the highest erosion potential class. This class is distributed over 79% of the region. According to the resource data, the soils are generally less erodible than those in the Red Wing-La Crescent Region, and the steepest maximum slope class is less extensive.

Forest management activity is also high in this region. A total of 85 operations were reported, which is second highest among the regions. Nineteen or 22.3 percent of these operations were rated as having a high potential for site disturbance.

All nineteen were recorded on the public landowners survey. These included 3 root and rock raking, 1 plowing, 1 firebreak, 1 permanent road-building and 13 temporary road-building operations.

3. AURORA TILL PLAIN

Most of the Aurora Till Plain is rolling to hilly topography with short irregular slopes, although areas of less rolling topography occur. Some 18 lakes, 160 acres or more in size and totalling 4,690 acres, are located in the region.

"The till is a reddish-brown calcareous silty clay. In some localities, it is capped with silt loam or loam 6 to 12 inches thick, and in places, up to 24 inches. Soils contain slightly lower clay percentages towards the southern portion of the region" (Minnesota Soil Atlas, Hibbing Sheet).

The Aurora Till Plain contains the third highest percentage of the highest erosion class, and this class is distributed over 55% of the region. The soils are potentially more erodible than those in the Itasca Moraine, but the maximum slopes are not usually as steep as those in either the Red Wing or Itasca Regions.

Forest management activity in this region was considerably lower than in either the Itasca or Red Wing region. All of the 30 operations occurring in this region were taken from the public landowners survey. Seven or 23.3 percent, belonged to the high site disturbance potential category. Four of these were road-building, and the remaining 3 were firebreak construction operations.

The three geomorphic regions discussed next contain a considerably lower percentage of the highest erosion class and the class is distributed over a smaller percentage of the region. Forest management activity was also less.

4. NICKERSON MORAINE

"The moraine is characterized by extremely short and irregular topography. Small wet depressions and small peat bogs are fairly common. There are six lakes and part of Sturgeon, each 160 acres or more in size, totalling about 2,650 acres."

"Textures of the till ranges from loam to clay. The drift includes areas of water sorted sand and gravel. The drift is reddish-brown and neutral to mildly alkaline. The water-holding capacity ranges from high to low in most of the region" (Minnesota Soil Atlas, Duluth Sheet).

Only 1.5% of the highest erosion class is contained within this region, but it is distributed over 38% of the region. This is probably due to the small size of the region. A little over 50% of the region is covered by soils in the highest erodibility class, but none of the slopes fall into the steepest class.

Forest management in this area was also low. Only 13 operations were recorded for this area, 5 of which were those in the high site disturbance potential class. Only one of these occurred on private land. Of those recorded on the public landowners survey, two were temporary road building operations, one was a plowing operation and one was a firebreak operation.

5. MARCELL MORAINE

"This is a prominent moraine with rolling to steep complex topography. Potholes and small bogs are common. Some 66 lakes, each 160 acres or more in size and totalling 26,560 acres are located in the region."

"Brown-colored, calcareous clay loam till, in places intermixed with deep sands and gravels, covers the region. A sand cap, generally less than a foot thick, covers much of the till. Soils are generally well to moderately well drained" (Minnesota Soil Atlas, Hibbing Sheet).

The Marcell Moraine contains a larger percent (4.0%) of the highest erosion potential class than the Nickerson Moraine, but because of its large size, the class is distributed over only 33% of the region. Sixty percent of the soils fall into the highest erodibility class, but maximum slopes in the highest class are completely absent.

Twenty-one forest management operations occurred in this region. Five of these (23.8% of the total) were in the high site disturbance potential class. Four of these were recorded on the public landowners survey and represent temporary road building operations. The one private operation was a combination of harvest and site preparation.

6. NASHWAUK-WARBA MORAINE

"Topographically, the Nashwauk-Warba Moraine is generally rolling, but includes lesser areas, which are gently rolling to steep. Slopes are relatively short and complex, and with numerous small bogs and potholes. There are 27 lakes, each 160 acres or more in size totalling 15,340 acres, in the region."

"A thick deposit of brown-colored calcareous, clay loam glacial till covers this region. Stones are common throughout and much of the area south of the Mesabi Range is intermixed till, sand and gravel. Relatively large areas of deep sand and gravel are located between Trout and Swan lakes. Shallow sand, 12 to 40 inches thick over-lying clay loam till, also occurs. Several small prominent areas of rock outcrop are delineated northwest of Chisholm" (Minnesota Soil Atlas, Hibbing Sheet).

Five percent of the highest erosion potential class is found in this region, but the class is distributed over only 29% of the region. However, this region is larger in size than either the Marcell or Nickerson Moraine. A large proportion (79%) of the soils are in the highest erodibility class, but none of the slopes fell into the highest slope class.

Twenty-five forest management operations occurred in this region. Of these, only 2 were on private land. Eleven operations were in the high site disturbance potential class. All of the high site disturbing operations recorded on the public landowners survey were temporary road building operations. The one on private land was a harvest and site preparation operation.

The three remaining geomorphics contain very low percentages of the high erosion potential class. This class is also distributed over a very low percent of the regions (15 percent or less).

7. MILLE-LACS MORAINE

"The soil materials are primarily red-colored clayey till. The topography is rolling to hilly, with a few nearly level areas. Along the west edge of the moraine, the materials are mixed with brown, sandy loam till" (Minnesota Soil Atlas, Duluth Sheet).

The Mille Lacs Moraine contains 3.5% of the highest erosion potential class. This class covers only 15% of the region. Only 5% of the sites fell into the highest soil erodibility class, but some slopes belonged to the highest slope class.

A proportionately large number of forest management operations were reported in this region. Twenty-seven of these were reported on the public landowners survey, and 13 on the private landowners survey.

Fourteen, or 35%, of the operations were in the high site disturbance potential class. The public landowners reported 10 temporary road building operations in this region. The private landowners reported 2 road building operations and 2 harvest and site preparation operations.

8. MESABI RANGE

"The region is covered with stony drift ranging from loamy sand to sandy loam in texture. The drift is very shallow in St. Louis County east of Chisholm and thicker west of Chisholm. Bedrock outcrops cover about 5 percent of the area. Numerous deep, open pit iron ore mines and large high dumps, have vastly changed the landscape of the Mesabi Iron Range. Gently rolling to rolling topography prevails in this area where not disturbed by mines and dumps. Reddish clayey till dominates with inclusions of brownish sandy loam and clay loam till" (Minnesota Soil Atlas, Hibbing Sheet).

The Mesabi Range contains only 2.0% of the highest erosion potential class. This class is distributed over approximately 14% of the region. If the mining areas are not included, this class would cover a larger percentage of the region (approximately 28%).

Forty-five percent of the region is in the highest slope class, and 15% is in the highest erosion potential class.

Twenty-one forest management operations were recorded in the surveys for this region. No operations were reported on the private landowners survey. Of the 21 reported on the public landowners survey, 7 or 33% were in the high site disturbance potential category. Six of these were temporary road-building operations, and one was a root and rock raking operation.

9. THOMSON-CLOQUET MORAINE

"The topography is rolling in most of the region, but includes hilly land. Small wet depressions and peat bogs are common. Some bedrock outcrops occur in the northern part. There are five lakes, each 160 acres or more in size and totalling about 2,300 acres."

"About 42 percent of the region is sandy loam to loam till. About 36 percent is water-sorted sand and gravel. Another 11 percent consists of intermixed coarse and loamy drift. The drift is reddish-brown and non-limy. The water-holding capacity ranges from high to low" (Minnesota Soil Atlas, Duluth Sheet).

The Thomson-Cloquet Moraine contains the smallest percent (.5%) of the high erosion potential class and it covers only 10% of the region. Approximately half of the geomorphic region has soils in the high erodibility class, but only 11% of the region is in the highest slope class.

Forest management activity was also the lowest in this region. Only 5 operations were reported. Of these 5, only 2 were in the high site disturbance potential class. Both of these were road building operations.

D. SUMMARY

An assessment of the potential hazards to the water quality of Minnesota stemming from forest management activities has been made on the basis of critical resource features and site disturbance characteristics associated with the activities. The focus of our analysis is on the relationship of these factors to surface land erosion since sedimentation is a potential result of this process. Sediment is generally considered to be the most significant type of pollutant associated with forestry activities. Although the potential for mass wasting is not systematically assessed in our analysis, the severity of problems associated with this process is generally believed to be quite low or insignificant in Minnesota.

Slope and soil K-factor characteristics were analyzed throughout the project study area, providing a basis for assessment of surface erosion potential. In general, forested areas of the state appear to be relatively stable in terms of susceptibility to soil loss. The topography is mostly flat or rolling, and only one area (Nemadge-River Basin) contains soils with clearly observed erosion problems. Certain regions, however, do exhibit variability in terms of these resource parameters, distinguishing some of them as relatively high in terms of erosion potential.

The southeast part of the project area, which includes the Red Wing-La Crescent uplands, exhibits the steepest topography and contains the most erodible soils. The highest erosion potential indicator class based on estimated average slope is localized in this region. Erosion potential indicator classes based on maximum slope estimates, which reflect the most extreme conditions of hazard, indicate that the most hazardous areas are located in the southeast, northeast and west central regions of the project area.

An inventory of all forest management activities has been performed on the basis of data from two written surveys. One was sent to public agencies and timber companies with large land holdings, and the other to small woodlot owners. Management operations were evaluated in terms of their potential hazard on the basis of the following criteria: 1) degree of mineral soil exposure, 2) amount of soil compaction, and 3) volume of growing material removed.

The public agency survey provided detailed data for approximately 1,600 management operations. Six types of practices have been rated as "high" in terms of site disturbance potential. Detailed data for individual operations are available for five of these practices, which are listed as follows: 1) clearing for firebreaks, 2) permanent access roads, 3) temporary access roads, 4) root and rock raking, and 5) plowing. In addition, certain types of recreational activities are considered to be in the high hazard category, and they are construction and use of campgrounds, picnic grounds, hunting trails, and ORV trails.

The intensity of each of the high site disturbance practices have been analyzed on the basis of geomorphic regions. Those regions with at least some portion of their area assigned to the highest erosion potential indicator class (based on maximum slope) were singled out for intensive analyses.

The Red Wing-La Crescent uplands is the most susceptible to surface erosion, as pointed out earlier. The total number of operations reported for this region is 99 (42 and 57 for the public and private surveys, respectively). Of this total, 20 operations were rated as "high" in terms of site disturbance potential, the highest number among the geomophic regions analyzed.

A total of 85 operations were reported for the Itasca Moraine, of which 19 were rated as high disturbance potential activities. In the Aurora Till Plain, 7 of the 30 operations were in the high disturbance potential category.

The three geomorphic regions mentioned thus far account for 82% of the area assigned to the highest erosion potential indicator class based on maximum slope. The total number of operations in the high site disturbance potential category among these three regions is 52, or 18% of the total for the project area. This means that approximately one-fifth of the high site disturbance operations reported in our surveys occurred on about 7% of the project study area. Furthermore, the total occurrences of operations involving firebreaks, plowing and root and rock raking was relatively small in comparison to road construction operations. Thus, the data indicates that a disproportionately high number of high site disturbance practices occurred in the regions of the state most prone to surface erosion. Also, it indicates road construction is the high site disturbance practice that occurs with the greatest intensity.

SEGMENT II

SECTION VI

ECONOMIC ANALYSIS

A. INTRODUCTION

The consideration of forest management practices as possible sources of pollution has emerged as a major policy issue since Section 208 of Public Law 92-500 was incorporated in the U. S. Codes (U. S. Congress 1972). In seeking answers to questions of public policy, administrators must weigh institutional, technological, socio-political and economic considerations. One persistent problem in pollution control programs has been the lack of consideration given to the relationship between control practices and costs (Howe 1971). Hopefully, this report will assist in choosing economically feasible pollution abatement strategies for forest management practices in Minnesota.

1. Purpose

The purpose of this report is to provide background information on the following subjects for a general audience:

(1) A perspective on the direct costs of current forest management practices in Minnesota.

(2) An estimation of the cost of modifying current management practices by adding erosion control measures.

(3) The economic impact of incurring additional costs in the forestry sector.

(4) The relative magnitude and distribution of this impact..

2. Scope

In order to provide continuity with preceeding segments of the Problem Assessment, plus meet the constraints imposed by available time, the analysis will be limited in the following manner:

(1) Only cost-price-revenue structures, and not benefits or economic efficiency,

will be analyzed.

(2) Focus will be on economic structures representative of the statewide situation - not specific regional or operational conditions.

(3) Impacts will be considered only in the forestry sector, and not extended through multipliers to the general economy.

(4) Consideration will be given only to those practices and situations which appear significant from the standpoint of the study (sample) data.

(5) Only key relationships will be explicitly treated - interdependencies and multiple linkages will be considered only through inference.

B. METHODOLOGY

Efforts to approximate economic behavior in the forestry sector have taken a number of different approaches. They can be separated into four major classes: trend models; nonspatial econometric models; spatial models; and quasi-spatial models (Adams, et. al. 1977). The methodology chosen for this study is essentially that of trend modeling with the addition of some nonspatial econometric modeling techniques.

1. Analytical Structure

Determining the impacts of alternative management practices, as influenced by changes in public policy, requires analyzing both the distribution of costs and their magnitudes. The specific parameters chosen to identify these cost factors, and their implications, are:

(1) The elasticity of price transmission in the forestry sector.[1]

[1] Elasticity of price transmission is, in simple terms, a measure of the ability to transfer costs from one party to another (e.g., from producer to consumer).

(2) The price elasticity of supply and demand in the forestry sector.[2]

(3) The rate of return on investment, or the margin for profit and risk, in the forestry sector.

The choice of analytical methodology and parameters is dictated, in part, by the need to limit the scope of analysis to the primary level of impact occurrence. A valid constraint, because programs which affect supply and supply functions have a greater impact at the primary level than at the retail level (Haynes 1977).

Lacking a definitive statistical relationship between the Problem Assessment data, or sample population, and the total population (i.e., actual, total occurrence of practices by sensitive areas, geomorphic regions, etc.) restricted the choice of methodologies. This choice was further restricted by time constraints, and by the unavailability of data specific to the forest sector of Minnesota's economy. Based on these restrictions a state wide approach was selected as the best possible means of providing tentative measures of cost and impact.

2. Limitations

The approach utilized in the analysis only applies to changes from one equilibrium point to another - i.e., it only gauges the cost implications before and after. The method does not provide any insight into the adjustment process while moving between those equilibrium points. The amount of data required for a complete analysis is quite substantial. In many instances, adequate data for Minnesota was unavailable, therefore estimates from other states were used. This has led to cost and impact estimates of somewhat questionable reliability.

[2] Price elasticity is a measure of anticipated change in the level of product demand (or supply) that is related to a specified change in price.

Obviously, with relationships determined on the basis of fixed proportions, substantial changes may take place during the period of time it takes to go from the "before" to the "after" situations referred to above. However, this is not viewed as a major limitation. In the case of forest management, assuming relationships on the basis of fixed proportions is not unreasonable (Haynes 1977). This is because, in the short term, technology and methodology tend to be very inflexible, and the planning horizons[3] for Public Law 92-500 are short relative to those of forest management.

It is important to reiterate that the analysis is conducted at the statewide level and does not attempt to measure differences at regional or local levels. Work done on the elasticity of price transmission at the national level indicates that disparities may exist between various forested regions (Haynes 1977). Therefore, we must assume that differences in costs, revenues and impact distributions probably exist between regions within the state of Minnesota, and are not accounted for in the analysis. The difficulties with the approach we have chosen stem from: (1) not explicitly recognizing differences in cost and production characteristics; (2) not identifying variabilities in factor linkages over time; and (3) not accounting for specific geographic differences in demand (Adams, et. al. 1977a). All of this leads to some uncertainty in specifying absolute dollar values for the cost and impact of water quality constraints on forest management practices. However, the analysis does provide reasonably accurate cost relationships between pollution control measures and current forest management practices in Minnesota.

3. Basic Assumptions

Several basic assumptions are employed to provide internal consistency, and help

[3] The 1983 and 1985 deadlines established by Public Law 92-500.

to "simplify" the analysis. Unfortunately, they also tend to separate the analytical world from the real world. Some of the major assumptions are:

(1) Firms and individuals are economically rational - i.e. their decisions are directed toward maximizing net benefits per unit of output at all times - surely an abstraction (Duerr 1960).

(2) The "Ceteris Paribus" (other factors being equal, or remaining unchanged) assumption common to all economic analyses.

(3) The use of average cost-price-revenue data assumes an operation of "average efficiency" - i.e., there are no differences between firms (or individuals).

(4) Employment of data not derived from Minnesota sources implies that the economic functions of forest management practices in Minnesota are not significantly different from those of the data source.

4. Underlying Considerations

To judge the impact of costs, it is necessary to know what the relationship is between costs and revenues, or profits. One measure of this relationship is called 'rate of return' (ROR). In a case study in southern Minnesota, an ROR for a typical harvesting operation was determined to be 13.7% (Weible 1978). Boise Cascade Corporation, a large forest products firm conducting operations in Minnesota, has established a 12% minimum ROR on all corporate projects, except those necessary to maintain facilities, and those necessary to meet legal requirements.[4] All of the available data indicates that an average ROR of 12.8% would be a fair estimate of the true ROR for the forest sector of Minnesota's economy, and was therefore used in this analysis.

[4] From a letter to stockholders by John B. Fery, Chairman of the Board and Chief Executive Officer, dated December 12, 1978.

Throughout the analysis, the words "average conditions" are used in reference to the Study Area, the various practices and their cost functions, et cetera. These average conditions can be composed of any number of different variables and values thereof, but to conduct an analysis some commonality must be established. With reference to geomorphics, erosion potential, and practice costs, the commonality is found in - SLOPE. Slope is the common variable between all three classifications which appears to be significant.

Slopes below 17% are not a significant cost variable, while slopes above 35 to 45 percent can cause operating costs to become prohibitive.[5] Because average, statewide costs have been used in the analysis, it is necessary to assume that they apply to the average, statewide slope. This average, statewide slope is assumed to be 11%, which is the weighted mean, Average Maximum Slope that is likely to be encountered in Minnesota (See Table 1).

According to the Problem Assessment data, potentially sensitive areas have slopes which are above 13 percent. This is where analytical concern should be centered if specific cost data were available. Without that data, we can only speculate that actual costs may be higher than the analytical estimates developed in the following pages. Based on the cost-slope relationships developed by Schillings (1969a), this cost increase may be on the order of 9 to 15 percent.

[5] Source: U. S. Forest Service Manual, Title 5100, page 5153.18b-1, Oct. 71, Amend. 35.

Table 1

Calculation of Weighted Mean, Average Maximum Slope

A	B	C	D
Slope Class (%)	% of the Study Area	Midpoint Value	B x C
0-4	31.8	2	63.60
5-8	16.5	6.5	107.25
9-12	21.1	10.5	221.55
13-20	15.4	16.5	254.10
21-40[a]	15.2	30.5	463.60
Total	100	--	1110.10

Assumed Weighted Mean = 1110.1 ÷ 100

= 11.1%

[a] 40% Average Maximum Slope is assumed to be the upper end of the range at which machinery costs are not considered to be excessive (adapted from U.S.F.S. Manual, Title 5100, page 5153.18b-1, Oct. 71, Amend. 35)

C. CURRENT PRACTICE COSTS

Consideration of current costs will be limited to those practices identified in earlier portions of the Problem Assessment. Those practices are:

(1) Temporary Road Construction

(2) Permanent Road Construction

(3) Fire Break Construction

(4) Planting Site Preparation Techniques

(5) Harvesting Operations (i.e., skidding)[1]

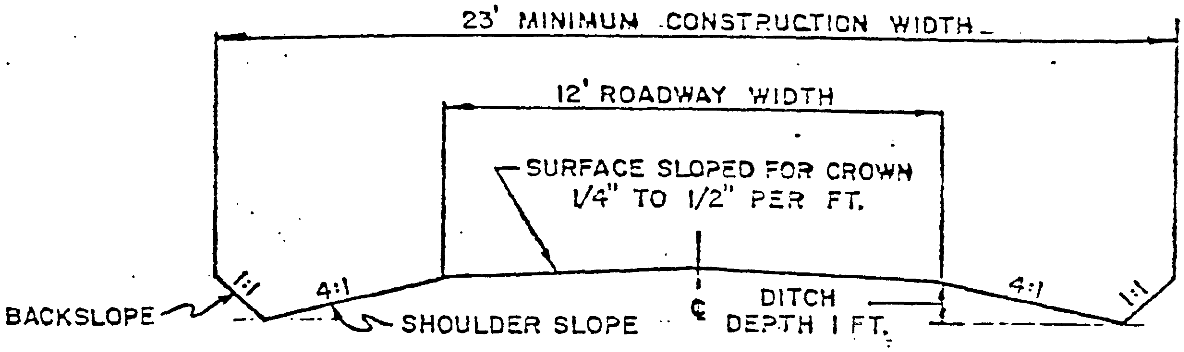
A review of the data compiled for the Problem Assessment indicates that a high correlation exists between machinery operations and nonpoint pollution potential. For this reason, the cost analyses will attempt to highlight the machinery functions of each identified practice, whenever possible.

1. Road Construction

The 'silvicultural practice' with the most significant nonpoint pollution potential is construction of the forest road network. For analytical purposes, this network was broken down into two catagories - temporary roads and permanent roads - with greater pollution potential attributed to the former.

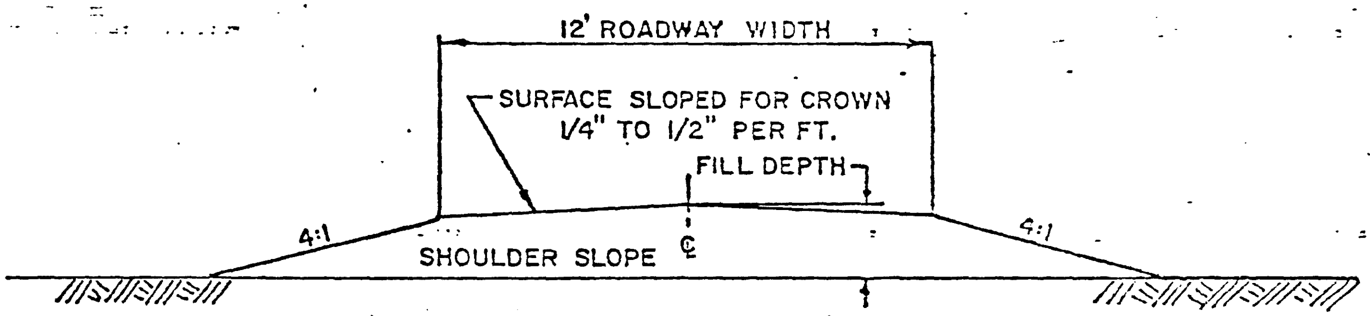
A temporary road is any travelway through the forest established by bulldozers or other blade-equipped machines. The only design standards are sufficient clearance and alignment (both horizontal and vertical) to allow passage of loaded trucks during

[1] Harvesting operations are included in this list because of the frequency of occurence and relationship to other listed practices.



BLADING AND SHAPING SECTION

SCALE: 1" = 5'



FILL SECTION

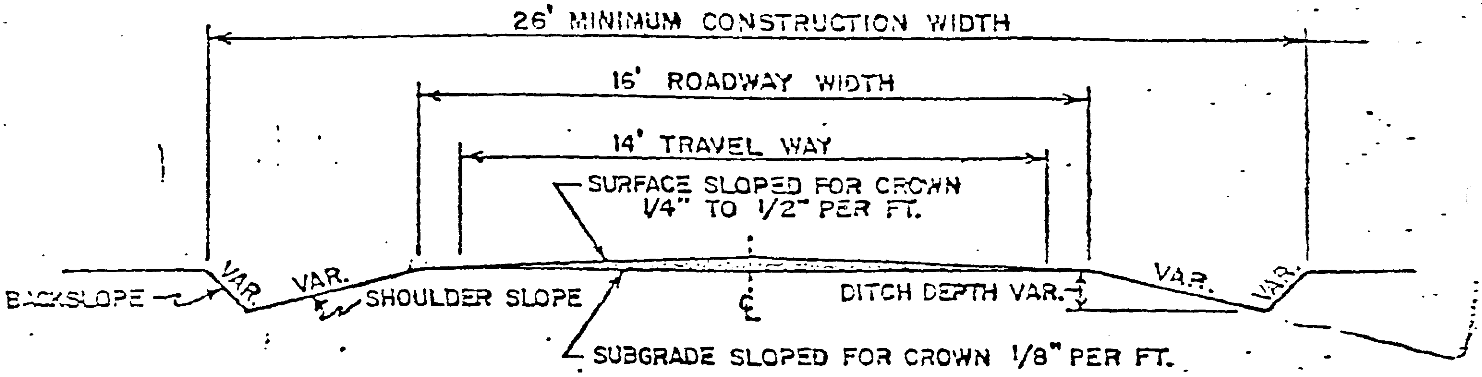
SCALE: 1" = 5'

MINNESOTA CONSERVATION DEPARTMENT

CONSTRUCTION DETAILS

12 FT. ROADWAY
SOIL SURFACE

SEC.	T. N. / R. W.	TH. P.M.
DRAWN JAJ 2-24-66	BUREAU OF ENGINEERING	SURVEY
CHECKED GJC 2-24-66		DATUM
REVISED	2-27-67 CHIEF ENGR.	
REQ. 60-1	SHEET 5	FILE T-OC



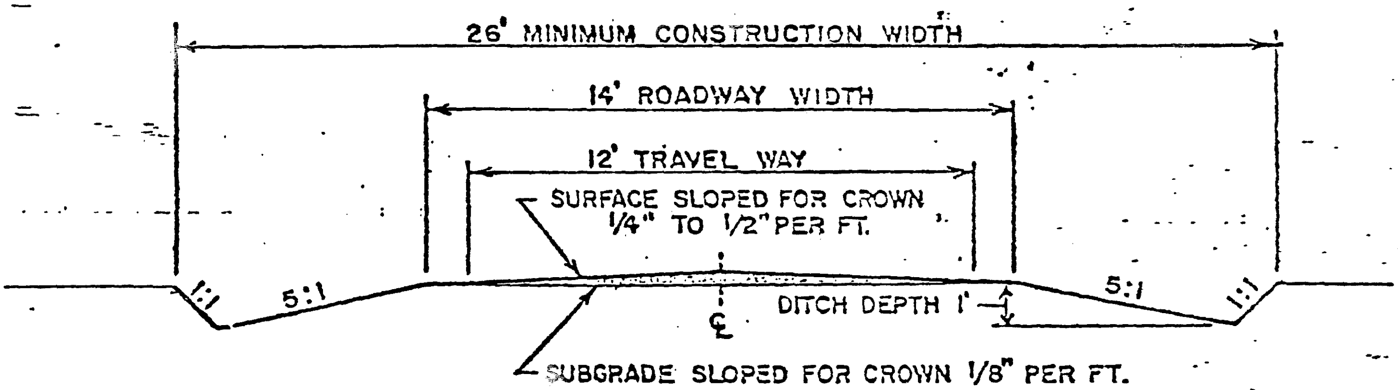
SCALE: 1" = 5'

SECTION ON FLAT GROUND

1:1 BACKSLOPE & 4:1 SHOULDER SLOPE GIVES 1' DITCH DEPTH
1:1½ BACKSLOPE & 3½:1 SHOULDER SLOPE GIVES 1.2' DITCH DEPTH

CLASS "C" FOREST ROAD DESIGN

MAXIMUM STANDARDS (2 LANES)



SCALE: 1" = 5'

SECTION ON FLAT GROUND

CLASS "C" FOREST ROAD DESIGN

MINIMUM STANDARDS (SINGLE LANE WITH TURNOUTS)

MINNESOTA CONSERVATION DEPARTMENT
DIVISION OF FORESTRY
CONSTRUCTION DETAIL

FOREST ROAD
CLASS "C"

SEC.	T. N. R. W.	
DESIGN J.G. 1-9-63	BUREAU OF ENGINEERING	SU
DRAWN A.F.F. 6-5-63		
CHECKED M.W.R. 8-5-63		DATUM
REVISED JAJ 9-28-65	CHIEF ENGR.	
REQ. 60-6	SHEET 4	FILE

a harvesting or other silvicultural operation.

A permanent road is any travelway constructed to allow use well beyond the duration of the silvicultural or harvesting operation which necessitated its installation. Its design standards include construction details at least equal to those shown in Figure 1, but do not exceed Class "C" minimum standards as shown in Figure 2.

Given these conditions, the estimated average cost of current road construction practices in Minnesota would be:

(1)	Temporary road construction	$500 per mile[2]
(2)	Permanent road construction	$5,400 per mile[3]

2. Fire Break Construction

A review of fire break construction costs (i.e., hourly machinery rates) conducted by the Northwest (Bemidji) Region of the DNR[4] indicates that costs vary by type of machine used (bulldozer vs. skidder), its age and size classification. Another source (Schillings 1969b) indicates that machinery costs also vary due to differences in ground cover, soil type and slope. The estimated costs for fire break construction practices in Minnesota are given in Table 2. In later analyses, $42 per hour or $40 per mile will be used as the average cost of fire break construction. Note that the type of firebreak

[2] Source: Mn DNR estimates averaged with U. S. Forest Service estimates (from unpublished correspondence).

[3] Source: average of Mn DNR and International Paper Company (Fisher and Taber 1975) contract prices.

[4] Equipment Rate Summary for the 1976 Fire Season, unpublished data, Minnesota Division of Forestry, Northwest Region, Bemidji, 1977.

construction referred to here would occur only on the larger, more severe, wildland fires in Minnesota. On the "average" Minnesota fire, alternative and less disruptive practices are employed in fire break construction.

Table 2

Fire Break Construction Costs

Machinery Type	Cost Range ($/hr.)	Range Midpoint ($/hr.)	Range Midpoint ($/mi.)[a]
Crawler Tractors:			
Large[b]	13-75	44	43
Small[c]	12-37	25	25
Articulated Skidders:	10-29	20	19
All Types:	10-75	42	40

a Assumed rates based on information found in Schillings (1969b)

b Catapiller Model D-6 or equivalent and larger machines

c Catapiller Model D-5 or equivalent and smaller machines

3. Planting Site Preparation

In previous sections of the Problem Assessment, root and rock raking and plowing were site preparation techniques identified as having nonpoint pollution potential. Plowing is somewhat of a misnomer for bulldozer piling of slash and debris, when the machine is equipped with a standard dozer blade rather than a rake or K/G blade. Table 3 summarizes site preparation costs experienced by the Minnesota Division of Forestry.

Table 3

Site Preparation Costs by Type of Operation[a]

Type of Operation	Average Cost/Acre[b]
Shearing	$76
Dozing (Plowing)	56
Raking	43
Furrowing	28
Disking	15

[a] Source: Mn Division of Forestry Annual Reports for last year of record (1971-72) available at time of analysis.

[b] Assumed 1978 rate derived from source data by applying Wholesale Price Index inflators.

4. Harvesting Operations

Timber harvesting operations - stump to millyard - have an extremely complex structure of cost variables (Conway 1976). The roundwood hauling function, alone, is subject to some 43 different variables of which 17 are highly significant (Martin 1971). The focus on harvesting operations, from a nonpoint pollution standpoint, centers around the skidding function - both the type of machine used and the form in which the wood is skidded (moved from stump to truck).

The type of harvest operation (clearcut vs. partial cut) will influence costs of production - the need for working around residual trees in a partial cut increases costs (Conway 1976). Apparently, the form in which the cut tree is handled - i.e., shortwood, treelength, or wholetree - does not significantly influence the cost structure (Zasada 1971). The greatest influence exerted on the cost structure stems from the rate of skidder production as determined by type of machinery employed (Host & Schlieter 1978, Granskog 1978, Schillings 1969a, Gardner 1966).

The most common form of harvesting operation in Minnesota is the combination of clearcutting with treelength wood handling by means of articulated skidders. Estimates of average stump to truck production costs for this typical operation have been developed by a number of different authors, and are summarized in Table 4. Analysis of the data suggests that skidding accounts for 70% to 80%, or roughly 75% of all stump to truck logging costs. Hence, for the purposes of this study, the estimated average cost for skidding is assumed to be $10.50 per cord harvested, or $135 per acre harvested.

Table 4

Estimated Harvesting Costs[a]

Methodology	Cost $/cord	$/acre[b]
1. Gardner, 1966	14.65	190.45
2. Zasada, 1971	13.04	169.52
3. Weible, 1978; Estimate #1	17.46	226.98
4. Weible, 1978; Estimate #2	11.84	153.92
5. Composite[c]	12.06	156.65
Average, all methods (to nearest whole dollar)	14	180

[a] Direct costs, stump to truck basis; does not include stumpage or hauling

[b] Assumed 13 cords per acre (the approximate average on current Mn DNR timber sales)

[c] Adapted from Granskog 1978 x Host & Schlieter 1978

Note: All estimates reflect, to the maximum extent possible, equivalent assumptions of labor rate, equipment value, et cetera.

D. MODIFIED PRACTICE COSTS

In previous portions of the Problem Assessment, surface erosion was "identified" as the most significant form of nonpoint pollution from forest management practices. Due to the overview nature of the assessment procedure, only general suggestions, and not 'Best Management Practice' recommendations, can be made for meeting the goals of the 1972 Water Quality Amendments. As was pointed out, the most logical approach to achieving these goals is site-specific analysis and practice adaptations. Obviously, existing legal requirements (e.g., stream crossing regulations) and common sense (e.g., no skidding in streams) are also recommended. Unfortunately, at this time most of these "recommendations" cannot be quantified and evaluated for their costs and economic impacts.

A number of states have established what are believed to be inexpensive yet effective means of minimizing the erosion potential of forest management practices. The Indiana Division of Forestry (Owen 19___) has compiled a list of recommended practices, along with standards for their application, for use on their logging roads and skid trails. Some of the more applicable practices from this list are used in the following analyses.

1. Road Construction

Included in the Indiana list of Best Management Practices for roads and skid trails are:

(1) Improved standards of Road Construction

(2) Use of Broad Based Dips on temporary roads

(3) Use of Water Bars on temporary roads

(4) Seeding of temporary roads

The first practice on the list can be viewed as a change from building temporary roads to building permanent roads. The cost of this change would be $4,900 per mile. The costs for the other three modifications are developed below. All of these modified practice costs were estimated using construction standards applicable to Minnesota Sensitive Area Conditions.

a. Broad Based Dips -

Standards: 14 ft. wide, 40 ft. long, spaced 150 ft. apart

Dips per mile = 5280 ÷ 190 = 27.8 or 28

Assume a "working time" cost rate of $80 per 5,280 ft.[1]

Working Time Cost = $80 (28 x 40/5,280) = $16.97

Travel between Dips = .66 hrs. at $21/hr. = $13.86[2]

Total Costs = $16.97 + $13.86 = $30.83 or $31 per road mile

b. Water Bars -

Standards: 14 ft. wide, 6 ft. long, spaced 150 ft. apart on temp. roads

Water bars per mile = 5,280 ÷ 156 = 33.8 or 34

Working Time Costs = $80 (34 x 6/5,280) = $3.09

Travel Costs = .79 hrs. at $21/hr. = $16.59

Total Costs = $3.09 + $16.59 = $19.68 or $20 per road mile

c. Seeding -

Weible (1978) documents the cost of seeding, using a hand-held seeder, and estab-

1 Twice the per mile rate for fire break construction used to approximate machinery costs for this "final grading" type work.

2 Travel time = .0078 hrs/50 ft (Schillings 1969b) at ½ the hourly rate for fire break construction.

lished a cost of $32.48 per acre (1977 dollars) for Minnesota conditions. In 1978 dollars this rate would be $35.44 per acre.

(1) 1 mile of temporary road 14 ft. wide = 1.7 acres

1.7 acres x $35.44 = $60.25 or $60 per mile

(2) 1 mile of permanent road (ditch and backslopes only) = 1.5 acres

1.5 acres x $35.44 = $53.16 or $53 per mile

Note that fertilizing was not considered in this analysis because the cost of this practice is excessive (Weible 1978). Also, it was assumed that the machinery to construct Broad Based Dips and Water Bars was available, on-site. If this machinery had to be hauled in to complete the work, $50 to $200 in additional costs would be incurred on each project as "move in" charges.

2. Fire Break Construction

Fire suppression, and hence, fire break construction, is a 'public good' (i.e. use by one person does not diminish the quality or quantity available to others). Due to the multiple economic ramifications of a public good, fire suppression is normally supplied by government rather than the private sector. This necessitates a separate and distinct treatment, especially when a dichotomy exists in public policy between providing fire protection, and controlling nonpoint pollution.

In Minnesota, forest fire fighters may in the performance of their duties, "...dig or plow trenches...without incurring a liability to anyone, except for damages arising out of willful or gross negligence (MSA 88.10, Subd. 1)." Digging or plowing trenches, especially by mechanical means (e.g., bulldozers), is a proven, effective and efficient means of controlling wildfires, but it can also be a potential source of pollution under certain conditions (i.e., highly erodable soils on steep slopes near bodies of water). Under the stress and immediacy of a wildfire situation, it is necessary to accept current fire break construction practices, and simply ameliorate any nonpoint pollution problems later.

For analytical purposes, it was assumed that water bars and seeding would be applicable to fire break construction. The costs of these modifications are developed below:

a. Water Bars -

Standards: 14 ft. wide, 6 ft. long, spaced 40 ft. apart on fire breaks

Water bars per mile = 5,280 ÷ 46 = 114.8 or 115

Working Time Costs = $80 (115 x 6/5,280) = $10.46

Travel Costs = .72 hrs. at $21/hr. = $15.12

Total Costs = $10.46 + $15.12 = $25.58 or $26 per mile of fire break

b. Seeding -

Using the cost data on seeding from Weible (1978)

1 mile of fire break 14 ft. wide = 1.7 acres

1.7 acres x $35.44 = $60.25 or $60 per mile

3. Planting Site Preparation

The goals of site preparation and erosion control are potentially conflicting. That is to say, exposure and disturbance (loosing) of mineral soil, while highly desirable in preparing a planting site, may also be undesirable when excessive soil erosion and water quality impairment are likely to occur. Such conditions are generally described in terms of excessive slope and proximity to water. If subsequent, in-depth studies can determine what the ciritical levels of soil disturbance, slope and proximity to water are, then it will be possible to specify 'Best Management Practices' for site preparation techniques.

If one accepts the premise that reducing soil disturbance levels is the key to the erosion/water quality problem - it may be that cost savings and not additional costs will be the result of modifying current site preparation practices. In the list of site preparation practices, raking and dozing (plowing) are among the most expensive practices. They are also associated with the highest levels of soil disturbance - perhaps 60% to 80% or more. Other practices, such as furrowing and disking, are lower cost alternatives which also result in less soil disturbance - perhaps no greater than 40% to 50%. The implication is obvious. Unfortunately, some site conditions (i.e., slash cover) require the use of dozers and rakes if silvicultural objectives are to be met.

The Duluth and Park Rapids Areas of the Minnesota Division of Forestry have experimented with a site preparation technique called "Mini-Windrowing". In this technique, the raking or dozing takes place on strips one or two blade-widths wide, each of which is separated by a like strip of untreated area. The end result is a treatment pattern similar to that of contour farming. By using this technique, overall costs can be reduced while meeting silvicultural objectives,[3] and reducing erosion potential. This is one example of a modified practice which can achieve all of the desired goals simultaneously.

4. Harvesting Operations

Based on Indiana's list of 'Best Management Practices' (Owen 19___), water bars and, under extremely sensitive conditions, seeding are recommended for use on skid trails after logging has been completed. The costs of these modifications for Minnesota practices are estimated to be:

[3] From Division of Forestry correspondence files and communications with personnel involved.

a. Water Bars -

Standards: 8 ft. wide, 6 ft. long, spaced 40 ft. apart on skid trails

Assume that skid trails are 8 ft. wide and disturb 60% of a logged acre,

then there are 3,267 lineal feet of skid trails per acre

Water bars per acre = 3.267 ÷ 46 = 71.02 or 71

Working time costs = \$80 (71 x 6/5,280) = \$6.46

Travel Costs = .44 hrs. at \$21 per hour = \$9.30

Total Costs = \$6.46 + \$9.30 = \$15.76 or \$16 per acre logged

b. Seeding -

1 logged acre x .6 disturbed x \$35.44 = \$21.26 or \$21 per acre logged

Note that filter strips and buffer strips have not been included here because they require some very specific information which is beyond the scope of this analysis. See Weible (1978) for a detailed, exemplary analysis of these practices.

5. Cost Summary

The costs of current practices and the costs of erosion control measures associated with those practices are summarized in Table 5. Note that building temporary roads to higher standards would preclude the need for broad based dips and water bars. Furthermore, seeding of skid trails may be unwarranted because grasses would compete with tree regeneration, necessitating increased site disturbance to achieve reforestation objectives.

The cost implications of utilizing "Mini-Windrowing" or some other form of less disturbing site preparation practice are difficult to estimate. Preliminary data indicates only that cost savings may result if these methods are employed. Further experimentation must be undertaken before accurate estimates of cost-savings and cost-effectiveness can be made. Beyond this, the limited availability of specialized equipment such as "patch" scarifiers precludes widespread utilization at this time. It can only be speculated that cost reductions of perhaps 10% or more may be achieved when these various site preparation techniques become operational.

Table 5

Summary of Additional Costs

Present Practice	Present Cost	Additional Costs[a] Higher Stds.	Broad Based Dips	Water Bars	Seeding
Temporary Roads ($/mile)	500	4900	31[b]	20[b]	60
Permanent Roads ($/mile)	5400	--	--	--	53
Fire Breaks ($/mile)	40	--	--	26	60[c]
Site Preparation ($/acre)	43 to 76		See Text		
Harvesting (i.e. skidding) ($/acre)	135	--	--	16	21[c]

[a]All costs listed are direct costs (on-site costs) and do not reflect any equipment "move in" charges which may be incurred.

[b]Cost per unit may be lower if done in conjunction with other erosion control measures.

[c]May be an unnecessary activity if natural or artificial reforestation takes place.

E. COST ACCRUAL AND IMPACT

In determining the economic impact of the direct costs of possible nonpoint pollution control strategies, the questions that must be answered are:

What will the cumulative costs be?

To whom will these costs accrue?

and

What effect will this accrual have?

Assuming that cost savings as well as decreased erosion potential result from innovative site preparation techniques, then the forest management practices for which the above questions must be answered are:

(1) Temporary Road Construction

(2) Permanent Road Construction

(3) Fire Break Construction

(4) Harvesting Operations (i.e. skidding)

In the following analyses, temporary road construction has been included with harvesting operations because the Problem Assessment data indicates that they are, for the most part, interrelated activities.

1. Road Construction

It is estimated that there are approximately 250 to 300 miles of forest road built in Minnesota each year. Of this total, perhaps only 50 to 60 miles fit the definition of a permanent road as stated earlier. These permanent roads are paid for, predominantly, by the landowner whose forest will benefit through their establishment. Permanent road building occurs almost exclusively in northeastern Minnesota, on public lands, and is paid for either directly or through contractual agreements (i.e. stumpage credits) on timber sales.

The cost analysis indicate that the unit cost of permanent road construction would increase by approximately 1% with the addition of nonpoint pollution control measures (i.e. seeding). Based on the occurrence of permanent road construction practices by erosion potential indicator class, approximately 85% of the practice may require the addition of erosion control measures. If so, then the cost of applying these measures would be $2,000 to $3,000 annually.

The majority (roughly 60%) of the permanent forest road construction activity in Minnesota is paid for by the U.S. Forest Service, predominantly through stumpage credits on timber sales contracts. The balance of the construction activity is paid for by private industrial firms as a direct expense of their logging operations, except that a small proportion (7%) is built and paid for by state and federal wildlife management agencies as a part of their habitat improvement programs. Given the available data, it is hard to speculate on the effect a $2,000 to $3,000 cost increase will have on a program costing $270,000 to $324,000 annually. Obviously, there will be some minor reduction in stumpage revenues on the National Forests and in the profitability of some forest industry operations in northeast Minnesota.

2. Fire Break Construction

In Minnesota, the costs of wildfire suppression are borne by government agencies and, hence, the taxpayer, unless responsibility for the fire can be fixed. In the latter case, the State Forestry Act (MSA 88.02 to 88.21) specifies that the responsible party shall provide reimbursement for damages, including payment to the State for all fire suppression costs. However, pending the results of legal action, the costs are paid out of the Division of Forestry's Fire Fund, or a similar fund established by other agencies providing fire protection in Minnesota.

The results of the cost studies indicate that the unit cost of fire break construction would be increased substantially by the addition of erosion control measures. These increases would be on the order of:

(1) + 65% if water bar construction is required

(2) +150% if fire break seeding is required

(3) +215% if both of the above are required

If the proportions in the Problem Assessment sample data are indicative of the statewide situation, then roughly 31% of the state may be sensitive to hazardous practices. Assuming fires occur randomly over the state, then 31% of fire break construction in Minnesota may require erosion control measures, and if so, then cost increases at the statewide level would be:

(1) +20.2% if water bars are applied "where needed"

(2) +46.5% if seeding is required "where needed"

(3) +66.6% if both measures are used simultaneously

Relating these percentage cost increases to actual dollars, the budgetary appropriations for fire beak construction in Minnesota are estimated to be $68,800 annually.[1]

[1] Estimate taken from Budgetary support documents of MDNR - Forestry.

Based on the Minnesota Division of Forestry's experience, actual expenditures can exceed appropriations by as much as 300%.[2] Therefore, the direct cost of implementing erosion control measures may range from as little as $4,300 to $56,800 or more in any one year. Based on the distribution of sensitive areas and fire occurrence in Minnesota, approximately 75% of this total cost burden will accrue to the state Division of Forestry, while 20% will accrue to the United States Forest Service, and the balance will accrue to other units of government. Ultimately, it will be Minnesota's taxpayers who must bear the burden of paying the additional costs of the nonpoint pollution control measures. Given present budgets, either government appropriations will have to be increased, or other services will have to be curtailed if nonpoint pollution control measures are to be applied to current fire break construction practices in Minnesota.

3. Harvesting Operations

Minnesota loggers face oligopolistic conditions (i.e., few sellers and many buyers) in the market for their raw materials, and oligopsonistic conditions (i.e., many sellers and few buyers) in the market for their cut products. From an economic standpoint, the sellers of stumpage and the buyers of cut products are relatively mobile, while the logger is relatively immobile. On the other hand, standing timber is immobile in terms of its location and accessibility. The timber owner, however, has great flexibility in terms of time. He can grow different products (e.g. pulpwood or sawlogs) from the same trees by varying the rotation age at which he harvests. If harvesting is delayed, even for several years, there is little financial penalty involved as rotation age is not critical from either a theoretical or practical standpoint (Gregory 1970).

[2] Source: Fiscal Expenditure Reports, Statewide Accounting System.

One characteristic of the timber market is that the incidence of any cost is shifted by those parties that are mobile to those that are inflexible (Duerr 1960). Another characteristic is that buyers tend to arbitrarily set prices they are willing to pay for roundwood, and merely adjust those prices over time to meet their own wood requirements while keeping their suppliers reasonably happy (Duerr 1960), but not necessarily economically satisfied. Furthermore, the geographic structure of the market limits both the number of buyers for any one tract of timber and the number of tracts of timber available to any one buyer (Gregory 1970).

a. Basic Relationships

The relationship between changes in end-product price and price changes in the market for roundwood is quantified as the 'elasticity of price transmission' (Haynes 1977). This estimate of elasticity is determined by the formula:

$$\text{Elasticity of Price Transmission} = \frac{\text{\% Change in End Product Price}}{\text{\% Change in Stumpage Price}}$$

Adams, et. al. (1977) and others have reviewed the research done on elasticity of price transmission in the forest products sector. Their summary provides the following information:

Type of Product	Elasticity Range
Lumber and Wood Products	.53 to .73
Pulp and Paper Products	.21 to .26

The long term (1950 to 1975) price trend for pulp and paper products is +7.8%, while that for lumber is 10.19% annually.[1] The stumpage price trends (1970 to 1978) for pulpwood and sawlogs in Minnesota are +11.61% and +12.19% per year, respectively.[1] Applying this data to the elasticity of price transmission formula gives:

Type of Product	Elasticity Value
Lumber and Wood Products	.84
Pulp and Paper Products	.67

Both of these values are relatively high, indicating that roundwood supplies are economically scarce in Minnesota as compared to the national norm. In addition, the exceptionally high value for pulp and paper indicates that the forest products economy of Minnesota is highly pulpwood oriented.

Price increases above the generally accepted trend may have adverse affects on product demand. In the pulp and paper industry, fluctuations in end-product price are relatively mild, but quantities produced and sold vary much more markedly (Duerr 1960). In the lumber industry, a 1% price increase (above the trend) produces a 2 to 10% reduction in quantity demanded (Mills and Manthy 1974). Price decreases, on the other hand, may adversely affect quantities being supplied. Mills and Manthy (1974) estimate that a 1% reduction in end-product price will reduce the quantity being supplied by .62 to .83%. In either case, these changes at the end-product level will translate into larger changes at the stumpage level (Duerr 1960). The magnitude of this change is approximately

[1] Source: price data compiled by Minnesota Division of Forestry.

twice that of the change at the end-product level.[2] That is to say, if one less ton of product were needed or wanted, then two tons of roundwood would no longer be harvested and processed. This characteristic of the forest products market is referred to as the 'acceleration effect of stock'.

b. Cost Accrual

The starting point for analysis is a cost-revenue profile for a harvesting operation of average efficiency (see Table 6). The analysis was qualified by assuming that requiring high standards of road construction was uneconomical for the typical, small, independent Minnesota harvesting operation (i.e. an operation with restricted revenue potential). In order to achieve some degree of reality it was further assumed that:

1. The rational logger has an alternative ROR at or below which he would not continue to log.
2. The rational forest owner has a 'reservation price' below which he will not sell his stumpage.
3. The rational forest products firm will pay no more than necessary to acquire its raw material supply.
4. The rational erosion control program involves selecting least-cost, efficient, site-specific control measures.

According to Haynes (1977), "the return to a factor (e.g. stumpage) is an economic rent and presumes that the factor is fixed in supply; hence, the return to the factor is

[2] As estimated by Mn DNR Forest Products Marketing and Utilization personnel.

market determined and, therefore, consistent with market equilibrium concepts." The forestry profession's traditional 'residual value' approach to stumpage pricing is derived from rent theory (Gregory 1970). Under this pricing approach, the costs of production, including a margin for profit and risk, are subtracted from the value of the end product, and any remaining balance becomes the value of the stumpage being harvested. Adding erosion control costs to the cost-revenue profile from Table 6 and applying rent theory produces a modified profile as illustrated in Table 7.

(continued on page 216)

Table 6

Cost and Revenue Profile

for an

Operation of Average Efficiency

Factor	Pricing Bases	Total	
Stumpage	$4/cd., 130 cds[a]	$ 520	
Roads	$500/mi., 1.25 miles	625	
Felling, etc.	$45/a., 10 acres	450	
Skidding	$135/a., 10 acres	1350	
Hauling	$6/cd., 130 cds[a]	780	
Misc.	Estimate[b]	360	
Total Production Costs		$4085	
Total Revenues	$36/cd., 130 cds[a]	$4680	
Business Taxes	12% (4680-4085)	$ 71	
Profits	4680-(4085+71)	$ 524	(ROR-12.82%)

[a] Based on rates paid at Blackduck, MN, January 1979 (unpublished correspondence).

[b] Author's estimate of Social Security, Unemployment and Worker's Compensation charg

Table 7

Cost/Revenue Profile with Erosion Control

Constraints Added

(Rent Theory Approach)

Factor	Value	Percent Change
Stumpage	$ 260	-50%
Roads	725[a]	+16%
Felling, etc.	450	-
Skidding	1510[a]	+12%
Hauling	780	-
Misc.	360	-
Total	$4085	-
Revenues	$4680	-
Taxes	$ 71	-
Profits	$ 524	-
ROR	12.82%	-

[a] Water bars plus seeding on roads, water bars plus natural forest regeneration on skid trails and logged over area.

Unfortunately, the rent theory approach is biased toward the manufacturer and discriminates against the timber owner. It only recognizes demand functions, and does not consider stumpage supply conditions, particularly the possibility of a reservation price on the part of forest owners (Gregory 1970). As the sale of timber is the major source of revenue for most forest owners, realistic stumpage prices become the key to the successful practice of forestry (Duerr 1960; Gregory 1970). As forestry is part of the overall economy, the economic laws of both supply and demand must, over time, influence the returns to roundwood production and ownership. If a supply-demand model is applied to the cost-revenue profile, with erosion control costs added, a modified profile as illustrated in Table 8 is produced.

Rent theory and residual pricing are valid only in the short term or during periods of declining end-product prices. In the long term or during periods of rising end-product prices, a supply-demand model is more appropriate (Gregory 1970). Based on all available evidence, as set forth above, it is speculated that:

(1) In the very short term, until rent theory/residual pricing and the stumpage and roundwood markets adjust to the imposition of erosion control costs, the costs of nonpoint pollution control will be borne mainly by the logger.

(2) During an extended but short-term time-frame, it will most likely be the forest landowner who will bear the costs of nonpoint pollution control measures.

(3) In the long-term, as the influence of all market factors is felt, the costs of nonpoint pollution control will accrue in part to the logger, and in part to the consumer of roundwood.

However, in all three cases, some portion of the total costs will be borne by the general public in the form of reduced tax revenues.

Table 8

Cost/Revenue Profile with Erosion Control

Constraints Added

(Market Theory Approach)

Factor	Value	Percent Change
Stumpage	$ 520	
Roads	725[a]	+16%
Felling, etc.	450	-
Skidding	1510[a]	+12%
Hauling	780	-
Misc.	360	-
Total	$4345	+ 6%
Revenues	$4764[b]	+ 2%[c]
Taxes	50	-30%
Profits	369	-30%
ROR	8.5%[d]	-4.32%

[a] Water bars plus seeding on roads, water bars plus natural forest regeneration on skid trails and logged over area.

[b] Calculated on the basis of the assumed minimum ROR constraint.

[c] Based on total revenues; $84 increase = 16% increase based on stumpage value.

[d] The average, long term (15+ yr.) U.S. Treasury Note yield rate as suggested by the U.S. Water Resources Council (Howe, 1971).

c. Cost Implications

A pulpwood harvesting example was chosen for presentation because the vast majority of the logging operations in Minnesota are associated with that product. If a sawlog example had been utilized, the percentage changes shown in Tables 7 and 8 would still apply, except that total costs would increase by only 4%, stumpage would decrease by only 22%, and no increase in revenues would be necessary to meet the minimum ROR constraint. These factors seem to indicate that the cost implications of erosion control would be less far-reaching for lumber products than for pulpwood products. In any case, if harvesting operations are uniformly distributed throughout the various slope rating classes in the study area, then perhaps no more than 31% of the operations occurring in Minnesota would require the addition of some form of erosion control measure. If this is true, then approximately 80% of the total erosion control needs and, hence, costs would occur on operations in the Red Wing-LaCrescent Uplands, Itasca/Nashwauk-Warba Moraine complex and Aurora Till Plain regions of the state.

Based on data compiled by the Minnesota Department of Economic Development (1978) and the Division of Forestry,[3] it is possible to develop the following economic picture of Minnesota's forestry sector in 1978:

Level of Processing	Current Value
Stumpage	$ 9,500,000
Roundwood	85,700,000
Milled Product	568,400,000
Wholesale Product	1,142,400,000

[3] Unpublished preliminary data from FY78 annual report of the Division of Forestry. Minnesota Department of Natural Resources.

Utilizing these values and the various relationships developed earlier, it becomes possible to estimate the probable cost and impact of implementing erosion control measures on timber harvesting operations in Minnesota. These costs and their relative distribution are displayed in Table 9.

Table 9

Distribution of the Total Costs
of Erosion Control on Harvesting
Operations in Minnesota[a]
(all values in thousands)

	Time Frame		
Cost/Distribution	Very Short Term	Extended Short Term	Long Term
Total Direct Costs:	$1,400	$1,400	$1,400
Reduced Stumpage	--	1,390	--
Reduced Logger Profits	1,200	--	800
Reduced Tax Revenues	200	10[b]	100
Increased Product Prices	--	--	500

a All values have been rounded for ease of display - costs were calculated on only 31% of total estimated operations in Minnesota.

b Calculated on the basis of a capital gains treatment on privately owned stumpage only.

It would be difficult to apply the various price elasticity formulas or to compute the 'acceleration effect of stock' without knowing the exact mix of products that will be affected by the addition of nonpoint pollution control costs. Even if this product mix were known, the results of any calculations would be dependent on the general rate of wholesale price inflation from all factors of production, not just logging, and on the rate of growth in total consumption of end products. However, it can be speculated that, with the imposition of costs of the magnitudes shown in Tables 7 through 9, there will be -

(1) Simultaneous, counteracting reductions in both the supply of and the demand for forest products in selected localities;

(2) a concentration of harvesting activities and competition for stumpage on land outside of the highly sensitive areas, thereby increasing the risk of environmental damage to these less sensitive areas;

(3) relatively inefficient operators will either be forced out of business, or restricted as to where they can conduct their business, while the relatively efficient operator may be placed in a cost squeeze, thus adversely affecting their financial situations.

F. SUMMARY AND CONCLUSIONS

The preceeding analyses deal with the direct costs of nonpoint pollution abatement to individual economic entities. They do not deal with the indirect costs or opportunity costs of pollution abatement to society as a whole, nor do they deal with the benefits which may result from nonpoint pollution abatement. Based solely on the analyses, it may be that requiring forest management practitioners to absorb the costs of pollution abatement is not economically efficient under the constraints of Pareto Optimality.[1] It is assumed that the treatment of pollution at its "source" is less costly than downstream treatment, and less costly than the value of water uses foregone if pollution were left unabated. However, this assumption was made without analyzing either the total or marginal costs of downstream treatment.

In a free society, the economy is supposed to serve all individual preferences as revealed in the marketplace. Society, through government, is not supposed to dictate preferences, nor make decisions regarding resource use. All use of water, be it drinking or absorbing pollutants, is economically legitimate for it is essentially private in the sense that it benefits an individual economic entity (Meyers and Tarlock 1971). If society is going to impose allocation of water uses on individuals, then society should employ a program of allocation which simulates the results of a competitive market, without the usual externalities associated with the water resource. This implies that the incentive for private gain can be employed to further the goals of society as a whole. Perhaps this could be accomplished through a combination of pollution abatement payments rather than treatment subsidies, and pollution discharge fees (based on downstream costs) rather than fines or legal sanctions (Meyers and Tarlock 1971).

An economically efficient approach to pollution abatement, as alluded to above, requires far more information than is currently available. However, such an approach needs much less information than would be required to achieve the same end through direct regulation of individual pollution sources (Meyers and Tarlock 1971). Given the

[1] Pareto Optimality asserts that an allocation of resources (including cash) is optimal if no reallocation could make some members of society better off without making others worse off (Meyers and Tarlock 1971).

current lack of data, some form of educational and/or subsidy program appears to be the most logical means of implementing nonpoint pollution abatement measures at this time. In any case, the control measures selected for implementation must be based on technical, economic and political considerations consistent with state and local needs. Furthermore, they must be geared to differences in regional situations and the actual timing of nonpoint pollution in relation to stream flows (Meyers and Tarlock 1971).

The occurrence of forest management activities on Minnesota lands is very cyclic, and implies that nonpoint pollution associated with those activities would also be very cyclic. Coupling this premise with the lack of definitive data on the costs and benefits of nonpoint pollution control and the information presented in this portion of the Problem Assessment, leads to the conclusion that:

(1) Statewide application of abatement procedures regardless of need would be uneconomical as it would cost more than is necessary to attain target levels of nonpoint pollution reduction.

(2) Application of abatement procedures only where necessary would be far less costly, but would impose costs only on selected practitioners, in selected locations, which would be hard to justify on equity grounds.

(3) Minnesota's typical, private practitioner of forest management activities, be he landowner or logger, is in an extremely precarious financial situation, with little room to absorb any additional costs without incurring financial hardship, or ruin.

(4) Any attempt to resolve the cost-benefit distribution dilemma of nonpoint pollution control in forest management in an efficient and effective manner requires far more specific data than is currently available.

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VII. RECOMMENDATIONS

A. INTRODUCTION

The objective of this section is to identify and describe measures that reduce or prevent non-point sources of water pollution stemming from forestry activities in Minnesota. The results of the Analysis Section of this report provided a framework from which formulation of recommendations were made.

Forest management practices have been identified on the basis of their potential to disturb sites, using data collected from written surveys and application of the following criteria: 1) amount of growing material removed, 2) degree and extent of soil compaction, and 3) amount of mineral soil exposure (see Analysis Section V).

Practices placed in the "high" site disturbance potential category were road construction, site preparation by either plowing or root and rock raking, and firebreak construction. The measures or Best Management Practices identified and recommended in this section specifically address these activities.

B. BEST MANAGEMENT PRACTICES

1. BACKGROUND

Regulations to implement the Federal Water Pollution Control Act Amendments of 1972 (i.e., P.L. 92-500) indicate that Best Management Practices (BMPs) may be an acceptable approach to mitigate adverse effects on water quality caused by forest management activities. The U. S. Environmental Protection Agency has developed procedures to be followed in the preparation of water quality management plans (Federal Register, 40, 1975). One of the elements of such plans is identification of non-point source control needs for each category of pollutant sources. This would include an "evaluation of all measures necessary to produce the desired level of control through application of best management practices".

The term best management practice means "a practice, or combination of practices, . . . to be the most effective, practicable (including institutional and economic considerations) . . . means of preventing or reducing the amount of pollution generated by non-point sources to a level compatible with water quality goals" (Federal Register, 40, 1975).

A list of general criteria follows which provide a basis for development selection of BMPs:

1) should manage "pollution generated by non-point sources",
2) should achieve water quality "compatible with water quality goals",
3) should be "effective in preventing or reducing the amount of non-point source pollution generated", and
4) should be "practicable" (Federal Register, 40, 1975).

The BMPs recommended in this report were developed with the above considerations in mind. Some important limitations, however, in the application of these criteria to the BMPs need to be addressed.

1) The BMPs discussed in this report were developed expressly for forest management activities. No attempt has been made to formulate BMPs that are applicable to other types of activities known to cause disturbances similar to those associated with forestry (e.g., agricultural and construction activities). Ideally the interrelationships between all the different types of activities known to be sources of non-point pollution should be evaluated in the BMP development process (Conservation Districts and 208 Water Quality Management, 1977). The scope of this report, however, is confined to just forestry activities.

2) Water quality goals have not been defined in terms of target levels of abatement for the various types of pollutant materials, which include those associated with forestry practices. Establishment of goals

on this basis is not feasible at this time. Natural or background levels of some of the key water quality indicators affected by forestry activities are unknown for most of the water bodies and streamcourses in the state. Therefore, measurement or evaluation of the achievement of such goals is not possible.

3) The effectiveness of the recommended BMPs cannot be evaluated in terms of the expected reductions of pollutant loadings following their implementation. As mentioned previously, the amount of pollutant loadings caused by a specific forestry practice is unknown, thus making the amount of reduction or abatement brought about by a specific BMP impossible.

The BMPs identified in this report are those which have been shown to be effective in past use. Studies on the subject reported in the literature, Forestry Practices Acts, U. S. Forest Service Manuals, and some other sources of information, provide the basis for derivation of the recommended BMPs.

4) BMPs should be feasible in terms of economic, legal, and institutional factors, in addition to being technically sound. For instance the marginal cost of using a particular BMP to achieve a given level of pollution abatement may exceed the marginal cost of an alternative measure (such as downstream treatment) that would result in the same water quality for users. This illustrates how a given BMP may potentially fail to be cost effective. Although economic variables are alluded to in this report, an in-depth discussion of the legal and institutional arrangements that would most effectively deliver a water quality management program to forest management practitioners is not attempted.

The BMPs outlined in this section appear to be sound and reasonable measures which serve water quality protection objectives. It is important to note, however, that any given BMP is not necessarily practical and effective in all situations. The feasibility of a given BMP for implementation in the field must be determined on a site by site basis. Another consideration is that a requirement for application of abatement measures only where necessary would likely result in an inequitable distribution of costs since only selected forest management practioners would be affected. Thus, the BMPs discussed in this report are general in nature, and are intended to serve as guidelines which should be considered in the decision making process as it relates to forest management. The appropriateness or inappropriateness of a given BMP for a particular operation must ultimately reside with forest managers in the field.

2) ROAD SYSTEMS

a) PLANNING & DESIGN

The planning and design of roads should be accomplished with the overall management objectives of the forest in mind. Water quality protection should be one of the goals in the management of a forest, and therefore, consideration should be given to the needs of the water resources in layout and construction.

Wherever feasible roads should be designed to fit the natural topography, following existing contours to the extent possible. Ideally the design should minimize the amount of cuts and fills adjacent to stream channels.

b) LAYOUT & LOCATION

The placement of logging roads should avoid to the extent feasible those areas known to be hazardous in terms of erosion potential. Where such areas cannot be avoided, special precautions should be taken to prevent serious environmental problems.

In general benches and ridges are most suitable for road placement since the need for excavation is minimized. Side cast or fill material should be placed in a safe location above a specified flood plain elevation (e.g., 50 year storm) whenever cut and fill operations become necessary. Layout of roads in parallel with stream channels which are in proximity to them is not recommended. Long, steep gradients should also be avoided.

c) CONSTRUCTION

The actual clearing and excavation of road construction should be scheduled to minimize mineral soil exposure during periods of intense rainfall and/or runoff. Construction should be avoided on poorly drained soils where erosion is likely to lead to sedimentation.

Road gradients should be kept as low as possible, except where steep sections provide the advantage of topography that allows avoidance of excessive cut and fill. In some cases a layer of gravel should be spread over a road bed when the natural bed is composed of highly erodable material, or the road is on flat terrain with poor drainage.

Drainage ditches are recommended for road sections that otherwise would have poor drainage of surface water. In addition, adequate cross drainage is required to protect the road surface and shoulders from surface runoff. If drainage water flow from a road surface does occur, it should be controlled to prevent the runoff from directly entering water bodies.

d) MAINTENANCE

Permanent logging roads should be graded and ditched as often as necessary to insure that drainage from road centers to ditches is unhampered. Wheel ruts should not be permitted to allow channel water to run downslope. Water bars are recommended on roads that drain surface runoff. Logging roads not designed for all weather usage should be restricted during periods of wet weather if possible.

e) RETIREMENT

Logging roads should be closed to vehicular traffic following completion of the logging operation, unless they were originally planned for other uses. When a road is no longer open to vehicular use, it should be "put to bed". This may entail any steps necessary to insure revegetation, such as seeding.

3) SITE DISTURBANCE ACTIVITIES

a) SITE PREPARATION AND REHABILITATION

The soil and forest floor should be disturbed to the least extent possible in any of the treatments applied to sites for purposes of reforestation, if surface erosion is to be minimized. Prior to implementation of site preparation operations, the soils and slopes of the area should be evaluated in terms of potential hazards to the site and surface waters. Heavy equipment usage should be avoided when soil moisture conditions are such that undue soil compaction is likely to result. Practices that cause significant exposure of mineral soil are not recommended on sites where surface erosion is likely to result in sedimentation. Special precautions to prevent potential sedimentation should be taken whenever they are needed, such as placement of a buffer strip between the distrubed area and any water body subject to impact.

b) FIREBREAKS

Erosion control measures should be constructed or put in place as needed on firebreaks. Such measures may include dips, water bars, cross drainage, and ditches.

C. ADDITIONAL RECOMMENDATIONS

1. SUGGESTED GUIDELINES FOR PRACTICES AND ACTIVITIES NOT ASSIGNED TO THE HIGH SITE DISTURBANCE POTENTIAL CATEGORY

a) SKIDDING

Skidding should be done with the butt end of the logs lifted off the ground to minimize the amount of disturbance to the forest floor caused by the dragging. If logging on steep slopes or other types of sensitive areas is a necessity, the activities should be scheduled to avoid wet soil conditions. Logs should be winched off steep slopes whenever possible if erosion and sedimentation would result from conventional skidding.

Skidding across live or intermittent streams should be avoided. All possible alternatives should be considered before skidding in stream beds is done. This may mean installation of temporary stream crossings to preserve the integrity of the stream. When crossing of streams or drainageways is necessary, they should be forded by the most direct route. Ideally fords should be located where the banks are stable and the grades are gentle along the approach to the shoreline.

b) GRAZING

Livestock should not be permitted in forested areas where their presence and/or activities cause erosion or the potential for sediment and other pollutants to reach water bodies.

2. RESEARCH NEEDS

The amount of available information about the impacts of forest management activities on surface waters does not justify development of a regulatory program designed to achieve a specific amount of pollution abatement. Generation and delivery of pollutant materials to aquatic ecosystems caused by forestry activities is dependent on a wide array of variables, and the "interrelationships of these variables (to management activities and water quality impacts) are ill-defined and will not be defined by mid-1979" ("Sensitive Area" definition, personal communication from Jeff St. Ores).

The establishment of an experimental watershed is recommended as a long term means to provide the necessary opportunities for study and research of forestry and water quality impacts. Definitive determination of pollutant loadings generated in response to specific activities could be ascertained on a quantitative basis under properly conducted research projects. In addition the cost effectiveness of various control measures could be examined. The southeast part of the state would seem to be the most logical location for such a project since the highest erosion potential indicator class is widespread in that region.

3. PROGRAMS FOR IMPLEMENTATION OF BEST MANAGEMENT PRACTICES

Three types of programs are usually cited as possible approaches to achieve use of the most desirable forestry practices: 1) educational, 2) subsidy, and 3) regulatory (Skok and Gregerson, 1975; Ellefson, 1976). In general a combination of these is the most effective (at least in a socio-political sense) in achieving the use of the most desirable forestry practices (Cubbage, 1978).

A combination of education and subsidy programs is recommended as the most desirable alternative in Minnesota. Since the evironmental effects of forestry practices are complex and often difficult to predict, particularly with respect to water quality, educational assistance programs should be beneficial to anyone with woodlands not trained in forest management. Advice and technical assistance rendered by professionally qualified foresters and/or specialists (e.g., forest hydrologists) can be given on matters involving road location and design, use of specific types of equipment, application techniques for chemicals, etc., for the expressed purpose of prevention and/or control of adverse impacts on water quality.

Subsidy programs for the benefit of forest landowners are structured according to two basic forms: 1) direct payments to landowners to defray a portion of the cost of desired practices, and 2) indirect payments, such as tax incentives, to landowners who comply with BMP recommendations (Skok and Greggerson, 1975; Ellefson, 1976). The need for cost sharing is indicated by a study of the economic impacts associated with the use of non-point source control measures. The results of the study showed that small woodlot operators perform their labor close to the margin, and that constraints required for the sake of sediment control could impose economic hardship on them (Weible, 1978).

At the present time a combination of educational and subsidy programs appears to be the most sensible approach to the control of non-point source pollution originating from forest management activities. As more data becomes available, other approaches should be given consideration to insure that programs are cost effective as possible.

GLOSSARY

BASE FLOW - That portion of the water flowing in a stream which is due to ground water seepage into the channel.

BEDROCK WEATHERING - The chemical or mechanical alteration of the solid rock underlying soil or lying at the surface. Agents of weathering include frost, mild acids present in soils, oxygen, and water.

BIOLOGICAL OXYGEN DEMAND (BOD) - A measure of the demand on a water body's dissolved oxygen supply which will be generated (over some specific period of time) by the biological decomposition of organic matter.
A high BOD may temporarily, or permanently, so deplete oxygen in water as to kill aquatic life. The determination of BOD is perhaps most useful in evaluating the impact of wastewater on the receiving water bodies.

BIOTIC - All the living organisms in a planning area and their life processes.

BOARD FOOT - A unit of measure represented by a board 1 foot long, 1 foot wide and 1 inch thick. abbr. Ft. b.m.; bd. ft. In finished or surfaced lumber the board-foot measure is based on the measurement before surfacing or finishing. In practice the working units is 1,000 board feet. Abbr. M bd. ft.; M B.M.; M B.F.

BROKER - One who buys timber from loggers and sells timber o mills.

BUTT ROT - A fungal infection of the butt of a tree causing a weakening and deterioration of fiber and strength.

BROWSE -
1. That part of the current leaf and twig growth of shrubs, wood vines, and trees available for animal consumption.
2. The act of consuming browse.

BUFFER - A strip of undisturbed vegetation that retards the flow of runoff water, causing deposition of transported material and thereby reducing sedimentation of receiving streams.

BURNING, PRESCRIBED - Skillful application of fire to natural fuels under conditions of weather, fuel moisture, soil moisture, etc. that will allow confinement of the fire to a predetermined area and at the same time will produce the intensity of heat and rate of spread required to accomplish certain planned benefits to one or more objectives of silviculture, wildlife management, grazing, hazard reduction, etc. Its objective is to employ fire scientifically to realize maximum net benefits at minimum damage and acceptable cost.

CANOPY - The cover of green leaves and branches formed by the crowns of all trees in the forest.

CATIONS - Positively charged atoms.

CHIPPER - A machine which transforms whole trees into chips.

CLEANING - The elimination of competing vegetation from stands not past the sapling stage; removal of weds, climbers, or sod-forming grasses, or of trees of similar age or of less desirable species or form than the crop trees which they are or may soon be overtopping.

CLIMAX - The final stage of a succession which continues to occupy an area as long as climatic or soil conditions remain unchanged.

CODOMINANT - Trees with crowns forming the general level of the crown cover and receiving full light from above, but comparatively little from the sides; usually with medium-sized crowns more or less crowded on the sides.

CONTAINERIZED SEEDLINGS - Seedlings grown in plastic tubes or similar containers. Containerized seedlings may be out-planted when they are a few months old at any time during the growing season.

CORD - Standard - a pile of stacked wood containing 128 cubic feet within its outside surfaces. The standard dimensions are 4 by 8 feet, or sticks 4 feet long, piled 4 feet high in a rick 8 feet long.

CORDUROY - The process of incorporating logs in a roadbed in wet areas.

CROWN DRIP - That portion of precipitation that is intercepted by the canopy and subsequently drips from the crowns of the intercepting trees.

CULL - A tree or log of merchantable size rendered unmerchantable because of poor form, excessive branching, rot, or other defect. A tree or log will be considered as cull if more than 50% of the total volume is defective.

CULTURAL WORK - Any of the timber stand improvement practices.

CULVERT - A drain or conduit under a road or embankment.

CUT AND FILL ROAD - A type of forest road, constructed on a hillside, where the soil material is cut from the hillside to make a roadbed and is filled in on the downslope side of the cutroad.

CUTTING CYCLE - 1. The planned interval between major felling operations in the same stand. 2. The plannned period within which all portions of a working circle are logged in orderly sequence.

CUTTING, METHODS OF:

1. Clearcutting:
    1. Removal of the entire stand in one cut.

    2. An area on which the entire stand has been so removed.

        a. With artificial reproduction. Reproduction after cutting obtained artifically by direct seeding or by planting.

b. <u>With natural reproduction</u>. Regeneration after cutting obtained by seeding in from the marginal stand or from trees cut in the clearing operation.

2. Coppice. A method of renewing the forest in which reproduction is by sprouts. Syn. Sprout method.
3. Harvest. A general term for the removal of financially or physically mature trees. (In contrast to cuttings which remove immature trees.)
4. Improvement. A cutting mader in a stand past the sapling stage for the purpose of improving its composition and character, by removing trees of less desirable species, form, and condition in the main crown canopy. (See timber stand improvement.)
5. Partial. A cutting by which only a part of the stand is removed. It usually implies a series of such cuttings.
6. Regeneration or reproduction. Any cutting intended to encourage or make regeneration possible.
7. Salvage. A cutting made to remove trees killed or injured badly to utilize merchantable material before it becomes worthless. (See also Sanitation.)
8. Sanitation. A cutting made to remove trees killed or injured by fire, insects, fungi, or other harmful agencies (and sometimes trees susceptible to such injuries), for the purpose of preventing the spread of insects or disease. (See also Salvage.)
9. Seed-tree. Removal of the mature timber in one cut, except f0r a small number of seed trees left singly or in small groups. Called a group cutting when the seed trees are left in groups; also a reserve cutting when specially selected seed trees are left for growth as well as to furnish sed.
10. Selection. Removal of mature timber, usually the oldest or largest trees, either as single scattered trees or in small groups at relatively short intervals, commonly 5 to 20 years, repeated indefinitely, by means of which the continuous establishment of natural reproduction is encouraged and an uneven-aged stand is maintained.
11. Selection - group. A modification of the selection method whereby the mature timber is removed in small groups rather than by single trees.
12. Shelterwood. Removal of the mature timber in a series of cuttings, which extend over a period of years equal usually to not more than one-quarter and often not mora than one-tenth of the time required to grow the crop, by means of which the establishment of natural reproduction under the partial shelter of seed trees is encouraged. (Syn. Uniform method; Compartment method.) In theory the series of shelterwood cuttings is divided into three parts as follows:
    1. preparatory cuttings, which fit the stand for its regeneration by the removal of dying and defective trees and undesirable species, and prepare the seedbed and encourage seed production.
    2. Seed cutting, which further opens the stand before seeding takes place, to make available the amount of light and heat that the expected seedlings will require.

3. Removal cuttings, which gradually remove the remainder of the mature stand which after establishment of reproduction retards the development of young trees. The final cutting is the last of the removal cuttings. Group Shelterwood is a modification whreby the successive cuttings spread outward from groups rather than extending uniformly over the stand. In strip shelterwood, the excessive cuttings are applied stripwise rather than uniformly over the area. A modification of strtip shelterwood is known as Wagner's method.

13. Rim Cut. A clearcut strip of timber of varying width (usually not more than twice the tree height) which is removed from the edge of a stand.

DBH - (Diameter Breast Height) - The diameter of a tree 4 1/2 feet above ground level.

DECIDUOUS - Trees which shed their leaves annually.

DEEP PERCOLATION - Water which percolates below the root zone and cannot be used by plants.

DEFECT - Any irregularity or imperfection in a tree, log, piece product, or lumber that reduces the volume of sound wood or lowers its durability, strength, or utility value. Defects in lumber may result from such factors as insect or fungus attack, growth conditions and abnormalities, manufacturing or seasoning practices, etc.

DOMINANT - Trees with crowns extending above the general level of the crown cover and receiving full light from above and partly from the side; larger than the average trees in the stand, and with crowns well developed but possibly somewhat crowded on the sides.

ECOLOGY - The science which deals with the relation of plants and animals to their environment and to the site factors that operate in controlling their distribution and growth. (See Silvics.)

EDAPHIC - Pertaining to the soil.

ENERGY GRADIENT - Change in energy per unit length in the direction of flow or motion.

ENVIRONMENTAL ANALYSIS REPORT (EAR) - A report on environmental effects of proposed Federal actions which may require an Environmental Impact Statement (EIS) under section 102 of the National Environmental Policy Act (NEPA). The EAR is an "in-house" document which becomes the final document on environmental impacts for those projects which, because their effects are minor, do not require and EIS.

EROSION - Detachment and movement of the solid material from the land surface by wind, water, or ice, or by gravity as in landslides.

EUTHROPHICATION - The term "eutrophic" means well-nourished, and "eutrophication" refers to the natural or artificial addition of nutrients to bodies of water and to the effects of any resulting stimulation of algae growth.

EVAPOTRANSPIRATION - Water transpired by vegetation plus that evaporated from the soil.

EVEN-AGED MANAGEMENT - The actions that will result in a forest or stand composed of trees having no or small differences in age.

FELLING - The cutting down of standing trees.

FIRE BREAK - A natural or artificial barrier usually created by the removal of vegetation and used to prevent or retard the spread of fire.

FORB - A broad-leaved, flowering herb whose stem, above ground, does not become woody and persistant.

FOREST - A collection of individual stands administered as an integrated unit.

FOREST FLOOR - Litter, humus, and organic matter lying on the mineral soil surface.

FOREST MANAGEMENT PRACTICES - Forest management is concerned with the administration of a "forest" in order to achieve a sustained annual yield of products. The term "products" includes all benefits derived from the forest; water; recreation; forest crop; fish and wildlife. A forest management practice would, therefore, include any activity which takes place on forest stands and involves management of those stands or the products listed above.

GEOMORPHIC REGION - A region having a particular pattern of relief features or land forms that differs significantly from that of adjacent regions.

GROUNDWATER - Water within the earth that supplies wells and springs. Specifically, water in the zone of saturation where all openings in soils and rocks are filled - the upper surface of which forms the water table.

GROWTH. See Increment.

GULLY EROSION - The removal of soil by the formation of relatively large channels or gullies cut into the soil by concentrated runoff. In contrast to rills, gullies are too deep to be obliterated by ordinary tillage practices.

HAND RELEASE - See RELEASE

HARDPAN - A hardened soil layer caused by cementation of soil particles with organic material or with minerals such as silica or calcium carbonate.

HARVESTING - The cutting, initial processing if any, and extraction of any forest product. See LOGGING.

HEAVY METALS - Metals having a specific gravity (i.e., weight in comparison to the weight of an equal volume of water) of 5.0 or over, and generally toxic in relatively low concentrations to plant and animal life. Such metals can persist in animal tissue and are capable of increasing in concentration as they pass upward through the food chain. Major source of heavy metal contamination are pesticides, limestone and phosphate fertilizers, manures and sewage sludges, and mine wastes. Examples include lead, mercury, cadmium, and arsenic.

HECTARE - A unit of land measure in the metric system equivalent to 2.47 acres.

HERB - Any flowering plant except those developing persistant woody stems above ground.

HERBICIDE - A substance used to inhibit or destroy plant growth. It its effectiveness is restricted to a specific plant or type of plant, it is known as a selective herbicide.

HYDROLOGIC CYCLE - The circuit of water movement from the atmosphere through various stages or processes on the ground (such as precipitation, interception, runoff, infiltration, percolation, storage0 and then back to the atmosphere again by evaporation and transpiration.

HYDROLOGY - Science dealing with the properties, distribution and flow of water on or in the earth; study of the hydrologic cycle.

IMPOUNDMENT - An enclosure for the storage of water.

INCREMENT - The increase in diameter, basal area, height, volume, quality, or value of individual trees or stands during a given period. Gross increment refers to values uncorrected for losses by mortality or deterioration; net increment to values including such corrections. Sny. Growth.

INFILTRATION - Downward entry of water into soil.

INFILTRATION RATE - The maximum rate at which the soil under various specified conditions (including the presence of an already excess amount of waer) can absorb falling rain or melting snow.

INTERCEPTION - That portion or precipitation intercepted by vegetation. Interception is disposed of by drip, stem flow, or evaporation.

INTERFLOW - That portion of rainfall which infiltrates into the soil and more laterally through the upper soil horizons until intercepted by a stream channel or until it returns to the surface at some point down slope from its point of infiltration.

INTERMEDIATE - Trees shorter than those in the dominant and codominant classes, but with crowns either below or extending into the crown cover formed by codominant and dominant trees, receiving a little direct light from above, but none from the sides. Usually with small crowns considerably crowded on the sides.

INTOLERANCE - The incapacity of a tree to develop and grow in the shade of and in competition with other trees.

INVENTORY - The quantity or count of physical entities (such as trees, lakes, etc.) in an area.

LEACHING - Removal of soluble material from soil or vegetation by the passage of water over or through it.

LITTER - The uppermost layer of organc debris on the ground under a vegetation cover - (i.e., essentially the freshly fallen or only slightly decomposed vegetable matter, mainly from foliage but also bark fragments, twigs, flowers, fruits, etc.)

LOGGING - The cutting and extraction of timber, particularly logs. In imprecise usage logging, harvesting, and silviculture are used seemingly interchangeably by different people, often with vehemence as to which is the correct term in a given situation. According to Ford-Robertson (1971) "silviculture" has as its primary concern the establishing, growing, and tending of forests. "Harvesting" and "logging", however, deal specifically with the extraction of resources from the forest; with logging restricted to the cutting and extraction of timber and "harvesting" expanding this to include the cutting, initial processing if any, and extraction of any forest product.

LOGGING, aerial - A system for hauling timber from the stump to a collection point which employees aerial means of transportation - e.g., balloons or helicopters.)

LOGGING, cable - A method for transporting logs from stumps to colection points which utilizes a cable system. (See Logging, skyline; Logging, high-lead; and Logging, ground-lead.)

LOGGING, ground-lead - A cable logging system using a powered cable passed through a block fastened close to the ground level to drag logs along the ground.

LOGGING, skyline - A cable logging system using a heavy cable stretched between to high points to function as an overhead track for a load carrying trolley. Logs are lifted up by cables or other devices attached to the trolley and powered cables are used to move the load back and forth along the main cable.

LOGGING, tractor - Any logging method which uses a tractor (skidder) as the motive power for transporting lots from the stumps to a collecting point - whether by dragging or carrying the logs.

MASS-WASTING - A general term for any of the variety of processes by which large masses of earth material are moved downslope by gravitational forces - either slowly or quickly.

MAST - Nuts collectively, such as acorns, beechnuts, chestnuts, and seeds of certain pines, especially when considered as food for domestic livestock and deer.

MECHANICAL SITE PREPARATION - Use of a machine (i.e., caterpillar, bulldozer, plow) to prepare the areas where trees have been cut, for the planting or seeding of new trees. This usually involves the piling or crushing of tree remains and the exposure of topsoil. Spraying of chemicals or burning are other methods of site preparation which may be used separately or in combination with the mechanical methods.

MICROCLIMATE - The atmospheric conditions existing in or immediately surrounding a small area or locality such as a nursery bed, a patch of reproduction, a shelterbelt. Usually the locality is sharply defined.

MILACRE - A sample plot of 1/1000 acre (usually 1/10 chain square) used in reproduction or vegetation surveys.

MINERAL SOIL - A soil consisting predominantly of,, and having its properties determined predominantly by inorganic matter.

MINERAL STAINS - An extensive disfiguring stain that is olive to greenish-black, high in ash content, and having the tendency to effervesce with hydrochloric acid. An infection of sugar maple.

MISLETOE - A flowering plant of the family Loranthaceae; parasitic on trees and other woody plants. The misletoes are divided into:

Dwarf. A group including members of the genus Arceuthobium (Razoumofskya), all without apparent leaves; occurring only on conifers Syn. Lesser misletoes.

Leafy. A group including in temperate North America members of the genus Phoradendron, mostly with thick flat, green leaves but sometimes without apparent leaves; they usually occur on hardwoods but some species on conifers.

NON-POINT SOURCES OF POLLUTION - Those activities of man which alter or use the land so that concentrations of organic and inorganic constituents in the dispersed run-off from the land are increased over the natural background levels. This pollution may best be controlled through manipulation of land management activities. Activities that may contribute to non-point source pollution include farming, construction, logging and mining.

NURSERY STOCK - Seedlings grown in a nursery, commonly designated 2-0, 3-0, or 2-2 stock. The first number refers to the number of years the tree grew in the seedbed; the second number refers the number of years the tree grew in the transplant bed. Transplanting of seedlings improves the hardiness of the stock.

NUTRIENT CYCLE - The cycling of chemical elements such as nitrogen, carbon, etc. in specific pathways from the non-living (inorganic) portions of the environment into the organic substances in plants and animals and then back again into inorganic forms.

ORGANIC SOIL - A soil that contains a high percentage (greater than 20 or 30 percent) or organic matter in the upper layers (where living roots are primarily found).

OVERLAND FLOW - The rain storm or snowmelt runoff water which flows over the ground surface as a thin layer - as opposed to the channelized runoff which occurs in rills and gullies.

OVERSTORY - The trees in a forest of more than one story that form the upper or uppermost canopy layer.

PARENT MATERIAL - The unconsolidated, chemically weathered mineral or organic matter from which the upper layers of soil develop.

PERCHED WATER TABLE - A water table, usually of limited area, maintained above the normal groundwater supply by the presence of an intervening, relatively impervious confining soil layer.

PERCOLATION - The downward movement of water through soil.

PESTICIDES - All materials, mostly chemicals, that are used for the control of undesirable insects, diseases vegetation, animals, or other forms of life.

PERCOLATION - The downward movement of water through soil.

PESTICIDES - All materials, mostly chemicals, that are used for the control of undesirable insects, diseases, vegetation, animals, or other forms of life.

pH - A measure of the acidity of a substance, expressed as the logarithm of the reciprocal of the hydrogen ion concentration.

PIONEER - A plant capable of invading bare sites (e.g., a newly exposed soil surface) and persisting there until supplanted by successor species.

PROGRESSIVE STRIP CUTTING - Clearcutting progressing against the prevailing wind in strips.

PRUNING - The removal of life or dead branches from standing trees. This may be done artifically or naturally. Natural pruning results from such causes as deficiency of light, decay, snow, ice, etc.

RAINDROP EROSION - The spattering of small soil particles caused by the impact of raindrops on wet soils. The loosened and splattered particles may or may not be subsequently removed by surface runoff.

RECREATION, dispersed - Scattered, individual outdoor recreation activities normally not identified with developed facilities or areas of group concentration.

RECREATION, intensive - High-density recreational activities - (e.g., developed camp and picnic grounds, swimming beaches, hiking trails that are major access routes into wilderness areas, all-terrain vehicle areas (except snowmobile trails), etc.)

REFORESTATION - The natural or artificial restocking of an area with forest trees; most commonly used in reference to the latter. (See Afforestation.)

REGENERATION - See Reproduction.

RELEASE - Freeing a tree or group of trees from competition by cutting or or otherwise eliminating growth that is overtopping or closely surrounding them.

REPRODUCTION - The process by which a forest or range is renewed.
Artificial: Renewal by direct seeding or planting. (See Reforestation.)
Natural:
1. Renewal by self-sown seeds, sprouts, rhizomes, etc. (Syn. Regeneration. See Cutting, methods of.)
2. Seedlings or saplings of any origin. (Syn. Young growth.)

RILL EROSION - The process by which numerous small channels, at the most only several inches deep, are formed on recently cultivated or exposed soils.

ROCK, igneous - Rocks formed by solidification from a molten or partially molten state - e.g., various types of lava. Igneous rocks are subdivided into those rocks that solidified below the surface (plutonic) and those that solidified from molten materials that were extruded onto the surface (volcanic). Examples: gabbro (plutonic), basalt (volcanic).

ROCK, metamorphic - Rocks which have been formed in the solid state under the conditions of high pressure, high temperature, and the introduction of new chemical substances that, in general occur at great depths within the earth. Examples: slate, greenstone.

ROCK, sedimentary - Rocks that have been formed from deposits of sediment. Examples: sandstone, shale, limestone.

ROTATION - The period of years required to establish and grow timber crops to a specified condition of maturity.

RUNOFF - The portion of precipitation or irrigation water which does not infiltrate into the soil,, but moves over the surface.

SAMLING - A loose term for a young tree greater than a few feet tall and an inch or so in diameter at breast height.

SCALE - The act of making volume measurements of cut timber.

SCALE, consumer, or MILL SCALE - Scaling done at the mill or by a broker.

SCALE, ground - Scaling done by a forester at the log landing.

SEDIMENT - Solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site or origin by air, water, gravity, or ice and has come to rest on the earth's surface.

SEEPAGE - Movement of water into, through, or from soil.

SEROTINOUS - In botany, late ripening of fruits. In forestry, cones that remain closed without allowing dissemination of the enclosed seeds long beyond the time of maturing. In some species such as black spruce, dissemination may occur over a period of two to five years. In others, such as jack pine, the cones may remain closed on the tree unless subjected to high temperatures.

SHEET EROSION - The removal of a fairly uniform layer of soil from the land surface by runoff water or wind.

SILVICS - The life history and general characteristics of forest trees and stands, with particular reference to environmental factors. (See Ecology.)

SILVICULTURE - That part of forest management which deals with the science and art of cultivating forest crops through various treatments which are applied to stands in order to maintain and enhance their productivity. The term includes all activities related to this purpose from the preparation of an area for restoration of forest vegetation, the establishment, culture and protection of the growing crop, to that crops harvest and transport from the production area.

SITE - An area considered in terms of its environment, particularly as this determines the type and quality of the vegetation the aea can inherently produce.

SITE INDEX - An expression of forest site quality based on the height of the dominant stand at an arbitrarily chosen age, usually 50 years.

SITE PREPARATION - Chemical, prescribed burn, machine or hand methods of preparing the harvested area for the seeding or planting of the desired reproduction.

SKIDDING - The transportation of logs from stumps to a collecting point by sliding or dragging along the ground. The logs may slide wholly along the ground or with their forward end supported.

SLASH - The residue left on the ground after timber cutting and accumulating there as a result of storm, fire or other damage. It includes unutilized logs, uprooted stumps, broken or uprooted stems, branches, twigs, leaves, bark and chips.

SNAG - A standing dead tree from which the leaves and most of the branches have fallen.

SOIL HORIZON - A layer of soil, approximately parallel to the soil surface, with comparatively uniform characteristics produced by soil-forming processes.

SOIL MOISTURE - Water stored in soils, usually expressed as a percentage by dry weight or volume or as depth of water per foot of soil.

SOIL PREMEABILITY _ Capacity of the soil to transmit fluids.

SOIL PROFILE - The succession of soil horizons beginning at the surface that have been altered by normal soil-forming processes, particularly by leaching and oxidation.

SOIL SERIES - A group of soils which have similar soil profile characteristics and which are derived from similar parent materials. A soil series is usually named for the locality where the typical soil was first recorded.

STAND - A contiguous group of trees sufficiently uniform in species composition, arrangement of age classes, and condition to be a homogeneous and distinguishable unit.

STEM FLOW - That portion of precipitation that is intercepted by the canopy and subsequently flows down the stem of the intercepting trees.

STOCKING - A more or less subjective indication of the number of existing trees as compared to the desirable number for maximum production of wood or other resources.

STREAM - Any well defined channel which carries water during part or all of the year. A stream may be perennial, intermittent, or ephemeral.

Perennial:	Water flows throughout the entire year.
Intermittent:	Flow of water stops and starts at seasonal intervals (i.e., may only flow in spring or fall.)
Ephemeral:	Short-lived flow of water; usually associated with flash floods resulting from heavy rainfalls; temporary.

STRUCTURE - The distribution and representation of age, size, crown, or other tree classes in a stand or forest.

SUCCESSION - The gradual supplanting of one community of plants by another until the climax community is reached.

SUCKER - A shoot from the lower portion of a stem or especially from the root. (Syn. Sprout.)

SUPPRESSED (or Overtopped) - Trees with crowns entirely below the general level of the crown cover receiving no direct light either from above or from the sides.

SURFACE EROSION - Erosion which removes materials from the surface of the land as distinguished from gully or channel erosion. The two main types of surface erosion are sheet erosion and rill erosion.

SUSTAINED YIELD MANAGEMENT - Continuous production so planned as to achieve, at the earliest practical time, a balance between growth and harvest.

SURFACE WATER - Water stored on or flowing over the surface of the soil.

THINNING - Cutting in an immature stand to increase its rate of growth, to foster quality growth, to improve composition, to promote sanitation, to aid in litter decomposition, to obtain greater total yield, and so recover and use material that would be lost otherwise. Four district types of thinnings are recognized, each based on a different principle in selecting trees to be removed. These are crown thinning, lot thinning (thinning from below), selection thinning, and quality thinning.

1. Crown thinning. Cutting is made principally in the upper crown classes by the removal of codominant and dominant trees that are competing strongly with the most promising individuals of these classes. Cutting in the lower crown class is directed toward removing trees that are competing strongly with the most promising individuals of these classes. Cutting in the lower crown class is directed toward removing trees that will die and be wasted before the next cutting and is carried on only if such trees have a positive net conversion value. (Syn. Thinning from above; High thinning; Crop tree thinning.)
2. Low thinning. Anticipates natural thinning of stand through competition, by working upward from overtopped to dominant trees, in five recognized intensities of cutting, as follows: Grade A-light. Removes the poorest overtopped trees. Grade B-moderate. Removes all overtopped trees and the poorer intermediate trees. Grade C-heavy. Removes all overtopped and intermediate trees and often a few codominant trees. Grade D-very heavy. Removes all overtopped and intermediate trees and many to most of the codominant trees.
3. Mechanical thinning. The stand is thinned to a predetermined spacing by the removal of rows of trees or the removal of trees within rows.
4. Selection thinning. The largest dominant trees and the poorest overtopped trees if possessing a positive net conversion value are cut, the former to remove potential wolf trees of relatively low value and the latter to utilize these trees before they become a total loss.

THINNING, NATURAL - Death of trees in a stand as a result of competition.

THERMAL POLLUTION - Altering the amount of energy available in the environment by the addition of heat or cold.

THRIFTY - A condition applied to individual trees or forest types denoting a health, growing condition.

THROUGH FALL - Precipitation reaching the ground beneath a forest canopy; includes crown drip but not stem flow.

TIMBER STAND IMPROVEMENT (TSI) - All cuttings not a part of a major harvest felling, made during the life of a forest stand for the general purpose of improving the stand as regards composition, condition, or rate of growth. (See Cutting, methods of; Thinning.)

TOLERANCE - The capacity of a tree to develop and grow in the shade of and in competition with other trees.

TOPOGRAPHY - The configuration of a surface including its relief, elevation, and the position of its natural and man-made features.

TYPE, FOREST - A descriptive term used to group stands of similar character as regards composition and development due to certain ecological factors, by which they may be differentiated from other groups of stands. The term suggests repetition of the same character under similar conditions. A type is temporary if its character is due to passing influences such as logging or fire; permanent if no appreciable change is expected and the character is due to ecological factors alone; climax if it is the ultimate stage of a succession of temporary types. A cover type is a forest type now occupying the ground, no implication being conveyed as to whether it is temporary or permanent.

UNDERSTORY - Generally, those trees and woody species growing under an overstory.

UNEVEN-AGED - A class of forest or stand composed of intermingled trees or groups of trees that differ markedly in age.

VENEER - A thin sheet of wood cut on a veneer machine. There are three kinds of veneers: sawed, sliced and rotary cut.

VIGOR - The degree to which a forest tree is capable of producing sustained, high quality, rapid growth in competition with surrounding vegetation.

VOLUME REGULATION - A method of planning for sustained yield which relies on the volume harvested in a given time period under even-aged management.

WATERCOURSE _ Term incluees artificial and natural watercourses: Any channel having definable beds and banks capable of conducting generally confined runoff from adjacent lands. During floods water may leave the confining beds and banks bur under low and normal flows water is confined within the channel. A watercourse may be perennial, intermittent or ephemeral.

A. perennial: flows throughout the entire year.
B. intermittent: flow stops and starts at seasonal intervals.
C. ephemeral: short-lived flow, usually occurring after large storms associated with flash floods; temporary.

WATER EQUIVALENT - The depth of water that would result from melting snow.

WATER POLLUTION - A degradation of the quality of water for a specified use.

WATERSHED - Total land area above a given point on a stream or watercourse that contributes water to the flow at that point.

WATER TABLE - The upper surface of the groundwater or that depth below which the soil is saturated with water.

WINDTHROW - Uprooted by the wind. The strength and extent of a tree's root system develops as a response to the forces of wind, snow, and ice that the tree is subjected to. These forces may increase for a particular tree if the surrounding trees are removed. If the tree does not have a root system capable of absorbing the additional stress, it will be blown down. Trees with shallow root systems on wet sites are particularly susceptible.

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APPENDIX A

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

MINNESOTA

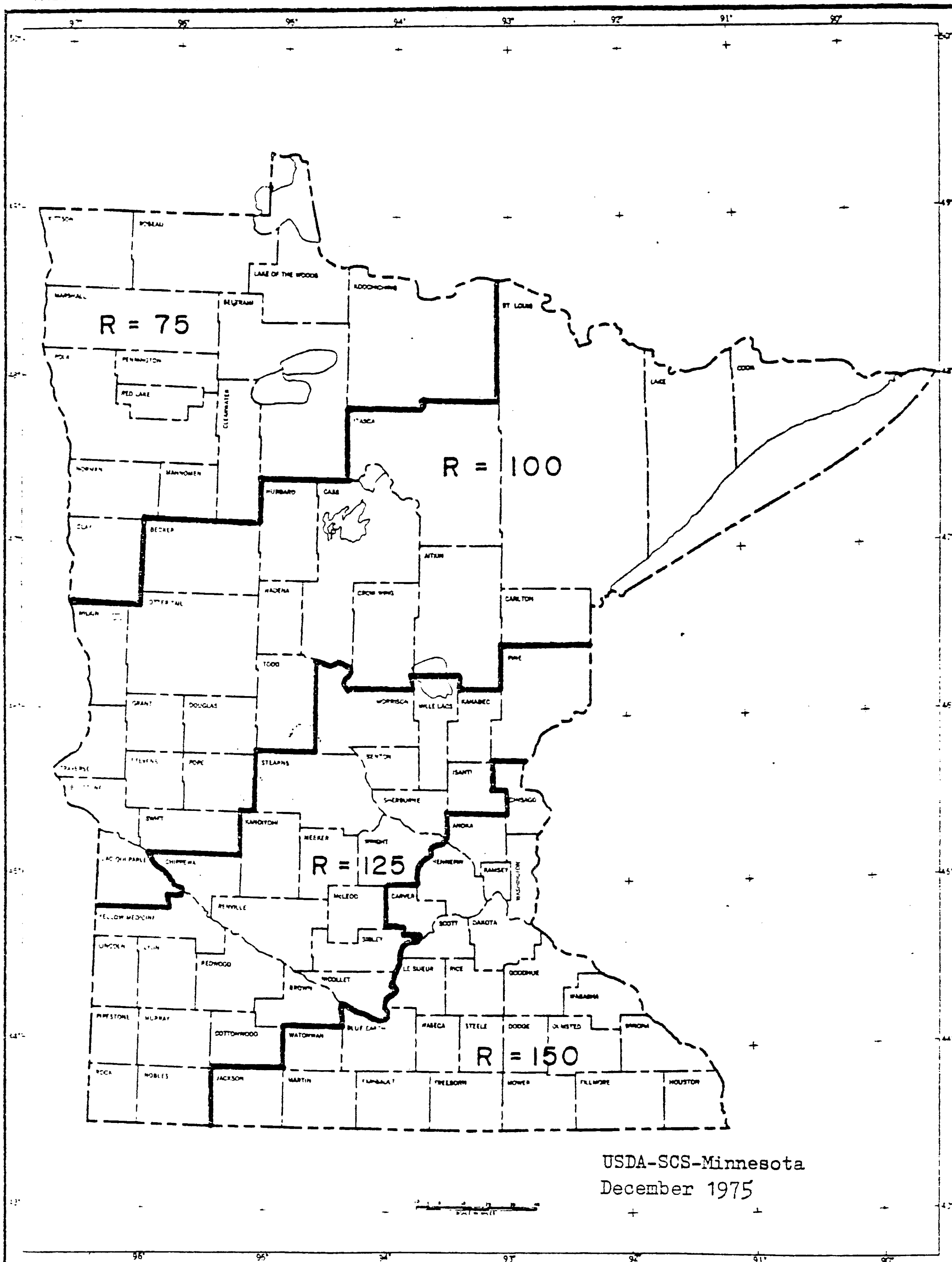


CHART NO. 1

APPENDIX B

WOODLAND SUITABILITY GROUPINGS

Forest soils in Minnesota are ordinated into Woodland suitability groupings. A three part symbol is used to designate these groups, such as 2o2 or 2r1. The first part of the symbol, always a number, indicates the site index or relative productivity for a common forest type or specie. Site index is the average height the larger (dominant and codominants) trees will reach at 50 years of age. Average yields and other data have been developed by site index for many species of trees based on normal or other stocking rates.

The second part of the symbol is a lower case letter. This letter indicates the most important soil property that imposes a hazard, restriction, or limitation for woodland use or management. The letter o indicates that the soils have few limitations; r indicates slope steepness; w indicates wetness; s indicates sandiness; c indicates clayiness and d indicates restricted rooting depth.

The third part of the symbol, a number, subdivides a group on the basis of species adaptability to soil conditions.

In each ordinated woodland suitability group the hazards and limitations are the same. However, when species or forest types are different the groups are refined in tables by Land Resource Areas.

Woodland Suitability Group 2r1

Description: This group consists of well drained and moderately well drained, moderately coarse to moderately fine textured soils. Slopes range from 12 to 40 percent. In LRA's 103, 104 and 105 these soils are dominantly in coves or on north and east slopes. Most soils have low to high natural fertility and moderate to very high available water capacity.

Seedling mortality is slight to moderate, plant competition is moderate to severe, equipment limitations are moderate to severe, and hazard of erosion is moderate to severe.

Soils in this group are:

WOODLAND SUITABILITY GROUP 2r1

	POTENTIAL PRODUCTIVITY			SPECIES SUITABILITY	
LAND RESOURCE AREA	Important Wood Crops (Species)	Av. Site Index	Basis (No. of Plots)	To Favor in Existing Stands	For Planting
88,90,91	Red pine Jack pine White pine White spruce Basswood Red oak Sugar maple Aspen White birch	60 60 55 60 50-60 50-60 50-55 70-80 60-75	EST	Red pine White pine White spruce Red oak Jack pine Basswood	Red pine White spruce Jack pine Red oak Basswood
103,104, 105	Black walnut Red oak White oak White birch Basswood White pine	50-65 50-75 50-70 50-65 50-65 55-65	EST	Black walnut White oak Red oak Basswood White pine	White oak Red oak Black walnut White pine Basswood

Woodland Suitability Group 2c1

Description: This group consists of well drained to somewhat poorly drained soils with thin medium textured surface layers over fine textured subsoils. Slopes range from 0 to 25 percent. Most soils have medium to high natural fertility and moderate to high available water capacity.

Seedling mortality is slight to moderate, plant competition is severe, equipment limitations and hazard of erosion are slight to severe.

Soils in this group are:

WOODLAND SUITABILITY GROUP 2c1

	POTENTIAL PRODUCTIVITY			SPECIES SUITABILITY	
LAND RESOURCE AREA	Important Wood Crops (Species)	Av. Site Index	Basis (No. of Plots)	To Favor in Existing Stands	For Planting
88,90,91	Aspen Red pine White pine Jack pine White spruce Red oak Basswood Sugar maple	77 55 49 52 52 57 50 51	18 7 8 1 4 1 1 2	Red pine White pine White spruce Red oak	Red pine White spruce White pine

Woodland Suitability Group 3r1

Description: This group consists of well to somewhat excessively drained soils with moderate available water capacity. Most are moderately fine textured soils underlain by coarse textured. materials or bedrock. Slopes range from 12 to over 25 percent. Most of these soils have medium natural fertility. Bedrock restricts rooting depth in some soils.

Seedling mortality is slight on north and east slopes and moderate to severe on south and west slopes, plant competition is moderate, equipment limitations are moderate to severe, and hazard of erosion is moderate to severe.

Soils in this group are:

WOODLAND SUITABILITY GROUP 3r1

LAND RESOURCE AREA	POTENTIAL PRODUCTIVITY			SPECIES SUITABILITY	
	Important Wood Crops (Species)	Av. Site Index	Basis (No. of Plots)	To Favor in Existing Stands	For Planting
88,90,91	Red pine White pine Jack pine White spruce Aspen Red oak	55-60 55-60 60-65 55-60 70-80 55-60	Est	Red pine White pine Red oak	Red pine Red oak White spruce
103,104 105	White pine Red oak White oak Bur oak Basswood	50-60 50-65 50-65 50-60 50-65		White oak Red oak Basswood	White oak Red oak Basswood White pine

Woodland Suitability Group 4d1

Description: This group consists of shallow to deep, well drained to excessively drained, medium to coarse textured soils underlain by bedrock within 20 inches. Slopes range from 12 to 55 percent. Most of these have low to medium natural fertility and low to very low available water capacity.

Seedling mortality is moderate to severe, plant competition is slight, equipment limitation is moderate to severe, and hazard of erosion is moderate severe.

Soils in this group are:

WOODLAND SUITABILITY GROUP 4d1

	POTENTIAL PRODUCTIVITY			SPECIES SUITABILITY	
LAND RESOURCE AREA	Important Wood Crops (Species)	Av. Site Index	Basis (No. of Plots)	To Favor in Existing Stands	For Planting
88,90,91	White pine Red pine Jack pine Aspen White birch	50 50 50 55 50	Est	White pine Red pine Jack pine	Red pine White spruce
103,104, 105	Bur oak White oak Basswood White pine	50 50 50 50	Est	White pine White oak	White pine

Woodland Suitability Group 4s1

Description: This group consists of well drained to excessively drained, medium to coarse textured soils underlain by sand or sand and gravel. Slopes range from 12 to over 25 percent. Most of these soils have low natural fertility and low to very low available water capacity.

Seedling mortality is severe, plant competition is slight, equipment limitation is moderate to severe, and hazard of erosion is moderate to severe.

Soils in this group are:

WOODLAND SUITABILITY GROUP 4s1

	POTENTIAL PRODUCTIVITY			SPECIES SUITABILITY	
LAND RESOURCE AREA	Important Wood Crops (Species)	Av. Site Index	Basis (No. of Plots)	To Favor in Existing Stands	For Planting
88,90, 91	Red pine White pine Jack pine White spruce	50-60 50-60 55-65 45-60	Est " " "	Red pine White pine	Red pine Jack pine
103,104, 105	Bur oak Hickory Pine species	20-60 1/ 20-60 45-60	Est	Bur oak Hickory	White pine Red pine Jack pine

1/ Lower site index is predominantly on south and west slopes.

APPENDIX C

FREQUENCY		LEVEL	SYMBOL	LEGEND
160	1.7%	1		040 - RED WING-LACRESCENT UPLANDS, STEEP
487	5.3%	2		019 - TOWER-ELY GLACIAL DRIFT AND BEDROCK COMPLEX
63	0.6%	3		021 - NASHWAUK-WARBA MORAINE, BROWN
5	0.0%	4		03B - NORTHOME MORAINE, LOAMY
332	3.6%	5		003 - ALEXANDRIA MORAINE COMPLEX
140	1.5%	6		011 - ITASCA MORAINE COMPLEX, ROLLING
67	0.7%	7		028 - AURORA TILL PLAIN, RED CLAYEY, SLOPING
49	0.5%	8		016 - MESABI RANGE
130	1.4%	9		52A - HIGHLAND MORAINE, LOAMY, ROLLING TO HILLY
132	1.4%	10		009 - ST. CROIX MORAINE COMPLEX, LOAMY, ROLLING TO HILLY
49	0.5%	11		053 - NEMADJI-DULUTH LACUSTRINE PLAIN, CLAYEY
7456	82.2%	12		ALL OTHER GEOMORPHIC REGIONS

APPENDIX D

SILVICULTURAL GUIDES

The following section describes the silvicultural theory and guidelines currently used by foresters in Minnesota. The guides are written for the eleven major types of forest trees identified in Part A. The guidelines explain the general theories and recommended practices for efficient and successful harvest and regeneration of each type. Field personnel, however, may occasionally use alternative methods when other factors necessitate. The types discussed are the following:

Red Pine

Jack Pine

Black Spruce

Northern White Cedar

Tamarack

Lowland Hardwoods

Lowland Conifers

Upland Spruce-Fir

Trembling Aspen

Northern Hardwoods

Oak

1. RED PINE (NORWAY PINE)

Red pine is a versatile species, yielding a variety of products from even-aged pure stands. It is found in natural stands on sandy and gravelly soils in the northern conifer region of Minnesota but red pine is planted throughout the state. Red pine is sometimes found in mixed stands with jack pine, white pine, or aspen (Fowells, 1965).

Red pine is intolerant of shade. Establishment of new stands usually requires clearcutting and site preparation to expose a mineral seedbed. Sites that are suitable for red pine are generally more fertile and less droughty than jack pine sites, but less fertile and more droughty than white pine sites (Fowells, 1965).

Management objectives for red pine are to "control establishment, composition, and growth of the stand so that intermediate thinnings will provide useful products (pulpwood, posts, poles, and small saw timber) and final harvest will yield high quality saw timber and veneer." Management objectives also include considerations for recreation, wildlife, and water (Benzie, 1977).

CLEARCUT

Clearcutting followed by mechanical site preparation and seeding or planting, is the most common method of regenerating red pine (Benzie, 1973). Clearcutting:

1) removes all residual stems. Residual stems would otherwise provide shade which slows seedling growth and favors shrub growth.
2) is economical. Harvest operations are more economical on clearcuts of 40 acres and more. Clearcutting red pine is feasible for highly mechanized systems unless the trees are very large.

3) facilitates site preparation. Removal of all stems is usually necessary for adequate exposure of mineral seed beds, or elimination of slash and brush.

4) facilitates machine planting.

Disadvantages of clearcutting are reduced aesthetic appeal and the possibility of increased runoff which may cause soil erosion.

STRIP CUT

Strip cuts may be employed where aesthetics are important. Advantages and disadvantages of this system are the same as for clearcutting but are of a lesser magnitude (USDA, 1973).

SEED TREE

Seed tree harvesting systems have not been effective due to the erratic and undependable nature of red pine's seed production (Benzie, 1977).

SHELTERWOOD

Shelterwood systems are also hindered by infrequent seeding. However, these systems are useful when mature trees are needed on the site to bridge the gap from a fully stocked stand of mature trees to a full stocked stand of seedlings (Benzie, 1977). Mechanical site preparation and supplemental seeding or planting are often required.

UNEVEN-AGED MANAGEMENT

Selection or group selection cuttings require close and continuous attention. These methods can be used to maintain high forest cover in small stands (Benzie, 1977).

THINNING

Intermediate thinning of red pine is recommended due to the value and long life of the crop. Intermediate thinning (Benzie, 1977):

1) puts the most growth on the best trees
2) maintains uniform growth rates for crop trees
3) removes diseased, injured, and suppressed trees
4) shortens the rotation
5) increases yields
6) provides cash returns before the end of the rotation

Thinning can be accomplished in either of two ways, thinning from below or row thinning (Smith, 1962).

Thinning from below mainly involves the removal of smaller, slower growing trees. High risk, poor quality, and damaged trees are also cut. Trees of other species are cut when they are not needed to maintain full stocking.

Row thinning is often used for the first thinning in plantations. It has the advantage of being more economical but cannot be used to select the best crop trees and remove poor stock.

An ideal treatment schedule for red pine might be:

Year 0	Plantation establishment
Year 2 or 3	Examination of seedling survival and release needs followed by the required treatment
Year 30	Thin for pulpwood (row thinning)
Year 60	Thin for poles, posts, and small saw timber (thin from below
Year 90	Thin for small saw timber (thin from below)
Year 120	Clearcut

LOGGING SYSTEM

Red pine is harvested by all types of logging systems, the determining factors being the logger's preference and equipment. However, tree length logging would probably be ideally suited to the final harvest for two reasons. Since mature red pine have few limbs, these could be removed at the stump. Long logs may be graded higher than short logs, thereby, bringing higher returns to the logger.

Full tree harvesting can also be used in clearcuts and shelterwood cuts of mature trees. Advantages include: slash is removed, site preparation is not needed, logging is done efficiently, and brush is set back (Benzie, 1971, Harvesting for Red Pine).

SITE PREPARATION

Site preparation is used to prepare a mineral seedbed and/or to eliminate competition for light, water, and nutrients. Three methods are commonly used (Benzie, 1977):

1) preparation of seeding or planting spots (scalping). This method protects the site from soil erosion and severe drying but may require frequent follow-up release.
2) complete site preparation. This method may reduce the need for follow-up release, but it may expose the site to erosion, severe drying, and create an eye sore. This method is valuable where brush is a problem or where mineral soil must be exposed.
3) full tree skidding. This logging system may adequately accomplish site preparation in some situations.

Complete Site preparation may be accomplished using (Benzie, 1977):

1) mechanical equipment, such as bulldozers, shearing blades, heavy duty discs, roto tillers, plows, root rakes, rock rakes, or drum choppers
2) herbicides
3) prescribed burning

REGENERATION

Regeneration usually involves planting of nursery stock following site preparation. Planting is done in the spring or fall. Planted seedlings have a greater advantage over competing vegetation than natural seedlings do, since they are 3 or 4 years older when the plantation is established. However, natural seeding is relied upon for shelterwood systems (Benzie, 1977).

Containerized seedlings may be used rather than conventional nursery stock. Containerized seedlings are grown for several months, usually in plastic tubes, and can be planted anytime during growing season. Because of their small size, their use may require additional release treatments (Benzie, 1977).

RELEASE

Release is often needed 2 or 3 years after planting to eliminate competitive shrubs and hardwoods. Release can be done by hand or with herbicides.

Hand release can be employed if competition is not too extensive. Several cuttings may be required at intervals of 2-3 years (Benzie, 1977). Hand release, under most circumstances, is not economically feasible. However, government programs have supplied funds to hire crews for this work in some areas.

Herbicide application during mid-August can eliminate hardwood and brush competition without damaging red pine seedlings. In most cases, one treatment is sufficient. Herbicide applications should comply with established guidelines for safe use.

DISEASE AND INSECT CONTROL

Red pine has relatively few serious insect and disease problems compared to other native pines (Fowells, 1965).

Light infestations of pine root collar weevils and introduced pine sawflies were reported in scattered plantations in northern Minnesota during 1977 (DNR, 1977).

Two diseases may be important in red pine management. The Lake States strain of Scleroderris canker has infected some northeastern Minnesota plantations. Diplodia tip blight, together with Ips pini bark beetles, is causing some mortality in north central Minnesota. These diseases were still in the observation stage in 1977 (DNR, 1977).

OTHER RESOURCES

Red pine can be managed for recreation. Minimum stocking levels can be used to promote fast growth. If new stands are established regularly, continuous stands of old growth trees will be provided for the future. Rotations can be extended up to 200 years in aesthetic interest areas, and cultural operations can be confined to the off-season (Benzie, 1977).

Water resources can be affected by manipulation of stocking levels, low levels yielding more water. Site preparations, clearcuts, and herbicide treatments have the potential to affect water quality (Benzie, 1977).

Red pine is generally poor wildlife habitat, but is used for nesting by American bald eagles and other birds. Lack of forage species can be improved at the cost of timber production by use of minimum stocking levels and prescribed burning (Benzie, 1977).

Aesthetics are improved by making clearcut boundaries follow natural physiographic or forest type lines, and by slash disposal.

2. JACK PINE

Jack pine is a pulpwood species that is found in even-aged pure stands on sandy soils in the northern conifer region of Minnesota (Fowells, 1965). It is sometimes found in mixed stands with black spruce, trembling aspen, or paper birch.

Jack pine is one of the most shade intolerant species, and is therefore dependent on disturbances such as logging and fire for regeneration. It tends to be a temporary forest type on the better sites (loamy sands), but more permanent on poor sites (deep, dry outwash sands), (Benzie, 1977).

On sites for which jack pine is the best suited species, the management objective is to maintain jack pine. This objective can be accomplished through use of clearcut, seed tree, or shelterwood systems depending on tree and site characteristics. (Benzie, 1977)

On sites for which another species is better suited, the management objective is to convert to that species at the end of the rotation. In some cases, these sites may be the best jack pine sites, but conversion to red pine is more desirable. (See "Insect and Disease Control.") Rotations for jack pine occur when trees are 40-70 years old, trees are 8-12 inches in diameter, and are 50-80 feet tall (Benzie, 1977).

Choice of silvicultural system depends on 1) seed tree quality, 2) cone habit, 3) available slash disposal methods, and 4) seed beds (Benzie, 1977).

CLEARCUT

Clear cutting is the best amd most commonly used silvicultural system for jack pine (Ohmann et al., 1978). It is particularly useful when no desirable seed trees are present or when the stand has serotinous cones. Clearcutting provides an opening where shade intolerant jack pine seedings can develop.

Most jack pine cones are serotinous. They remain closed until exposed to intense heat, as from a fire. This makes jack pine ideally suited to revegetating burned areas. The cones may also open if scattered on the ground and exposed to direct sunlight on a 80 degree day (Fowells, 1965). Therefore, prescribed burning or scattering of cones is usually done after harvest if seeding of jack is desired.

SEED TREE METHOD

The seed tree method is employed when good quality seed trees with serotinous cones are present. Seed trees should be windfirm, hold a good crop of cones, be of desirable form and vigor, and be well distributed throughout the stand. These trees are left standing on the site after the rest of the stand is harvested. Prescribed burning follows soon after harvest to provide heat to open the cones (Benzie, 1977).

SHELTERWOOD

Shelterwood harvests can be used where non-serotinous cones are prevalent. However, this situation is not too common and use of this system is limited to stands where landscape and wildlife values are especially important (Ohmann, et al., 1977).

SITE PREPARATION

Site preparation is required to expose mineral soil if natural seeding is the planned means of regeneration, and to eliminate competitive vegetation and slash. Site preparation treatments may involve prescribed burning, full-tree skidding, or mechanical treatments (Benzie, 1977). Good jack pine sites, especially, tend to be brushy and require treatment (USDA, 1973).

REGENERATION

Regeneration is accomplished through seeding or planting. Seeding can be done by using a seed tree or shelterwood harvest, by scattering branches containing cones over the site, or by sowing repellent-treated cones. (Benzie, 1977) Planting of nursery stock or containerized seedlings may be done by hand or by machine.

RELEASE

Release may be required 2 or 3 years after regeneration to control competing vegetation. This may be accomplished using herbicides or hand tools as described for red pine.

THINNING

Thinning may be done around age 30 if the stand has a high site index and is being managed for poles and small saw timber (Benzie, 1977). Thinnings may increase yields up to 90 percent (Fowells, 1965). No thinning is usually done in pulpwood stands.

INSECT AND DISEASE CONTROL

Jack pine is susceptible to more diseases and insect attacks than is red pine. This and the fact that more management alternatives and a greater variety of products exist for red pine points to red pine's greater popularity for timber production.

Insect pests of jack pine that are currently important are jack pine budworm and jack pine sawfly (DNR, 1977). Jack pine budworm has been a problem in recent years, causing scattered mortality following defoliation of stands in Roseau and Beltrami counties. Control of this pest has been effected through harvest of infested merchantable stands and accelerated rotations in the surrounding area. Jack pine sawfly has maintained low populations and is primarily damaging only to open grown trees. No control is currently needed. No outbreaks of disease of jack pine have been reported lately (DNR, 1977).

OTHER RESOURCES

Recreationists frequently look for jack pine standings during blueberry season since blueberries are commonly found on the same sites. Aesthetics can be managed by regulating clearcutting to make openings blend into the landscape.

Young jack pine are frequently browsed by white-tailed deer. Mature stands are often brushy, which makes them good habitat. Most wildlife species benefit from management efforts to provide a good distribution of age classes in adjacent stands (Benzie, 1977).

3. BLACK SPRUCE

Black spruce is a valuable pulpwood species that is found in extensive, even-aged, pure stands on organic soils in the northern conifer region of Minnesota. The species also grows on the mineral soils of the Laurentian Shield in northeastern Minnesota. On mineral soils, black spruce generally occurs in mixed stands with white spruce, jack pine, balsam fir, aspen, or tamarack (Fowells, 1965).

Black spruce is tolerant of shade, but seedling development is superior in openings. Establishment of new stands is most successful where a seedbed of slow growing sphagnum is present or where the surface layer has been removed by fire or compacted by skidding (Fowells, 1965).

The best sites for black spruce typically have a regional water table, have excessive brush, and are periodically ravaged by fire (USDA, 1973). On these sites, management objectives generally are "production of a high sustained yield of pulpwood as efficiently as possible without adversely affecting other forest values," (Johnston, 1977). This objective is met through management of fairly large, even-aged stands, similar to virgin stands, resulting in efficiency for cultural operations and mechanical harvest (Johnston, 1977).

CLEARCUT

The best method for harvest and reproduction of black spruce is clearcutting (Johnston, 1977). Clearcutting:

1) reduces windthrow. Black spruce has a shallow root system and, on upland sites, is susceptible to butt rot when 70-100 years old which increases its susceptibility to wind breakage. Partial cutting and strip cutting increase the risks of windthrow (USDA, 1973).

2) is economical. Harvest operations on clearcuts of 40 acres or more become increasingly more economical (Johnston, 1977). Clearcuts in black spruce readily lend themselves to highly mechanized logging systems (Benzie, 1971, Silvicultural Interpretations).

3) facilitates broadcast burning. Broadcast burning is often required in order to regenerate black spruce (Johnston, 1977). This will be discussed later.

4) controls dwarf mistletoe infection (Johnston, 1977).

The disadvantage of clearcutting is that direct seeding will often be required. Natural seeding cannot be depended on to regenerate the center of a large clearcut; its effectiveness is limited to a distance equal to 3-5 times the tree height (Smith, 1962).

PROGRESSIVE STRIP CUT

Progressive strip cuts may be employed in large stands that are windfirm and do not require broadcast burning. Strips should be perpendicular to, and progress towards, the prevailing wind direction to maximize natural seeding and minimize windthrow (Johnston, 1977). The strips can be up to 400 feet wide.

THINNING

No thinning is recommended for black spruce. Thinning cannot be justified economically and it increases the stand's susceptibility to wind damage. Maintenance of a dense stand lessens susceptibility to dwarf mistletoe infection (Johnston, 1977).

HARVEST SYSTEM

Full tree harvest is well suited to black spruce management. If used when temperatures are above 0 degrees F., the harvest area will be left slash-free. If skidding is not confined to trails, much of the brush and residual stems will be killed, thereby reducing competition. If this system is used when temperatures are below 0 degrees F., branches will snap off while the tree is being skidded to the landing, thereby eliminating the job of limbing and distributing slash for thorough broadcast burning.

Shortwood harvest is a traditional method used with black spruce. Many operators prefer this method because it involves lower investments in equipment. Slash distribution is good for thorough broadcast burning.

BROADCAST BURNING

Broadcast burning is often necessary or desirable.

Broadcast burning:

1) kills residual stems. Residual stems are often trees of poor form and slow growth. If these trees reproduce, the resulting stand may inherit these undesirable characteristics. If residual stems are abundant, their shade will retard seedling development (Johnston, 1977).
2) kills hardwoods. Hardwood competition is undesirable and should be eliminated. Herbicides are more effective on species that reproduce from stump sprouts or root suckers (Johnston, 1977).
3) kills brush. Without treatment, many of the best black spruce stands will regenerate to brush. In addition to broadcast burning, herbicide release is often required (Johnston, 1977).
4) improves seedbed. After clearcutting, feather mosses dry up and die, making very poor seedbeds. If more than 40 percent of the area is covered by feather mosses, removal of the surface layer by fire or by machine is recommended (Johnston, 1977).
5) removes slash. Slash removal may be desired to aid reproduction, reduce fire hazard, or increase aesthetic appeal (Johnston, 1977).
6) controls dwarf mistletoe infection. Clearcutting, followed by broadcast burning to kill infected residual stems and slash, is the prescribed treatment for control of dwarf mistletoe (USDA, 1973).

REGENERATION

Natural seeding is the cheapest method of regeneration. It is most reliable when progressive strip harvesting has been used. Heavy seed crops are produced every four years, but since black spruce cones are often serotinous, seed supplies are fairly constant (Fowells, 1965).

Direct seeding is the most frequently used method of regenerating black spruce when natural seeding cannot be relied upon (no black spruce in surrounding area, in the case of large clearcuts, or when genetically improved stock is desired). Direct seeding is done between March and mid-May of the first year following burning. Aircraft or snowmobiles may be used for direct seeding (Johnston, 1977). Planting of seedlings is often done on upland sites to establish pure upland stands and to use improved genetic stock.

The use of herbicides to release seedlings is often necessary on better sites where brush and hardwoods are a problem. Spraying should be done in early August when the new growth of black spruce has hardened off (Johnston, 1977). New stands should be examined 2 or 3 years after initiation to determine whether release and/or additional seeding or planting are needed.

'POOR' SITES

Poor black spruce sites are usually uneven-aged, have a perched water table, have a site index less than 25, and have sparce brush cover. The management objective is Christmas tree production, accomplished by partial cutting on a 10 year cycle (Johnston, 1977). These sites are also used for spruce grouse management.

DISEASE AND INSECT CONTROL

Dwarf mistletoe is the major pest problem in black spruce management. Dwarf mistletoe causes witches'-broom, stunts growth and eventually kills the tree (Fowells, 1965)., Control is effected through clearcutting of the infected area, followed by broadcast burning. Susceptibility to infection is reduced by maintainance of dense stands.

Butt rot is common on upland sites when black spruce reaches 70-100 years old. Control is effected by shortening rotations on these sites to 70 years (Johnston, 1977).

OTHER RESOURCES

Wildlife habitat is enhanced by allowing some shrubs and hardwoods to be mixed in. Non-commercial clearcuts or strip cuts improve spruce grouse habitat.

Water quality is affected very little by large clearcuts on organic soils unless streams are located within or very near the harvest area (Johnston, 1977).

Aesthetics are improved by making clearcut boundaries follow natural physiographic or forest type lines, and by slash disposal.

4. NORTHERN WHITE CEDAR

This forest type is found in extensive even and uneven-aged stands in the northern region of Minnesota. Most commercial stands are located in swamps but stands established in old fields may exhibit superior growth (Fowells, 1965). Associated species are balsam fir, aspen, balsam poplar, paper birch, and black ash (Johnston, 1977).

Although northern white cedar is tolerant to very tolerant of shade, it grows best in the sun. Very dense, fire-originated stands may provide such a tight canopy that seedlings cannot grow, resulting in an even-aged stand.

Management objectives are (Johnston, 1977):

Poor sites - manage extensively for small posts and deer browse;

Good sites - manage more intensively for logs, poles, deer shelter, posts, and browse.

On average sites, 80 to 100 years are required to grow a 6 inch diameter tree, 50 to 80 years to grow a post, 150 to 175 years to grow a tie, 200 years to grow a 20 foot pole (Fowells, 1965).

Poor sites are characteristically defined by poorly decomposed, acidic organic soil; by little water movement except during snowmelt; and by their long distance from drainageways. These sites have a site index less than 25. The silvicultural prescription for these sites is to clearcut in strips at rotation age (100-160 years) and dispose of slash to ensure reproduction (Johnston, 1977).

Clearcutting in strips will increase browse production on the cut strips while retaining a seed source on the leave strips.

Good sites usually contain well decomposed organic soil derived from woody plants or sedges, and have a neutral to slightly alkaline pH. They are often near streams and have actively moving soil water. These sites produce optimum browse conditions at 25 to 40 years and best deer shelter after 60 years. They can be managed on rotations of 70 to 160 years, depending on their rate of growth (Johnston, 1977).

Good sites justify more intensive silviculture to produce high quality products and ensure regeneration. Intermediate treatments, treatments preparatory to harvest, and site preparation may be warranted.

INTERMEDIATE TREATMENTS

The advantages of intermediate treatments are to improve stand composition and to produce high quality timber and deer habitat on a short rotation. The disadvantage is that they seldom yield an immediate financial return (Johnston, 1977).

Intermediate treatments include:

1) removal of overtopping vegetation in young stands. The use of herbicides is most economical for this work but the sensitivity of northern white cedar to available herbicides is unknown and streams are usually nearby (Johnston, 1977). Thus, release by hand may be more practical.

2) thinning in older stands. Thinning may be done commercially or at low cost. Thinning improves timber quality and deer habitat. If done in winter, the slash will furnish browse for deer (Johnston, 1977).

TREATMENTS PREPARATORY TO HARVEST

These treatments may be necessary to ensure reproduction of northern white cedar in the next stand. It can be justified financially only on the best sites and is most valuable on sites where no intermediate treatment has been done (Johnston, 1977).

Treatment preparatory to harvest involves the removal or killing of tree species that are not desired in the next stand. Merchantable trees and trees that will provide browse can be felled. Other trees may be girdled or herbicide may be applied to a frill at the tree's base. Care must be taken to maintain heavy stocking to prevent seeding or sprouting of the undesirable trees (Johnston, 1977).

HARVEST METHODS

Harvest should be made during winter, if possible, to provide browse for deer (DNR, 1962). The best method of regenerating northern white cedar is to make progressive strip cuts (Verme, 1965 and Johnston, 1977). The harvest units should be large (40 to 160 acre blocks), composed of narrow strips (66 to 180 feet wide). Large blocks will exclude deer while regeneration is established since deer avoid large open areas due to the deep snow and lack of cover. The block shape minimizes edge effect to further discourage deer (Verme, 1965).

Regeneration in clearcuts is hampered by a lack of seed sources. Regeneration in selection cuts and shelterwood-clearcut strip cuts is destroyed by over-browsing (Verme, 1965). Therefore, these methods are less desirable.

SLASH DISPOSAL

Slash disposal should be delayed a few days if deer are in the vicinity to allow them to browse on the cuttings. Disposal of slash is not needed if the stand was poorly stocked and slash is evenly spread. Two disposal methods are available on other sites:

1) Broadcast burn

This method eliminates most slash, kills residual conifers, discourages residual hardwood and brush growth, and probably improves seedbeds (Johnston, 1977). Broadcast burning should not be done on narrow strip cuts due to the risk of burning the leave strips.

2) Full tree skidding

This method may be as effective as broadcast burning if most stems are merchantable. Full tree skidding may be used in narrow strip cuts (Johnston, 1977).

REGENERATION

Seeds from the leave strips are wind-disseminated in the fall. Reproduction should be checked after 4 years and, if adequate, the leave strips should be harvested to prevent the new stand from becoming too dense (Johnston, 1977).

DAMAGING AGENTS

White-tailed deer and snowshoe hare: Northern white cedar browse is highly palatable and nutritious. It is the only species that can by itself sustain deer through the winter (Verme, 1965). An average deer requires 4½ lb. of cedar browse per day, an amount equal to the browse within a deer's reach on a tree of average size and 3 inches in diameter (Fowells, 1965). However, trees are only damaged by browsing while they are seedlings and saplings. Snowshow hares can cause at least as much damage as deer (Verme, 1961). Use of the progressive strip cut in large blocks discourage this type of damage.

Other wildlife: Porcupines girdle the stems of northern white cedar (Johnston, 1977). Red squirrels eat flower buds and clip cone-bearing limbs (Johnston, 1977). Moose use the species for browse and red-backed voles will cut the terminal leaders (Verme, 1961). These types of damage are not as extensive as that caused by deer and hares.

Impeded drainage and flooding caused by beaver dams and improper highway construction cause mortality (Johnston, 1977).

Carpenter ants are the major insect pests, often invading trees that have butt or heart rot (Johnston, 1977).

Major diseases of northern white cedar are butt and heart rots. These are not of major economic importance (USDA, 1971).

Windthrow may occur, especially in uneven-aged stands, since northern white cedar has shallow roots. However, extensive root grafting provides some natural defense against windthrow.

Northern white cedar is especially susceptible to damage by fire due to its shaggy oily bark.

OTHER RESOURCES

Deer yards are an especially important feature of northern white cedar stands. Management aspects concerning production of browse and shelter have been already mentioned.

Trout streams may originate in northern white cedar stands. These streams may be protected by leaving a border of standing timber along the stream, making cuts not larger than 40 acres, and by making cuts a small proportion of the watershed area (Johnston, 1977).

Aesthetics can be improved by making harvest boundaries follow natural lines and by removing slash.

5. TAMARACK

Tamarack bears the distinction of being the only major timber species in Minnesota that is a deciduous conifer. It is found mainly on organic soils but will also grow on extremely dry sites. Its range in Minnesota is the northern conifer region (Fowells, 1965).

Tamarack is the fastest growing swamp conifer in the state and it comprises the fourth largest timber type. Products made from tamarack include poles, piling, mining timber, posts, and pulpwood (DNR, 1962).

Tamarack is very intolerant of shade. It is the first forest tree to invade swamps. On poor sites, it is succeeded by the more shade tolerant black spruce. On good sites, it is succeeded by shade tolerant species such as northern white cedar, balsam fir, and the swamp hardwoods (Fowells, 1965).

Regeneration of tamarack is a problem without a proven solution. Clearcutting or seed tree cutting is required since seedlings require full sunlight (Johnston, 1975). Research currently is directed towards the use of seed tree cutting followed by burning (Johnston, 1973 and 1975). Rotations are 90 to 120 years long (DNR, 1962).

SITE PREPARATION

Slash and brush are known to obstruct and retard the growth of seedlings. However, broadcast burning has not been effective for site preparation (Johnston, 1975).

Piling slash and burning may be an answer; full-tree skidding may also be solution (Johnston, 1975).

REGENERATION

Regeneration is generally accomplished by natural seeding. Tamarack seeds are small and are wind-dispersed for up to 200 feet. The best seedbeds are of moist mineral or organic soil, free of brush but having a light cover of herbs or grass (Fowells, 1965).

As much as 40 percent of the seed crop is consumed by an undetermined moth or butterfly. Seeds are also eaten by red squirrels and American red crossbills. Of those seeds that fall, 50 percent may be eaten by rodents. Fungi and bacteria will reduce the amount of seed capable of germination to 4 to 5 percent (Fowells, 1965).

Use of direct seeding would help regenerate stands but seed collection is difficult (Johnston, 1975).

Nursery stock may be planted on upland sites with good results (Jeffers, 1975).

Follow-up treatments may be needed to ensure adequate stocking. Herbicide release will likely be needed (Johnston, 1975). Seedling survival may be affected by damping off, mechanical injury, drought, flooding, larch sawfly, and snowshoe hares (Fowells, 1965). Reseeding or replanting may be required.

INSECTS AND DISEASE

Larch sawfly is the principle insect pest of tamarack. Moderate to heavy defoliation was reported in stands in Aitkin County in 1977 (DNR, 1977). Trees are killed if defoliated 6 to 8 years in a row (Fowells, 1965).

Diseases of tamarack are few and relatively insignificant (USDA, 1971). Tamarack is susceptible to fire on wet sites, flooding, windthrow, deer browsing damage, and dwarf mistletoe infections, but these problems are not severe (Fowells, 1965).

Few stands in Minnesota have not been affected by porcupines which feed on the inner bark, strip the upper stems, or girdle the tree (Fowells, 1965).

6. LOWLAND HARDWOODS

This forest type contains black ash, American elm, balm of Gilead (balsam poplar), and red maple in mixed stands. These species form a long-lived subclimax type on wetter sites and may be the climax type on the wettest sites (USDA, 1973). Lowland hardwood forests are found throughout most of the state.

Because this type is of low value for timber, harvest decisions will depend largely on available markets (DNR, 1962). Several harvest systems are available for use in lowland hardwoods (USDA, 1973):

1) Selection cutting

   Selection cutting favors shade tolerant species (all species but balsam poplar). Too heavy a harvest may increase the stand's susceptibility to windthrow. American elm that is infected, or may be expected to contract Dutch elm disease, should be removed.

2) Clearcut

   Regeneration following clearcutting is uncertain. Grasses and shrubs may invade and occupy the site for several decades before they are succeeded by desirable tree species. Otherwise, the stand may be regenerated by undesirable stump sprouts.

3) Shelterwood

   This system may be used to favor more tolerant species which establish themselves easily on undisturbed forest floors.

WILDLIFE

Wildlife habitat production may constitute the prime motivation for management of the lowland hardwood type. Red maple and yellow birch are favorite browse species of white-tailed deer (USDA, 1973).

INSECTS AND DISEASE

Dutch elm disease is the major insect-disease related problem in this forest type (DNR, 1977). Control is effected through salvage of diseased elms.

Red maple is subject to numerous canker diseases, rots, and insect pests. It is very sensitive to wounds that may occur during selection or shelterwood cutting (Fowells, 1965).

Black ash is relatively free of insect and disease problems (Fowells, 1965).

7. LOWLAND CONIFERS

* This type is a composite of black spruce, tamarack, northern white cedar, balsam fir, and other minor species. Management of lowland conifers can follow guidelines offered for the desired species of the above list.

8. UPLAND SPRUCE-FIR

Upland spruce-fir is the third most important forest type in Minnesota (DNR, 1962). The major species in this forest type is balsam fir. A substantial amount of white spruce and some black spruce may be present. Even-aged stands as well as uneven-aged stands are common throughout the northern conifer region of Minnesota. Other conifers and hardwoods may be present in mixed stands.

Balsam fir is very shade tolerant; the spruces are tolerant (Fowells, 1965). Therefore, this type can reproduce in its own shade. It is the climax forest type for many sites in Minnesota. It is found on a wide variety of sites, but development is poor on extremely moist or droughty sites.

Management objectives for spruce-fir are:

Good sites: Develop well-stocked thrifty stands, managing for maximum quantity and quality of balsam fir pulpwood and white spruce pulpwood and sawtimber. Improve composition by increasing the proportion of spruce and other desirable species (USFS, 1958).

Poor sites: Convert to red pine or jack pine. (USFS, 1958).

Management alternatives for spruce-fir are more diverse than for any other forest type in Minnesota (Ohmann et al., 1978). Even-aged management may utilize clearcutting or shelterwood systems. Uneven-aged management may entail individual or group tree selection. The spruce-fir type can be managed with aspen, using uneven-aged systems (Ohmann, et al., 1978).

Rotations for balsam fir range from 50 to 70 years. Rotations for white spruce are longer, up to 90 years (Ohmann, et al, 1978).

CLEARCUT

Clearcutting is particularly well-suited to mature and overmature even-aged stands. Clearcutting is done in narrow strips or small patches to allow seeding. Large clearcuts should be avoided because they offer too harsh an environment for regeneration and the interior gets too little seed. Small to medium sized clearcuts will improve the overall appearance of extensive areas of spruce-fir (Ohmann, et al., 1978)

SHELTERWOOD

Shelterwood cutting allows larger areas to be harvested at a time. This system involves a series of light cuts; too heavy a cut may increase the trees' susceptibility to windthrow, (Ohmann, et al., 1978). The system provides a seed source, protection for regeneration, and rapid quality growth on the residual trees (Smith, 1962).

INDIVIDUAL OR GROUP TREE SELECTION

Individual or group tree selection in uneven-aged stands gives ideal regeneration conditions. However, these systems yield lower economic returns than even-aged management. Selection cutting improves the visual appeal of stands that are not extensive (Ohmann, et al, 1978).

SITE PREPARATION

Removal of slash and scarification will help regeneration become established (USFS, 1958).

REGENERATION

Regeneration of white spruce is generally accomplished by natural seeding. The best seedbed for growth and survival of spruce seedlings is a moist mineral soil (USFS, 1958). Wind dispersal of seed is good; white spruce can disperse seed up to 1,000 yards but seeding may not be adequate at distances farther than 5 times the tree height from surrounding stands (Smith, 1962). White spruce seedlings are being planted throughout the northern conifer region of Minnesota to establish the type on good sites where a seed source does not exist.

A reserve of advance balsam fir reproduction is usually present in the stands.

THINNING

Stands may be thinned when the trees are large enough to make it economically worthwhile (30-50 years) (USFS, 1958). In order to decrease the amount of balsam fir in the stand, thinnings can take a larger percentage of balsam fir than white spruce. Light thinnings can be made earlier to remove Christmas trees.

STAND IMPROVEMENT

White spruce should be favored over balsam fir for the following reasons:

1) White spruce is more marketable.
2) White spruce can be managed on a longer rotation (Ohmann, et al., 1978)) giving more management alternatives.
3) White spruce yields a larger variety of products (Wisconsin DNR, 1977).
4) White spruce is less susceptible to spruce budworm infestations and to butt rot infection than is balsam fir (Fowells, 1965).

Increasing the amount of white spruce in a stand is a problem since balsam fir is much more agressive in regeneration and growth.

DISEASE AND INSECT CONTROL

The spruce budworm is the most important deterrent to growth of the spruce fir type (USFS, 1958). Despite its name, spruce budworm infests balsam fir more readily than the spruces. It causes defoliation which is followed by extensive root mortality and invasion of disease (USDA, 1971). Stands attacked by spruce budworm are fire hazards (Sando and Haines, 1972). Control is effected through salvaging of infested stands, harvesting prior to overmaturity, and increasing the spruce component in the stand (USFS, 1958).

Butt rot is the second most serious problem for balsam fir, infecting trees at advanced ages, especially on sandy dry sites (USDA, 1971). Control is effected through maintaining rotations of 70 years (USDA, 1971).

The yellow-headed spruce sawfly is a major pest of white spruce. Infestations have defoliated stands in northeastern Minnesota. Control methods include salvage of infested trees and the use of sawfly parasites (DNR, 1977).

OTHER RESOURCES

Wildlife benefits include good winter cover provided by the dense canopy of fully stocked stands and forage available in the understory of lightly stocked stands (Ohmann, et al., 1978).

As mentioned earlier, aesthetics can be managed by clearcutting in extensive stands or by employing shelterwood cuts in small stands.

9. TREMBLING ASPEN (QUAKING, ASPEN, POPPLE)

Trembling aspen comprises the most common forest type in Minnesota. It supplies half of the pulpwood produced in the state (Blyth & Hahn, 1977), and is the species most often regenerated after harvest (Beckwith, 1978). Trembling aspen is primarily a pulpwood species but is also used for manufacture of studs, veneer, and plywood. Its range covers all of Minnesota (Fowells, 1965).

The best soil for trembling aspen is porous, loamy, humic, and rich in lime. Aspen is a soil improver, especially beneficial for recycling nitrogen after fire (Fowell, 1965). It usually occurs in pure stands but may be found in mixed stands with jack pine, spruce-fir, black spruce, or paper birch.

Aspen cannot reproduce in its own shade, and therefore, is replaced by other species (Spruce-fir or maple-oak) when natural ecologic succession is not interrupted by fires, logging or windstorms (Ohmann, 1978). However, when a stand has been opened by some disturbance, thousands of aspen suckers per acre will sprout from the shallow roots of the parent trees. Thus, trembling aspen is able to become the dominant species on a site where it formerly had been only a minor component (Fowells, 1965).

"Management objectives should provide for the conversion of poor and some medium sites to higher value coniferous species were practicable. Good and some medium sites should be managed for pulpwood and sawtimber products." (DNR, 1962).

CLEARCUT

Clearcutting is the only recommended means of harvesting and regenerating aspen. For regeneration by suckering, a minimum of 50 aspen per acre must be present in the parent stand. After harvesting all stems in the area, light and heat reaching the forest floor will stimulate suckering, and a new stand will develop (Perala, 1977).

THINNING

Well-formed, disease-resistant stands on good sites should be thinned once at age 30. These stands can yield significant amounts of sawtimber and veneer at age 50 or 60. On the best sites, a precommercial thinning at age 10 and a commercial thinning at age 30 will increase yields further (Perala, 1977). Thinning on poor and medium sites cannot be justified economically.

HARVEST SYSTEMS

Full-tree and tree-length systems are ideally suited to aspen harvest. The trees are easily handled by highly mechanized systems. The site is scarified during skidding, thereby reducing the need for site preparation (Zasada, 1971).

SITE PREPARATION

When the shortwood logging system is used, or when full-tree length skidding does not adequately destroy competitive brush, site preparation may be required. Available site preparation methods are (Perala, 1977):

1) felling or girdling residual stems. This method is good only if understory is not brushy and forest floor is not sodded.
2) shearing. This method is effective for eliminating residual stems and brush, and for breaking sod.
3) crown herbicide (aerial). This method kills residual hardwoods and some brush but does not kill residual conifers nor affect sod.
4) prescribed burning. This method eliminates residual trees and brush, and weakens sod. The heat associated with burning warms the soil to stimulate suckering.

REGENERATION

Suckering is the primary means of regenerating trembling aspen. Suckers may grow several feet the first year after harvest. Natural seeding may account for some regeneration but is not considered as important (Fowells, 1965).

CONVERSION TO OTHER SPECIES

Stands with a site index of 60 or less should be considered for conversion. Such sites will be more productive if managed for a less nutrient or moisture demanding species, such as conifers (Perala, 1977).

DISEASE AND INSECT CONTROL

Three major diseases affect the growth of trembling aspen. Shepard's crook is a disease of young aspen stands. Shepard's crook usually only blackens and kills the terminal, allowing the new growth to recover the following year (DNR, 1977).

Hypoxylon canker is the second most important disease of aspen in Minnesota. The disease infects stands of all ages and kills 3 percent of all trembling aspen annually. The only control is to maintain full stocking throughout the rotation to assure an adequate final crop. Highly susceptible stands should be converted to another species (Perala, 1977).

Heart rot is the main limiting Factor to growing aspen on rotations of more than 50 years. Heart rot (Phellinus ignarius) causes the decay of the heartwood of trembling aspen nearing maturity. In later stages, the desease causes defects in lumber and eventually causes the log to be culled. A conk on the trunk of the tree indicates that the final stage of the disease extends 2 to 5 feet above and below the conk. However, the absence of a conk does not mean the absence of decay. Control is effected by using a rotation of about 50 years (Perala, 1977).

Trembling aspen has few serious insect pests, the most notorious of which is the forest tent caterpillar. The forest tent caterpillar defoliates pole-sized and mature stands but the main effect is only growth loss, not mortality (Fowells, 1965).

OTHER RESOURCES

Water yield and nutrient loss may increase after clearcutting but rapid vegetative regrowth causes these effects to diminish rapidly (Perala, 1977).

Trembling aspen is an essential species for ruffed grouse, white-tailed deer, moose, and beaver. Clearcutting benefits ruffed grouse, white-tailed deer, and moose if harvest areas are limited to 10, 40, and 100 acres, respectively. Other wildlife species for which aspen is important are the American bald eagle, osprey, eastern timber wolf, and various song birds (Perala, 1977).

Aesthetics can be enhanced by limiting the size of clearcuts, by making clearcuts with irregular shapes that follow natural physiographic or forest type lines, and by avoiding regular spacing of harvest areas (Perala, 1977).

10. NORTHERN HARDWOODS

The predominant species in the northern hardwood type is sugar maple (hard maple). Other associated species include American basswood, elm, red maple, and ironwood. This type occurs in uneven-aged stands thorughout most of Minnesota. This is the climax cover type for many sites in the state.

These species are moderate to very tolerate of shade and will respond to release at advanced ages. Sugar maple is the largest and longest lived of the northern hardwoods, followed by elm and American basswood. Red maple and ironwood are smaller trees, their crowns often being under the forest canopy (Fowells, 1965).

Management ojectives for northern hardwoods are diverse. For each management objective, a different silvicultural prescription may be made. The following paragraphs will discuss these alternatives.

Management objectives:

1) timber production. Clearcutting can be performed in northern hardwoods to obtain a maximum short run economic return from timber and to maximize harvesting efficiency. However, clearcutting is the least desirable harvesting method for regeneration of stands (Tubbs, 1977; Metzger and Tubbs, 1971). It should be used when the major high-value tolerant species are inherently poorly formed, and the only desirable species are intolerant (yellow birch, black cherry, aspen, white ash) (Tubbs, 1977; USDA, 1973). Other impacts of clearcutting include a maximization of wildlife habitat production (Tubbs, 1977) and an extreme impact on visual appeal.

High-grading is also used to maximize short run financial returns from northern hardwoods. High-grading is a harvesting method that "takes the best and leaves the rest". Its use results in a high number of cull trees and a depreciation of the value of the stand (Smith, 1962).

Shelterwood harvesting may be a better system for delivering moderate economic returns, and a good sustained yield from even-aged stands. Visual appeal is heightened and wildlife habitat production is maximized on a short-term basis. This system favors sugar maple, American basswood, white ash, and yellow birch (Metzger and Tubbs, 1971).

Individual or group tree selection is the traditional system for northern hardwoods management. However, this system yields the poorest short-term economic returns and minimized harvesting efficiency. It may be best suited to production of high-quality veneer and sawlogs and to other management objectives (USDA, 1973).

2) small woodlot management. Individual or group tree selection is probably best suited to this objective. It will produce sustained yields on a small acreage. Aesthetic and recreational values, and environmental quality are maximized (USDA, 1973). This system is well suited to shortwood logging which would usually suit the small woodlot owner. Selection cutting may minimize wildlife habitat production.

3) aesthetics and environmental quality. Individual or group tree selection is best suited to this objective. This system should be used in areas where aesthetics are of extreme importance, as in parks, and in areas that are extremely sensitive to environmental disturbances, such as along unstable slopes and near watercourses. This system tends to favor sugar maple and American basswood (Metzger and Tubbs, 1971).

4) wildlife habitat production. This objective is maximized through clearcutting, since clearcutting will encourage brush and understory vegetation which may persist and prevent establishment of tree seedlings (Tubbs, 1977). Shelterwood provides good understory growth for a short time, favoring wildlife until the young trees grow beyond their reach.

5) optimize all forest outputs. To obtain optimum outputs of timber, wildlife habitat, species diversity, regeneration, aesthetics and environmental quality, the shelterwood system is a good compromise.

REGENERATION

If clearcutting is used to convert a stand to an intolerant species that is better suited to the site, some site preparation should be used to discourage maple regeneration. This can be done with scarification, herbicides, or prescribed burning (Tubbs, 1977). Regeneration will then result from suckering of existing roots and stumps or from planting of desired species. If conifers are planted, a release treatment may be required within the first 5 years (Tubbs, 1977).

Shelterwood harvests should be scheduled when advance reproduction is sufficient to restock the stand. Logging during both the initial and the final cut must be done when the ground is snow-covered to protect seedlings (Tubbs, 1977). The final cut may be made when the reproduction reaches 3 to 4 feet tall. If advance reproduction on a site is inadequate, a three-cut shelterwood system can be employed. In this system, the initial cut opens the stand to encourage reproduction. The second cut is made when regeneration is 4 feet tall. The final cut comes before regeneration 15 feet in height (Tubbs, 1977).

Regeneration of stands is a continous process when the selection cutting system is used. Regeneration is encouraged by manipulation of age-classes and crown closure (Tubbs, 1977).

THINNING

Thinning is important in even-aged silvicultural systems. (Clearcut and shelterwood). The method that is used is to select crop trees at specified intervals and then release them from surrounding competitive trees (Tubbs, 1977). Thinning is not necessary in the selection cutting system since this purpose is accomplished during the harvest cuts.

DAMAGING AGENTS

Logging damage can occur when selection cutting or shelterwood is employed. Damage may be done to large trees as they are bumped by a skidder or hit by a falling tree. Damage to reproduction may seem extensive after uneven-aged harvests but this damage is silviculturally insignificant. Logging must be done during the winter to protect reproduction in the shelterwood system (Tubbs, 1977).

Browsing by white-tailed deer and snowshoe hares is not significant in managed stands. However, browsing by farm animals can be damaging and should be avoided.

Diseases affecting northern hardwoods species include Dutch elm disease, anthracnose, and shoestring root rot. Dutch elm disease is now established throughout the state. Control methods include cutting and removal of disease trees. Anthracnose infests basswoods, maple, ash, and walnut, causing some early leaf drop. Shoestring root rot infects most softwood and hardwood species but damages and kills only trees that have been weakened by unfavorable environment, injuries, insects, or other diseases. Control is effected through salvage of infected trees and maintainance of species that are best suited to the site (DNR, 1977; USDA, 1971).

Other defects that have a serious impact on the grade of maple lumber are (DNR, 1978):

1) sapstreak, a wilt disease caused by organisms that gain entry through damaged roots, stems, and branches,
2) mineral stains,
3) frost cracks.

Insect problems in northern hardwoods are negligible.

OAKS

The oak or oak-hickory forest type is primarily composed of white oak, northern red oak, and hickory (bitternut and shagbark). This type is found mostly in even-aged stands ranging through the deciduous forest region of the southeastern part of the state.

The oaks are classified as intermediate in tolerance to intolerant of shade (Fowells, 1965; USDA, 1973). The oak forests in Minnesota became established in two ways. Some oak stands succeeded the retreating spruce-fir type as a result of climatic change. Others succeeded the tall grass prairie when Minnesota adopted a prairie fire suppression program early in this century (Deters, 1940). On moist deep soils, the oak type is not permanent and is now giving way to a maple-basswood forest. Oak stands are more permanent on dry, shallow soils and narrow ridges (DNR, 1978).

Management objectives for oak-hickory are to maintain the type on average sites where good oak currently dominates the stand. Clearcutting is practiced on these sites to yield high quality sawtimber, veneer, and pulpwood. On the best sites, where maple-basswood reproduction is abundant in the understory, management objectives usually dictate selection cutting to create a mixed oak-maple-basswood forest. On poor sites, where bur oak predominates, objectives may be management for pulpwood, convert to pine, or no management (DNR, 1978; Svien, 1978).

CLEARCUT

Clearcutting is required for good regeneration of the oak-hickory type. Advance reproduction should be present before harvest. Regeneration following clearcutting consists of stump sprouts and sprouts from the roots of seedlings that existed before harvest. These sprouts grow fast and are able to compete with shrubs. Planting and artificial seeding have not been successful due to competition from shrubs (Sander, 1977).

If advance reproduction is inadequate, the overstory may be thinned in an attempt to encourage natural seeding. Recommended rotations range from 90-120 years for poor sites to 60-75 years for good sites (Sander, 1977). Where succession favors a maple-basswood type, only 1/2 to 2/3 of the resulting stand may be oak. These sites are expected to be nearly pure maple-basswood types in 150 years (2 rotations) (DNR, 1978).

SELECTION CUT

Selection cutting speeds the rate of succession and results in a maple-basswood type in a shorter time. Openings made through selective harvests favor sugar maple and basswood reproduction since these species are more shade tolerant than oak. Some oak will regenerate from stump sprouts (Sander, 1977).

DIAMETER LIMIT

Diameter limit is loosely defined as an even-aged system which involves harvest of all trees with diameters above a certain limit, often 12-14 inches (DNR, 1978). It is also much like a selection cutting because its effect is to encourage maple-basswood where those species exist in the understory.

HIGH-GRADING

High-grading is the practice of removing the biggest and best stems, almost invariably leading to irregular stands composed largely of undesirable trees (Smith, 1962). This practice is used in oak forests for the purpose of obtaining high financial yields on a a short-term basis.

SITE PREPARATION

All undesirable trees should be killed during harvest. Oak forests in Southern Minnesota tend to be brushy and some control, or set-back, of this brush would be desirable (DNR, 1978). However, no site preparation methods have proven effective. Scarification and the use of fire have been tried but have not been successful (Sander, 1977). Herbicides are not available for broadcast spraying that will kill competing vegetation without killing the desirable trees (DNR, 1978). Thus, brush control is a major obstacle to management.

REGENERATION

Oaks and hickories sprout prolifically from stumps of young trees and from the roots and root collars of seedlings. Sprouts compete for light and nutrients better than seedlings and are more likely to survive (Fowells, 1965). Planting of oaks has not been proven successful (Sander, 1977). Adequate regeneration requires clearcutting to remove shade and competition.

Planting of other speices on oak sites is successful and is done to create a high-value mixed stand. Currently, black walnut, American basswood, and eastern white pine are being planted. However, the cost of planting on steep hillsides may be prohibitive (DNR, 1978).

Sites that are succeeding to maple-basswood generally have adequate advance reproduction of these species.

THINNING

Thinning of even-aged stands should start at age 10 or 20 and continue on a 10 year cycle until age 40 or 50. Such a program will reduce the time required for trees to reach a given diameter and increase yields (Sander, 1977).

Thinning of uneven-aged stands is not needed since selection cutting accomplishes this end.

CONVERSION

Stands with site index of 45 or lower may be converted to pine species. Such sites may produce red pine, jack pine, or white pine with site indexes of 95-100 (DNR, 1978).

APPENDIX E

GEOMORPHIC REGIONS

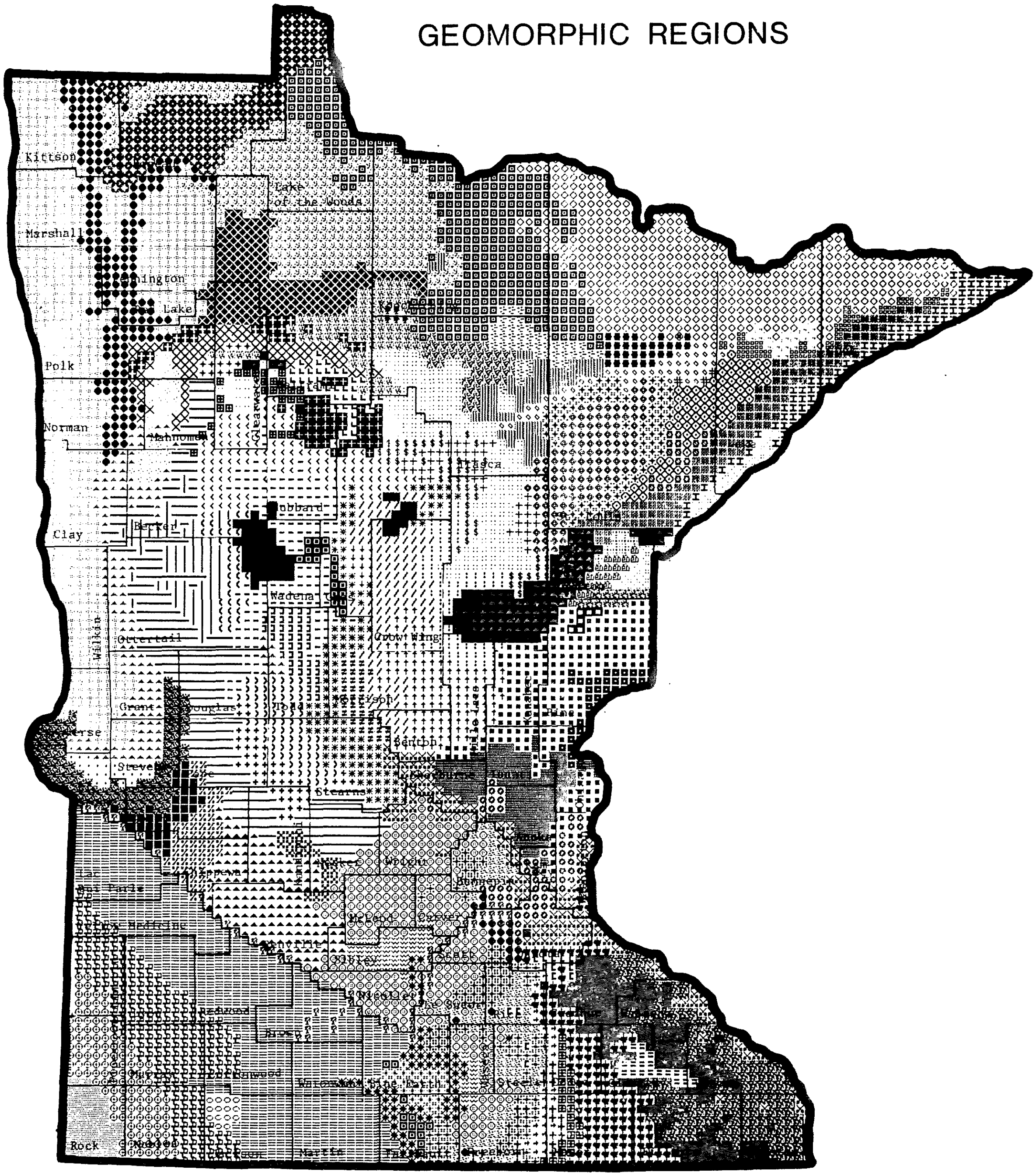


FIG. 1 GEOMORPHIC REGIONS

A GEOMORPHIC REGION IS A BROAD PHYSIOGRAPHIC FEATURE DETERMINED PRIMARILY BY THE CONTOUR OR RELIEF ALONG WITH THE SOIL PARENT MATERIAL.

SOURCE INFORMATION: GEOMORPHIC REGIONS WERE COMPILED FOR THE MINNESOTA SOILS ATLAS BY THE UNIVERSITY OF MINNESOTA GEOLOGY DEPT. AND THE U.S. GEOLOGICAL SURVEY. SOILS ATLAS PREPARED COOPERATIVELY BY THE UNIVERSITY OF MINNESOTA SOILS DEPT. AND THE U.S. SOIL CONSERVATION SERVICE. PUBLISHED BY AGRICULTURAL EXPERIMENT STATION, UNIVERSITY OF MINNESOTA, 1971-1977.

5 KILOMETER DATA FILE

MAP PRODUCED BY
MINNESOTA LAND MANAGEMENT
INFORMATION SYSTEM

25 0 20 40 80
KILOMETERS

NORTH

MLMIS

MINNESOTA STATE PLANNING AGENCY
LAND MANAGEMENT INFORMATION CENTER
15 CAPITOL SQUARE BUILDING
550 CEDAR STREET
ST. PAUL, MN. 55101

K - FACTOR

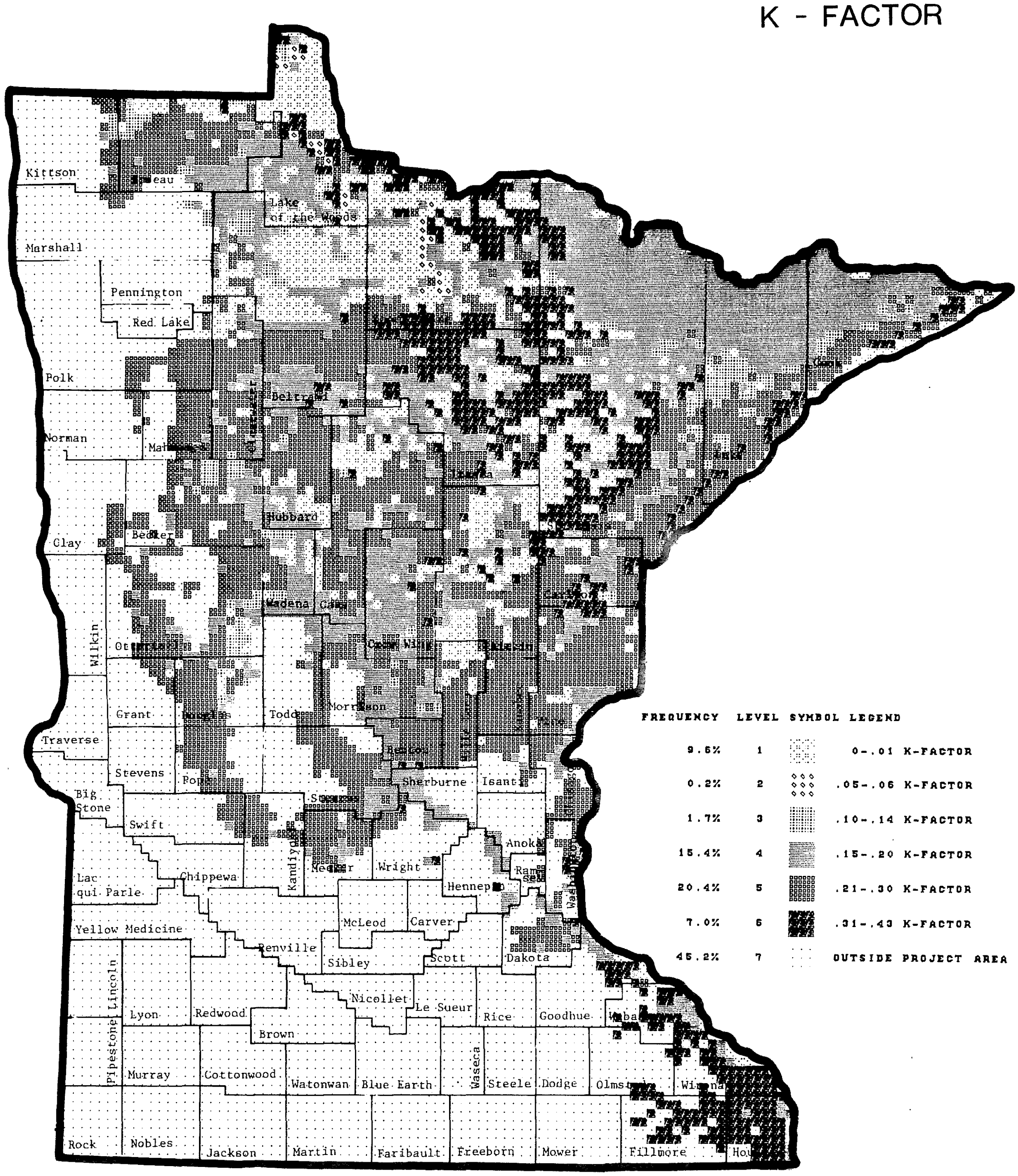


FIG. 2 RANGES OF K-FACTOR ESTIMATES ASSIGNED TO SOIL LANDSCAPE UNIT / GEOMORPHIC REGIONS

EACH FIVE KILOMETER SQUARE DATA CELL HAS AN ASSIGNED SOIL LANDSCAPE UNIT AND GEOMORPHIC REGION. THE VALUES OF K CODED FOR EACH COMBINATION AND ENTERED INTO THE MLMIS IS READ BY A COMPUTER AND ASSIGNED TO THE APPROPRIATE RANGE (K-FACTOR IS A SOIL PARAMETER THAT REFLECTS INHERENT ERODIBILITY).

DATA SOURCES: PUBLISHED SOIL ATLASES, USDA-SCS SOIL INTERPRETATION SHEETS, AND UNIVERSITY OF MINNESOTA SOIL SCIENTISTS AFFILIATED WITH SOIL ATLAS PROGRAM.

5 KILOMETER DATA FILE

MAP PRODUCED BY MINNESOTA LAND MANAGEMENT INFORMATION SYSTEM

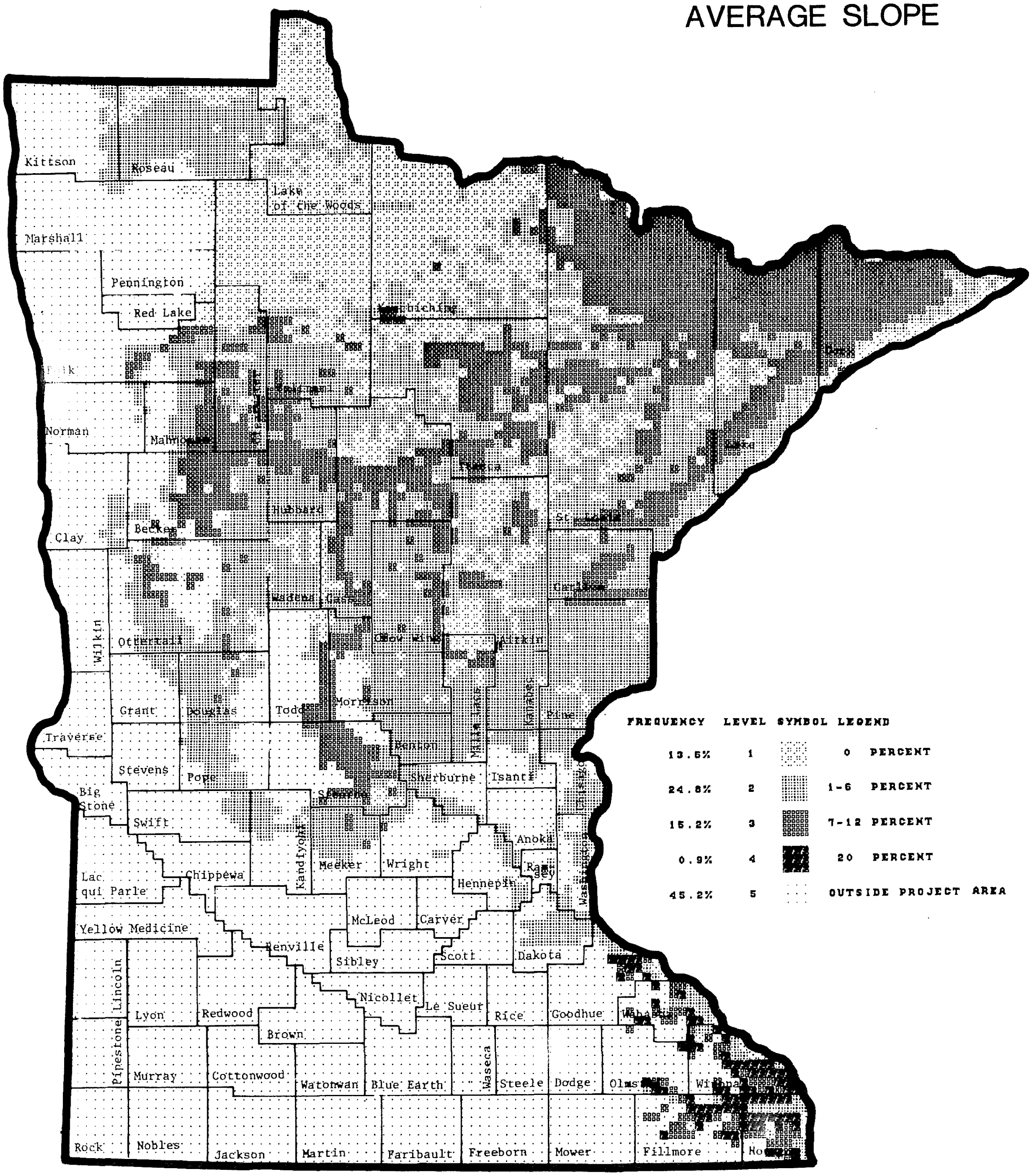
25 0 20 40 80
KILOMETERS

NORTH

MLMIS

MINNESOTA STATE PLANNING AGENCY
LAND MANAGEMENT INFORMATION CENTER
15 CAPITOL SQUARE BUILDING
550 CEDAR STREET
ST. PAUL, MN. 55101

AVERAGE SLOPE



FREQUENCY	LEVEL	SYMBOL	LEGEND
13.5%	1		0 PERCENT
24.8%	2		1-6 PERCENT
15.2%	3		7-12 PERCENT
0.9%	4		20 PERCENT
45.2%	5		OUTSIDE PROJECT AREA

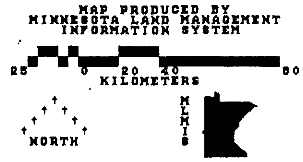
FIG. 3 RANGES OF AVERAGE SLOPE ESTIMATES ASSIGNED TO SOIL LANDSCAPE UNIT / GEOMORPHIC REGIONS

EACH FIVE KILOMETER SQUARE DATA CELL HAS AN ASSIGNED SOIL LANDSCAPE UNIT AND GEOMORPHIC REGION. THE VALUES OF AVERAGE SLOPE CODED FOR EACH COMBINATION AND ENTERED INTO THE MLMIS IS READ BY A COMPUTER AND ASSIGNED TO THE APPROPRIATE RANGE.

DATA SOURCES: INFORMATION PROVIDED BY UNIVERSITY OF MINNESOTA SOIL SCIENTISTS AFFILIATED WITH SOIL ATLAS PROGRAM.

5 KILOMETER DATA FILE

MAP PRODUCED BY MINNESOTA LAND MANAGEMENT INFORMATION SYSTEM



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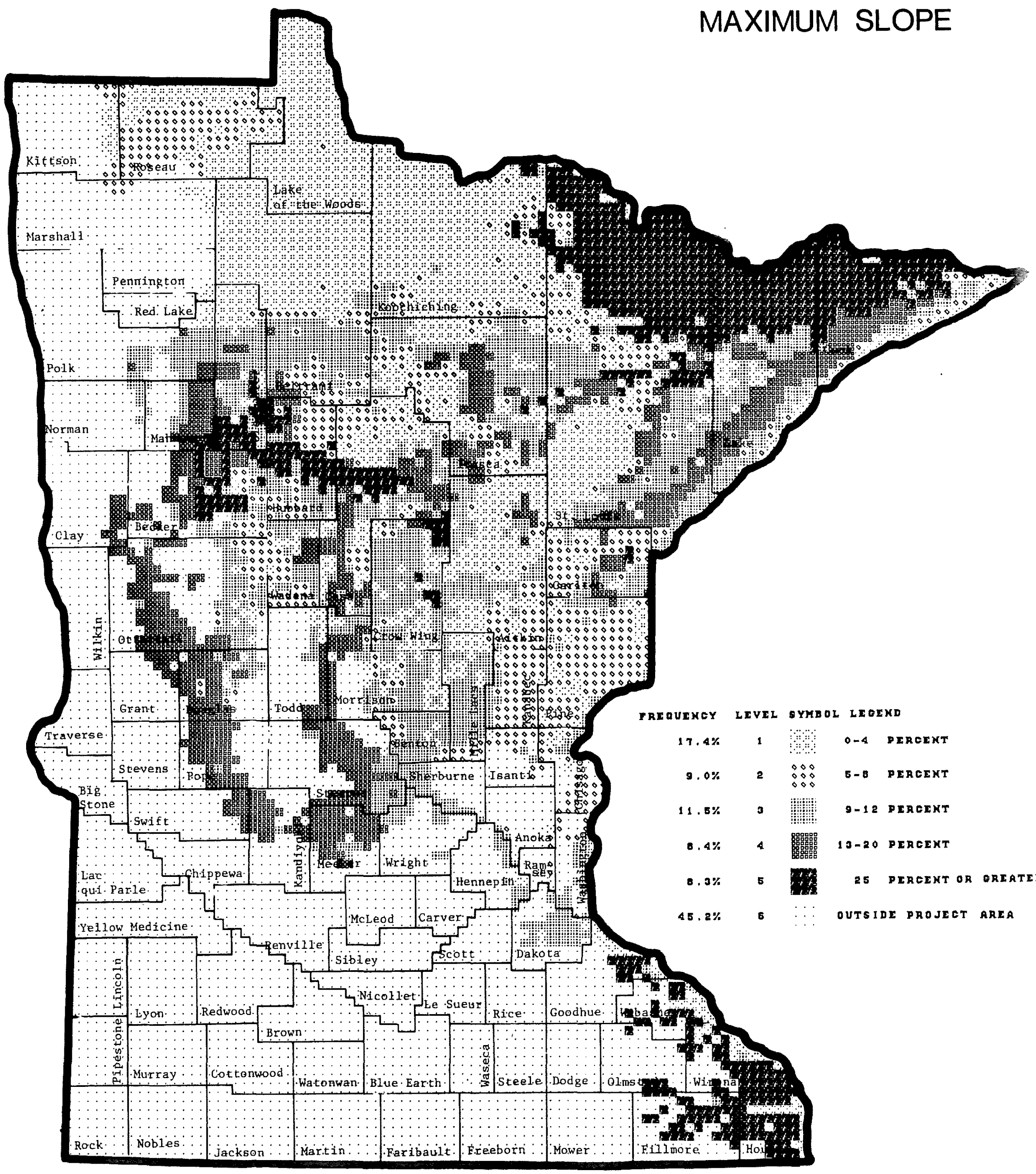
MAXIMUM SLOPE



FREQUENCY	LEVEL	SYMBOL	LEGEND
17.4%	1		0-4 PERCENT
9.0%	2		5-8 PERCENT
11.5%	3		9-12 PERCENT
8.4%	4		13-20 PERCENT
8.3%	5		25 PERCENT OR GREATER
45.2%	6		OUTSIDE PROJECT AREA

FIG. 4 RANGES OF MAXIMUM SLOPE ESTIMATES ASSIGNED TO SOIL LANDSCAPE UNIT / GEOMORPHIC REGIONS

EACH FIVE KILOMETER SQUARE DATA CELL HAS AN ASSIGNED SOIL LANDSCAPE UNIT AND GEOMORPHIC REGION. THE VALUES OF MAXIMUM SLOPE CODED FOR EACH COMBINATION AND ENTERED INTO THE MLMIS IS READ BY A COMPUTER AND ASSIGNED TO THE APPROPRIATE RANGE.

DATA SOURCES: INFORMATION PROVIDED BY UNIVERSITY OF MINNESOTA SOIL SCIENTISTS AFFILIATED WITH SOIL ATLAS PROGRAM.

5 KILOMETER DATA FILE

MAP PRODUCED BY
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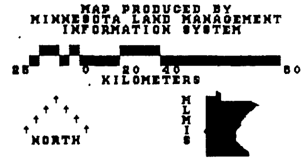

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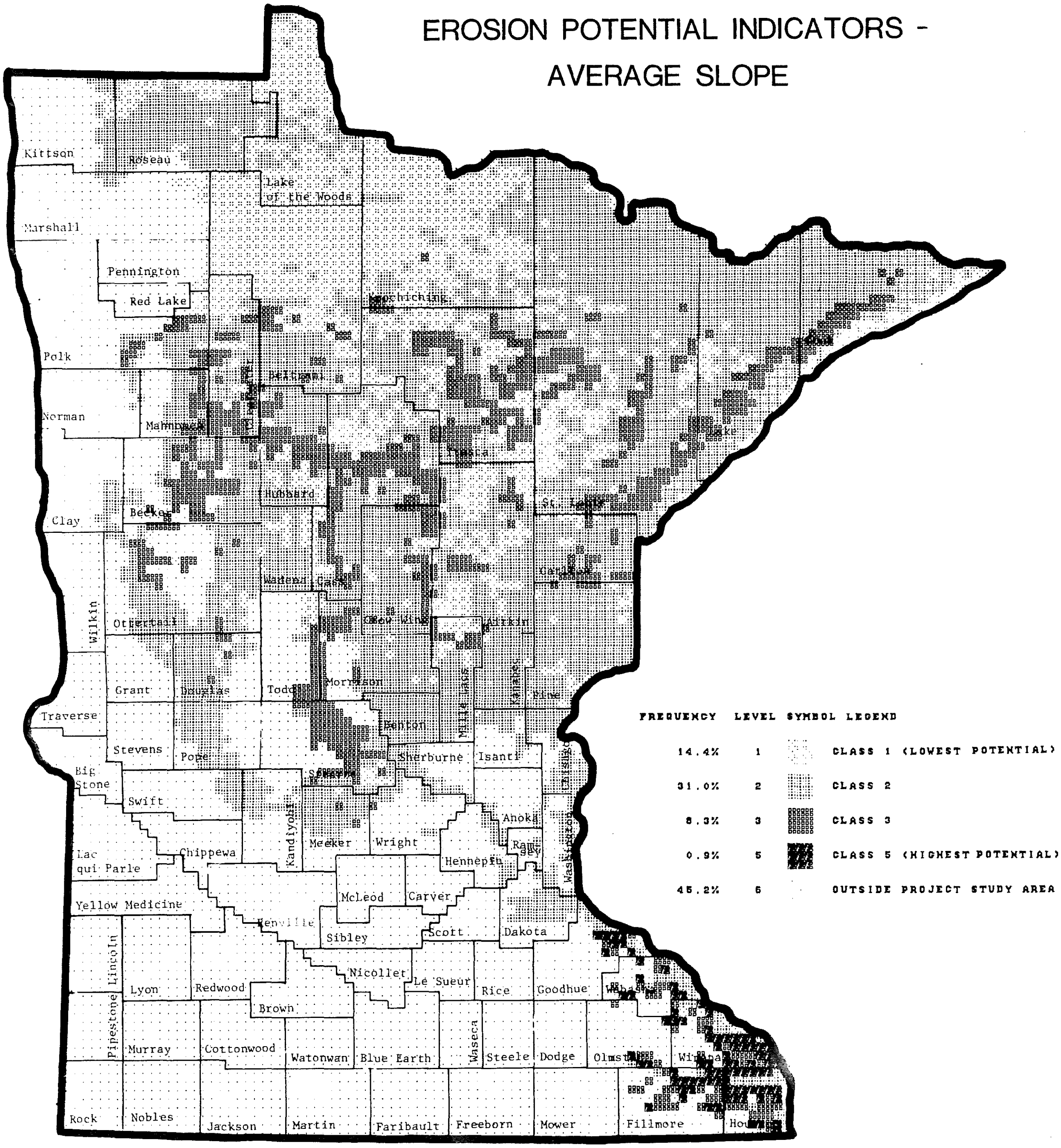

FIG. 5 RATINGS INDICATIVE OF RELATIVE EROSION POTENTIAL BASED ON ESTIMATED AVERAGE SLOPE AND SOIL ERODIBILITY (AS MEASURED BY K-FACTOR)

EACH FIVE KILOMETER SQUARE DATA CELL HAS AN ASSIGNED VALUE OF AVERAGE SLOPE GRADE AND K-FACTOR. THE COMBINED EFFECTS OF THESE PARAMETERS ON EROSION ARE EVALUATED AS IF THEY WERE INSERTED INTO THE UNIVERSAL SOIL LOSS EQUATION. THE RATINGS ON THE MAP REPRESENT CLASSES ASSOCIATED WITH RELATIVE EROSION POTENTIAL.

DATA SOURCES: PUBLISHED SOIL ATLASES, USDA-SCS SOIL INTERPRETATION SHEETS, AND UNIVERSITY OF MINNESOTA SOIL SCIENTISTS.

5 KILOMETER DATA FILE

MAP PRODUCED BY
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INFORMATION SYSTEM

25 0 20 40 80
KILOMETERS

NORTH

MLMIS

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EROSION POTENTIAL INDICATORS - MAXIMUM SLOPE

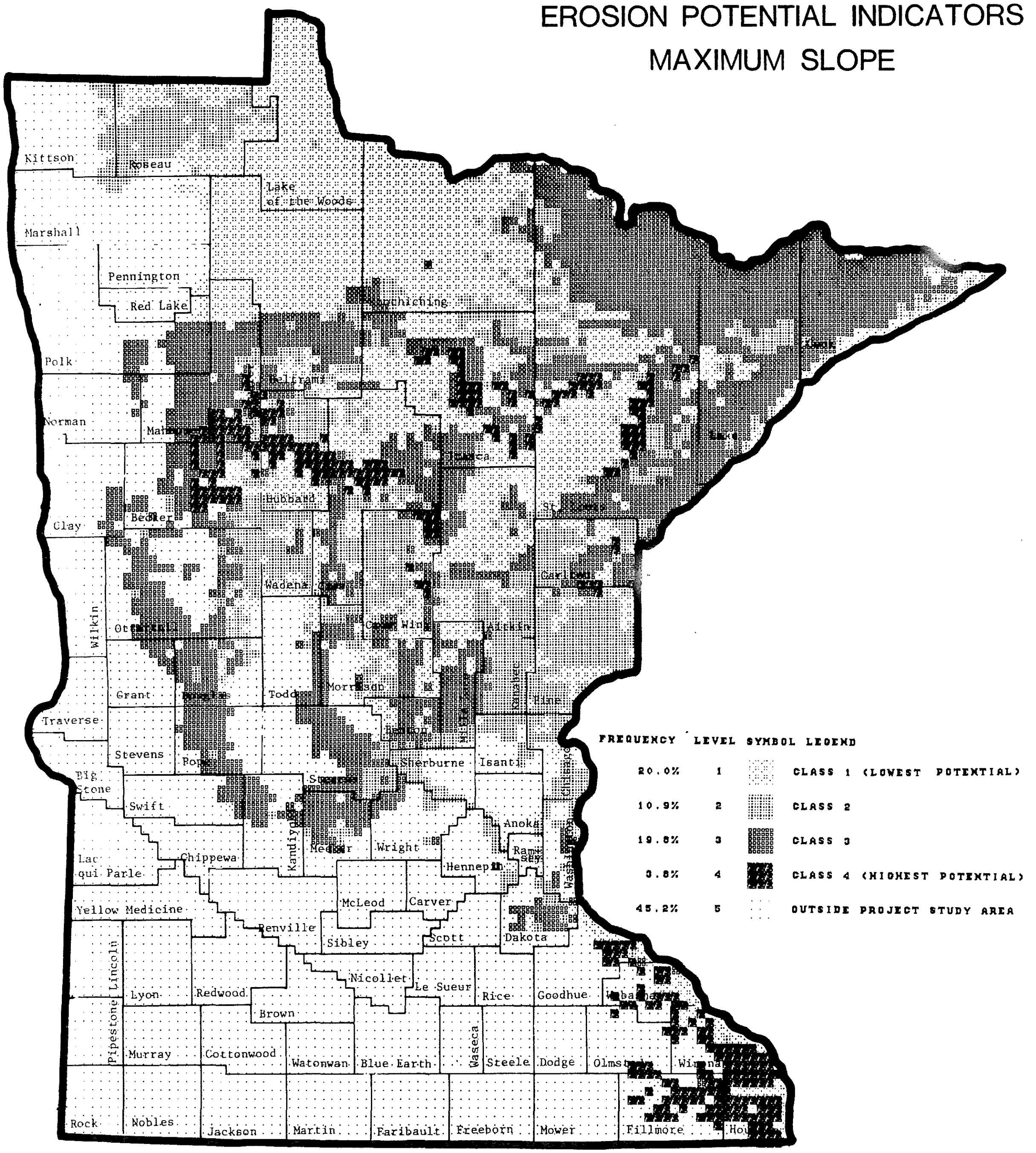

FIG. 6 RATINGS INDICATIVE OF RELATIVE EROSION POTENTIAL BASED ON ESTIMATED MAXIMUM SLOPE AND SOIL ERODIBILITY (AS MEASURED BY K-FACTOR)

EACH FIVE KILOMETER SQUARE DATA CELL HAS AN ASSIGNED VALUE OF MAXIMUM SLOPE GRADE AND K-FACTOR. THE COMBINED EFFECTS OF THESE PARAMETERS ON EROSION ARE EVALUATED AS IF THEY WERE INSERTED INTO THE UNIVERSAL SOIL LOSS EQUATION. THE RATINGS DISPLAYED ON THE MAP REPRESENT CLASSES ASSOCIATED WITH RELATIVE EROSION POTENTIAL.

DATA SOURCES: PUBLISHED SOIL ATLASES, USDA-SCS SOIL INTERPRETATION SHEETS, AND UNIVERSITY OF MINNESOTA SOIL SCIENTISTS.

5 KILOMETER DATA FILE

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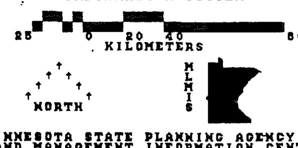

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WOODLAND SUITABILITY RATINGS - AVERAGE SLOPE

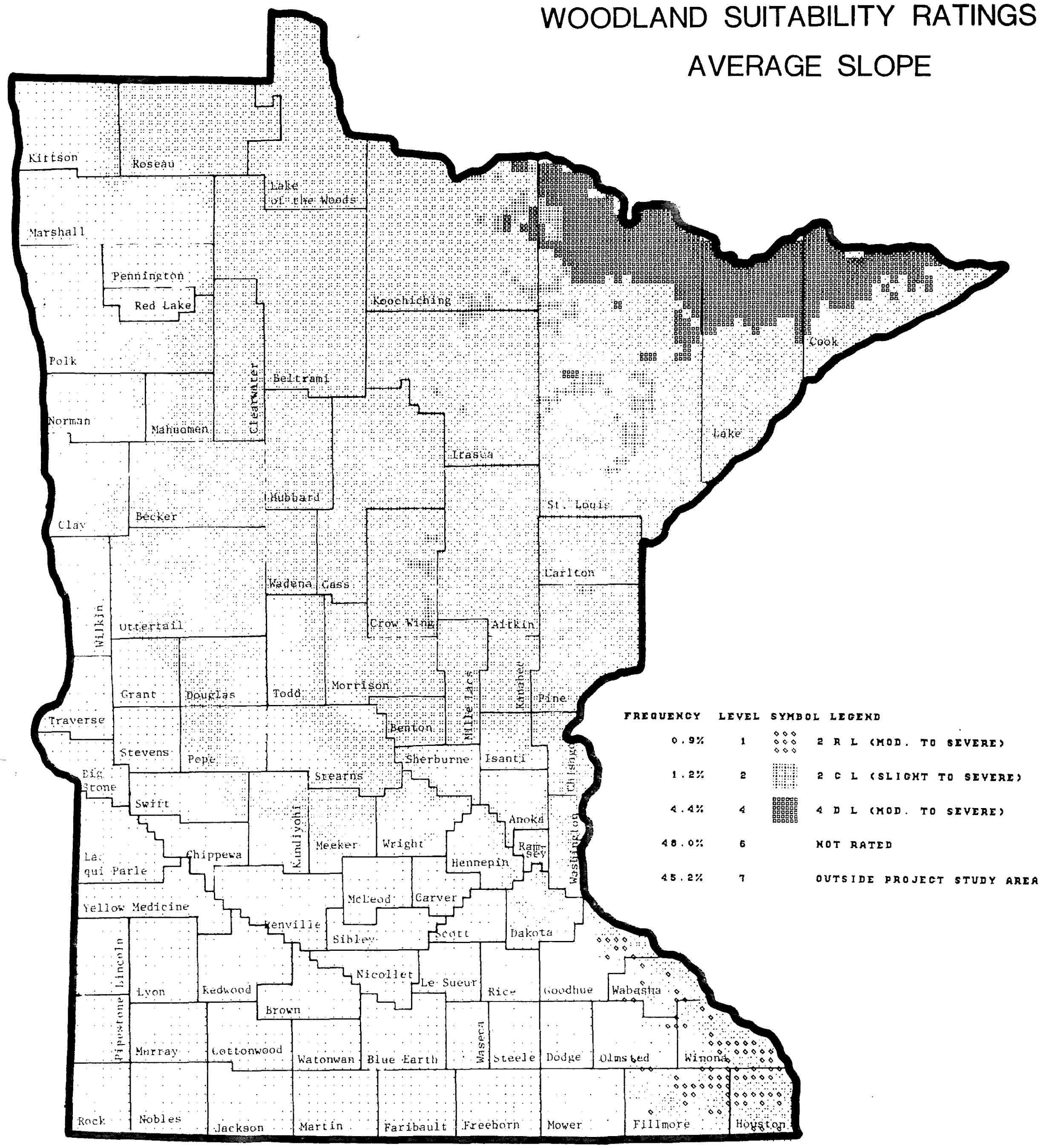

FIG. 7 WOODLAND SUITABILITY RATINGS BASED ON AVERAGE SLOPE ESTIMATES AND REPRESENTATIVE SOIL SERIES

EACH FIVE KILOMETER SQUARE DATA CELL HAS AN ASSIGNED SOIL LANDSCAPE UNIT AND GEOMORPHIC REGION. THE WOODLAND SUITABILITY RATINGS DISPLAYED ON THE MAP CORRESPOND TO THE REPRESENTATIVE SOIL SERIES, AND IN SOME CASES AVERAGE SLOPE GRADE, ASSOCIATED WITH THE LANDSCAPE UNIT / GEOMORPHIC REGION COMBINATIONS. EACH RATING DISPLAYED IS ASSOCIATED WITH A POTENTIAL EROSION HAZARD PROBLEM.

DATA SOURCES: PUBLISHED SOIL ATLASES, USDA-SCS SOIL INTERPRETATION SHEETS, AND TECHNICAL GUIDE II-F-1 (WOODLAND SUITABILITY GROUPINGS) PUBLISHED BY USDA-SCS.

5 KILOMETER DATA FILE

MAP PRODUCED BY
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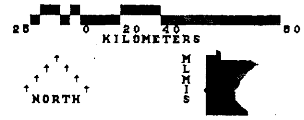
INFORMATION SYSTEM



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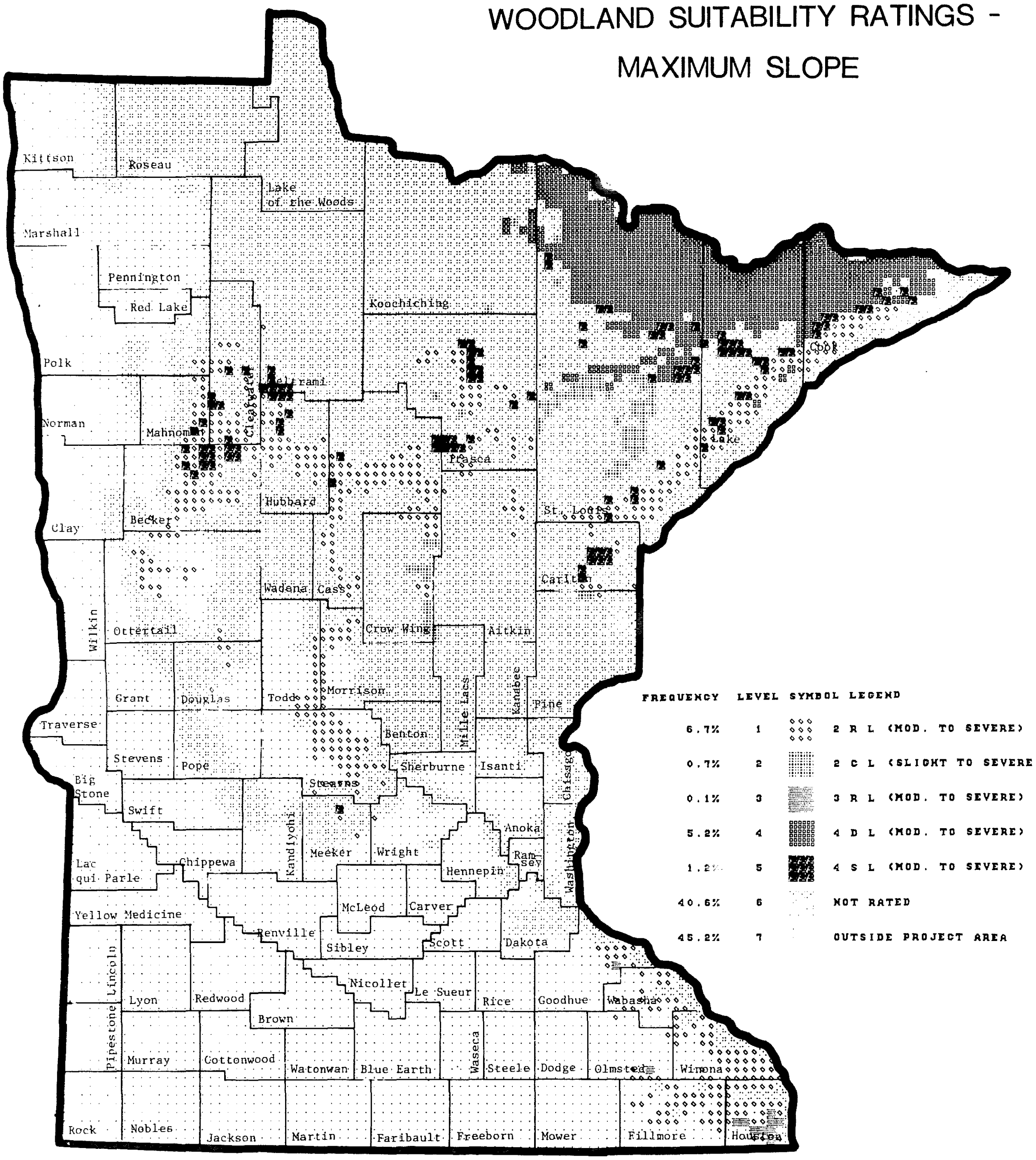

FIG. 8 WOODLAND SUITABILITY RATINGS BASED ON MAXIMUM SLOPE ESTIMATES AND REPRESENTATIVE SOIL SERIES

EACH FIVE KILOMETER SQUARE DATA CELL HAS AN ASSIGNED SOIL LANDSCAPE UNIT AND GEOMORPHIC REGION. THE WOODLAND SUITABILITY RATINGS DISPLAYED ON THE MAP CORRESPOND TO THE REPRESENTATIVE SOIL SERIES, AND IN SOME CASES MAXIMUM SLOPE GRADE, ASSOCIATED WITH THE LANDSCAPE UNIT / GEOMORPHIC REGION COMBINATIONS. EACH RATING DISPLAYED IS ASSOCIATED WITH A POTENTIAL EROSION HAZARD PROBLEM.

DATA SOURCES: PUBLISHED SOIL ATLASES, USDA-SCS SOIL INTERPRETATION SHEETS, AND TECHNICAL GUIDE II-F-1 (WOODLAND SUITABILITY GROUPINGS) PUBLISHED BY USDA-SCS.

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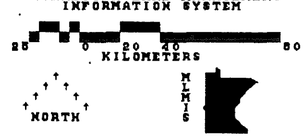

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SELECTED GEOMORPHIC REGIONS

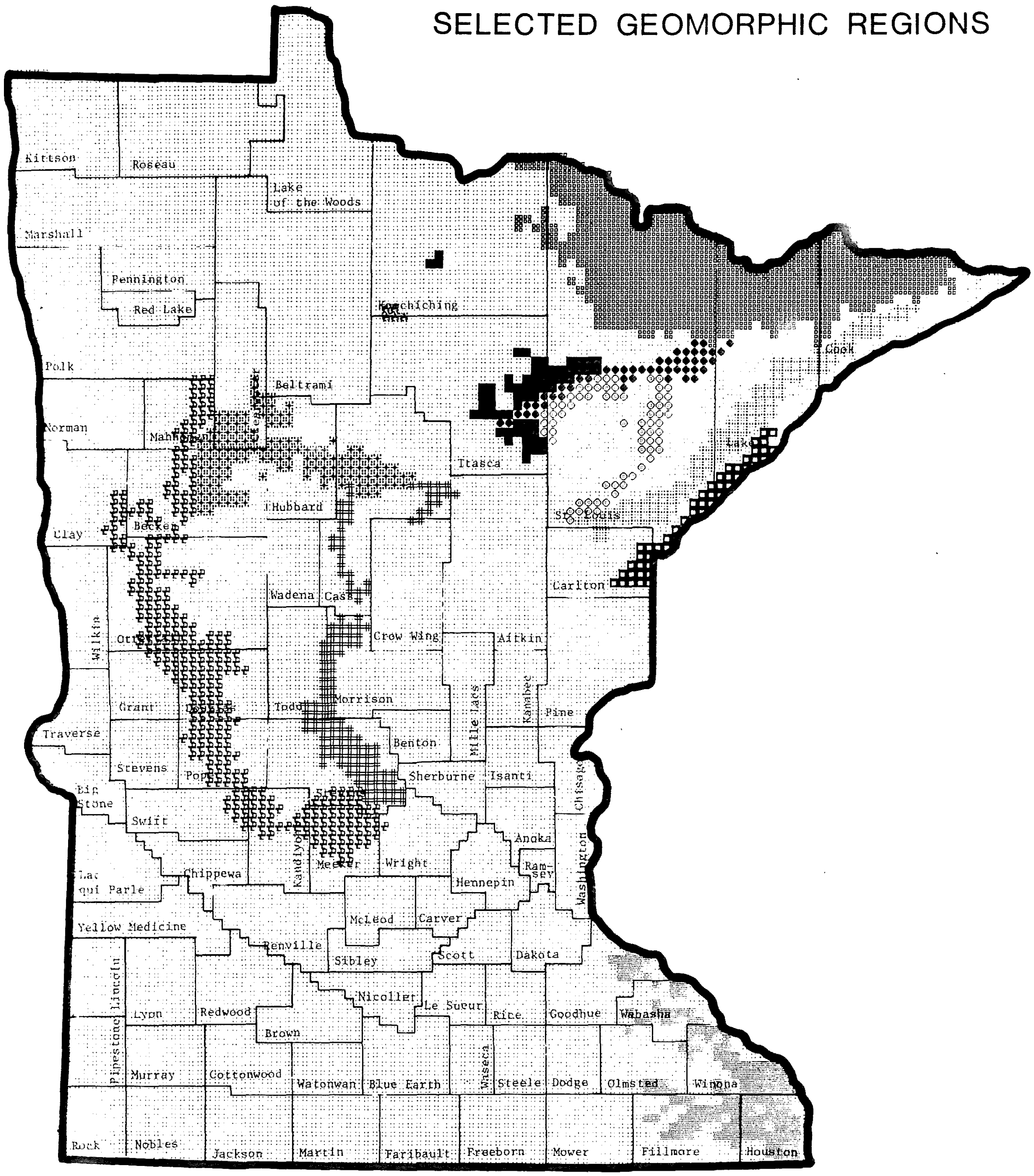

FIG. 9 SELECTED GEOMORPHIC REGIONS

A GEOMORPHIC REGION IS A BROAD PHYSIOGRAPHIC FEATURE DETERMINED PRIMARILY BY THE CONTOUR OR RELIEF ALONG WITH THE SOIL PARENT MATERIAL.

SOURCE INFORMATION: GEOMORPHIC REGIONS WERE COMPILED FOR THE MINNESOTA SOILS ATLAS BY THE UNIVERSITY OF MINNESOTA GEOLOGY DEPT. AND THE U.S. GEOLOGICAL SURVEY. SOILS ATLAS PREPARED COOPERATIVELY BY THE UNIVERSITY OF MINNESOTA SOILS DEPT. AND THE U.S. SOIL CONSERVATION SERVICE. PUBLISHED BY AGRICULTURAL EXPERIMENT STATION, UNIVERSITY OF MINNESOTA, 1971-1977.

5 KILOMETER DATA FILE

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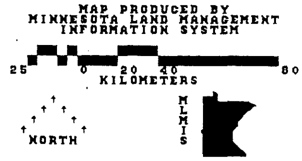

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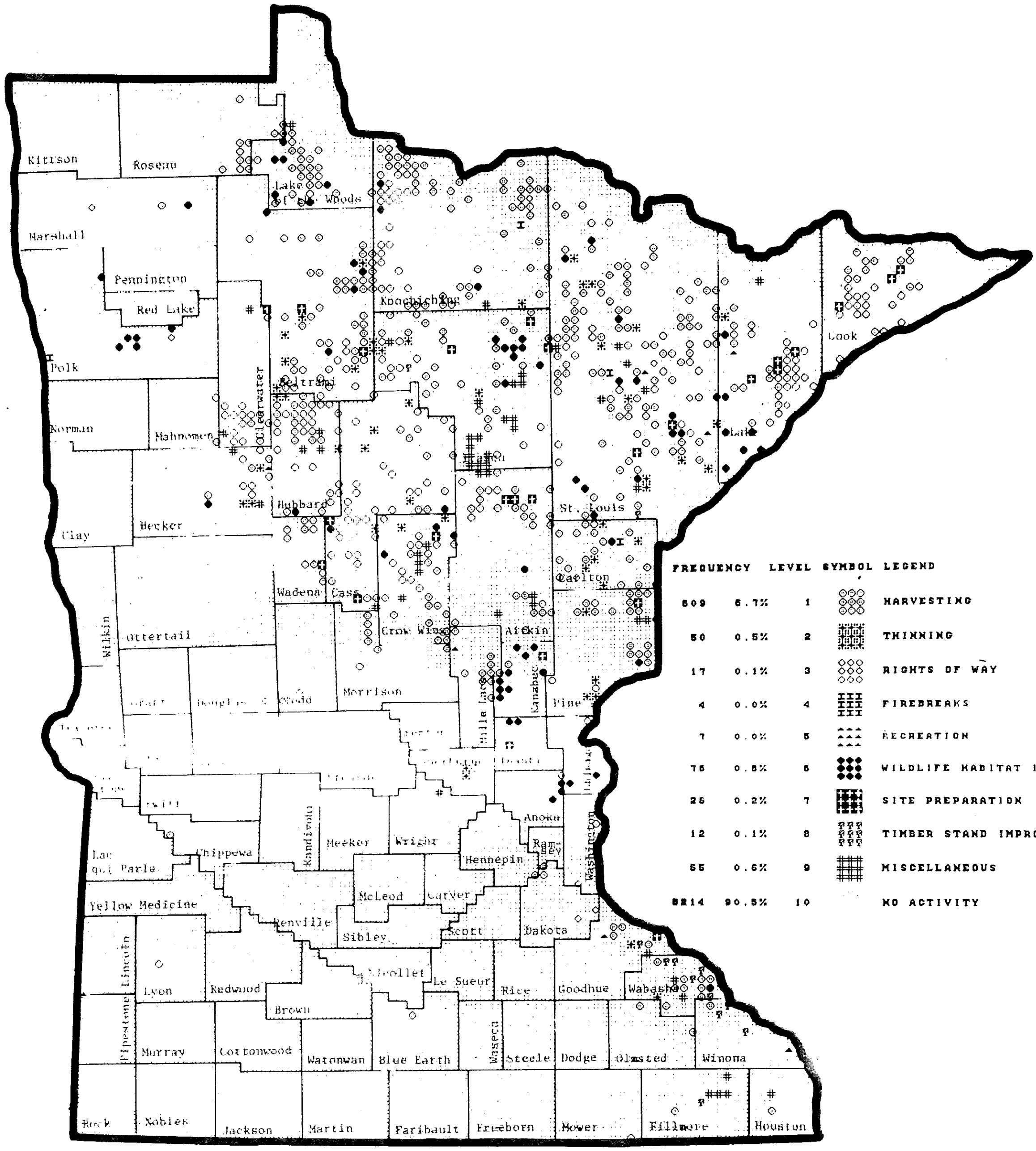

FREQUENCY		LEVEL	SYMBOL	LEGEND
609	6.7%	1		HARVESTING
50	0.5%	2		THINNING
17	0.1%	3		RIGHTS OF WAY
4	0.0%	4		FIREBREAKS
7	0.0%	5		RECREATION
75	0.8%	6		WILDLIFE HABITAT IMPROVEMENT
25	0.2%	7		SITE PREPARATION
12	0.1%	8		TIMBER STAND IMPROVEMENT
55	0.6%	9		MISCELLANEOUS
8214	90.8%	10		NO ACTIVITY

FIG. 10 DISTRIBUTION OF FOREST MANAGEMENT ACTIVITIES BASED ON PUBLIC LANDOWNERS SURVEY

EACH FIVE KILOMETER SQUARE DATA CELL HAS BEEN ASSIGNED A FOREST MANAGEMENT ACTIVITY. THE ACTIVITIES DISPLAYED ON THE MAP REPRESENT THE FOREST MANAGEMENT ACTIVITY WHICH OCCURS MOST FREQUENTLY WITHIN THAT CELL.

DATA SOURCES: 208 PROJECT PUBLIC LANDOWNERS SURVEY. DATA WAS TAKEN FROM A QUESTION REGARDING PURPOSE OF OPERATION. INCLUDES DATA RECEIVED FROM PRIVATE INDUSTRY. REPRESENTS FISCAL YEAR 1977.

5 KILOMETER DATA FILE

MAP PRODUCED BY
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INFORMATION SYSTEM

25 0 20 40 80
KILOMETERS

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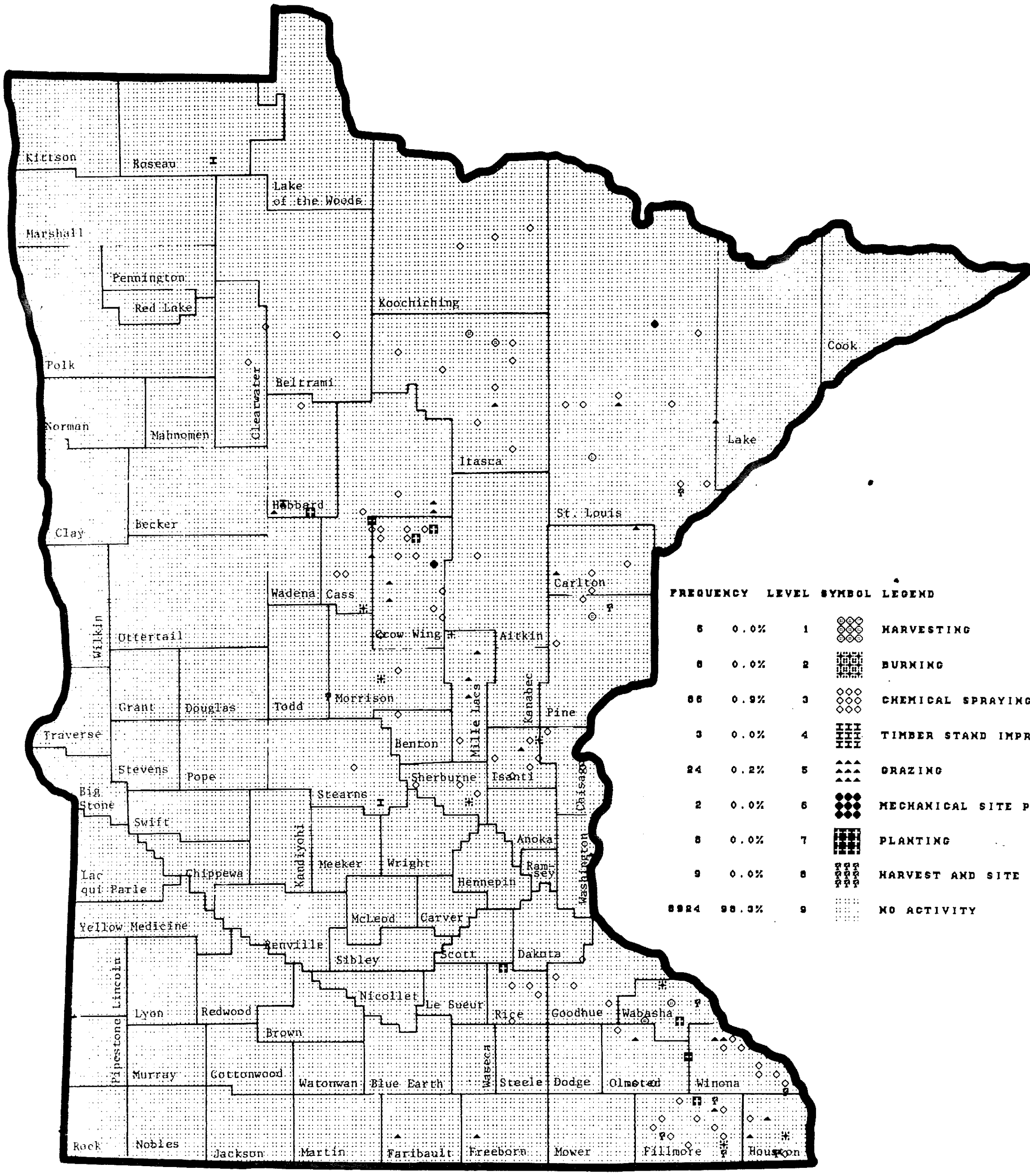

FREQUENCY		LEVEL	SYMBOL LEGEND
6	0.0%	1	HARVESTING
8	0.0%	2	BURNING
86	0.9%	3	CHEMICAL SPRAYING
3	0.0%	4	TIMBER STAND IMPROVEMENT
24	0.2%	5	GRAZING
2	0.0%	6	MECHANICAL SITE PREPARATI
8	0.0%	7	PLANTING
9	0.0%	8	HARVEST AND SITE PREPARAT
8924	98.3%	9	NO ACTIVITY

FIG. 11 DISTRIBUTION OF FOREST MANAGEMENT ACTIVITIES BASED ON PRIVATE LANDOWNERS SURVEY.

EACH FIVE KILOMETER SQUARE CELL HAS BEEN ASSIGNED A FOREST MANAGEMENT ACTIVITY. THE ACTIVITIES DISPLAYED ON THE MAP REPRESENT THE FOREST MANAGEMENT ACTIVITY WHICH OCCURS MOST FREQUENTLY WITHIN THAT CELL.

DATA SOURCES: 208 PROJECT PRIVATE LAND OWNERS SURVEY . DATA WAS TAKEN FROM THE QUESTION REGARDING THE TYPE OF ACTIVITY.

5 KILOMETER DATA FILE

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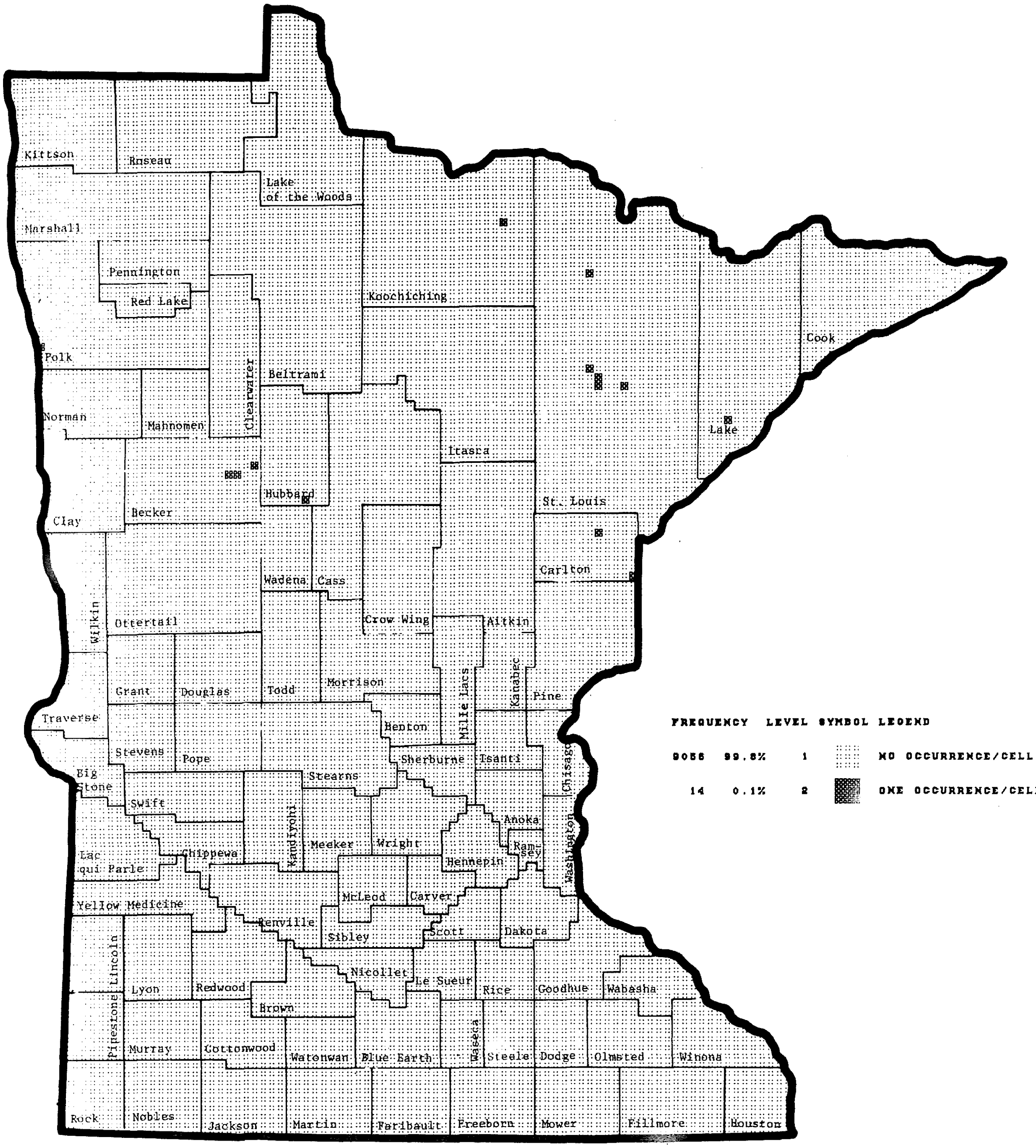

FIG. 12 FIREBREAK INTENSITY

ALL FIVE KILOMETER CELLS WHERE A FIRE-BREAK OPERATION WAS REPORTED HAS BEEN ASSIGNED A SYMBOL. THE SYMBOL REPRESENTS THE NUMBER OF TIMES THIS ACTIVITY OCCURRED WITHIN THAT CELL.

DATA SOURCES: 208 PROJECT PUBLIC LANDOWNERS SURVEY .

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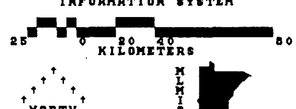

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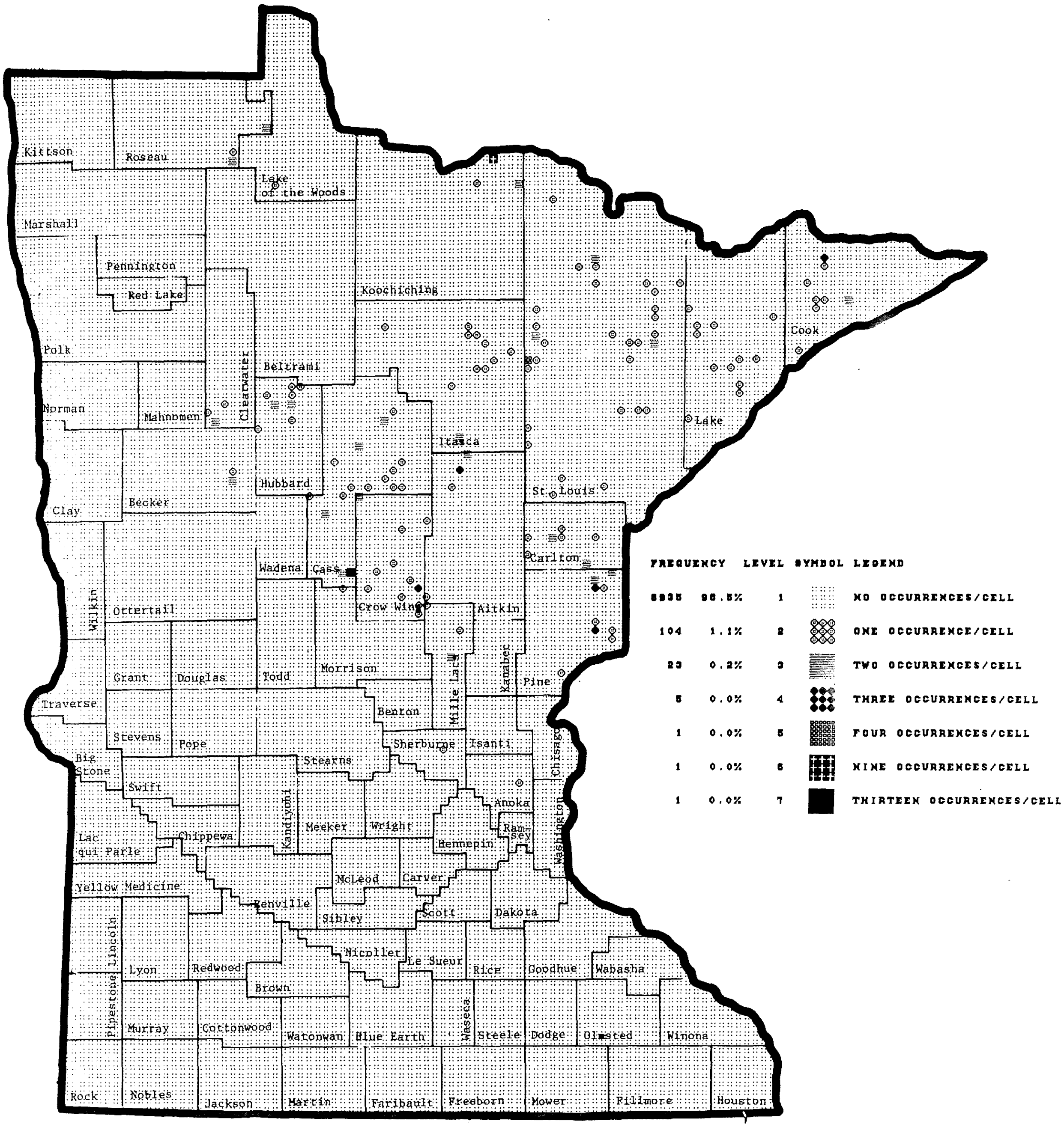

FIG. 13 DISTRIBUTION OF TEMPORARY FOREST ROADS CONSTRUCTED IN FISCAL YEAR 1977 IN CONNECTION WITH A FOREST MANAGEMENT ACTIVITY - BASED ON PUBLIC LANDOWNERS SURVEY

ALL FIVE KILOMETER SQUARE CELLS WHERE A TEMPORARY ROAD WAS CONSTRUCTED IN FISCAL YEAR 1977 WERE ASSIGNED A SYMBOL. THE SYMBOL REPRESENTS THE NUMBER OF TIMES THIS ACTIVITY OCCURED WITHIN THAT CELL.

DATA SOURCES: 208 PROJECT PUBLIC LANDOWNERS SURVEY .

5 KILOMETER DATA FILE

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KILOMETERS

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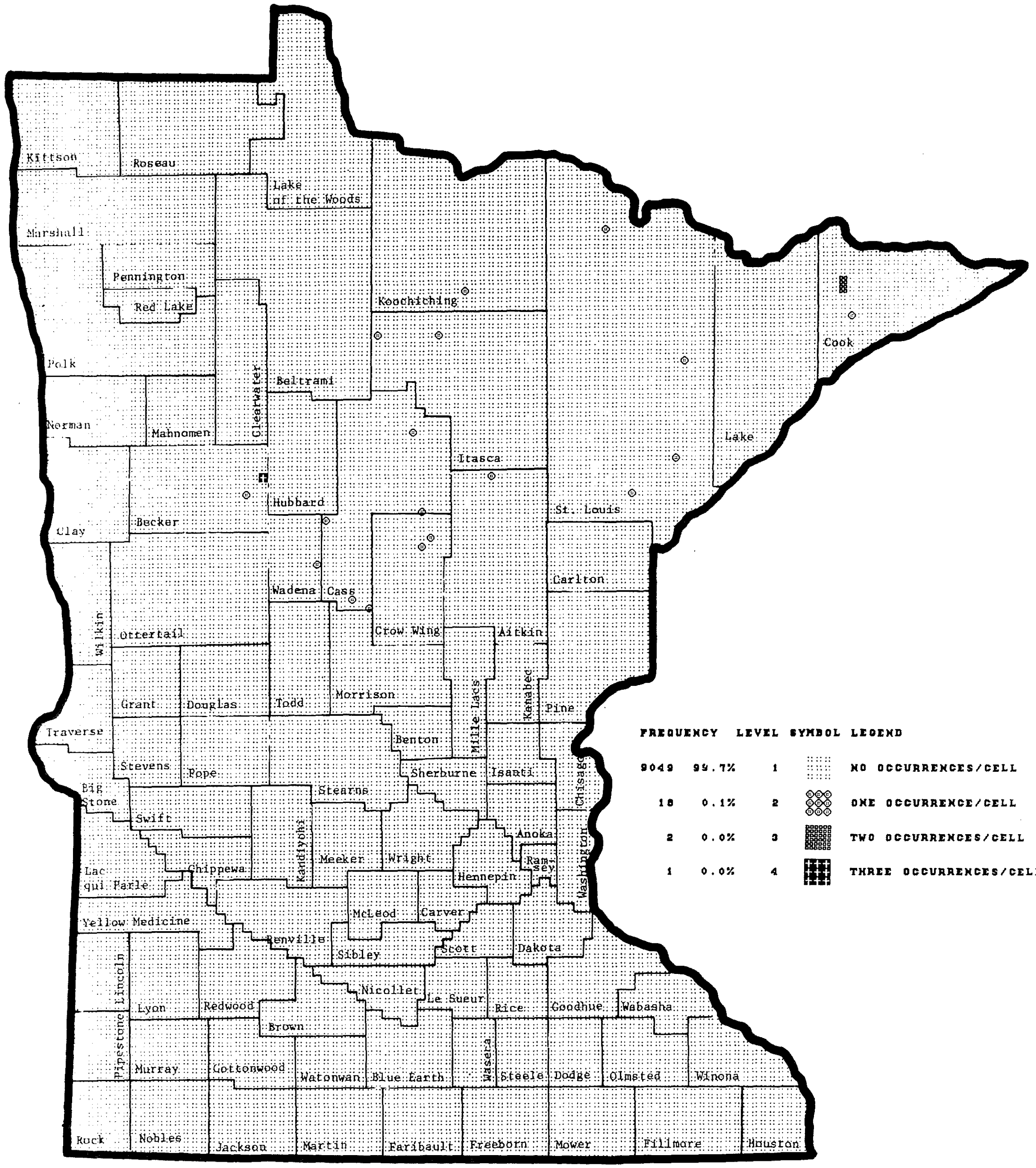

FIG. 14 DISTRIBUTION OF ROOT RAKING AND ROCK RAKING OPERATIONS FOR SITE PREPARATION, WHICH OCCURED IN FISCAL YEAR 1977 - BASED ON PUBLIC LANDOWNERS SURVEY.

ALL FIVE KILOMETER SQUARE CELLS WHERE ROOT RAKING OR ROCK RAKING SITE PREPARATION ACTIVITIES OCCURED WERE ASSIGNED A SYMBOL. THE SYMBOL REPRESENTS THE NUMBER OF TIMES THE ACTIVITY OCCURRED WITHIN THAT CELL.

DATA SOURCES: 208 PROJECT PUBLIC LANDOWNERS SURVEY . TAKEN FROM QUESTION REGARDING TYPE OF SITE PREPARATION.

5 KILOMETER DATA FILE

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INFORMATION SYSTEM

25 0 20 40 80
KILOMETERS

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550 CEDAR STREET
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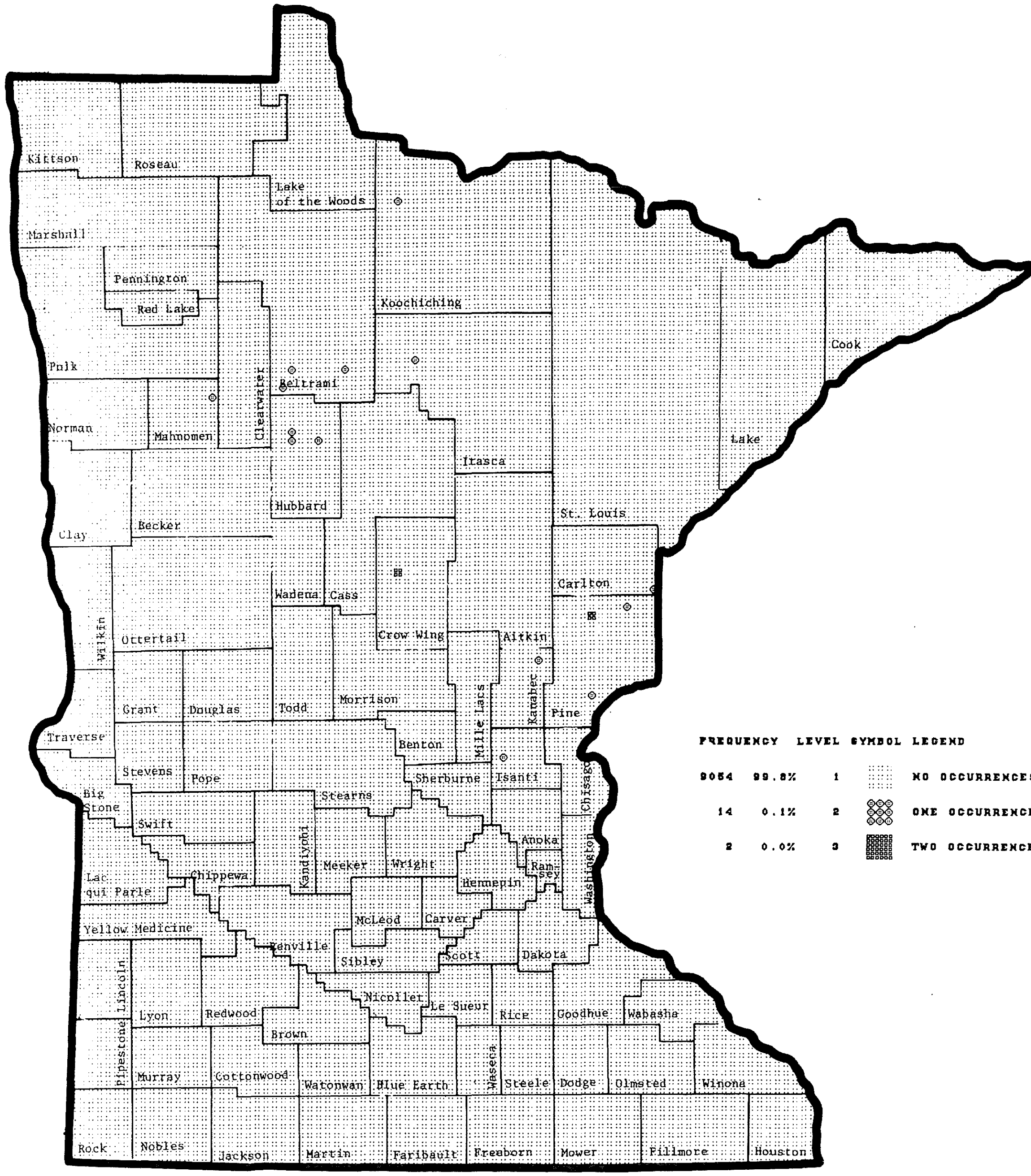

FREQUENCY		LEVEL	SYMBOL	LEGEND
9054	99.8%	1		NO OCCURRENCES/CELL
14	0.1%	2		ONE OCCURRENCE/CELL
2	0.0%	3		TWO OCCURRENCES/CELL

FIG. 15 DISTRIBUTION OF PLOWING OPERATIONS FOR SITE PREPARATION WHICH OCCURED IN FISCAL YEAR 1977, BASED ON PUBLIC LANDOWNERS SURVEY.

ALL FIVE KILOMETER SQUARE CELLS WHERE PLOWING OPERATIONS FOR SITE PREPARATION OCCURED WERE ASSIGNED A SYMBOL. THIS SYMBOL REPRESENTS THE NUMBER OF TIMES THE ACTIVITY OCCURED WITHIN THAT CELL.

DATA SOURCES: 208 PROJECT PUBLIC LANDOWNERS SURVEY, TAKEN FROM QUESTION REGARDING TYPE OF SITE PREPARATION.

5 KILOMETER DATA FILE

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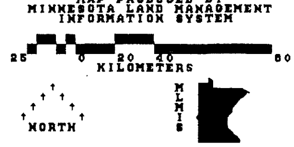
INFORMATION SYSTEM



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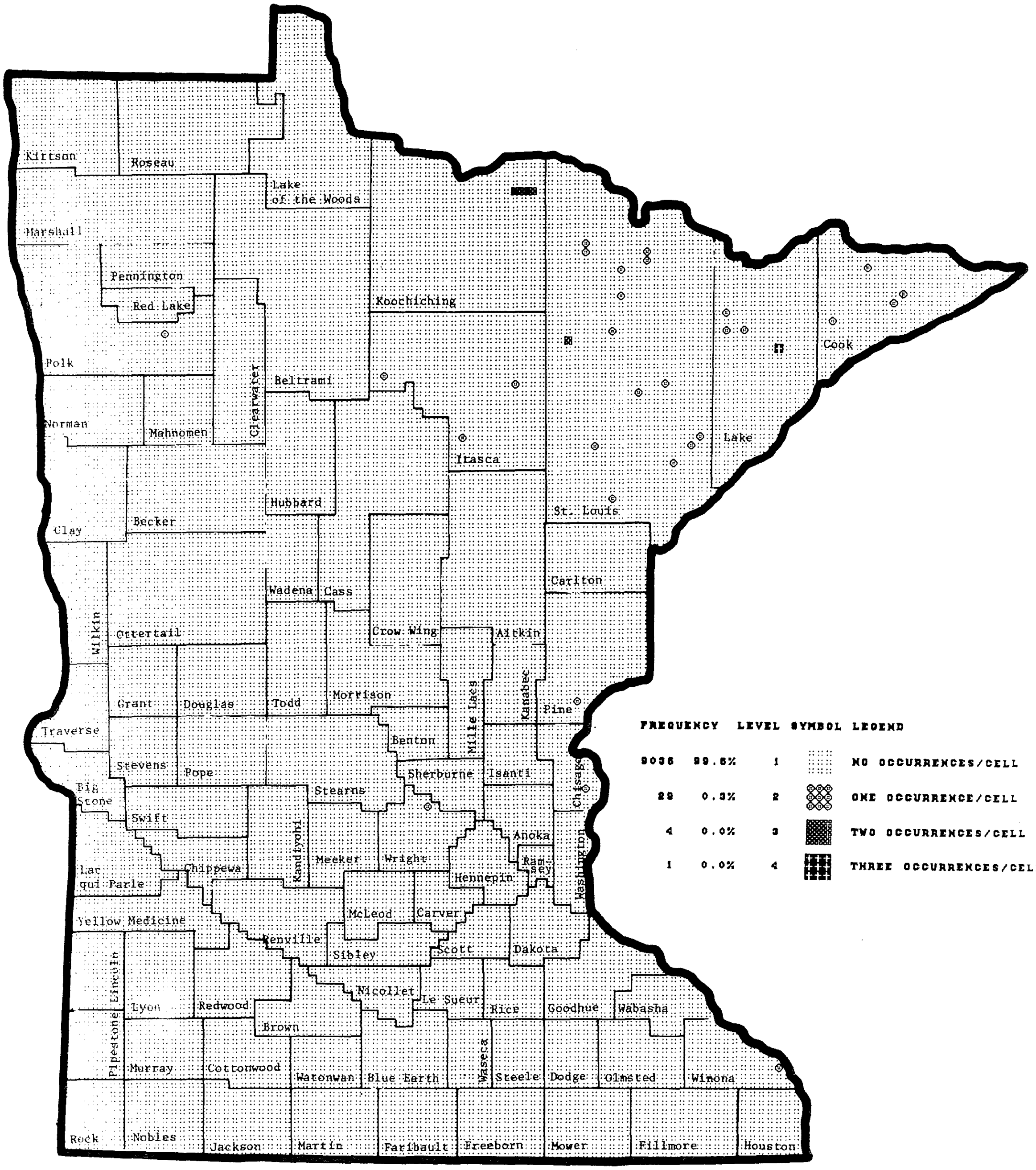

FIG. 16 DISTRIBUTION OF PERMANENT, GRAVEL-SURFACED FOREST ROADS, CONSTRUCTED IN CONNECTION WITH A FOREST MANAGEMENT ACTIVITY, IN FISCAL YEAR 1977, BASED ON PUBLIC LANDOWNERS SURVEY.

ALL FIVE KILOMETER SQUARE CELLS WHERE A GRAVEL-SURFACED PERMANENT ROAD WAS CONSTRUCTED WERE ASSIGNED A SYMBOL. THIS SYMBOL REPRESENTS THE NUMBER OF TIMES THE ACTIVITY OCCURRED WITHIN THAT CELL.

DATA SOURCES: 208 PROJECT PUBLIC LANDOWNERS SURVEY .

5 KILOMETER DATA FILE

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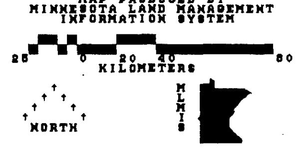

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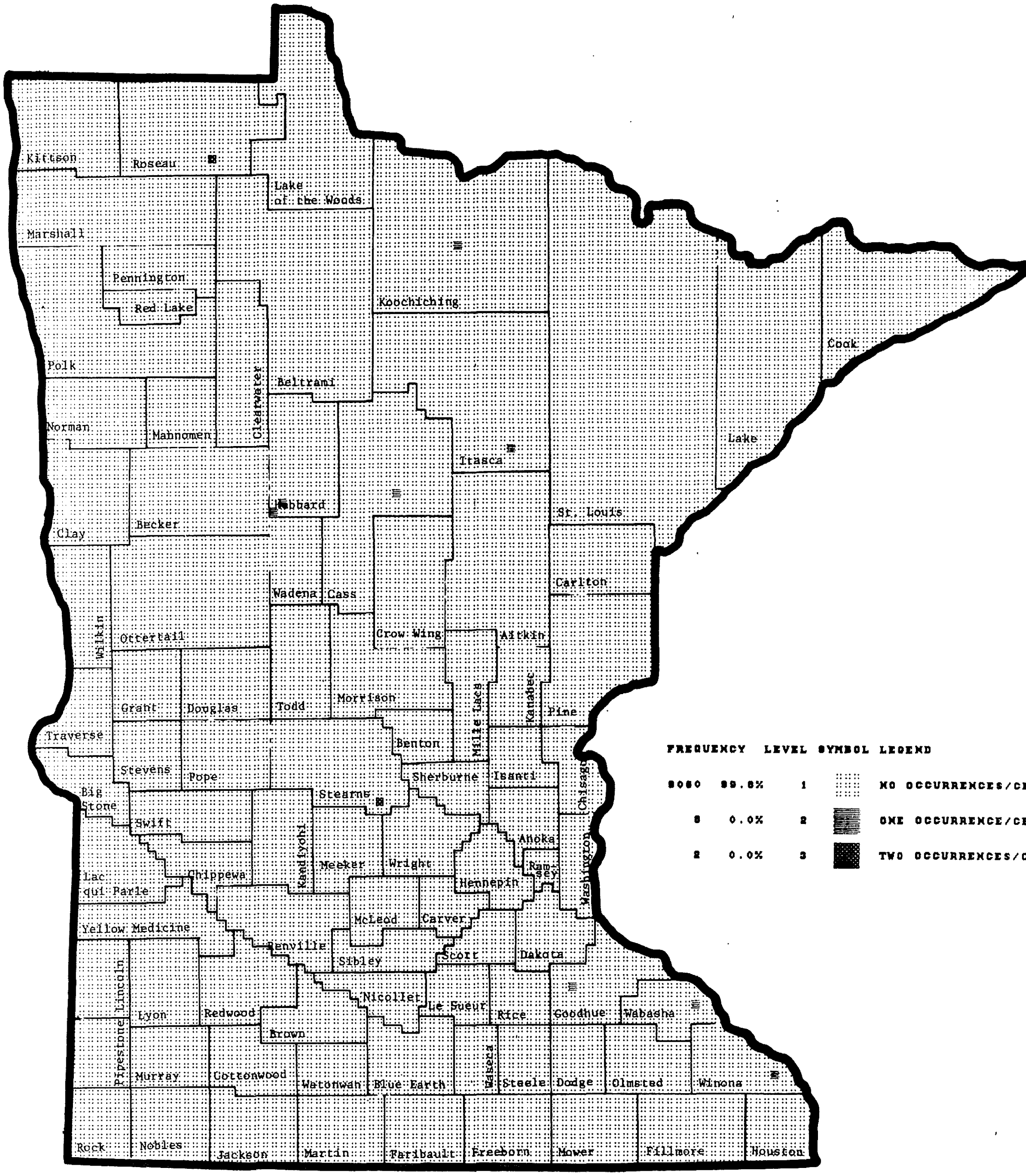

FREQUENCY LEVEL SYMBOL LEGEND

8080	99.8%	1	⁘	NO OCCURRENCES/CELL
8	0.0%	2	▒	ONE OCCURRENCE/CELL
2	0.0%	3	▓	TWO OCCURRENCES/CELL

FIG. 17 DISTRIBUTION OF MECHANICAL SITE PREPARATION OPERATIONS ON PRIVATE WOODLOTS.

ALL FIVE KILOMETER SQUARE CELLS WHERE ASSIGNED MECHANICAL SITE PREPARATION OPERATIONS OCCURRED WERE ASSIGNED A SYMBOL. THIS SYMBOL REPRESENTS THE NUMBER OF TIMES THE ACTIVITY OCCURRED WITHIN THAT CELL.

DATA SOURCES: 208 PROJECT PRIVATE LAND OWNERS SURVEY .

5 KILOMETER DATA FILE

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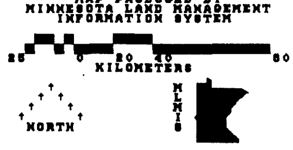
INFORMATION SYSTEM



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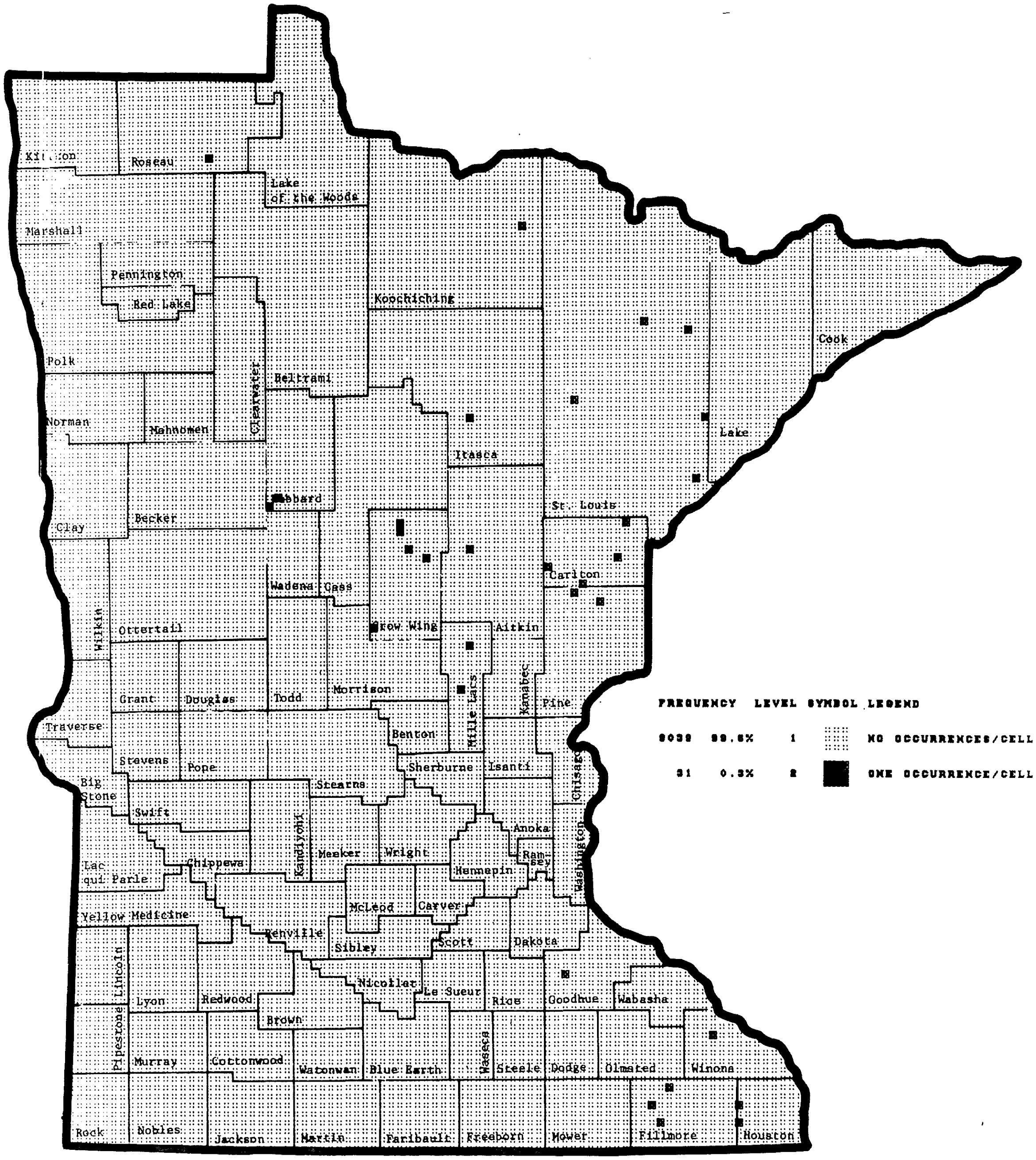

FIG. 16 DISTRIBUTION OF ROADS BUILT ON PRIVATE WOODLOTS

ALL FIVE KILOMETER CELLS WHERE A ROAD WAS BUILT ON PRIVATE LAND WERE ASSIGNED A SYMBOL. THIS SYMBOL REPRESENTS THE NUMBER OF TIMES THE ACTIVITY OCCURRED WITHIN THAT CELL.

DATA SOURCES: 208 PROJECT PRIVATE LANDOWNERS SURVEY

5 KILOMETER DATA FILE

MAP PRODUCED BY
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INFORMATION SYSTEM

25 0 20 40 60
KILOMETERS

NORTH

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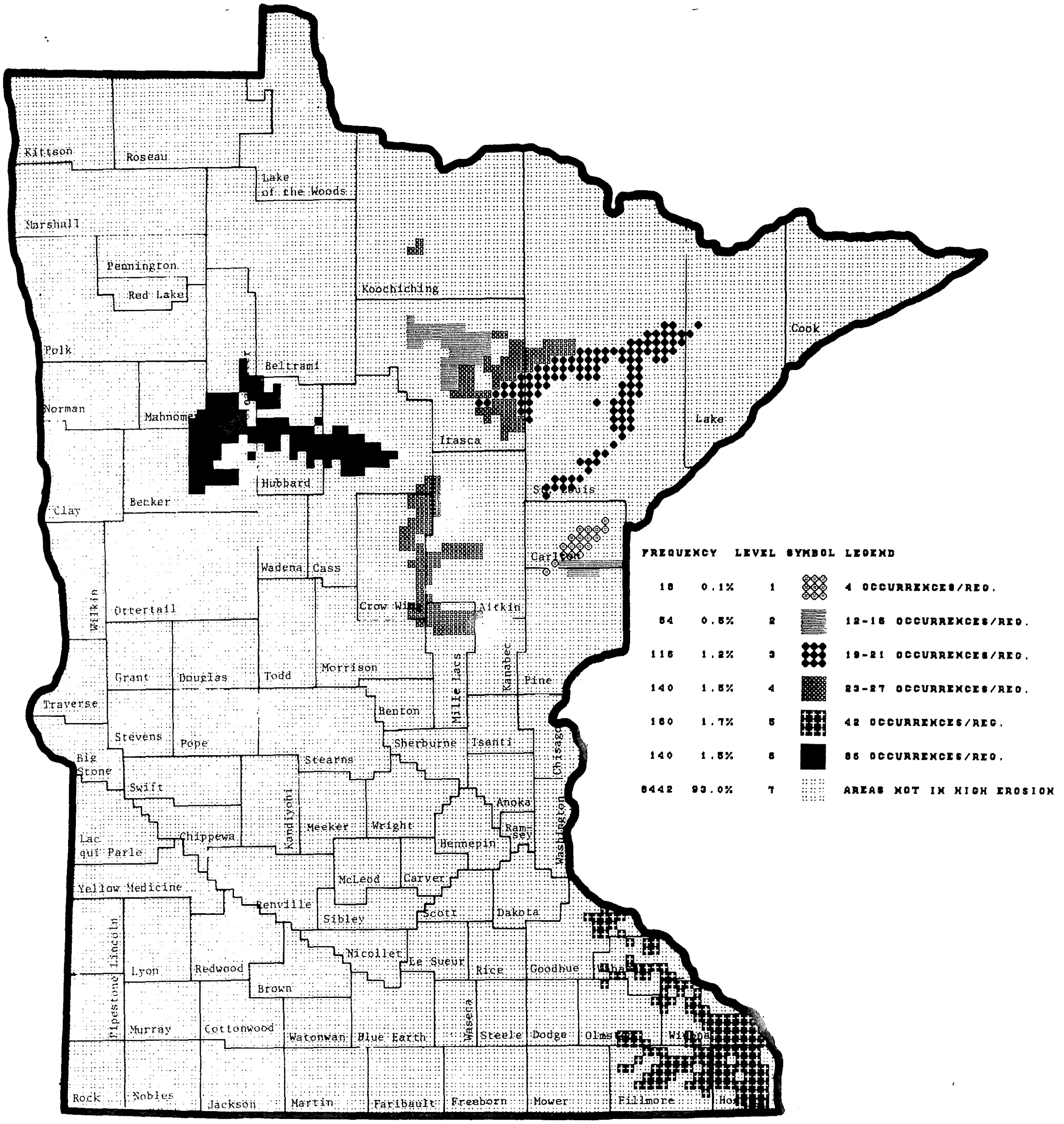

FIG. 19 INTENSITY OF FOREST MANAGEMENT ACTIVITY IN GEOMORPHICS EXHIBITING A HIGH EROSION POTENTIAL INDICATOR CLASS FOR FISCAL YEAR 1977 - BASED ON PUBLIC LANDOWNERS SURVEY.

FIVE KILOMETER SQUARE CELL DATA HAVE BEEN SUMMARIZED BY GEOMORPHIC REGION FOR ALL FOREST MANAGEMENT ACTIVITIES. THE NUMBER OF ACTIVITIES PER GEOMORPHIC REGION WERE TALLIED. THE SYMBOLS DISPLAYED REPRESENT THE INTENSITY OF FOREST MANAGEMENT ACTIVTIES WITHIN EACH OF NINE GEOMORPHIC REGIONS WHICH ARE IN THE HIGH EROSION POTENTIAL INDICATOR CLASS.

DATA SOURCES: 208 PROJECT PUBLIC LANDOWNERS SURVEY, PUBLISHED SOIL ATLASES AND USDA-SCS SOIL INTERPRETATION SHEETS.

5 KILOMETER DATA FILE

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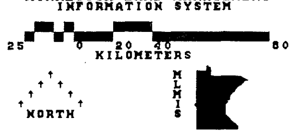

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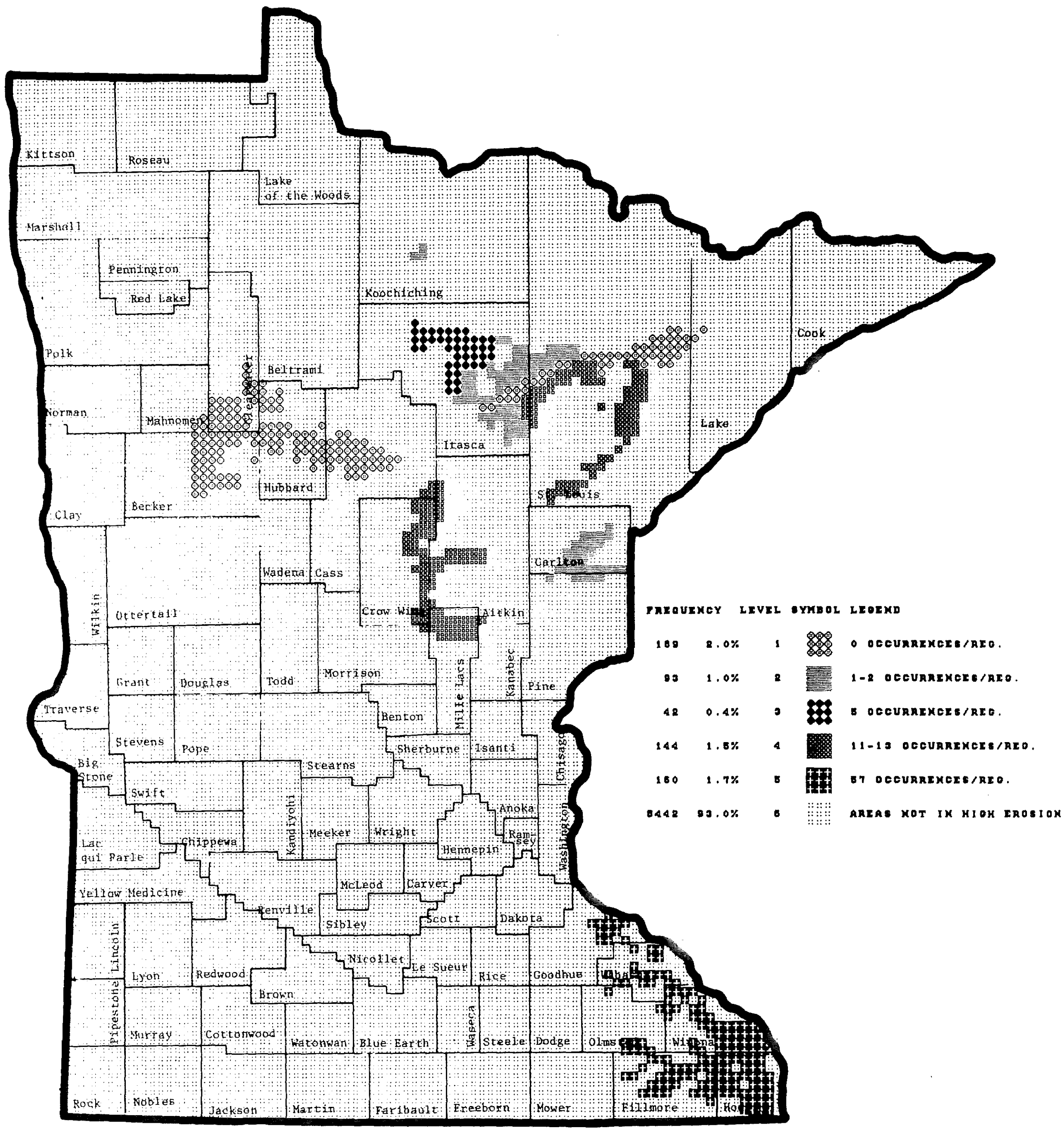

FIG. 20 INTENSITY OF FOREST MANAGEMENT ACTIVITY ON PRIVATE WOODLOTS IN THOSE GEOMORPHICS IN THE HIGH EROSION POTENTIAL INDICATOR CLASS.

FIVE KILOMETER SQUARE CELL DATA FOR TOTAL FOREST MANAGEMENT ACTIVITIES ON PRIVATE WOODLOTS HAVE BEEN SUMMARIZED BY GEOMORPHIC REGIONS. THE NUMBER OF ACTIVITIES PER GEOMORPHIC REGION WERE TALLIED. THE SYMBOLS DISPLAYED REPRESENT THE INTENSITY OF FOREST MANAGEMENT ACTIVITIES WITHIN EACH OF NINE GEOMORPHIC REGIONS WHICH ARE IN THE HIGH EROSION POTENTIAL INDICATOR CLASS.

DATA SOURCES: 208 PROJECT PRIVATE LANDOWNERS SURVEY , PUBLISHED SOIL ATLASES, AND USDA-SCS SOIL INTERPRETATION SHEETS.

5 KILOMETER DATA FILE

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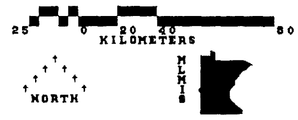

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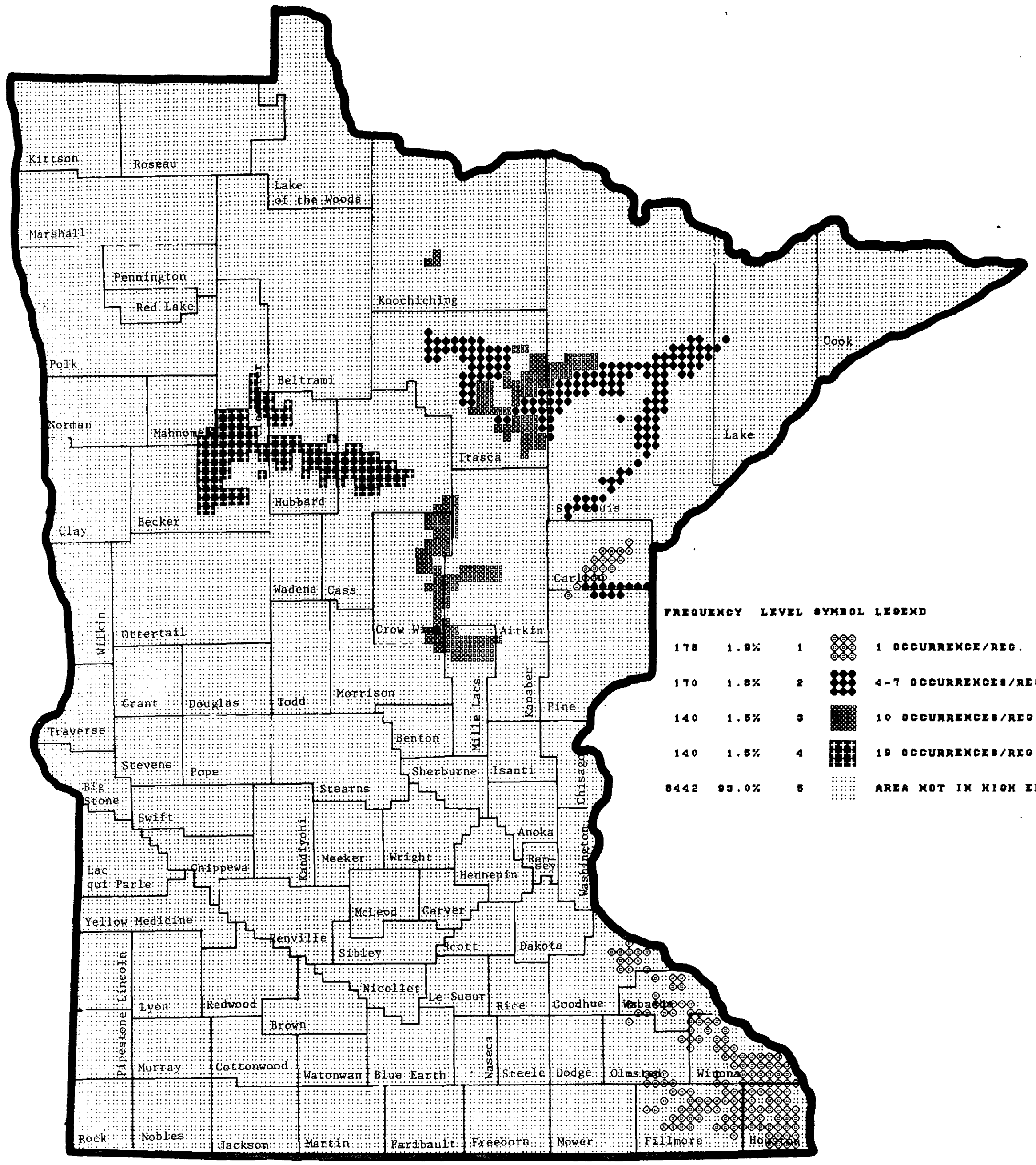

FREQUENCY		LEVEL	SYMBOL	LEGEND
178	1.9%	1		1 OCCURRENCE/REG.
170	1.8%	2		4-7 OCCURRENCES/REG.
140	1.5%	3		10 OCCURRENCES/REG.
140	1.5%	4		19 OCCURRENCES/REG.
8442	93.0%	5		AREA NOT IN HIGH EROSION CL

FIG. 21 INTENSITY OF THOSE FOREST MANAGEMENT ACTIVITIES IDENTIFIED AS HAVING A HIGH SITE DISTURBANCE POTENTIAL, BY GEOMORPHIC REGION FOR FISCAL YEAR, 1977.

FOREST MANAGEMENT ACTIVITIES WERE ANALYZED ON THE BASIS OF THREE SITE DISTURBANCE POTENTIAL FACTORS. THOSE ACTIVITIES WHICH WERE IDENTIFIED AS HAVING A HIGH POTENTIAL FOR SITE DISTURBANCE WERE ASSIGNED TO A FIVE KILOMETER SQUARE CELL. THESE DATA WERE THEN GROUPED INTO GEOMORPHIC REGIONS. THE SYMBOLS DISPLAYED REPRESENT THE INTENSITY OF THOSE FOREST MANAGEMENT ACTIVITIES WITH A HIGH SITE DISTURBANCE POTENTIAL BY HIGH EROSION POTENTIAL GEOMORPHIC REGIONS.

DATA SOURCES: 208 PROJECT PUBLIC LANDOWNERS SURVEY , PUBLISHED SOIL ATLASES, USDA-SCS SOIL INTERPRETATION SHEETS,AND MINN. FORESTRY RESEARCH NOTES.

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25 0 20 40 80
KILOMETERS

NORTH

MLMIS

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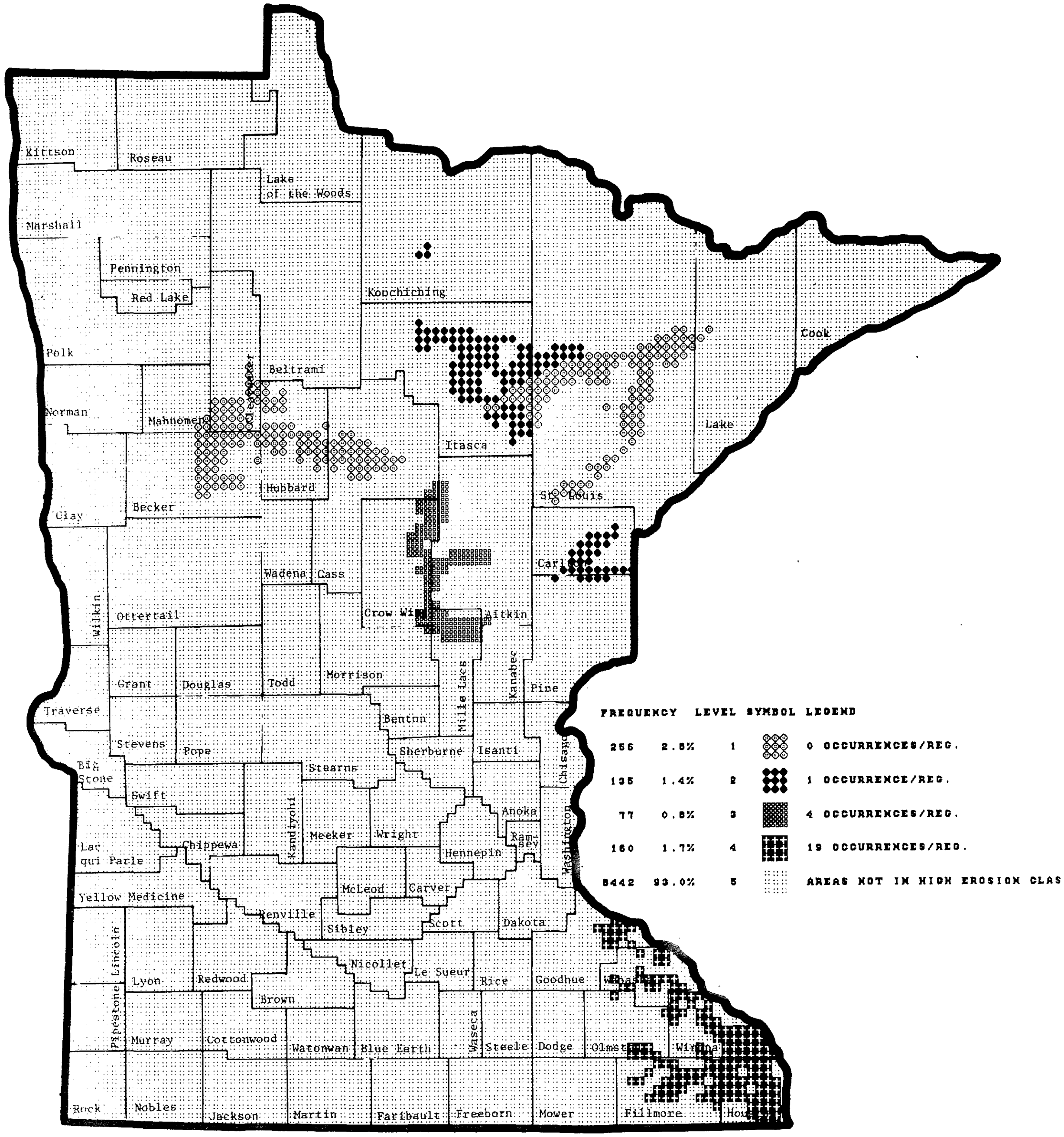

FIG. 22 INTENSITY OF THOSE PRIVATE FOREST MANAGEMENT ACTIVITIES IDENTIFIED AS HAVING A HIGH SITE DISTURBANCE POTENTIAL, BY GEOMORPHIC REGIONS.
PRIVATE FOREST MANAGEMENT ACTIVITIES WERE ANALYZED ON THE BASIS OF THREE SITE DISTURBANCE POTENTIAL FACTORS. THOSE ACTIVITIES WHICH WERE IDENTIFIED AS HAVING A HIGH POTENTIAL FOR SITE DISTURBANCE WERE ASSIGNED TO A FIVE KILOMETER SQUARE CELL. THESE DATA WERE THEN GROUPED INTO GEOMORPHIC REGIONS. THE SYMBOLS DISPLAYED REPRESENT THE INTENSITY OF THOSE FOREST MANAGEMENT ACTIVITIES WITH A HIGH SITE DISTURBANCE POTENTIAL, WHICH OCCURRED IN HIGH EROSION POTENTIAL GEOMORPHIC REGIONS.

DATA SOURCES: 208 PROJECT PRIVATE LANDOWNERS SURVEY, PUBLISHED SOIL ATLASES, USDA/SCS SOIL INTERPRETATION SHEETS, AND MINN. FORESTRY RESEARCH NOTES.

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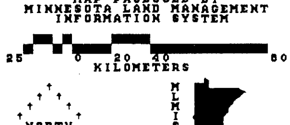

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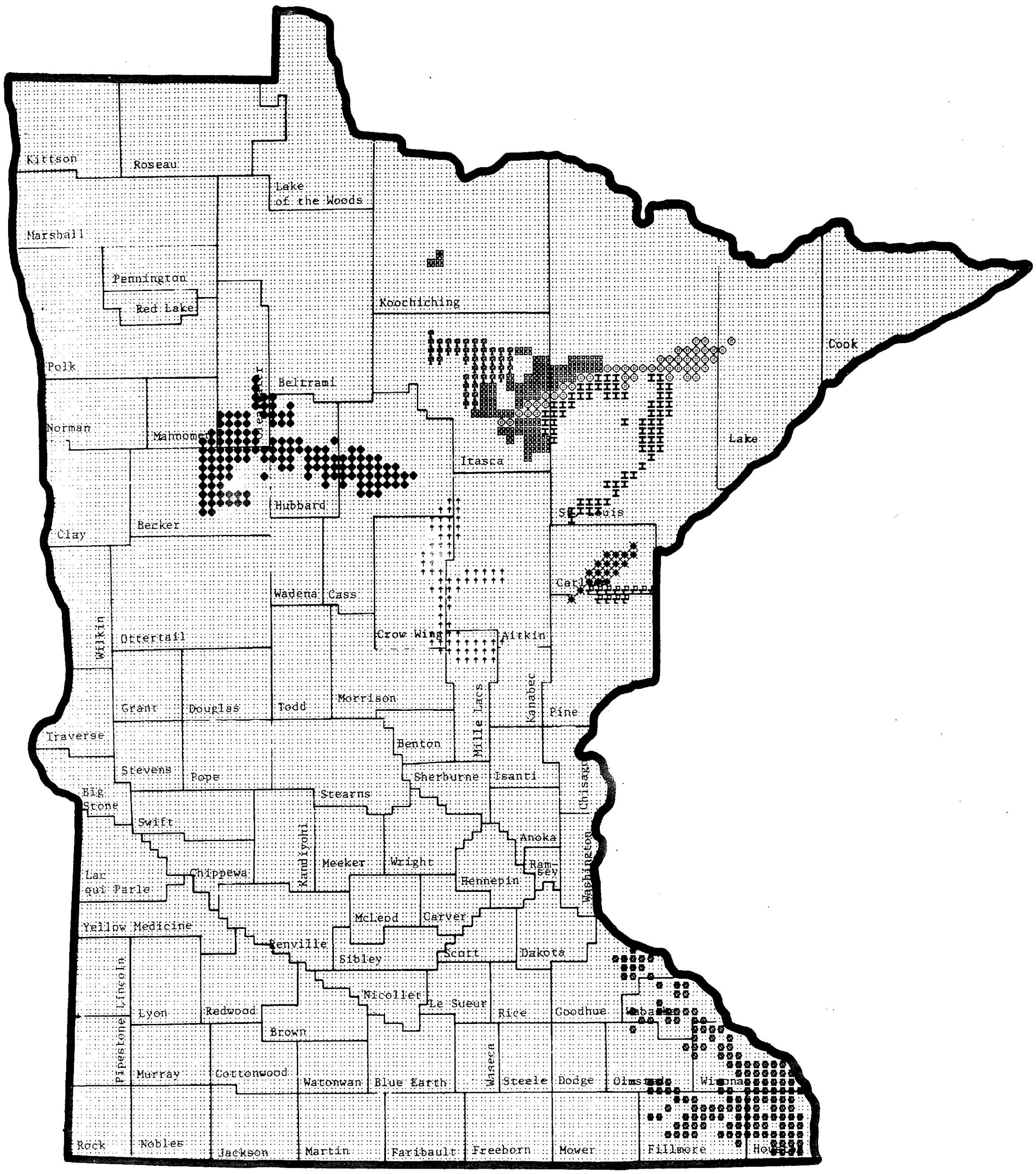

FIG. 23 GEOMORPHIC REGIONS WITH THE HIGHEST EROSION POTENTIAL INDICATOR CLASS (BASED ON MAXIMUM SLOPE)

DATA SOURCES: 208 PROJECT PUBLIC LANDOWNERS SURVEY, PUBLISHED SOIL ATLASES AND USDA-SCS SOIL INTERPRETATION SHEETS.

5 KILOMETER DATA FILE

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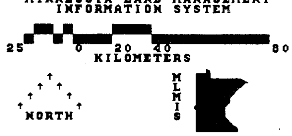

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