The Revegetation of Drastically Disturbed Lands

by Chuck Mrena

A Practicum Submitted in
Partial Fulfillment of the
Requirements for the Degree
Master of Natural Resources Management

The Natural Resources Institute
University of Manitoba
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THE UNIVERSITY OF MANITOBA

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Abstract

During the extraction of natural resources such as timber and minerals. and in the development of infrastructure and mega-projects, areas of land are disturbed and in many cases remain so for extended periods of time. For the purpose of this project, land is considered to be drastically disturbed if the native vegetation and animal communities have been removed and the topsoil is lost or altered, exposing a biologically barren subsoil surface condition. There are two basic approaches that can be taken in revegetating drastically disturbed sites devoid of topsoil or organic matter. They are: (1) Allow natural succession to take place: or (2) Give succession a "kickstart".

The purpose of this study was to identify and evaluate revegetation strategies and techniques which may serve to "kickstart" succession on drastically disturbed lands within the Manitoba Model Forest (MMF) region. The objectives of this study were: (1) To identify and review the revegetation strategies and techniques currently being used by various agencies; (2) To assess the identified revegetation strategies and techniques for use in Manitoba; (3) To evaluate the chosen revegetation strategies and techniques through field trials; (4) To make recommendations for the revegetation of drastically disturbed lands based upon the review of strategies and techniques, and the results of field studies: and (5) To develop guidelines for "post-study" monitoring and analysis of field studies.

Field trials were used to assess the potential of hydroseeding and mulching around established trees and shrubs in the revegetation of drastically disturbed lands within Manitoba and the MMF. The materials that were evaluated included currently available hydroseeding products, specifically, a bonded fiber matrix and a wood fiber product with tackifiers. These exhibited excellent adhesive qualities under a variety of slope conditions and supported germination rates of 50-80%. In addition, a paper mill sludge was evaluated for its potential as a component of a hydroseeding slurry and as a protective mulch (both as a dry mulch and a "hydromulch") for established trees and shrubs (Jackpine, *Pinus banksiana*; White spruce, *Picea glauca*; Buffaloberry (soap berry), *Shepherdia argentia*; Dogwood, *Cornus stolonifera*; Acute willow, *Salix acutifolia*: Wild rose, *Rosa sp.*; Hawthorn, *Crataegus arnoldiana*).

The paper sludge was easily applied as a component of a hydroseeding slurry. It exhibited excellent erosion control properties and supported germination rates of 60-80%. In evaluating its performance as a protective mulch for established trees and shrubs, the results show that neither of the protective mulches (dry or hydromulch) had any apparent effect on the over-wintering success of the plants. Survival rates ranged from 94-100% in all treatments (with only one species, buffaloberry, at 88%). With regard to the effects of the treatments on plant quality, the plants that received the "hydromulch" treatment exhibited the best plant quality ratings. Five of the seven species benefited from the dry mulch treatment versus the control treatment, with only hawthorn and Jackpine not showing any apparent derived benefits.

Recommendations include: (1) utilizing commercially available hydroseeding products as a technique for revegetating drastically disturbed sites in Manitoba; (2) undertaking further research into the use of the paper mill sludge as a viable hydroseeding component; (3) utilizing the paper sludge, both as a dry mulch and "hydromulch" to provide protection for established trees and shrubs. and (4) further research into the use of the dry mulch to provide impetus for succession, based upon its apparent ability to support the establishment of pioneer and ruderal species in the trials.

Acknowledgments

I would like to thank Mr. Stan Kaczanowski for his support of this project and his patience throughout the process. This project originated with Stan and I sincerely hope that the results and final product met with his expectations. Thank you to Dr. John Sinclair for his guidance and advice as my faculty advisor. Thank you to my Practicum Committee, Dr. John Sinclair (Natural Resources Institute), Stan Kaczanowski (Provincial Forester. Province of Manitoba), Brian Bailey (Reclamation Specialist, Province of Manitoba) and Dr. Rod Bollman (University of Winnipeg) for their invaluable input and constructive criticism.

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Table of Contents

List of Tables

List of Figures

List of Photos

List of Appendices

Chapter 1: Introduction

1.0 Background and Study Rationale

During the extraction of natural resources such as timber and minerals, and in the development of infrastructure and mega projects, such as hydroelectric dams, areas of land are disturbed and in many cases remain so for extended periods of time. The definition of drastically disturbed land varies between cultures and between individuals within a culture. For the purpose of this project, land is considered to be drastically disturbed if the native vegetation and animal communities have been removed and the topsoil is lost or altered, exposing a biologically barren subsoil surface condition.

The lack of soil or growing medium makes it difficult, if not impossible, for revegetation and natural succession to take place. Therefore, the revegetation process may need to be aided by altering or enhancing the soil conditions so as to develop a new growth medium, and stimulating the natural revegetation of the site.

1.1 Drastically Disturbed Lands

The causes of drastic disturbance are varied with most being associated with activities related to settlements such as cities and towns and the supporting infrastructure. Activities such as construction, forestry and mining as well as the infrastructure that support these, such as roads and railways, pipelines, utilities, drainage ditches, dams and dikes, all lead to the drastic disturbance of land. These disturbed lands have social, environmental and economic implications associated with them. In forestry, a disturbance such as a road cut or borrow pit represents a loss of potentially productive timber land, in some cases lost recreational potential and a loss of wildlife habitat. In mining, tailings and spoils represent a particular challenge due to the potentially harsh condition associated with them. Properties such as extreme pH, lack of organic matter and the presence of heavy metals may leave a negative impact on the surrounding environment and make the process of revegetation difficult. In agriculture, drastically disturbed lands represent lost production potential, can result in the further loss of valuable soil through erosion, may lead to the contamination of adjacent water bodies by fertilizers and pesticides by allowing run-off to occur, and may result in the invasion of the site and adjacent land by undesirable plants.

The revegetation of drastically disturbed lands begins to address the environmental, economic and social issues that are associated with them. Revegetated lands are aesthetically pleasing, can support recreational activities, can provide wildlife with habitat, will lead to a reduced negative impact on the environment and can have a positive economic impact by becoming productive again.

However, in the absence of remedial measures, the revegetation of such lands through natural succession may be unacceptably slow. Therefore, it may be necessary to encourage revegetation and natural succession by providing either a growing medium or the conditions to support the revegetation processes that are to be accelerated, thus reducing the duration and impact of the negative consequences associated with these sites.

Photo 1.1 shows some of the harsh conditions that can be found on drastically disturbed lands. In this case, the site is a sand and gravel extraction site located south of the town of Birds Hill, Manitoba. Photo 1.2 provides more examples of the conditions that may be present at many exhausted sand and gravel pits. The lack of vegetation and the presence of high slope gradients can result in excess erosion. The lack of revegetation is also aesthetically displeasing.

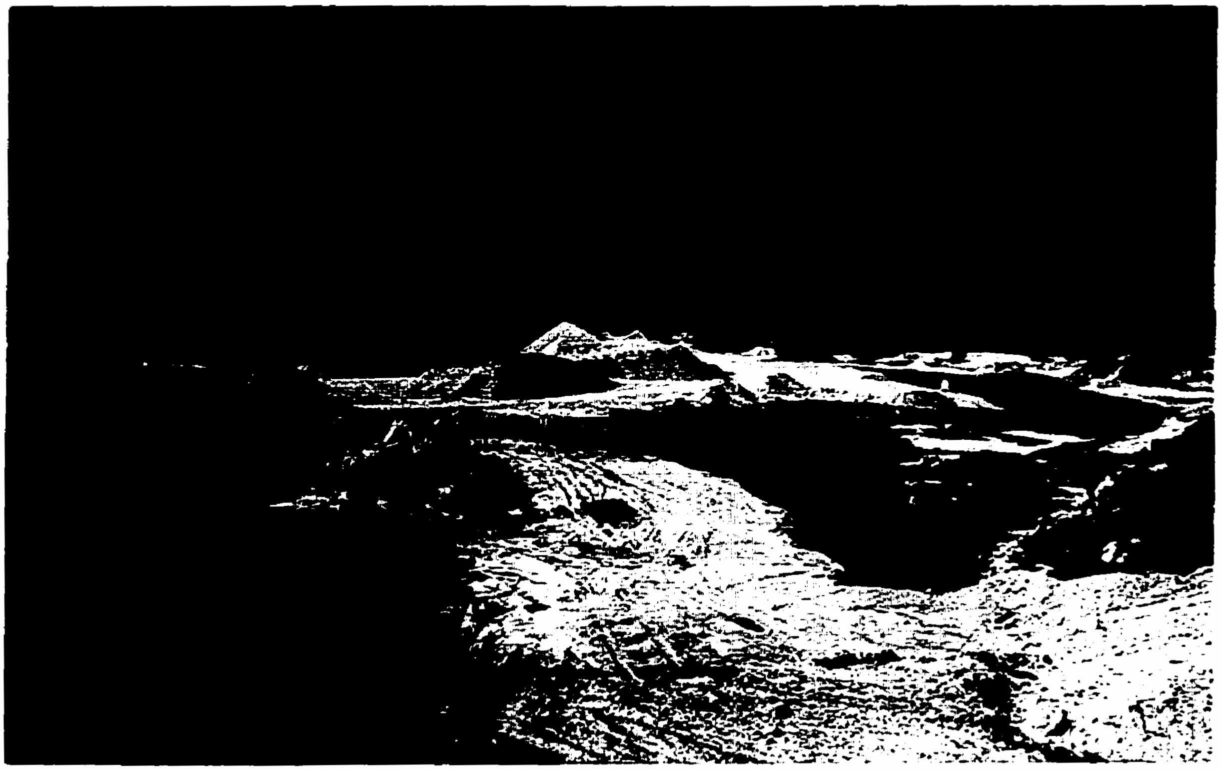


Photo 1.1: An example of a drastically disturbed land: A sand and gravel extraction site located south of Birds Hill town, Manitoba.

Photo 1.2: An example of site conditions present at many sand and gravel pits. A lack of vegetation and high slope gradients result in excess erosion. The lack of revegetation can have a negative impact on the environment and is aesthetically displeasing.

1.2 The Manitoba Model Forest Program

This project originated with the Manitoba Model Forest Program (MMF), which identified drastically disturbed lands, such as sand and gravel pits, as sites that require revegetation in order to provide for the sustainable use of forest resources (Kaczanowski pers. comm. 1996). The location of the MMF appears in Figure 1.1. The Manitoba Model Forest Program (MMF) is mandated to develop forest management practices that will lead to the sustainable use of forest resources. Specifically, the objectives of the MMF Program are:

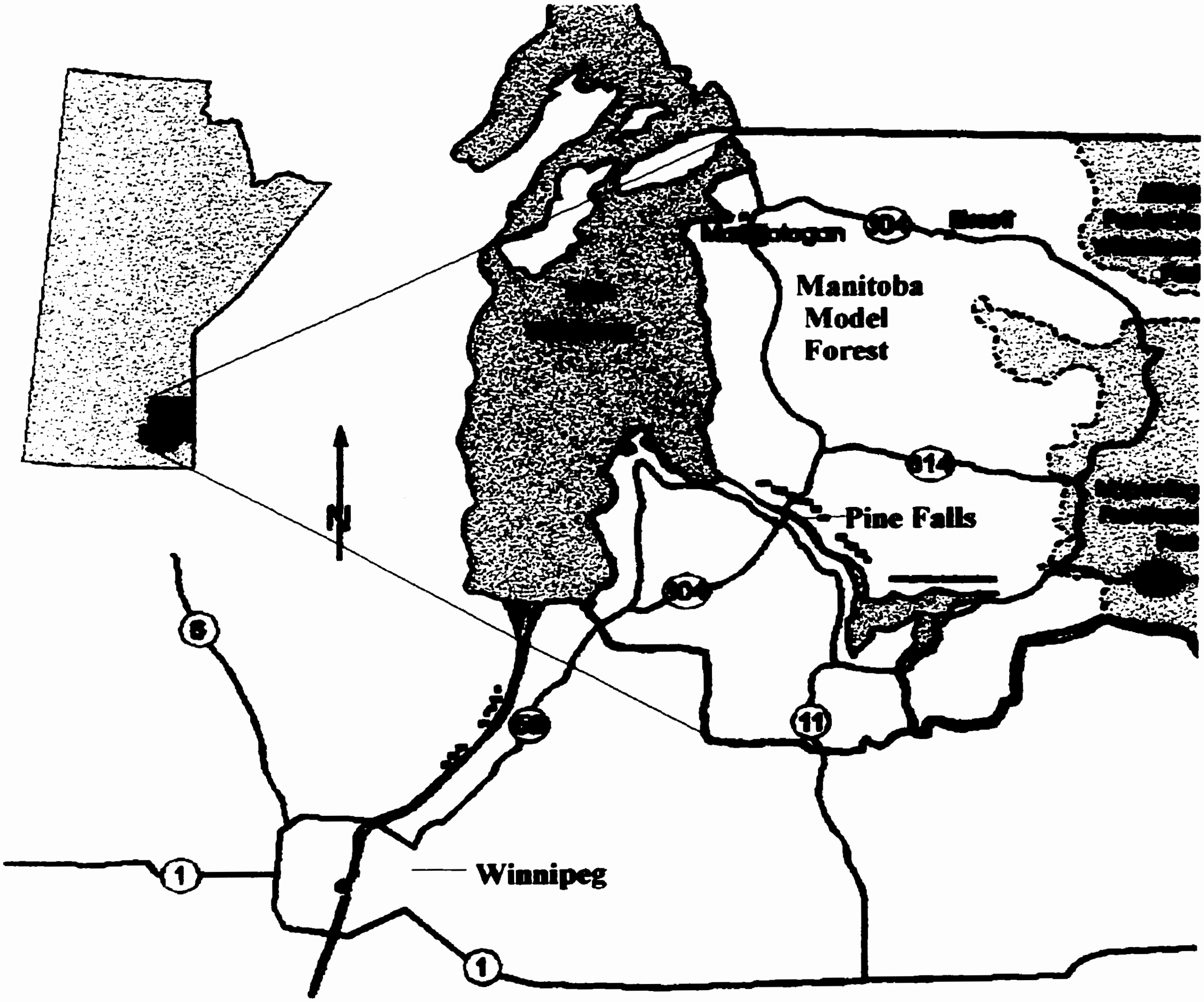
1. To accelerate the implementation of sustainable development in the practice of forestry;
2. To apply new and innovative approaches, procedures, techniques and concepts in the management of forests; and
3. To test and demonstrate the best forestry practices utilizing the most advanced technology and forest practices available.

(Canadian Forestry Service 1996)

This project begins to address the need to revegetate drastically disturbed lands within the MMF. It falls within the mandate of the MMF as it tests and demonstrates new and innovative techniques and approaches that may aid in the sustainable development of forest resources. In addition, the methods that are identified can be applied to the sustainable development and management of other resources, and to other sectors. The findings of this practicum may also be applied to the revegetation of drastically disturbed lands outside of the MMF.

Figure 1.1 Location of the Manitoba Model Forest Area

Location of the Manitoba Model Forest (MMF)



1.3 Purpose

The purpose of this study is to identify and evaluate revegetation strategies and techniques which may serve to "kick start" plant succession on drastically disturbed lands within the MMF region.

1.4 Objectives

The objectives of this study are:

(1) To identify and review the revegetation strategies and techniques currently being used by various agencies;

(2) To assess the identified revegetation strategies and techniques for use in Manitoba:

(3) To evaluate the chosen revegetation strategies and techniques through field trials;

(4) To make recommendations for the revegetation of drastically disturbed lands based upon the review of strategies and techniques, and the results of field studies; and

(5) To develop guidelines for "post-study" monitoring and analysis of field studies.

1.5 Methodology

To meet the objectives of this practicum the following methodological steps were taken:

- Review of revegetation strategies and techniques available:
- Selection of strategies and/or techniques for field evaluation;
- Selection of sites for field trials:
- Evaluation of strategies and techniques through field trials: and
- Analysis and discussion of data.

These are detailed in Chapter 3 of the Practicum.

1.6 Organization of this Practicum

This Practicum is organized into five Chapters. Chapter One outlines the practicum's purpose and objectives, and provides a general overview of the methodology employed to address the purpose and meet the objectives. Chapter Two provides a review of revegetation approaches used, and the strategies and techniques that are used in those approaches. Chapter Three details the methodology used to meet the objectives and to evaluate the strategies and techniques selected for evaluation by field trials. Chapter Four provides a discussion and analysis of the field trial data. Chapter Five provides conclusions of this practicum highlighting specific recommendations for the Manitoba Model Forest Program to consider. The Bibliography and Appendices follow.

Chapter 2: The Revegetation of Disturbed Sites

2.0 Preface

This chapter will review the literature related to the revegetation of drastically disturbed lands. It begins with an overview of the approaches and principles applied in the revegetation of such lands, then details the considerations related to those processes. A review of best management practices of sites is included, an overview of using native versus non-native plant species is provided, and descriptions of soil amendments and the associated advantages and disadvantages of each are provided. The document refers to the practices of other jurisdictions and to relevant case studies. Examples from Manitoba of revegetation practices are lacking. The compilation of a list of potential techniques and methods for consideration was the first step taken to meet the purpose and objectives of this practicum. The chapter summary distills the findings of the literature reviewed.

2.1 Introduction

As a first step, the review of literature was used to set out the principles that are involved in the revegetation of drastically disturbed sites. This project focused on sites that lack any topsoil or other organic material, therefore the methods and techniques used to promote revegetation under in such conditions were of most interest.

Revegetating lands involves soil conservation when possible, soil development when required, the amendment of existing soils, erosion control methods, reforestation approaches, horticultural and agricultural practices, the use of native and non-native plant species. biological inputs on occasion and the practices of bioengineering. The practice of revegetation combines these disciplines and approaches, as the situation requires.

2.2 Background

The process of revegetation involves speeding up or bypassing the natural process of invasion by pioneering plant species (Coppin and Styles 1995). The speed with which natural succession takes place depends upon the hostility of the site or degree of stress of the existing ground surface (Coppin and Styles 1995). Therefore, in revegetating drastically disturbed lands it is important to establish a vegetative cover as quickly as possible to provide erosion control for the short term, which can then support the development of a viable soil that in turn, can support a viable plant community for the long term.

A number of obstacles are associated with the revegetation of drastically disturbed lands. The site may be characterized by extreme slopes and associated high erosive forces. the pH of the soil may have been altered, and there may be heavy metals or other phytotoxins present. To overcome these obstacles, engineering techniques. agronomic principles and horticultural knowledge are applied. Horticultural and agricultural knowledge and techniques are employed in the development of a suitable growing medium. By applying this knowledge the soil characteristics required for optimal water-plant relationships can be put in place. As part of this process, the consideration of necessary soil amendments or nutrients also takes place. Here. both engineering principles and the appropriate agricultural principles dealing with soil, fertility and soil structure are utilized (Box 1978).

With the growing medium in place, the establishment of plants becomes the main focus of the revegetation effort and the application of agronomic and horticultural practices continues to be important. Seedbeds must be prepared, proper plant species must be selected, proper seed placement is required and the maintenance of these plants becomes of the utmost importance. After plants are established, it may be necessary to provide a monitoring and maintenance program to ensure the plants remain viable (Lowe 1979, Gerling 1996).

The application of what are known as bioengineering techniques is important when dealing with slope stabilization and erosion control. Bioengineering combines the use of plants and construction techniques in the control of erosion and when stabilizing slopes (Morgan and Rickson 1995). Sites that are particularly difficult to restore usually require the implementation of such approaches.

In all situations, the obstacles associated with the revegetation of these sites will require the application of available technology and the development of new methods and techniques through research (Box 1978).

2.3 Choosing a Revegetation Approach

Coppin and Stiles (1995) suggest that there are a combination of factors that affect the choice of approach to the establishment and management of vegetation. Ecological and environmental factors and constraints should be reconciled with functional requirements (Coppin and Styles 1995). Prior to the selection of vegetation for a site, a basic choice has to be made between two approaches:

1. Modifying the site or environmental conditions to suit the desired vegetation. This is the most appropriate when the situation requires a specific type of vegetation, or when money is no object.

Or

2. Selecting appropriate species to suit the prevailing site and environmental conditions (Coppin and Styles 1995). This choice is dependent upon the nature of any constraints due to site conditions and the extent to which there is provision to modify them, and on the flexibility of the desired vegetation and the functions it will be required to perform (Coppin and Styles 1995).

Some site conditions can be readily modified, such as fertility of the soil, while others are difficult if not impossible to modify, such as climate. In general, the main rule is "the less you modify the site conditions to suit the vegetation, the less management you will require, and the more you can utilize natural processes of vegetation development" (Coppin and Styles 1995). Therefore, a balance has to be struck between these approaches and in practice a combination is usually adopted (Coppin and Styles 1995).

Other considerations are also important, such as amenity, end use for the site, or the resources available for long-term management of the vegetation. In addition, the resources needed and available for each step in the revegetation process: design-establishment-aftercare-management, have to be understood and allowed for so that the vegetation can fulfill the required function in the long term (Coppin and Styles 1995).

2.4 Replanting vs. Natural Succession

Approaches to revegetation include natural succession, which entails leaving a site to natural processes for the re-establishment of plants and an eventually viable plant community, versus replanting, which involves the re-establishment of plants with human intervention. The lack of soil or organic matter on many disturbed sites is a difficult, hostile environment and places many constraints on the natural re-establishment process. As a result, approaches to deal with these difficult conditions have been developed.

When revegetating through replanting, two steps are common; establishment and maintenance. Coppin and Stiles (1995) define establishment "as a process that involves obtaining a vegetative cover using seeding and planting techniques". It includes a period of aftercare to fully establish the vegetation and may on occasion take an extended period of time. The process of maintenance requires periodic inputs and management in order to maintain vegetation in a required form and to prevent unwanted effects occurring (Coppin and Stiles 1995). The difference between replanting and natural succession is that establishment and maintenance are synonymous with replanting, and are absent in the latter approach.

Hardy (1989) describes the process of revegetation as a land management process rather than a "one- time" task. The process may involve obtaining suitable seed or plant materials, determining plant nutrient requirements, planting in stages as often as is required and finally, monitoring success and on-going maintenance.

Natural succession involves a sequence of developing plants from first colonizers of bare ground, through a series of stages, until a stable natural vegetation or climax is reached (Coppin and Stiles 1995). An example of a successional series appears in Figure 2.1. In the example, quick-establishing mobile pioneer species colonize the bare ground, stabilizing the soil and providing nutrients and organic matter through decomposition. Then the ruderal community develops, usually a herbaceous, grass dominated community. Webster's Dictionary (1965) defines a ruderal species as being "a weedy and commonly introduced plant growing where the natural vegetation cover has been interrupted (usually by man)". These species provide further stability to the soil and act as nutrient sources by fixing nitrogen and eventually decomposing. The development of a basic organic layer provides for the establishment of a more complex plant community with time. However, the rate and the direction that succession takes is dependent upon a number of environmental factors, particularly climate, and the availability of propagules like seeds or plant fragments (the importance of topsoil as a source of such material is discussed later in this document). Although sites that have been left to revegetate without human intervention will eventually do so, the time required for succession to take place can be quite long. Sites characterized by harsh climates, like those located in northern Manitoba, have been known to fail to regenerate even after 25 years (Carter 1995). Photo 2.1 provides an example of succession taking place in a borrow pit located within the MMF area.

Replanting of disturbed sites usually involves the establishment of a "nurse crop" such as grasses and legumes as a first step, the latter types because of their ability to fix nitrogen. Then, the planting of herbaceous plants or even trees may take place. The selection of plants is important for long term viability of a plant community and as such the surrounding plant community can serve as a source of information in this process. Identifying the pioneer species of a locale may result in greater success in the replanting effort (Shay pers. comm. 1996; Punter pers. comm. 1996).

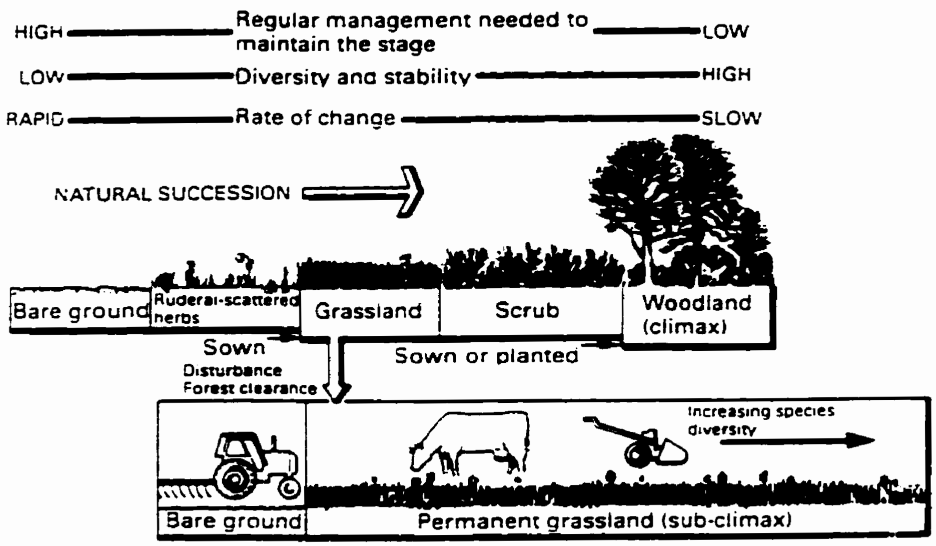


Figure 2.1: Natural succession in plant communities of temperate European climates (Coppin and Stiles 1995).

Photo 2.1: An example of the re-establishment of plants in a sand borrow pit within the MMF. Plants such as Equisetum sp., Salix sp. *and Red Osier dogwood begin the successional process here.*

Natural revegetation processes are known to work on small disturbances. Gerling *et al.* (1996) cite examples of such processes where Poplar species sucker onto reclaimed areas with time, and conifers seed naturally through water and wind dispersal - on sites that are less than two hundred meters wide. Placing slash over a disturbed site is another method used to provide for a natural source of seed.

2.5 Potential Land End Uses

The primary goal of revegetation projects is to return the disturbed site to a form of land use that is most appropriate for the location (Green *et al.* 1992). In some instances it is only logical to revegetate a disturbed site with the surrounding land use in mind. For example, a drastically disturbed site located in an agricultural area should be revegetated so that it has minimal impact on the surrounding agricultural land with the possibility that in the future it might once again become productive land. When disturbed lands are located in a productive forest they should be revegetated with the surrounding ecosystem in mind or to provide for timber production, or both. Simply put, the end use for a site should be based upon an analysis of the site and the desired long term goals for the local area (Box 1978; Green *et al.* 1992; Gerling 1996). The most appropriate revegetation process required to achieve the desired end use is then implemented. The specific end use is restricted by factors such as local climatic conditions, the remoteness of the location and the costs associated with installation and maintenance.

There are a variety of potential end uses, each with its own specific site preparation requirements including appropriate slope gradients, contouring preferences and plant species requirements. Possible end uses include agriculture, forestry, wildlife habitat, fish habitat, recreational use, and residential and industrial use. For example, to revegetate a drastically disturbed land so that it may act as wildlife habitat, it is recommended that as great a diversity of physical features be provided as possible. In this way the site can support a greater overall biodiversity. Figure 2.2 illustrates the optimal physical features recommended to increase biodiversity.

Both the desired end use and the amount of time that is available for the site to revegetate influence the method of revegetation to be used. For example, if the desired end use for a site is for timber production, it may be necessary to provide inputs on sites lacking topsoil as the natural revegetation process may take too long to make the site economically viable. In addition, there may be a desire to establish an economically viable species on the site where one did not previously exist (for example, softwood trees for pulp production). On sites where soil is lacking and a specific plant species is desired, it may be necessary to either enhance the development of a new soil, amend the soil material that is present, or provide some form of protection for the plants. By taking such an approach, natural succession of the site can be accelerated, or the desired plants can establish quickly and thrive. For situations like this a number of input options are available. Fertilizers can be added, mulches can be provided to protect trees and nurse crops may be established to begin the development of a new soil (Lowe 1979, Green *et al.* 1992, Gerling 1996).

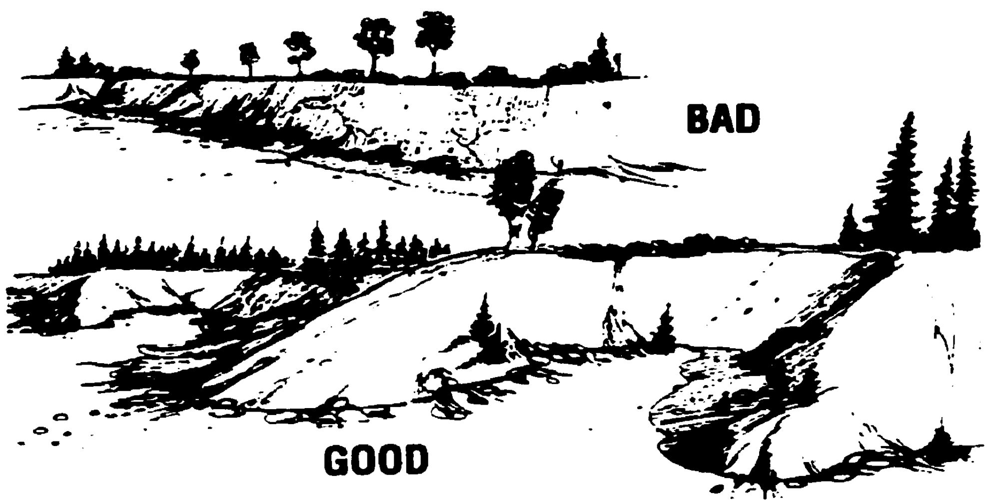


Figure 2.2: For the development of wildlife habitat, sites characterized by irregularly shaped edges and irregular contours are preferred over those with straight edges and regular contours (Green *et al.* 1992).

2.6 The Importance of Soil and Overburden

The importance of soils in the successful development of a viable plant community has long been recognized. Aristotle described soil as being the "stomach of plants" (Wilde 1958). The properties of soil, its organic content, physical and chemical characteristics, all influence the success of any revegetation effort (Wilde 1958). The topsoil and/or overburden can provide (1) a growing medium for plants: and (2) an increase in the infiltration and reduction of runoff of water, thus reducing erosion (Box 1978).

Soil, through its chemical and physical characteristics, has the ability to store water and nutrients, to act as a buffering agent, to provide erosion control and to act a home for a multitude of organisms (Wilde 1958). The soil's organic matter is described as "a key attribute of soil quality" with its role being the primary source of, and temporary sink for, plant nutrients (Gregorich *et al.* 1994). It also plays a vital role in the soil structure development which influences porosity, water infiltration, and oxygen and carbon dioxide exchange (Fuller pers. comm. 1997). Wilde (1958) states that in forests, without organic materials present, the development of a viable plant community will be hampered and in fact may not take place.

The soil and overburden are also important as a source of seeds and "cuttings" from the original native vegetation (Box 1978). If this source is lost, it becomes that much more difficult to revegetate the area with native plant species.

Loss of the topsoil results in a loss of potential nutrients, poor moisture retention, and reduces the cation exchange capacity of the soil. The cation exchange capacity (CEC) refers to the amount of exchangeable cations that can be held by a given mass of soil. Even the effectiveness of fertilizers is lost with the loss of the CEC by the soil. A reduced CEC means that the soil is unable to bind nutrients resulting in a condition where the nutrients are unavailable for uptake by plants. The type and amount of soil clay and the amount of organic matter affect the total cation exchange capacity. Those soils with higher amounts of smectite clays versus kaolitic clays have a high CEC. Smectite clays come from the family of 2-to-1 silicon (Si) to Aluminum (Al) clay minerals with a high surface area and exchange capacity, while kaolitic clays have a 1-to-1 Si to Al ratio and lower exchange capacity (Singer and Munns 1996). Similarly, those soils that have large amounts of organic matter also have a higher CEC than do those with the same amounts and types of clays but less organic matter (Singer and Munns 1996).

So when soil is lost, the revegetation approach must provide the conditions and/or nutrients required for plant re-establishment that will in turn lead to the eventual redevelopment of a new soil capable of supporting plant growth. Without the development of a viable soil capable of retaining moisture, providing nutrients and resisting erosion, the efforts of revegetation may be futile.

2.7 Plant Selection:

The selection of appropriate species requires careful consideration (Coppin and Styles 1995). The selected strategy must combine short-term and long-term requirements, site limitations and management constraints. Coppin and Styles (1995) suggest two possible strategies:

1. Establish the ideal long-term vegetation as quickly as possible by introducing the desired 'sub-climax' or 'climax' species, with perhaps a proportion of pioneer species as a nurse crop. This strategy usually requires a large amount of management input to achieve it in a short time scale and to maintain it against possible successional changes.

2. Establish a pioneer community which has the required functional properties and which will develop into a suitable climax or subclimax by natural succession. Less management should be required, sufficient only to ensure succession in the desired direction. The introduction of further species may be appropriate to encourage succession in a required direction.

Whichever strategy is adopted, it is important to understand how the plant communities will behave in the long term (Coppin and Styles 1995). Coppin and Styles (1995) suggest that the best way to define what is likely to be the natural vegetation and succession is to examine what is grown locally. If the natural vegetation is unlikely to fulfill the functional or ecological requirements, then it may be necessary to utilize different vegetation (Coppin and Styles 1995).

2.8 Native versus Non-native Plants

It is generally believed that native species are better suited to local conditions and as a result they have less difficulty re-establishing themselves onto disturbed sites. This makes them more desirable for use in revegetation efforts (Gerling *et al* 1996). A number of non-native plant species have also played a major role in revegetation efforts, including in Manitoba, because they are extremely competitive, for example Crested Wheat Grass (Bailey pers. comm. 1997). However, Windsor (pers. comm. 1998) states that in many situations in northern Manitoba where non-native species have been used to replant sand and gravel pits, these plants do establish themselves quickly but they die out after approximately five years. In contrast, native species establish themselves slowly on these sites and eventually develop a viable plant community that is present even after fifteen years (Carter 1995). Carter (1995) evaluated revegetation efforts by Manitoba Hydro on borrow pits in northern Manitoba and concluded that the selection of native species ultimately contributed to the stability and resiliency of the plant community by encouraging natural successional stages.

Until recently, the emphasis on revegetating disturbed lands has been on the use of tame or introduced species rather than on the use of the original or indigenous species, native to the pre-disturbed site (Gerling *et al.* 1996, Pitz pers. comm. 1997). The introduced species, predominantly grasses, have been planted because their aggressive growth characteristics give good protection against erosion. However, it is now known that native plants are quite capable of the providing the same erosion prevention (Gerling *et al.* 1996).

Ducks Unlimited Canada (DUC) has determined that the best way to accomplish their revegetation objectives is through the use of native grasses, forbes and shrub species (DUC 1996). DUC has been actively involved in wildlife habitat restoration for over 50 years and their efforts include restoration of wetlands and uplands. They find that native species are adapted to the conditions of the prairies and as a result are virtually permanent, with no need to re-seed them after several years, a contrast to many of the introduced species used (DUC 1996, Wark pers. comm. 1996).

The use of introduced species has come with problems (Gerling *et al.* 1996). It has been found that species like Crested Wheat grass and Russian wild rye do not maintain the chemical quality of native soils and are in fact allelopathic (Wark pers. comm. 1996). Allelopathic plant species possess the ability to inhibit another species by using noxious or toxic chemicals to reduced or eliminate competition (Recklefs 1996). In other examples, areas planted or seeded with introduced species do not resemble the surrounding landscape and have been known to prevent the encroachment of the native species onto the disturbed site. In Alberta, sites disturbed pre-1940 and left unseeded and uncultivated have been found to revert to vegetation closely resembling that of the native communities surrounding them without inputs (Gerling *et al.* 1996).

In British Columbia, the use of native plants, domesticated native plants and introduced agronomic species are considered useful for revegetation (BC Environment 1997). Plant selection is considered an important aspect of the revegetation process and while the use of agronomic species is an established technique for erosion control, the use of native plants has been shown to have advantages. Native plants have been found to be well adapted to low nutrient conditions and it has been determined that their use has a reduced adverse effect on biodiversity. In BC, consideration of plant species includes a review of the site conditions and rehabilitation objectives. Attributes of the plant species' including its root form, reproductive system, growth form, timing and adaptability are all considered when making selections.

Ontario Natural Resources and Environment Departments have moved toward the use of native plant varieties. This is in recognition of the need to maintain the environmental integrity of ecosystems and to avoid potential problems associated with the introduction of non-native species (Browning pers. comm. 1996, 1997, Gewurz 1986, Kinvig pers. comm. 1996, 1997). In a study of the natural revegetation of old quarry faces in the Niagara Escarpment, Browning (1993) reports that native plant species were found to quickly re-colonize sand and gravel pits, with more than 50% ground cover achieved in two years. However, the Ministry of Natural Resources still recommends that steep slopes, susceptible to severe erosion, cannot be left for natural succession to take place and should be seeded as quickly as possible with a grass/legume mixture (Browning 1993). Here, both native and non-native species are utilized but the choice of ground cover must be made carefully. In Great Britain, Andrews and Kinsman (1990), and Gunn *et al.* (1992) consider the use of native plant species as central to any revegetation effort.

2.9 Site Preparation

Regardless of the approach chosen to re-establish vegetation on a disturbed site, it is important to properly prepare the location and to implement best management practices as required. The related activities should include a site clean-up, the implementation of drainage and erosion control measures, and grading and sloping. They should be conducted with consideration for a specific end use for the site.

2.9.1 Site Clean-up

Regardless of the type of disturbed site, whether it is a roadside or borrow pit. site clean-up involves the removal of all debris and garbage from the land including the removal of any structures or apparatus. For example, in pit and quarry operations, large stones or boulders can be stockpiled for sale to construction and landscape contractors, can be buried beneath backfill or overburden, or used in the sloping and grading process as fill material.

The control of undesirable plant species is also an important component of the site clean-up, especially when the disturbed site is adjacent to agricultural land or residential areas. If the soil is contaminated, it may impede plant growth and must be remediated or considered for removal.

2.9.2 Grading and Contouring

Grading and contouring (resloping) is dependent upon a number of factors: regulations and guidelines, environmental impact considerations, local topography and desired end use. From a revegetation point of view, the objective of resloping is twofold: (1) to minimize potential erosion at the decommissioned site, and (2) prepare the site for a specific end use. The desired slope gradient may be extremely difficult to achieve and therefore expensive. In some situations, the local topography, natural gradient, or property boundaries may make it impossible to slope to the desired grade. Figure 2.3

illustrates various slope gradients. Even when sites are properly sloped and graded the erosive power of water may not be reduced, as illustrated in Photo 2.2. The deep rilling that is present is the result of water rushing uncontrollably down the slope.

Successful revegetation of a site usually requires a minimal slope gradient of 3:1 (Carter 1995). A steeper slope than this is known to result in the movement of surface materials and the subsequent "shearing off" of a plant's micro-roots, making re-establishment of plants difficult (D. Windsor, as cited by Carter 1995).

Sites characterized by compacted soil or surface material may require scarification both before and after the replacement of the organic materials. It is at this point that soil amendments and fertilizers may be added to the original materials to help provide an optimal growing medium.

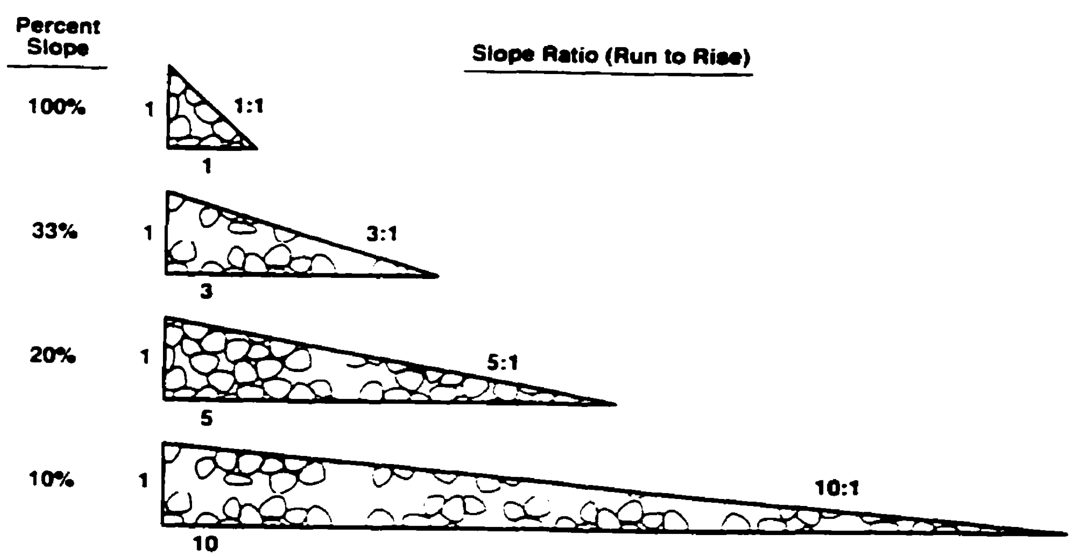


Figure 2.3: Slopes are expressed as the ratio of the horizontal run to the vertical rise (Green *et al.* 1992).

Photo 2.2: Even on sites with gentle slopes of better than a 3:1 gradient, rilling and surface erosion can take place. This makes the re-vegetation effort very difficult.

2.9.3 Site Drainage

Erosion is a serious threat to successful revegetation efforts. The risk of erosion can be reduced by providing proper site drainage and erosion control measures. Simple practices such as the proper orientation of caterpillar cleats can aid in the control of damaging erosion (Figure 2.4). Photograph 2.3 illustrates poor erosion control practices as the cleats are improperly oriented leading to excess erosion and in the siltation of the adjacent water body.

Drastically disturbed lands can be sources of silt and pollutants. For example, runoff from acid mine tailings is considered a major pollutant source in the mining industry and as such, prudent drainage control practices must be employed (Ripley *et al.* 1996). Sand and gravel pits that are to be closed either permanently or temporarily should also have the proper drainage and erosion controls in place (Green *et al.* 1992). Properly designed and installed controls can provide for adequate access to the remaining materials while mitigating the potential for siltation or pollution of any adjacent or nearby water bodies or lands.

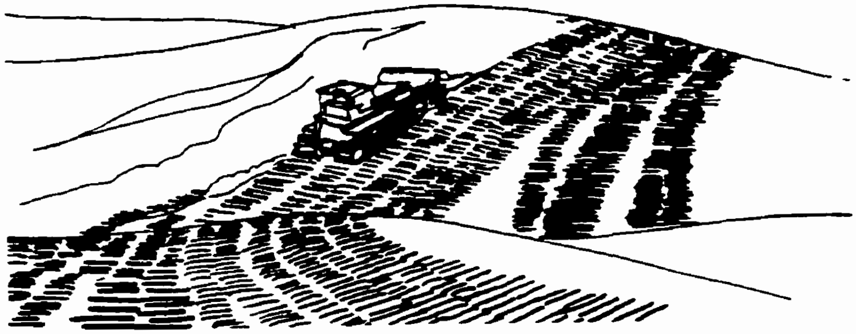
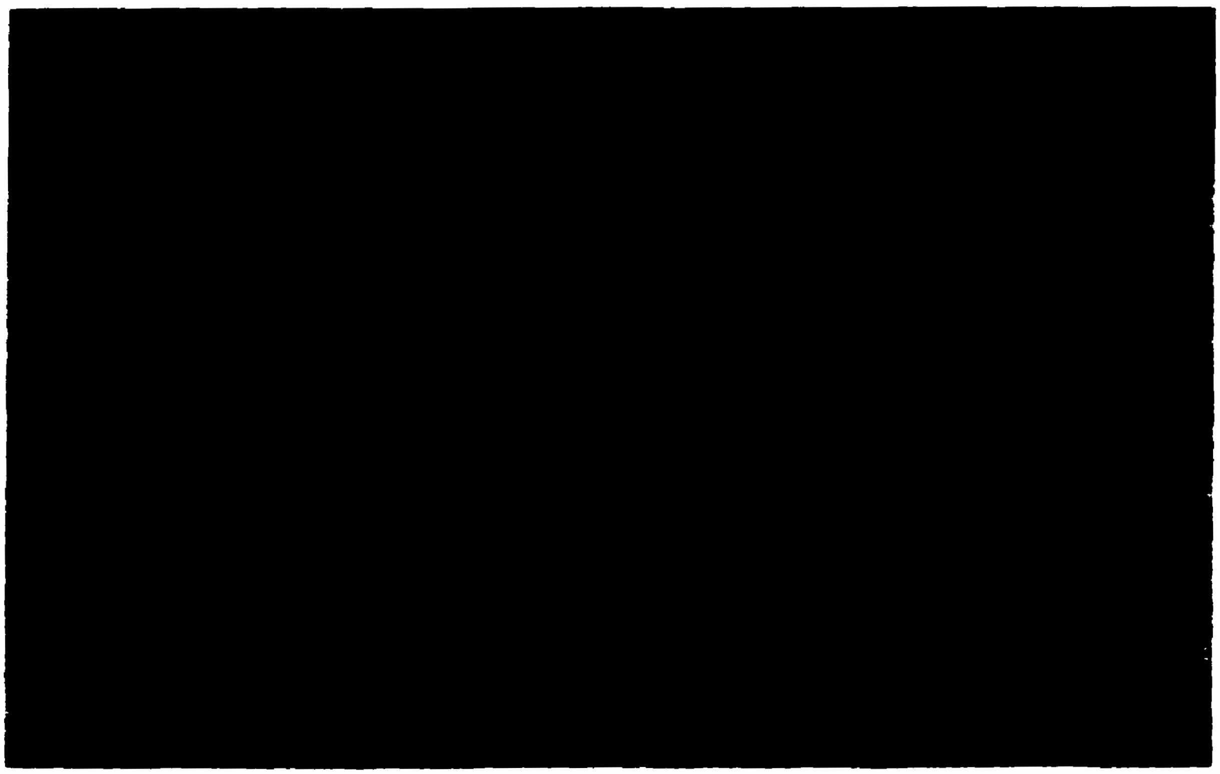


Figure 2.4: Soil erosion on slopes can be minimized by leaving cleat marks and ridges across the slope (Green *et al.* 1992).



Photograph 2.4 illustrates poor erosion control practices as the cleats are improperly orientation leading to excess erosion and in the siltation of the adjacent water body.

2.10 Soil Amelioration: Providing a Growing Medium

When a drastically disturbed land is characterized by a lack of topsoil or other organic matter, the revegetation process may require that some form of soil amelioration take place. A variety of materials have been identified and used as soil amendments, some more successfully than others.

2.10.1 Organic Amendments

The main role of organic amendments in the revegetation process is to assist in the reconstruction of a viable and self-sustaining soil system (Land Resources Network Ltd. (LRNL) 1993). The application of organic amendments serves not only to increase soil organic matter content to pre-disturbance levels for a given period of time, but ultimately serves to develop a quality soil-plant system that is equivalent to the surrounding undisturbed landscape. The amendment is a critical step in the restoration of the soil-plant system and natural cycles of the soil (LRNL 1993). In British Columbia, recommended organic materials for soil amendment include topsoil salvaged from nearby construction sites, manure, hay, straw, paper mill sludge and municipal compost (BC Environment 1997).

The importance of a developed organic layer in successful reforestation attempts can be seen along roadsides in Manitoba. Trees growing on land lacking organic matter are known to be significantly smaller in size and poorer in quality than those growing on land with even a minimal amount of organic matter (Kaczanowski pers. comm. 1996). Successful revegetation efforts are those that address the need for the redevelopment of a healthy and viable organic matter component.

A healthy soil is a living, breathing system with masses of organisms living in and depending on it, including microscopic bacteria, fungi and algae, to larger organisms such as nematodes and earthworms (LRNL 1993). Each organism has a role in the decomposition of dead animal and plant materials and in making nutrients available to plants. With the disturbance of soil at an extraction site come a number of other disturbances including the removal of vegetative cover and the stripping off of topsoil and overburden. As a result, the biological cycling of organic materials and plant materials from organic matter in the soil, into vegetation, and back into soil again, is disrupted. Even if rehabilitation of the site has taken place through the addition of soil and nutrients, and the establishment of plants, the soil organisms that are so important to the natural processes may be disrupted and this may have an adverse affect on both the physical and chemical properties of the soil (LRNL 1993).

Thus, the addition of appropriate soil amendments on the disturbed site can be considered a step to restoring a viable soil-plant system. Organic amendments may stimulate an increase in the soil organism populations. Some amendments, such as animal manure can act as an inoculation of new microbes which can "kick start" the nutrient cycling process. Once this takes place then the soil-plant system can begin to cycle organic materials and nutrients and ultimately produce and build up its own soil organic matter (LRNL 1993).

Organic materials that are used as soil amendments include:

- Animal manure
- Crop residues
- Peat
- Wood wastes

- Sewage sludge
- Compost
- Humates

The organic materials listed will be briefly reviewed, focusing on the benefits and drawbacks of the materials. and occasionally providing examples for their use in revegetation efforts.

2.10.1.1 Animal Manure

Benefits

- Manures can be a major source of nutrients, especially nitrogen, potassium and phosphorus;
- They are known to act as a slow release fertilizer;
- Manures are a good, temporary source of organic matter and increases the soil's organic matter content and stimulates biological activity;
- They can improve soil physical properties by increasing porosity, aggregate stability, water infiltration rates, increasing water holding capacity and by decreasing bulk density;
- Manure that has been composted is odour, insect and weed free and easy to handle.

The benefits of using manure as a soil amendment are not permanent. It is important that plants be established so as to maintain viable levels of organic matter. Plants will also add to the carbon supply of the soil.

Drawbacks

- There may be a loss of nitrogen through volatilization of NH4-N and runoff if manure is not incorporated into the soil soon after application.
- Salt may accumulate after years of application and may damage plants and soil structure.

- Manure can be a source of unpleasant odours, may attract insects and may be a source of weed seeds if not properly composted.
- Heavy metals may accumulate with years of heavy application;
- Manure may be a potential health pathogen:
- Manure may contaminate surface and ground water supplies especially with nitrates and phosphates.

Use for ***Revegetation***

Manure has been used to as a part of the revegetation process on many types of land disturbances. For example. the addition of manure to sand and gravel materials has resulted in more favourable pH conditions for seedling germination and root development, provided essential plant nutrients. and increased water content of the material when compared to fertilized controls (LRNL 1993).

When using manure as a soil amendment in revegetation, the following is recommended:

- Test the manure for nutrient content and potential problems such as high concentrations of salts, heavy metals and other contaminants;
- Use manure at rates that will meet nitrogen requirements as excess nitrogen can be leached;
- It should be incorporated into the soil as soon as possible after spreading to prevent odours, and to avoid nutrient loss through runoff and volatilization:
- It should be well incorporated into the soil and not applied in layers or left in piles;
- Manure should not be applied to ground that is covered by snow or frozen and subject to sudden runoff, such as a flood plain:
- It should be injected into the soil to avoid odour and insect problems: and
- Composted manure is a good choice for revegetation because it is odour, weed and insect free. and easy to transport and handle. If composted manure is not available, then non-composted but well rotted manure is a better choice.

2.10.1.2 Crop Residues

Crop residues include:

- turning under green manures;
- growing forages with or without other crops in rotation: and
- incorporating straw.

The objective of these practices is to increase and help maintain organic matter and nutrient content in the soil and improve the soil's physical characteristics.

Green manuring involves incorporating fresh, undecomposed plant material into the soil by plowing under a growing crop (LRNL 1993). Both legumes and non-legumes are used. It is recommended that legumes be inoculated with the appropriate *Rhizobium* bacteria prior to seeding for optimal growth and nitrogen fixation ability (LRNL 1993).

Forage crops include annual and perennial legumes and grasses. The inclusion of legumes provides for nitrogen fixation capability to the crop. The fibrous root system of grasses acts as a good soil stabilizer, essential for erosion control. This plant material is established as a permanent ground cover and provides for the development of a viable soil through the decomposition of its vegetative parts. Forages also act as animal feed as hay or pasture.

Straw can be incorporated into the soil, applied as a surface mulch or left as stubble. The straw of grains is used as a soil amendment. Straw acts as an erosion control and serves to increase soil organic matter.

General Benefits of Crop Residues

- Soil organic matter content can be increased;
- Soil physical properties can be improved, including infiltration rates, water holding capacity, aggregation and bulk density; and

- Soil erosion by wind and water can be controlled.

The benefits of a single crop residue are short lived and this technique is most effective when repeated at regular intervals.

Benefits of Green Manures (Biederbeck 1988 and Warman 1980 as cited in LRNL 1993).

- Increased available nitrogen, and therefore care must be given that additional fertilizer is not added in excess (Rowell 1978) :
- Improved microbiological activity and nutrient cycling;
- Reduced leaching of nutrients: and
- Increased yields of succeeding crops.

Drawbacks of Green Manures

- If legumes are not included as part of the crop a high carbon to nitrogen ratio may result in depressed nitrogen uptake by the succeeding crop;
- A poorly chosen green manure crop can deplete soil moisture in areas of low rainfall, with the result that succeeding crops may suffer from drought; and
- If legumes are used the seed is expensive, difficult to establish and results in a valuable feed crop, so that there may be some reluctance to turn the crop under.

Benefits of Straw (Brown *et al.* 1988, Norland and Vieth 1990 as cited in LRNL 1993).

As a mulch:

- Shading and moderation of temperature extremes;
- Conservation of soil moisture and decreased evaporation:
- Protection of soil from the sun, and from compaction by rain.

As stubble:

- Economic return from the grown crop:
- Protection of the soil and seedlings from wind erosion and excessive drying:
- Trapping of snow if stubble is left standing.

Drawbacks of Straw

Problems that can occur when using straw as a mulch (Brown *et al.* 1980 as cited in LRNL 1993):

- Difficulty of broad uniform application;
- Problems with harbouring weed seeds; and
- Difficulty of keeping mulch in place.

Disadvantage with the use of straw from annual crops (Brown *et al.* 1980 as cited in LRNL 1993):

- Competition with perennial seedlings;
- Persistence of plants if seeds are not harvested; and
- A succeeding crop may be necessary to prevent erosion in the winter months.

Benefits of Forages (Serecon Management Consulting Inc. 1992 as cited in LRNL 1993).

- Increased interception of precipitation;
- Increased trapping of snow:
- Increased nutrient recycling; and
- Break-up of soil compaction.

Drawbacks of Forages

There are few drawbacks to growing forages if they are appropriate for the location.

Use of Crop Residues in Revegetation

Forage production is a common end use for many rehabilitated areas. However, there is a lack of documentation on the effects of forage crops on soil properties. According to the Alberta Conservation Council publications, green manures are rarely used for rehabilitation. The integration of straw is practiced on well sites to break up compaction and improve water infiltration. Straw is also used as an erosion control measure on erosion prone sites.

A unique practice that uses crop residues in the revegetation of areas disturbed by mine activities involves what is known as "crimping". This process involves growing a cover crop for hay, then after harvest integrating the stubble, or "crimping" it into the soil using a dull disc. A variation on this approach involves laying straw over an area then integrating it into the soil with discs. The "volunteer" crop wheat or flax that germinates from seed from the straw can be mowed if it is competing with the native seedlings for light or water (Gerling *et al.* 1996). Crimping has been used in Alberta and in Manitoba (Pitz pers. comm. 1997).

In trials testing the effectiveness of soil amendments for revegetating strip-mine spoils in Illinois, Olsen and Jones (1989 as cited in LRNL 1993) incorporated crop residues and other organic amendments. They found that bulk densities were lower in the second year of treatments and organic matter was increased after two years. However, only manures were able to restore corn yields equivalent to the replaced topsoil treatment.

When using green manures it is important to establish the exact objective for using the crop residue amendment, before choosing the type of residue to use for revegetation (LRNL 1993). This approach can be useful in wind and water erosion control. increasing soil organic matter and nitrogen content and improving the soil's physical properties (Takyi *et al.* 1977; Rowell 1977, 1978, 1979; LRNL 1993).

2.10.1.3 Peat

Agriculture Canada defines peat as "unconsolidated soil material consisting largely of decomposed, or slightly decomposed, organic matter" (Agriculture Canada 1976). For the purposes of this document, peat includes what is commonly known as "peat moss" or "sphagnum peat moss" and originating from organic soils.

Benefits of Peat

- Peat improves physical conditions (tilth) of the soil;
- Peat increases the water holding capacity of the soil;
- Peat provides humus and acts a modest nutrient source; and
- Peat is longer lasting than other organic amendments.

Literature suggests that the greatest benefits are gained when peat is mixed into very sandy or heavy clay soils and the least benefits are gained with loam soils (LRNL 1993). The benefits of peat are not permanent, as it does not provide a permanent increase in soil organic matter.

Drawbacks of Peat

- Peat is a poor source of plant nutrients and high rates of fertilizer are recommended with its use (Rowell 1977, 1978, 1979; LRNL 1993);
- The acidity of peat may result in the need for liming;
- Micro nutrient deficiencies may characterize some soils;
- High rates may be required for benefits to be obvious; and
- Moist peat provides greater benefits than dry peat and is easier to handle.

Because peats decompose very slowly, they remain unaltered by soil organism for a long time. It therefore has minimal use for stimulating biological activity required for increasing nutrient cycling and availability.

Use of Peat in Revegetation

Peat is used regularly as an amendment for the revegetation of overburden from surface mining in the Athabaska Tar Sands near Fort McMurray with some success

(Takyi *et al.* 1977; Rowell 1977, 1978, 1979; LRNL 1993). The addition to overburden was shown to significantly increase the root penetration of grasses and legumes. There was also a noted increase in nutrient recycling associated with the addition of peat (Rowell 1978). In some situations using peat as a mulch rather than mixing it into the soil was found to be more effective for controlling water erosion and moderating soil temperature (Logan 1978, as cited by LRNL 1993). A rate of twenty five centimeters of peat to be mixed in, was recommended to improve the moisture retention capacity of the soil so as to ensure optimal plant growth and stabilize the tailing sand (Logan 1978, as cited by LRNL 1993). In a study in northern Minnesota (Norland *et al.* 1991, as cited by LRNL 1993) the use of peat as a soil amendment on iron ore tailings, found that as peat addition rates increased, pH decreased and total organic carbon, organic nitrogen, soil organic matter and extractable phosphorous concentrations increased. Total plant density was also found to increase. In Britain, Gunn *et al.* (1992) recommend that peat should be incorporated into quarry materials at a rate of five percent by volume (in the top fifteen centimeters) for best results when seeding.

Recommendations for the Use of Peat (From LNRL 1993)

- The pH of the peat to be used is critical. Lime requirements must be determined based on the pH of the peat to be used;
- The N mineralization rate of the proposed peat should be measured to determine if, and at what rates, nitrogen fertilizers should be added;
- Moist peat that has never dried is a more effective amendment than is air dried peat;
- Fertilizers containing both macro and micronutrients should be utilized when using peat to amend sandy soils;

- Mulching can be used to control water erosion and moderating soil temperatures. Incorporation is required for improving soil characteristics for plant growth: and
- Layering should be avoided so as to prevent the occurrence of vertical moisture movement.

2.10.1.4 Wood Waste

Wood waste includes a wide variety of by-products of the forest industry, including: sawdust, bark chips, and paper mill sludge. These wastes are generally disposed of by incineration and burning or landfilling, as in the case of sludge. Spreading wood waste sludges has been proposed and practiced as an alternative to landfilling, especially when mills are faced with ever increasing transportation costs and tipping fees. Sludges can provide some of the nutrient requirements of crops or general vegetative cover, with values of nitrogen of 5% and phosphorus of 0.5% being recorded (LRNL 1993, Canadian Forestry Service (CFS) 1994, Thacker and Macyk 1995). Dry wastes have also been used as a surface cover or mulch, or incorporated into the soil as a conditioner.

Paper mill sludge refers to the byproduct or waste materials resulting from the process of pulp production and/or as a result of either a primary waste treatment process or a primary and secondary waste treatment process. Paper mill sludges are also referred to as biosolids. In the MMF, the Pine Falls Paper Company (PFPC) mill produces a sludge as a result of its waste treatment plant. This material was being landfilled at the time of this project. In Kenora Ontario, the Abitibi paper mill plant also produces a sludge, which is also being landfilled.

In Ontario, Domtar Inc. has used paper mill sludges as soil amendments in orchards and tree plantations. Preliminary results show some benefit to the development of soil organic matter and other physical characteristics (Browning pers. comm. 1996, 1997). In Alberta, these materials have also shown to be beneficial as soil amendments, but may require the input of nitrogen fertilizers to be productive (Peel pers. comm. 1996, 1997). In British Columbia, experience has also shown that the use of paper mill sludge usually requires the addition of a fertilizer due to the high C:N ratio characteristic of this material (BC Environment 1997).

The use of the sludge as a soil amendment for rehabilitating disturbed sites such a borrow pits, is believed to be preferable to that of the practice of landfilling (Kaczanowski pers. comm. 1996).

Thacker and Macyk (1995) found that grass yields increased significantly as the rate of paper mill sludge increased. They found that at rates of thickness of three and five centimeters, dry matter yields increased by a factor of two for early season harvests (June) and a factor of three and five for late season harvest (August). Sludge was added in a uniform thickness then rototilled into the soil before grass was then planted. Macyk has consistently demonstrated that sludges from paper mills can be landspread and can be beneficial to both soil quality and plant growth. Field tests have shown that crop yield increases from 20 to 100 percent as a result of sludge application (Alberta Research Council 1997). In another study, Vogel and Rothwell (1988, as cited by LNRL 1993) found that the formation of endomycorrhizae in plants was increased by all rates of paper mill sludge when compared to lime fertilizer treatment. The extensive mycelium of the endomycorrhizae allowed for an increased ability of the host plant to absorb nutrients.

In a joint research project between Domtar Specialty Fine Papers and the Ontario Ministry of Natural Resources, varying amounts of paper mill sludge were applied to experimental plots. The purpose of the project was to determine whether or not the paper mill sludge would be beneficial to plant growth and/or act as a soil amendment. The material was integrated into the soil by discing and poplar tree seedlings were then planted. Initial results indicated that the higher amounts of paper sludge seem to benefit the seedlings as evident by better rates of growth (Browning pers. comm. 1996, 1997).

In a plot study in Wyoming, it was found that the highest rates of wood waste produced the greatest plant response (Belden *et al.* 1990. Moore *et al.* 1991 and Smith *et al.* 1985, 1986, as cited by LNRL 1993). The results were attributed to an increase in water infiltration and storage and leaching of salts from the root zone.

Benefits of Wood Waste

- Increased moisture retention;
- Increased aeration;
- Better tilth;
- Reduced erosion;
- Hindered weed emergence;
- Reduced evaporation; and
- Retain warmth if the soil is not excessively wet.

As mulch. wood wastes are easier to apply, longer lasting and less susceptible to blowing and fire than straw or leaves. The benefits of wood wastes are not permanent and do not provide a permanent increase in soil matter therefore it is important to establish plants for the maintenance of soil organic matter and eventual development of a viable soil system.

Drawbacks of Wood Waste

Disadvantages of using sawdust and bark as mulches and conditioners (Bollen and Glennie 1961 as cited by LNRL 1993):

- Competition with plants for available nitrogen;
- Retention of excess moisture;
- Retardation of temperature increases following cold periods;
- Decreased pH if material is strongly fermented;
- Packing of fine material; and
- Objectionable features like slivers and dust.

Wood wastes, such as sawdust and bark, are slow to decompose. As a result they remain unaltered by soil organisms for a long time. Therefore, they are not useful for stimulating biological activity or increasing nutrient cycling availability. However, they do provide some positive effects on the physical aspects of soil.

Disadvantages of using paper mill sludge as mulches and conditioners.

- Competition with plants for available nitrogen:
- Retention of excess moisture:
- Retardation of temperature increases following cold periods;
- Decreased pH if material is strongly fermented;
- Inconsistent fiber length necessary for use as hydroseeding component;
- Packing of fine material;
- Availability; and
- Associated hauling distance and costs.

Although paper mill sludges have been shown to be beneficial in promoting nutrient recycling and biological activity in soils (Thacker and Macyk 1995) there are concerns regarding the possible heavy metal content of these waste products (Jonasson pers. comm. 1996, 1997). In addition, the potential presence of dioxins is a concern, not only from mills producing bleached paper products, but those recycling newsprint and other paper (Browning pers. comm. 1996, 1997). Careful analysis of the sludge must be done when considering it for landspreading (Jonasson pers. comm. 1996, 1997; Browning pers. comm. 1996, 1997).

Use of Wood Waste in Revegetation

Sawdust and Bark

The use of wood wastes such as sawdust and bark has taken place in many rehabilitation projects. Mine spoils that have been amended with such materials have shown an improvement in water infiltration and storage, salts are more easily leached and plants exhibited increased productivity (Beldon *et al.* 1990, as cited by LNRL 1993). Studies also found that high rates of wood waste (90 or 135 Mg/ha) may be required for long term improvement of soil and enhancement of plant growth (Belden *et al.* 1990, Moore *et al.* 1991 and Smith *et al.* 1985, 1986, as cited by LNRL 1993). Voores *et al.* (1987) found that fall application of wood waste was more beneficial to plant growth than spring applications (LNRL 1993).

Recommendations for Using Wood Wastes (all types) (Modified from LRNL 1993)

- Five to thirteen kilograms of nitrogen, applied in split treatments, should be supplied per tonne of wood waste. This is sufficient to prevent nitrogen immobilization and reduce the risk of groundwater contamination.
- Most studies indicate that the higher the rate of application of wood wastes the better the result. However, optimal rates and frequencies of application will be

dependent on amounts of nitrogen fertilizer required, and the purpose of the amendment.

2.10.1.5 Sewage Sludge

The City of Winnipeg uses sewage sludge as a soil amendment for agricultural soils as part of its *Wingro* Program. The amount of material and frequency of its application are closely monitored by the City of Winnipeg's Waste Management Division in cooperation with the University of Manitoba's Soil Science Department. The application of this material has been shown to be beneficial as long as its use is limited. The greatest concern associated with the use of sewage sludge relates to the potential for the accumulation of heavy metals. Frequent application of the material has been known to result in the accumulation of heavy metals (Permute pers. comm. 1993; Racz pers. comm. 1995; Reuter 1997). Research into the use of sewage sludge in the rehabilitation of mine spoils has found that the productivity of such soils has been improved, when compared to other treatments (Reuter 1997). When used on borrow pits the ameliorative effects of the sewage sludge include increased vegetative growth, increased fertility, increased organic matter, decreased bulk density and increased available water capacity (LNRL 1993).

Benefits of Sewage Sludge (Adapted from Alberta Environment 1984, as cited in LRNL 1993)

- Increased crop production;
- Reduction in fertilizer costs;
- Recycling of nutrients;

- Soil conditioning: and
- Simple disposal of municipal waste.

As with many other amendments, the benefits of sewage sludge are short lived and it is important for plants to be established as soon as possible to begin the development of a viable soil and nutrient recycling.

Drawbacks of Sewage Sludge (Alberta Environment, as cited by LNRL 1993)

- Potential health hazards unless sterilized or incorporated immediately;
- Potential adverse effects on soil and groundwater if guidelines are not carefully followed;
- Potential for undesirable odours and aesthetic problems near populated areas;
- Some land cropping restrictions;
- Availability; and
- Associated hauling distance and costs.

2.10.1.6 Municipal and Yard Compost

Composting involves the process of controlled aerobic decomposition of solid waste materials, in this case yard wastes such as leaves. The utilization of this material in Manitoba is restricted to its limited availability. Literature on the use of composted materials for the rehabilitation of disturbed sites in Manitoba is limited. However, the compost that the City of Winnipeg produces through its "Leaf It With Us" initiative is used as a soil additive because of its apparent nutrient content, and organic matter content, especially useful in the clay rich soils of the Red River Valley.

Benefits of Compost

- Increased organic matter content of the soil;

- Improved soil structure, increased porosity and decreased bulk density;
- Increased water holding capacity:
- Increased infiltration and permeability of heavy soils;
- Reduced water losses and leaching in sandy soils;
- Increased action exchange capacity and buffering capacity of soils; and
- Control or suppression of some plant pathogens.

Drawbacks to adding compost to soils

- Possibilities of increased organic and heavy metal contamination:
- Slightly increased electrical conductivity of soils;
- Possible inhibition of seed germination with large additions of compost; and
- High C: N ratios that can immobilize soil nitrogen.

2.10.1.7 Humates

There are two types of commercial humates available, mined lignites and ammonium humate fertilizer. Mined lignites have been crushed and pulverized, have low water solubility and do not contain significant amounts of N, P or K. Ammonium humate fertilizer is soluble and contains available N, P, and K. Literature suggests that humates have little effect on plant growth and benefits to soil properties were minimal at best. Because of its poor performance in trials and its high cost, it is not recommended for use as a soil amendment in Alberta. In contrast, in the United States, the use of humates as a soil conditioner although not widespread, does take place. However, there is a lack of literature to documenting its possible benefits.

2.11 Fertilizers

The use of fertilizers is synonymous with revegetation efforts. The soil of drastically disturbed land is often characterized by low to non existent organic matter content resulting in a poor cation exchange capacity, an inability to retain moisture and nutrients, and a lack of a nutrient source. To aid in the establishment of new vegetation on such nutrient poor sites, the application of fertilizers is considered as a necessary component of the process.

Typically fertilizers are comprised of three "macro" nutrients; nitrogen, phosphorous and potassium. Each of these has a specific role in the development and maintenance of plants. Nitrogen's role is to provide the building blocks for the photosynthetic components of the plant. Potassium plays a role in a plant's ability to resistance diseases. Phosphorous is involved in root development and translocation system development.

When rehabilitating disturbed sites, the first goal is to establish vegetation as quickly as possible to provide for the stabilization of the soil, to aid in erosion resistance and to promote the development of a viable plant community which in turn will lead to the development of a viable soil. To this end, fertilizers that promote rapid root development and encourage increased photosynthetic capacity are used.

In addition to the nitrogen phosphorous and potassium, micronutrients are also important for the establishment of healthy plants and their maintenance. This group of elements includes sulfur, iron, zinc, boron and molybdenum. Any well-balanced fertilizer should include both the macronutrients and the micronutrients.

Benefits of Fertilizers

Fertilizers may be applied as either liquid or granular forms and are available in many formulations and as such, customized fertilization programs can be designed according to the specific requirements of a particular site. Fertilizers are also available in "organic" or natural form, such as bonemeal, bloodmeal or activated sewage sludge, or in synthetic forms such as urea or sulfur coated urea (SCU). Organic forms are generally more expensive due to limited availability, however their advantage is that they are very slow to release and as such will not as readily lead to the nitrification of water. Fertilizers can also be incorporated in revegetation efforts such as drill seeding or hydroseeding, thus saving money while providing required nutrients.

Drawbacks of Fertilizers

There is an added cost associated with fertilizing. Fertilizers can be bulky and difficult to transport and on slopes may simply runoff with rainfall or snow melt, possibly leading to contamination of waterways.

Use of Fertilizers in Revegetation

Fertilizing native plants is not recommended, as it seems to benefit competing weeds more than the intended plant. However, fertilizer is recognized as a requirement when using certain soil amendments to develop the organic matter in a soil. Amendments, such as paper mill sludges, should be supplemented with high nitrogen content fertilizers (Thacker and Macyk 1995). Even when planting trees and shrubs the use of fertilizer is not recommended as the seedlings' roots cannot make adequate use of it, and weedy vegetation will benefit instead (Lowe *et al.* 1992).

In a project in Great Britain aimed at reclaiming a quarry site and returning it to a "natural Daleside", Gunn *et al.* (1992) recommend applying fertilizers at a level of

60:100:10 kg per hectare NPK during the initial phase of grass establishment and as NP at a level of 50:50 kg per hectare in a series of after care treatments.

2.12 Biological Soil Inputs

2.12.1 Nitrogen-Fixing Bacteria

The ability to fix atmospheric nitrogen into usable forms such as ammonia and nitrates is essential for plant growth. Nitrogen is fixed in three ways: spontaneously by combustion, lightning and photochemical reactions; industrially, when making fertilizers, and: biologically, by nitrogen-fixing bacteria. The industrial production of nitrogen, which constitutes 25% of the fixed nitrogen, is extremely important, especially in the third world where population growth is high and food production needs are equally high. Microbial action accounts for 60% of the nitrogen fixed. Most nitrogen-fixing bacteria (Rhizobia) form symbiotic relationships with plants such as legumes, fungi, and liverworts. In this relationship the leguminous plants provide bacteria with carbohydrates and in return receive nitrogen compounds (Wilde 1958). Rhizobia bacteria can be purchased as inoculants in a variety of forms including powdered peat, granular, and liquid form, or as a frozen concentrate.

2.12.2 Mycorrhizal Inoculation

In the relationship involving mycorrhizal fungi, the mycelium of such fungi enters or envelops the plant's roots and at times may modify the tissues resulting in new "fungus-root" organs known as mycorrhiza (plural: mycorrhizae)(Wilde 1958). This alteration has physiological effects and permits the mutually beneficial exchange of soluble carbohydrates, nutrients, and even growth promoting substances between the higher and lower plants.

The practices of mine reclamation and sand and gravel pit rehabilitation have made use of mycorrhizal inocula to establish successful plant communities (Ripley 1996, Sturges 1997). The benefits of mycorrhizal inoculation have also been recognized by the forestry sector, where the inoculation of tree seedlings has become common place (Kaczanowski 1998). Mycorrhizae benefit the vegetation by increasing the plant's ability to survive in a nutrient poor and water deficient environment. Although mycorrhizae can occur naturally in undisturbed ecosystems, mined sites are chemically, physically and biologically altered and as such lack the mycorrhizal fungi population required to sustain a viable plant community.

Five types of mycorrhizae are recognized: ectomycorrhizae (ECM), vesicular-arbuscular mycorrhizae (VAM), and three others that are species restricted (Ericoid, Orchid, and ectendomycorrhizae). ECM are common to woody plants and characterized by a sheath of hyphae that surround the plant root. VAM penetrates the cell walls of the plant and forms arbuscules (used for nutrient transfer) and vesicles (recognized as sites of lipid storage) within the roots. VAM is host obligate, while ectomycorrhizae can exist without a plant host, but needs one to complete its life cycle. Both ECM and VAM can be found on mined sites, but VAM species have been found to colonize mine wastes more than ECM (Sturges 1997).

The dissemination of mycorrhizae can occur in several ways. Ungerminated spores can remain dormant in the soil for extended periods of time, thus avoiding unfavourable conditions. Water, wind or animals can disperse spores. Spores are also spread from infected roots to uninfected roots. Because sites of mineral or aggregate extraction are characteristically devoid of vegetative cover and therefore lack mycorrhizae, it may be difficult to establish a root system capable of stabilizing soil, maintaining moisture and obtaining nutrients.

Mining also affects many soil factors, such as pH, fertility, bulk density, and soil moisture, thus reducing the VAM propagules in the soil necessary for mycorrhizal dependent plants to thrive (Sturges 1997).

Sturges (1997) documents several benefits of mycorrhizae on mined lands. Mycorrhizal fungi act as providers and protectors for plants. For example, nitrogen, phosphorus, and potassium are usually deficient in mine soils and tailings, but their uptake by plants can be increased by the presence of mycorrhizae. The uptake of other essential nutrients such as calcium, magnesium, sulfur, iron, zinc, aluminum, and sodium have shown to be increased in the presence of mycorrhizal fungi. High concentrations of metals which can be harmful to plants (such as aluminum, arsenic, barium, boron, cadmium, copper, iron, lead, manganese, nickel, selenium, and zinc), can be filtered to tolerable levels by the fungi. Other noted benefits to plants include increasing plant hormones and acting as a barrier to plant pathogens. Mycorrhizae have also been found to alleviate the stress of higher surface temperatures and acidity that mined sites may have. Not only can mycorrhizae improve plant growth, but they can provide some resistance to drought and salinity as well.

In a study on an abandoned coal mine site in Palmer, Alaska local topsoil was used as a mycorrhizal inoculum and was to shown to improve the growth of balsam poplar and alder (Sturges 1997). In Pennsylvania, duel infections of bacterium and a mycorrhizal fungus resulted in increased vegetative success in coal wastes sites. Wilde (1958) states that some forest trees, such as black locust, also benefit from the nitrogen nutrition provided by *Rhizobia* and as such may require artificial inoculation for successful establishment. Wilde (1958) also documents increased vigor and growth rates of trees such as red pine when they are inoculated with mycorrhizal fungi. Other studies conclude that ectomycorrhizal development was essential for the establishment of seedlings of several tree species on mine spoils in Pennsylvania. Pine seedlings planted on acid mine spoils survived and grew better when inoculated with and ectomycorrhizal fungus. However, Vogel and Curtis (1978, as cited by Sturges) suggest that the best approach to encourage the revegetation of mine spoils may be to provide the most suitable habitat for the natural succession of soil fauna rather than artificially applying these organisms.

The use of mycorrhizal propagules have been proposed as a cost efficient long term technique to establish vegetation on mined land (Sturges 1997). Past revegetation efforts have used seed, typically grass and legumes, or transplants of woody species in conjunction with fertilization and irrigation. Lowe (1979), and Miller and Macintosh (1987) suggest that in order to provide a source of nitrogen for plant growth and development, seed mixes should include inoculated legumes. This has been found to be particularly successful on sandy, infertile sites. Finally, to determine which inoculum and technique would be best suited for possible applications, the resources, site and host specificity, environmental conditions and time commitment available need to be carefully reviewed and evaluated.

2.13 Establishment Aids

Plants being established on disturbed sites are subjected to very difficult conditions including temperature extremes, lack of shading, erosion by wind and water, and lack of moisture retention ability by the growing medium present. To deal with some of these harsh conditions a number of materials and approaches can be used to aid establishment. These materials are able to moderate temperatures, shade the sensitive stalks and root systems, provide erosion control and retain moisture.

2.13.1 Mulches

The use of mulching is recognized as an important tool in revegetation efforts and is considered essential for success in areas that are devoid of topsoil (Miller and Macintosh 1987). Mulches come in the form of bulk organic materials that are spread over the ground surface to protect seeds, encourage water infiltration and reduce erosion. They are also used to suppress weeds and improve soil moisture around planted stock (Coppin and Styles 1995, Schiechtl 1980). Materials used as mulch include straw, hay. compost, cellulose, wood chippings and other paper fiber material. Mulches are most commonly added mechanically after an area has been seeded or plants established.

This method is used both as an aid for establishing nursery stock and as an "after-establishment" aid (Marshall 1982, BC Environment 1997). It has been successfully used in the rehabilitation of disturbed sites in Ontario, particularly in orchards, because of the benefits it provides (OMNR 1987). In British Columbia, thick mulches include straw and hay, with a thickness of five to ten centimeters being recommended (BC Environment).

In Ontario, guidelines for the revegetation of roadsides suggest that mulches can be used to "improve the odds of successful revegetation by keeping seeds in place until germination can occur". In some situations, it may be necessary to scarify the pit surface to provide a suitable seed bed for germination. Mulches include straw, shredded paper, wood chips, matting and slash debris (OMNR 1987).

In Great Britain, Gunn *et al.* (1992) found that using a mulch rate of 4000 kg of peat per hectare for seed establishment provided the best results.

Advantages

By using machinery, large areas of land can be covered in a relatively short period of time.

Disadvantages

The site must be accessible by the machines that are used to spread the mulch and is therefore limited to slopes no steeper than 1 to 1.

Optimal Performance Characteristics of Mulches

Rate of decomposition: For revegetation projects using trees and shrubs it is important for the protective mulch to remain intact as long as possible. Therefore, any material should last at least two or three seasons so that the desired plants can become well established. If the material decomposes too quickly, encroachment by grasses and other less desirable plants would take place.

Erosion control ability: Protection from erosive forces is important for the establishment of plants. If the mulch itself is unable to resist erosive forces. then it cannot provide benefits to the plants being established.

Weed control performance: In some situations specific plant species are desired, such as commercially viable tree species. Here, it is important that the plants are established quickly to return the disturbed site to productive land as quickly as possible. In other circumstances, it is important that weeds be suppressed in favour of other more desirable plants, such as next to agricultural lands. And lastly, competition by weeds is known to reduce the successful establishment of desired plants (Lowe 1979. Miller and Macintosh 1987, Hilditch et al. 1988, Green et al. 1992, Gerling 1996. BC Environment 1997). It is therefore important that the mulch possess the ability to suppress weeds.

2.13.2 Geotextiles

Geotextiles are defined as permeable textiles used in conjunction with soil, foundation, rock, earth or any geotechnical engineering related material as an integral part of a man-made project (John 1987, as cited in Rickson 1995). They are designed for surface erosion control and come in the forms of three-dimensional erosion meshes. erosion blankets and mats, or honeycomb-shaped webs known as geocells. Occasionally, seed is incorporated into the material with this type of product being known as a seed mat.

Geotextiles are made with synthetic and natural materials and come in two types that are suitable as establishment aids:

1. woven meshes, with aperture sizes of five to fifteen millimeters, usually as jute or coir; and
2. mulch mats, consisting of a layer of chopped straw, shredded paper and or coir fiber ten to fifteen millimeters thick, retained between two layers of light string or plastic mesh (Rickson 1995).

These materials are laid over the prepared ground and pegged into place. Seed is then broadcast over the top of them to fall down within the material, preferably to the soil surface. The use of these mats requires moist, well-graded slopes. On gravel, an additional layer of binding material is usually recommended.

In British Columbia, geotextiles, also known as manufactured mulch mats, are used sparingly because of their high costs. The high cost of these materials also limits their use in Manitoba, however, they are suitable for use on very steep slopes where rapid erosion control is required (Pitz pers. comm. 1997).

Advantages

The mats are effective for a long time and are resistant to erosion.

Disadvantages

The cost of these materials is very high. Seed mats are recommended for use on well-graded sites.

2.14 Methods Used to Establish Vegetation

Although there many methods are used to re-establish vegetation, the goals of the revegetation effort remain constant and include: (1) erosion control, (2) establishment of a vegetative cover, and (3) the development of a viable soil that can support a viable plant community.

The use of a plant or collection of plants as an engineering material for slope stabilization and erosion control is known as bioengineering (Morgan and Rickson 1995). Vegetation provides a protective layer or buffer between the atmosphere and the soil (Styczen and Morgan 1995). Figure 2.5 summarizes the engineering role of vegetation. Bioengineering acknowledges that the use of vegetation can reduce the risk of failure of efforts to achieve slope stabilization and erosion control. General bioengineering tools and approaches include, but are not restricted to: soil amelioration, geotextiles, binders and glues, mulches, hydroseeding, seeding, sprigging and planting woody species in the form of bare root stock or as container grown stock. The bioengineering techniques outlined are the result of systematic refinement of traditional stabilization and erosion control methods that have evolved over a long time, in some cases over centuries (Coppin and Styles 1995). The techniques described include those listed above as well as live staking, brush or branch layering and live fascines.

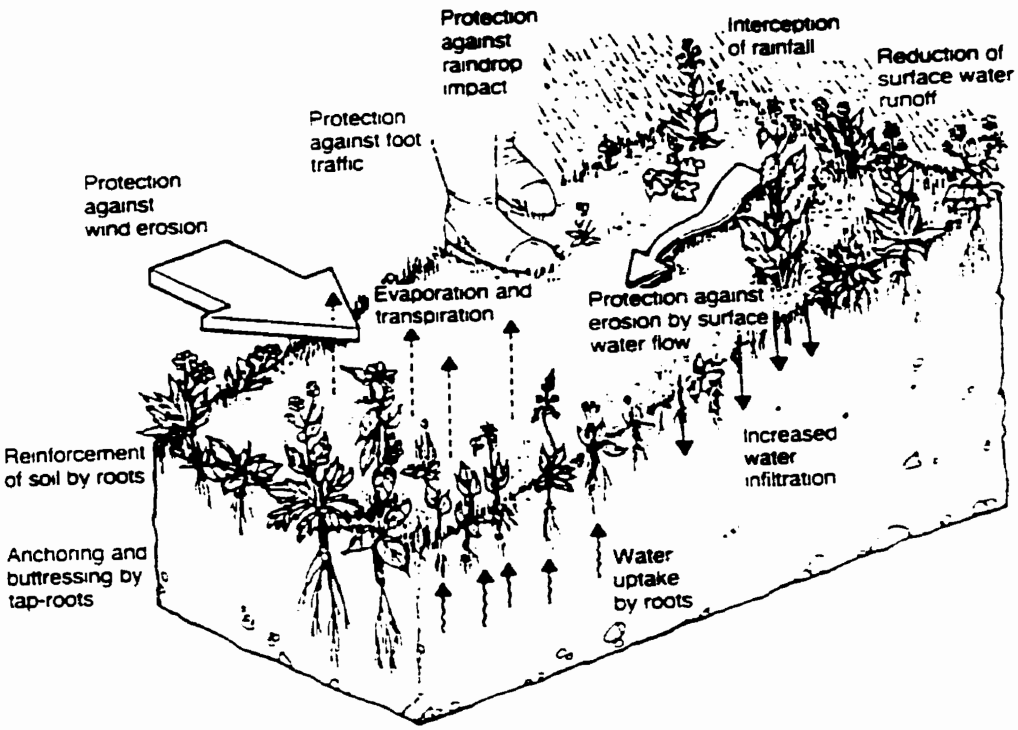


Figure 2.5: The engineering role of vegetation (Styczen and Morgan 1995 after Coppin and Styles 1990)

2.14.1 Broadcast Seeding

Broadcast seeding involves the application of seed by hand or with a broadcast spreader, in dry form over an area of existing material or over a prepared site. The requirements prior to seeding can vary from minimal grading and sloping to more involved activities such as scarification and/or the addition of soil amendments and/or topsoil.

Broadcast seeding is commonly used by Manitoba Department of Highways when revegetating roadsides and ditches (Pitz pers. comm. 1997). This technique is used by the British Columbia Ministry of Forestry to plant not only grasses and legumes, but also a variety of tree species as well (BC Environment 1995). In Alberta and Ontario it is recommended for establishing vegetation such as grasses and legumes as the first step in reducing erosion (Ontario Ministry of Natural Resources (OMNR) 1987. Miller and Macintosh 1987. Peel pers. comm. 1996). Timing of seeding is also important. with spring or early summer considered best. followed by seeding in mid-August to early September (Miller and Macintosh 1987).

Advantages

It is simple, fast and inexpensive *if* no topsoil is required.

Disadvantages

The applicability of broadcast seeding is greatly reduced in situations where there is an absence of cover material, such as soil, necessary to protect the seed against desiccation and/or erosion. This is particularly true of sites characterized by high slope gradients.

2.14.2 Drill Seeding

This refers to the mechanical installation of seed used by farmers for their crops. A tyne-like implement sets the seed at a predetermined depth in the growing medium, be it soil or sand. The application requires the use of a machine to pull the implement. Fertilizer can be integrated at the same time if so desired.

This is one of the most commonly used techniques to revegetate sand and gravel pits in Manitoba as well as other disturbed sites such as roadsides (Bailey pers. comm. 1996, Pitz pers. comm. 1997). It is considered an excellent method for controlling erosion and invasion by weeds. This technique is equally popular in other provinces (OMNR 1987, Miller and Macintosh 1987, BC Environment 1995, Peel pers. comm. 1996). Timing of seeding is again important, with spring or early summer considered best.

followed by seeding in mid-August to early September (Miller and Macintosh 1987). Photo 2.4 provides an example of drill seeding along the edge of a lake located in the center of an extraction site. The trees and shrubs were planted after the seeding was completed.

Advantages

If the growing medium is consistent, this can be a very effective way of seeding large areas quickly with a high rate of success.

Disadvantages

The requirement for machinery for installation limits the use of this method to sites characterized by gentle slopes, maximum 3:1. Successful germination depends upon proper depth of installation and good growing medium. It has a moderate to high cost associated.

*Photo 2.4: **An example of the results of drill seeding along the edge of a lake located in the center of an extraction site. The trees and shrubs were planted after the seeding was** completed.*

2.14.3 Hydroseeding

Hydroseeding is the mechanical application of seed and some form of "mulch" mixed into a slurry with water and sprayed under pressure onto a site (Coppin and Styles 1995, Schiechtl 1980, Myrowich pers. comm. 1996). The mulch component may take the form of straw, hay, cellulose, or other fibers such as recycled newsprint. Other constituents that may be added to the slurry include fertilizer and adhesives or tackifiers. The materials are mixed together along with an appropriate amount of water and applied using high-pressure spray systems by hose or through a "cannon" apparatus.

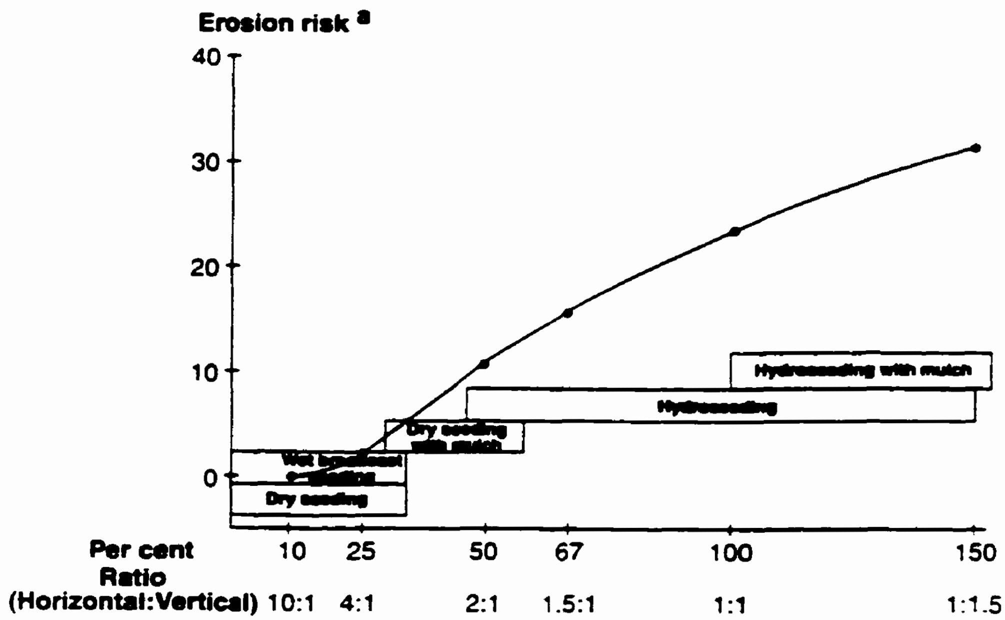
Hydroseeding is one of the most popular methods for re-establishing vegetation such as grasses and legumes. It is used specifically on steep slopes and areas that are susceptible to erosion as it provides rapid vegetative growth and establishment (Canmet Report 77-2, OMNR 1987. BC Environment 1995, Kinvig pers. comm. 1996, 1997, Myrowich pers. comm. 1996, Peel pers.. comm. 1996). It has been extremely popular in the United States and is considered an integral component of bioengineering approaches (Myrowich pers. comm. 1996). Legume and grass seeding, in conjunction with fertilization, is the recommended method for controlling erosion, with hydroseeding being the suggested method of application (BC Environment 1997). Figure 2.6 provides BC Environment's recommendations for the most suitable seeding technique based upon slope angles. Figure 2.7 provides a comparison of the relative costs and effectiveness of various seeding techniques (BC Environment).

Advantages

This method is extremely effective on steep slopes where other methods would be difficult and more expensive. It provides for rapid revegetation and is therefore effective as a form of erosion control.

Disadvantages

The site must be accessible to the hydroseeding equipment. The use of hoses limits the coverage to the length of the hose and the size of the pumping unit (its horsepower). The use of a "cannon" apparatus greatly reduces the range of coverage. down to approximately 20 meters in any direction (depending on the wind). Seeds applied in this way are subject to desiccation and as such require two or three waterings in the first 10 to 14 days after application in order to remain viable. This ensures a higher rate of seed germination. The requirement for irrigation limits the use of hydroseeding to areas where water is readily available or when timing of the applications can coincide with "wet" seasons to take advantage of precipitation. Hydroseeding is more expensive than standard seeding practices with prices being determined by the ingredients being incorporated.



[a] Based on the length-slope factor in the universal soil loss equation, representing relative soil loss per unit area for a 10-m slope of the same soil type.

Note: Mulch should be used on lower slope angles than shown when sites are subject to drought.

Figure 2.6: BC Environment's recommended seeding techniques for different slope angles (BC Environment 1997)

There are a number of critical properties or characteristics that a effective hydroseeding product must possess or display (Myrowich pers. comm. 1997). Therefore, the following criteria are used in the evaluation of hydroseeding materials:

- Germination Rate: The higher the rate of germination that a product can provide, the more effective it is, both economically and functionally. Germination rates for grasses and legumes of 60 - 70% are considered as acceptable with rates greater than

70% being considered exceptional (Weyerhaeuser 1996, Myrowich pers. comm. 1996).

- Viability of the product: A hydroseeding material must provide a stable substrate for as long a period of time as necessary so that seeds can become established (Weyerhaeuser 1996, Mid-Canada Hydroseeding 1996). It usually takes about six to eight weeks for grasses and legumes to become established and at least a growing season to acquire a sufficient 'foothold' to resist erosive forces. Therefore, the hydroseeding product must remain intact and viable for at least eight weeks, but preferably for at least the first growing season to ensure that plants are well established.

- Erosion Protection: Newly established grasses and legumes are vulnerable to erosion by wind and rain, especially on slopes. It is therefore important for the product to provide and maintain a durable matrix that conforms to the soil, also known as a "bonded system" so that erosive forces can be reduced (Mid-Canada Hydroseeding 1996).

- Ability to provide weed control: It is important for hydroseeding products to help in the establishment of desired plant species. To this end the mat formed by the product must provide some level of weed control in order to be successful.

- Rate of decomposition: As important as it is for the product applied to provide a stable substrate, it is equally important that the material not last so long that it begins to impede the propagation of plants. If newly formed seeds cannot germinate or establish themselves, or if propagation through shoots or runners cannot take place, then the material is not desirable. Therefore, the rate of decomposition of the material is important and more than two seasons of endurance would not be desirable as it would begin to impede the natural revegetation process desired.

Treatment	Effectiveness[a]		Relative Cost[b]
	Before	After	
Hand Broadcasting: seed, fertilizer	0	1-3	1
Wet broadcast seeding[b]	0	2-4	1
Hydroseeding: seed, fertilizer, binder[c]	1	4-6	1.5
Hydroseeding: seed, fertilizer, binder, wood fiber mulch at 1300 kg/ha[c]	2	5-7	2.5-3
Hydroseeding: seed, fertilizer, binder, wood fiber mulch at 2000kg/ha[d]	4	6-9	3-3.5
Hydroseeding: seed, fertilizer, binder, mats held with staples or pegs[e]	3	4-10	14-249

[a] Relative erosion control effectiveness rating after application before and after plant establishment; where 1 = minimal, 10 = excellent. Mulches and binders provide temporary erosion control benefits before plants are established.
[b] Cost relative to treatment by hand broadcasting.
[c] For helicopter seeding with 100-200 kg wood fiber mulch to aid application, relative cost is 3 to 3.5.
[d] Minimum mulch application rate for a true mulching effect to hold moisture and moderate temperature.
[e] Cost can vary considerably, depending on the specific mat product and site conditions; effectiveness rating assumes good mat contact with the ground surface.

Figure 2.7: Comparison of relative costs and effectiveness of various seeding techniques (BC Environment 1997).

2.14.4 Dry Mulch Seeding

This method is a variation on other seeding methods such as broadcast seeding. A heavy application of mulch is applied after seeding. Tackifiers or binders can be used to keep the material in place. Dry mulching is routinely used for tree and shrub seeding either after seeding or when using fine seeds, as a bed so as not to smother the seeds (Coppin and Styles 1995, Schiechtl 1980).

Advantages

This is an easy method of applying mulches, with the proper equipment. The mulch provides protection for the seeds against desiccation.

Disadvantages

Dry mulches are subject to wind and water erosion and may not perform well on slopes without tackifiers or binders, which increases the cost of the method.

2.14.5 Trees and Shrubs

The use of trees and shrubs is one of the most popular methods for re-establishing vegetation on disturbed sites. It is an approach that is usually part of a series of steps that work toward the development of a viable and self-sustaining plant community and usually follows the establishment of a ground cover of grasses and legumes (Marshall 1982, OMNR 1987). When the desired end use of an exhausted aggregate site is forestry, then trees can be planted directly into the existing materials using economically valuable species (Lowe 1979, Miller and Macintosh 1987, Hilditch *et al.* 1988, Green *et al.* 1992, Gerling 1996, BC Environment 1997). To ensure long term compatibility with the surrounding land uses, white spruce, Jackpine and Redpine have been planted (Miller and Macintosh 1987). If the desired end use is as wildlife habitat, then the use of shrubs in addition to trees is recommended (Lowe 1979, Miller and Macintosh 1987, Hilditch *et al.* 1988, Green *et al.* 1992, Gerling 1996, BC Environment 1997).

Trials conducted by Ontario Department of Natural Resources, aimed at increasing the biodiversity of revegetated pits, found that mixed plantings of native trees, shrubs and grasses (also known as "interplanting") can aid in weed control (Browning 1993). Plants, such as black locust, were found to provide competition control, wind protection and to increase soil nitrogen levels.

In Ontario, the recommended planting techniques for trees include hand planting and machine planting (Hilditch *et al.* 1988). Spring planting is found to be more successful than fall planting, but either is acceptable. The control of weeds and competing grass should take place for the first three or four years as part of a maintenance plan. A buffer zone of at least 0.5 meters from the stem is considered best. Fertilization of seedlings is not recommended before or during planting, as it seems to benefit weeds more than the desired plants. However, fertilization after four or five years of establishment is recommended, with a focus on meeting nutrient deficiencies (Lowe 1979, Miller and Macintosh 1987). Suitable shrubs for planting in Northern Ontario are found in Appendix 1.

Trees and shrubs used for revegetation are typically available in the following forms:

- Container grown stock;
- Plugs;
- Balled and burlapped (B&B); and
- Bare root stock.

2.14.5.1 Container Grown Stock

This refers to plants that have been grown in plastic or paper containers. These plants can be planted at any time of the year with little disturbance to the roots. The variety of plants is great with native species being readily available (Coppin and Styles 1995, Schiechtl 1980).

Advantages

The plants are subjected to a minimal amount of transplant shock as the entire soil ball within the container is installed. As long as the plants are irrigated regularly while in the container they can be stored indefinitely, or at least until "potbound" (this is the condition where the roots of the plant become confined by the size of the pot and begin to grow in a circle along the inside edge of the container). This form of plant material is convenient to transport.

Disadvantages

The size of the pot determines the size of the hole required to accommodate the plant's root ball. Therefore, in areas where digging is difficult, such as those characterized by heavy clays or large aggregate size, installation can be time consuming and labour intensive. The cost of plants grown by this method is high.

2.14.5.2 Plugs

This is a variation on container grown plants with seedlings raised in small containers or tubes. At present, this is the method of preference for replanting harvested areas in forestry and is known as silviculture. The most frequently used material are plugs in the form of either trees or shrubs grown in plastic trays for approximately two years (Schiechtl 1980).

In Alberta, it is recommended that tree plugs be at least two years old (Green *et al.* 1992, Gerling *et al.* 1996). In areas where grasses or forbes have previously been planted it may be necessary to use older trees or shrub plugs as it is known that the thick stand of grasses can out compete the small tree or shrub. Competition from grasses can be reduced through the use of native grass species and by seeding them at the lowest rate that is required to provide some erosion control. It is recommended that grass be kept at least 0.5 meters from tree stems to reduce competition (Green *et al.* 1992). However, it is recommended that grass seeding should be avoided when possible (Gerling *et al.* 1996).

Advantages

By using plugs there is little shock to the plant associated with transplanting and as a result, survival rates are high. Numerous tree species are available in this form. Installation is quick and easy with the potential for hundreds being planted in a day by one individual, depending upon terrain.

Disadvantages

The initial cost to grow plants in this form is high. The factor with the greatest affect on success rates is planting technique.

2.14.5.3 Balled and Burlapped (B&B)

Plants that come in this form are field grown then moved (transplanted) with the soil kept intact and around the roots as a root ball by using burlap as the container. On occasion the plant may be placed into a plastic or paper container for transport.

Advantages

The plant receives protection from the burlap and can therefore be maintained through irrigation and a mulch cover for extended periods of time. The plant should be a small enough size so as to minimize transplant shock and to provide for ease of planting.

Disadvantages

Because the plant is field grown, transplant shock does occur and removal of the specimen from its growing site can result in mechanical damage of the root system. The size of the hole must be large enough to accommodate the entire root ball to reduce transplant shock. Adequate irrigation is required after plant installation as the roots are susceptible to desiccation. Cost of this method of planting is high due to the initial cost of the product. It is also labour intensive and requires a greater amount of maintenance than other methods.

2.14.5.4 Bare Root Stock

Raising young plants in a nursery and transplanting them on site with bare roots is the most common method used for woody species (Coppin and Styles 1995). Plants are usually grown in a media such as a mulch or a soil-less mix, then, at the end of a growing season and when in dormancy, they are placed in cold storage until required the next spring. The timing and care of this type of plant material is important as the roots are subject to desiccation (Schiechtl 1980).

Advantages

Because of the small size of the plants installation is relatively simple and many plants can be installed in a day. The planting site does not require a great amount of disturbance to accommodate the small root system.

Disadvantages

The susceptibility of the roots to desiccation requires that care must be taken during transport and installation. If the roots are allowed to dry out at any point, even for a few minutes, damage to the plant can be extensive. Not all root systems are small and therefore installation of specific plant species may be labour intensive. The condition and composition of the planting medium directly affects the rate and quality of the installation. If heavy clays or large aggregate size characterize the site, then installation can be time consuming and labour intensive. Planting on slopes is difficult.

2.14.5.5 Cuttings

The use of this propagation method is restricted to those species that root freely from live wood. The cuttings can be used to produce bare-rooted plants, container grown or tube stock for planting on site, or can be planted directly on site to root *in situ* (Coppin and Styles 1995). Species such as willow and poplar are most widely planted by this method.

While the use of hardwood planting is becoming more widely accepted in British Columbia, the use of unrooted willow cuttings has had poor success (BC Environment

1997). However, the use of hardwood planting as pioneer species is recognized as a useful approach in rehabilitation efforts.

Advantages

The plants are easy to grow under the proper conditions and require little input. This is a very inexpensive way of propagating plants and cuttings can be kept in dormancy until needed.

Disadvantages

The variety of plants is somewhat limited to those that easily propagate from cuttings. A constant amount of moisture is required for successful establishment.

2.14.5.6 Live Staking

1/2 to 1 1/2 inches in diameter and 3 foot long live stakes are planted in the ground to a depth of 2-3 feet and in a triangular pattern with 2-3 feet of spacing. The stakes are either pounded into the ground or inserted into a hole created by a planting bar. Live staking requires access to vegetation that is suitable for live cut and transport techniques. This technique has been used to stabilize slopes along rivers (Bobrowski 1997).

Advantages

This technique is quick and easy, as holes do not need to be excavated to receive the plant material. Local materials that are suitable can keep the cost of materials and installation to a minimum.

Disadvantages

A project by the California Department of Parks and Recreation showed the susceptibility of live staking techniques to washout. Native willow stakes were planted along a riverbank with a 2:1 slope gradient. Unfortunately, large rainfall events caused loss of the stakes before root establishment took place, showing the importance of having proper knowledge of the local vegetation and the local climate conditions for the required establishment period (Bobrowski 1997).

2.14.5.7 Brush Layering

Brush layering involves the use of cuttings 1/2 to 11/2 inches in diameter and 2-5 feet long. These cuttings are laid in a trench and covered with soil so that they are approximately six to twelve inches below the surface. For successful application, it is recommended that a variety of plant species be used, along with an adequate amount of soil (Schiechtl 1980).

Advantages

The use of native plants in the form of cuttings makes this a desirable form of revegetation.

Disadvantages

This is a labour intensive method of revegetation and therefore may be expensive.

2.14.5.8 Live Fascines

Live fascines (also known as slope fascine or brush wattles) are used to mitigate shallow earth slides and gully erosion by increasing root area to positively affect shear slope strength (Schiechtl 1980). Trenches are dug perpendicular to the slope and bundles of plants are grown in them. This method was used successfully in a Northern Virginia project to stabilize earthen mounds along the meanders of a river. Slopes of 3:1 were stabilized using live vegetation cuttings of native willows (*Salix sp.*), red osier dogwood (*Cornus stolonifera*), elderberry (*Sambucus canadensis*), blueberry (*Vaccinium corymbosom*) and strawberry bush (*Eonymous americanus*) (Bobrowski 1997).

Advantages

This method has proven to be very effective in establishing vegetation on slopes prone to erosion.

Disadvantages

This is a labour intensive method of revegetation and therefore may be expensive.

2.14.5.9 Turves

Turves is plural for turf and is also known as sod (Webster 1965). Grass and herbaceous vegetation can be grown as turves for transplanting on site. Turves can be cut from natural ground or grown in "artificial" soils (Coppin and Styles 1995).

Advantages

This is a very quick method of establishing vegetation.

Disadvantages

This is a very expensive and labour intensive method.

2.15 Chapter Summary

The revegetation of drastically disturbed lands requires the application of a number of disciplines and specialties. Engineering, agronomics and horticulture are the main influences and a combined approach can lead to successful revegetation efforts.

Literature suggests that there are two basic approaches that can be taken in revegetating drastically disturbed sites devoid of topsoil or organic matter, they are:

1. Allow natural succession to take place. This entails the establishment of pioneer plant species on sites lacking any topsoil or organic matter. With time, stabilization of the soil by root systems reduces erosion, the development of a thin organic layer takes place a result of decomposition, which in turn will encourage establishment by other plants and eventually leads to a climax community

OR

2. Give plant succession a "kickstart". Provide inputs, to what ever degree is necessary based on the desired goal for the disturbed site. Inputs can be as simple as drill seeding with grasses and legumes, providing fertilizers to aid establishment, etc. Once a vegetative cover has been established, further inputs can then be made to encourage desired species to grow, such as pulp wood tree species or nature can be left alone to take its course.

The determining factors that influence the rate at which succession will proceed are climate and site conditions. Climate cannot be changed; however, some of the harsh conditions present may be mitigated. Soil amendments can be used to provide fertility or change the pH. Contaminants in the soil can be removed or the soil remediated. The severity of slopes can be reduced. erosion control devices can be used to prevent further loss of materials and enhance revegetative efforts. The degree of inputs is determined by economics, availability of resources, access to the site and societal and environmental significance of the disturbed site.

Successful revegetation efforts should include site clean up, and grading and contouring. The intended end use for the site should be identified as early in the extraction and/or development process as possible, then tailoring of the strategies and techniques to meet the intended goals should take place.

With a viable soil being absent, the revegetation approaches should begin with the addition of soil amendments such as fertilizers or manures to provide the conditions that are required to support plants. Establishment aids such as mulches and geotextiles can help plants become established. The technique of bioengineering, which integrates the use of plants with engineering approaches, is very common practice throughout the world. Revegetation techniques include hydroseeding, drill seeding and installing trees and/or shrubs as appropriate. Inoculating plants and/or soils with nitrogen fixing organisms or mycorrhizal fungi are other techniques that can aid in the establishment of plants on hostile sites.

When selecting plants, the use of native species is preferred over non-native species. Native plants have adapted to their ecozones and are more tolerant of adverse conditions than are non-native plants. This approach can also encourage the process of natural succession. Depending upon the desired goals of the revegetative effort, the maintenance of plants after the period of establishment is considered as a requirement of the process and not as an option.

In summary, when choosing the most appropriate approach to revegetate a drastically disturbed site, the process should consider, but not be limited to the following: (1) end use goal for the site, (2) timelines for the completion of the rehabilitation process, (3) identification of the necessary inputs and associated costs, (4) accessibility to the site, (5) availability of appropriate materials, including plants, ameliorants etc., and (6) long term maintenance requirements and costs.

The choice of the approach, that is whether to allow natural succession to take place without inputs or whether to intervene and provide inputs to "kickstart" the successional process, can be more easily made when the points above have been thoroughly considered.

Chapter 3: Methodology

3.0 Preface

The nature of this practicum was such that it required a field component to achieve the majority of the objectives. The first phase of the practicum, the review of literature, appears in the previous chapter. This chapter borrows from the literature reviewed to identify appropriate techniques and methods for evaluating the techniques chosen for field trials, and to identify the appropriate criteria to evaluate the performance of the techniques. The methodology for this project required that: suitable sites for the trials be identified, appropriate plot design take place, products be identified for consideration and evaluation, suitable plant materials be selected, and methods and criteria be developed to evaluate the physical performance of the plants in response to the treatments applied. These needs were met by using the findings of the literature review, and with input from ecologists and revegetation practitioners as well as the Practicum Committee. The needs of the MMF Program were also considered during the process.

3.1 Selection of Strategies and Techniques for Field Trials

The first step selecting the strategies and techniques for evaluation by experimental field trials was to compile a list of techniques that had been or were currently being practiced in revegetating disturbed lands. This list was compiled in consideration of the literature reviewed including case studies, and through consultations with individuals involved in the revegetation of drastically disturbed sites. To narrow the list of possible techniques being considered, a set of criteria were identified for use in the selection process. These criteria were used to assess the techniques for their applicability in Manitoba and to provide practical considerations. The criteria were as follows:

(1) Installation cost of the technique;
(2) Post installation maintenance requirements and costs (short term);
(3) The ability of any plants and/or products being considered to cope with Manitoba (prairie) climatic conditions; and
(4) The sustainability of the strategy or technique, specifically: source reliability, compatibility with future uses and long term maintenance requirements and costs.

As a result of applying the described criteria above, the following techniques were selected for field evaluation:

1. Hydroseeding technique and associated products; and
2. Evaluation of a paper mill sludge as a protective mulch for established plant material.

Hydroseeding was selected for the following reasons:

1. It was relatively inexpensive (approximately $.50 - $1.50 per square foot depending on inputs such as tackifiers, fertilizers and seed mixtures);
2. Post installation inputs and costs were minimal (watering may be required);
3. It has been successfully used in a variety of climatic conditions, from desert to alpine, as well as in other Prairie Provinces and northern climates. It is recommended for use on sites characterized by extreme slopes and gradients.
4. It provides flexibility in that a variety of seed materials can be used, including commercial (non-native) and native seed mixes, and even seeds of tree species;
5. Product sources are extensive, and the use of paper mill biosolids would promote the reuse of waste materials; and
6. Long term maintenance inputs and costs are negligible.

The paper mill sludge as protective mulches for tree and shrub plantings was selected because:

1. The cost of installing seedlings can be relatively low, depending upon planting conditions;
2. Planting of seedlings usually takes place in the spring or fall to take advantage of precipitation patterns, therefore post installation inputs and costs are low. Once the mulch is applied, it does not require any future inputs;
3. Plants that are native and therefore climatized, can be used: and
4. A source of paper mill sludge was available and would be remain so for the foreseeable future.

3.2 Site Selection for Field Trials

It was decided from the outset of the project that field trials should take place at appropriate borrow pits within the MMF. In this way the techniques could be evaluated for use in Manitoba and the MMF area and under the conditions of the prairie climate.

The criteria used to select the sites were:

- The sand or gravel pit, or area within the pit to be used for the trials, had been sloped and grading and as per the policies and guidelines of the Province of Manitoba, Department of Energy and Mines.
- There was little or no topsoil or organic matter present; and
- Little or no revegetative growth had taken place on the field trial area of the site.

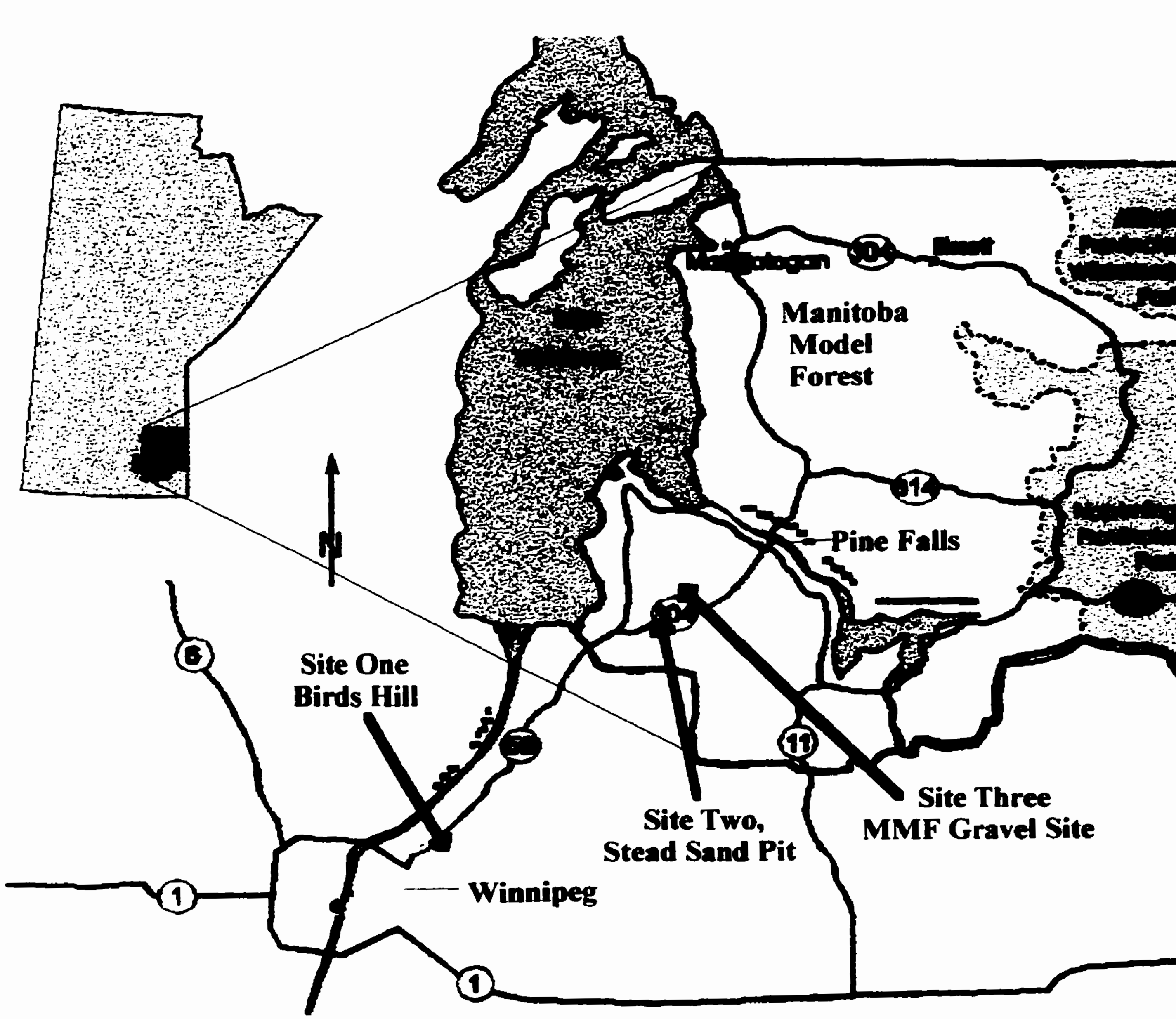
To meet the needs of the MMF the majority of the trials were to take place within the boundaries of the MMF, with at least one site selected that would not be open to public access. Crown Lands are open to public access and as such the experimental plots would be vulnerable to vandalism, which if occurred, would result in the loss of important data and time.

With this in mind and with input from Mr. Stan Kaczanowski, Regional Forester, Manitoba Natural Resources and MMF representative, and Mr. Brian Bailey, Rehabilitation Specialist, Manitoba Energy and Mines, and the application of the criteria listed above, the following four sites were selected as locations for field trials:

- Site 1: Birds Hill
- Site 2: Stead Sand Pit
- Site 3: MMF Gravel Site
- Site 4: Blumenort Site.

The location of the sites appears in Figure 3.1, Locations of Field Trials.

Figure 3.1: Locations of Field Trials



3.3 Description of the Field Evaluation Sites

The four sites that were identified by the selection criteria process were:

(1) Site 1: Birds Hill, Site 2: Stead Sand Pit, Site 3: MMF Gravel Site, and Site 4: Blumenort Site.

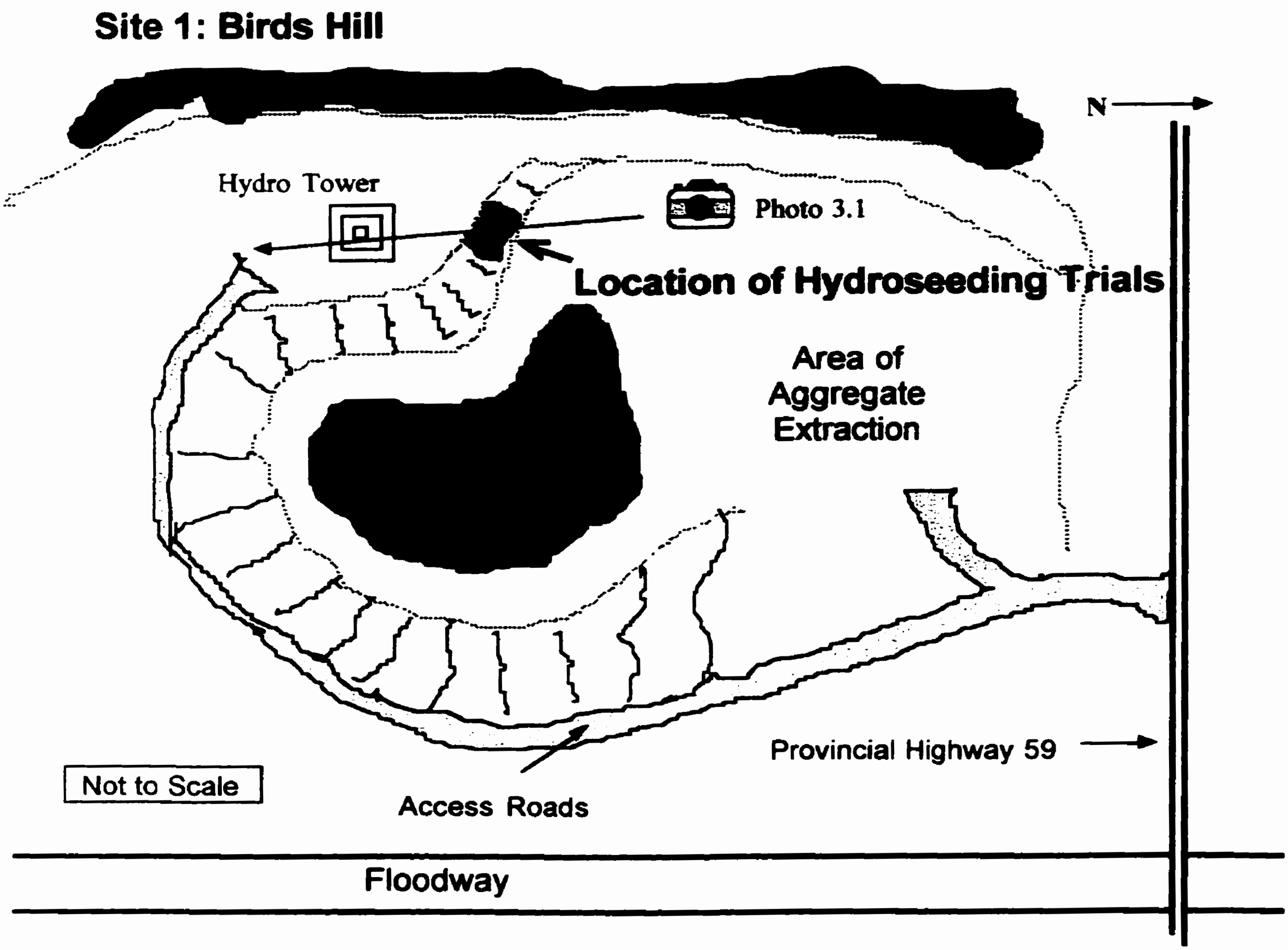
Site 4, the Blumenort Site was abandoned in July of 1996 because of severe erosion and loss of plants during a mid-summer storm. Data collected was limited and inconclusive. The decision to abandon the site was supported by the Practicum Committee.

Site 1: Birds Hill:

This gravel extraction pit is located on the southwest side of the Provincial Highway No. 59-Red River floodway bridge. This site has been in existence for more than 20 years (Bailey pers. comm. 1996). The portion of the site that was used is north facing and characterized by a mix of clay and silt materials, a slope of 1:1, and severe rilling. The material present is very coarse being composed of gravel from one to ten centimeters in diameter, with many field stones dispersed through out. Due to the extremely difficult growing conditions little or no revegetation has taken place on the site. See Photograph 3.1 and Site diagram, Figure 3.2.

Photo 3.1: Site 1, Birds Hill. (Photo: June 1997) The area that was treated (on May 17th, 1996) is from the base of the hydro structure, down the slope approximately 10 meters (30 feet), approximately 10 meters (30 feet) wide and appears as a faint tan patch.

Figure 3.2: Site 1, Birds Hill Diagram

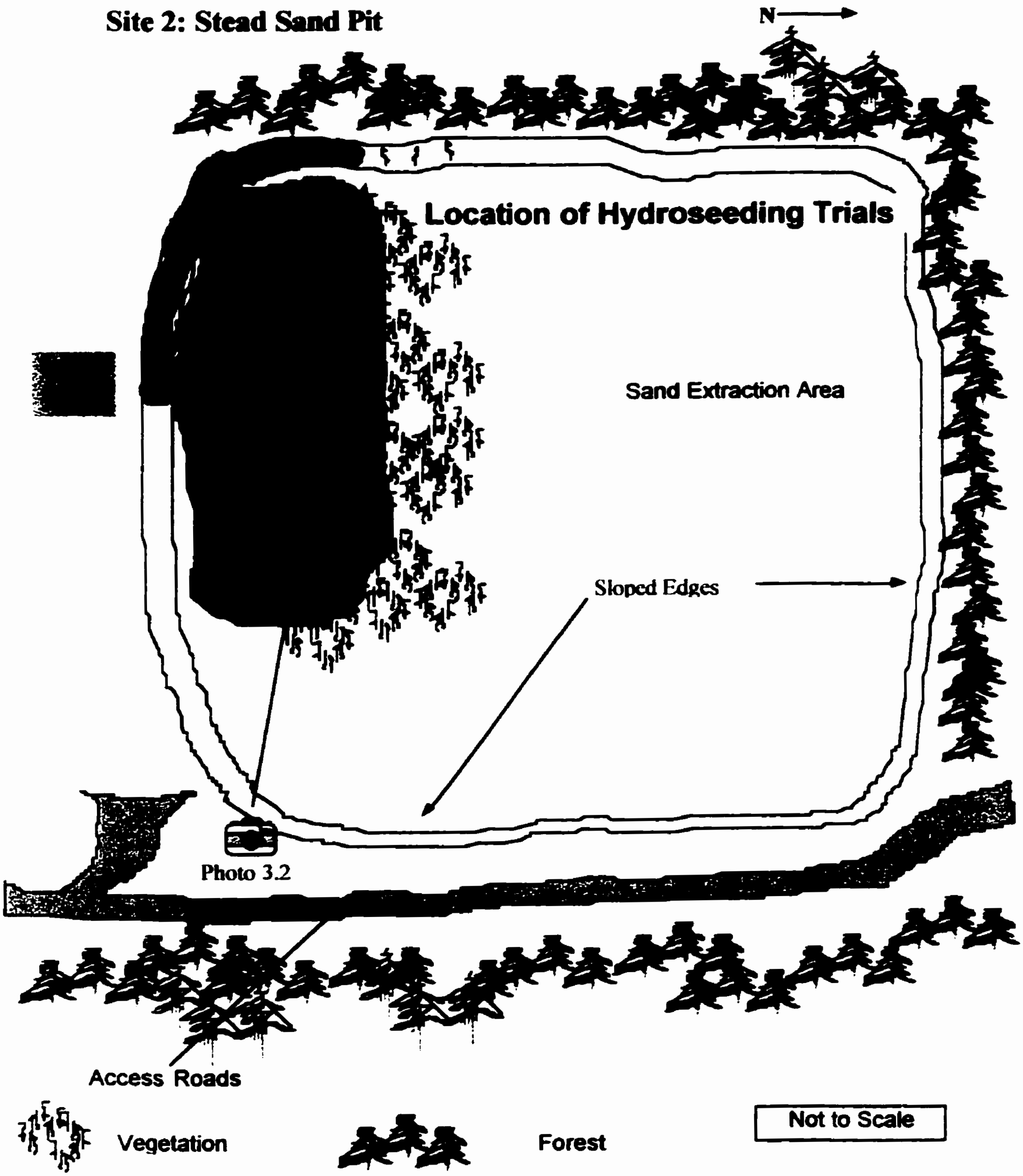


Site 2: Stead Sand Pit:

This site is located on Crown land within the Belair Provincial Forest and the Manitoba Model Forest Program area, approximately 90 kilometers north-northeast of Winnipeg, Manitoba and approximately three kilometers northeast of the community of Stead. This is a shallow sand borrow pit, approximately two to three meters in depth and covering approximately 8 acres (3.0 hectares). Now abandoned, this was the source of sand for the construction of Provincial Highway 304. The north, east and west sides have slope gradients of 2:1 while the fourth side, the south side (facing north), has a slope of 1:1. The trials were located in the south west corner of the pit. They begin on the north facing side, run approximately 70 meters (200 feet) to the corner, then around the corner to include part of the east facing side for approximately 30 meters (100 feet). The local water table has been exposed on the south side of the pit as is evident by the presence of water, even at the height of summer (Photo 3.2 and Figure 3.3).

Photo 3.2: Site 2, Stead Sand Pit. (Photo: May, 1996). The area used for the trials is in the far left corner of the pit, bordering the water's edge. It begins on the north facing side, runs approximately 70 meters (200 feet) then rounds the corner to include part of the east facing side for approximately 30 meters (100 feet)

Figure 3.3: Site 2, Stead Sand Pit

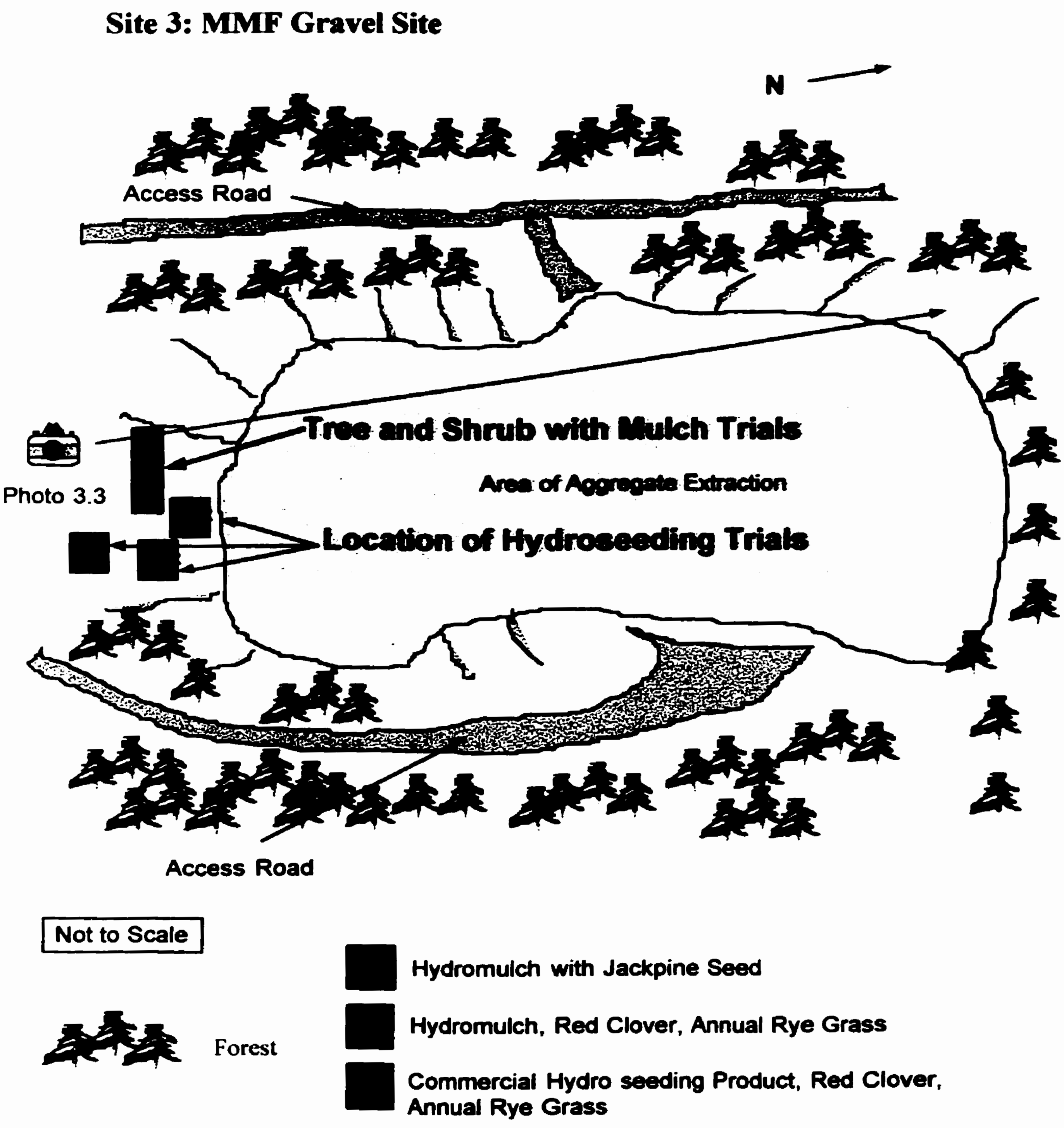


Site 3: MMF Gravel Site:

This is an active sand and gravel pit and is also located on Crown land within the Belair Forest and Manitoba Model Forest Program areas. It is approximately 100 kilometers north-northeast of Winnipeg, Manitoba and approximately ten kilometers northeast of the community of Stead. The materials from this pit were also used in the construction of Provincial Highway 304. The field trials were located on the most southerly end of the pit and face north. There is a 3:1 slope gradient and the materials are dominated by sand with small amounts of gravel and clay mixed in. There is little rilling present (Figure 3.4) (Photo 3.3)

Photo 3.3: Site 3, MMF Gravel Site. (Photo: May, 1996) The photograph was taken facing northward. The trials were located at the base of the photograph, in an area free of vegetative growth.

Figure 3.4: Site 3, MMF Gravel Site.



3.4 Evaluation of the Strategies and Techniques through Field Trials

To evaluate each of the selected strategies and techniques, appropriate field trial methods were identified and implemented. The design and installation of the field trials, as well as monitoring methods and data collection techniques were based upon the literature reviewed and consultations conducted (Ziemkiewicz 1984, Armstrong pers. comm. 1996, Schroeder pers. comm. 1996). Input from Ms. Llwellyn Armstrong of the University of Manitoba's Statistical Advisory Service and Mr. Bill Schroeder, Assistant Head of the Investigation Section for PFRA was used to determined the number of repetitions required to ensure statistical significance. Mr. Schroeder also provided assistance in the design of the trial plots.

Criteria were also identified to evaluate the two techniques that were selected for field trials. The criteria provided for an evaluation of the physical performance of the strategy or technique being tested and an evaluation of the effectiveness of the technique to support the revegetation process desired.

Results were subjected to appropriate statistical analysis with the assistance and advice of Ms. Llwellyn Armstrong and Mr. Bill Schroeder.

3.4.1 Field Trials

The two techniques selected for field trial evaluation were (1) hydroseeding and (2) the Pine Falls Paper Company mill sludge as a protective mulch for established plant material. Because these techniques were quite different from each other, they were evaluated in different ways. The specific method of evaluation for each technique is described in Parts One and Two that follow.

3.4.1.1 Part One: Evaluation of the Hydroseeding Technique:

The use of hydroseeding as a technique in revegetating drastically disturbed lands is limited in Manitoba. This is partially be due to a lack of regulatory requirement to rehabilitate these sites and secondly, it is related to the fact that earlier hydroseeding products were inferior and did not perform well in our climate (Myrowich pers. comm. 1996). However, in recent years new products that perform better in the prairie climate have become available. As well, the Province of Manitoba's commitment to the sustainable development of natural resources encourages the development and application of new techniques for the rehabilitation of such sites (Bailey pers. comm. 1997).

Hydroseeding Treatment Descriptions

The evaluation of the hydroseeding technique took place at the following sites: Site 1: Birds Hill. Site 2: Stead Sand Pit, and Site 3: MMF Stead Site.

The specific location of the various treatments tested at each of the field trial sites appear on the site diagrams (see Figures 3.2, 3.3 and 3.4). A description of the hydroseeding treatments, the associated products and the plant mixtures used appears in Table 3.1, "Summary of the hydroseeding treatments tested at each site."

Table 3.1: Summary of the hydroseeding treatments tested at each site.

Location	Treatment Applied
Site 1: Birds Hill	Mat Inc. Soil Guard™, tackifier, red clover and annual rye grass.
Site 2: Stead sand pit	Treatment 1: Mat, Inc. Soil Guard™, tackifier and Pickseed Canada Inc.'s "Custom Forage Mixture" (8% common cinquefoil, 8% white clover, 10% perennial ryegrass, 20% common bromegrass, 20% creeping red fescue, 10% rangeland alfalfa, 24% fylking Kentucky bluegrass) Treatment 2: Canfor's Ecoaegis™ and Pickseed Canada Inc.'s "Custom Forage Mixture". Treatment 3: Canfor's Ecofiber™ and Pickseed Canada Inc.'s "Custom Forage Mixture".
Site 3: MMF gravel site	Treatment 1: Mat Inc. Soil Guard™, red clover and annual rye grass. Treatment 2: PFPC based hydro mulch, red clover and annual rye grass. Treatment 3: PFPC based hydro mulch with Jackpine (*Pinus banksiana*) seed.

The site 1 treatments were applied by hand-held hose apparatus. The seed mixture used at Site 1, Bird's Hill, is a standard mix used by hydroseeding companies for use in southern Manitoba.

The use of the standard commercial mixture at Site 2, Stead Sand Pit, was prior to the realization that non-native plant varieties may be inadvertently introduced into a forest ecosystem. At this site, the treatment was applied both by canon apparatus and hand-held hose as conditions required.

The seed mixture used at Site 3, MMF Gravel site, was specifically chosen as it was a non-invasive, annual plant species that would not have a detrimental impact on the forest ecosystem. Tackifiers are materials that provide the hydroseeding mulch with the ability to adhere to the surface being revegetated. In this case, the tackifier was quar gum, a natural plant derivative that decomposes over time, long after the plants have established themselves. Dyes are used as a visual aid to ensure the optimal coverage of an area with the hydroseeding materials. The treatments were applied using a hand-held hose apparatus.

The seed used at the Site 2. Stead Sand pit was presoaked in water for 24 hours prior to use. The intention was to stimulate the seed to germinate quickly with the hope that it would then establish quickly (Myrowich pers. comm. 1996). Photos 3.4. 3.5. 3.6, 3.7 and 3.8 show the methods used to apply of the different treatments as well as close-ups of the various hydroseeding treatments at the various locations.

Photo 3.4: Hydroseeding treatments applied at Site 2, Stead Sand Pit. The treatments from left to right are: Treatment 1: Mat, Inc. Soil Guard™, tackifier and Pickseed Canada Inc.'s "Custom Forage Mixture" (green dye, both left and right); Treatment 2: Canfor's Ecoaegis™ and Pickseed Canada Inc.'s "Custom Forage Mixture" (yellow dye); Treatment 3: Canfor's Ecofiber™ and Pickseed Canada Inc.'s "Custom Forage Mixture" (brown dye, from position of the hydroseeder to the green on the right).

Photo 3.5: Treatment 1: Mat, Inc. Soil Guard™, tackifier and Pickseed Canada Inc.'s "Custom Forage Mixture". Appears as the green dye.

Photo 3.6: Treatment 2: Canfor's Ecoaegis™ and Pickseed Canada Inc.'s "Custom Forage Mixture". Yellow dye.

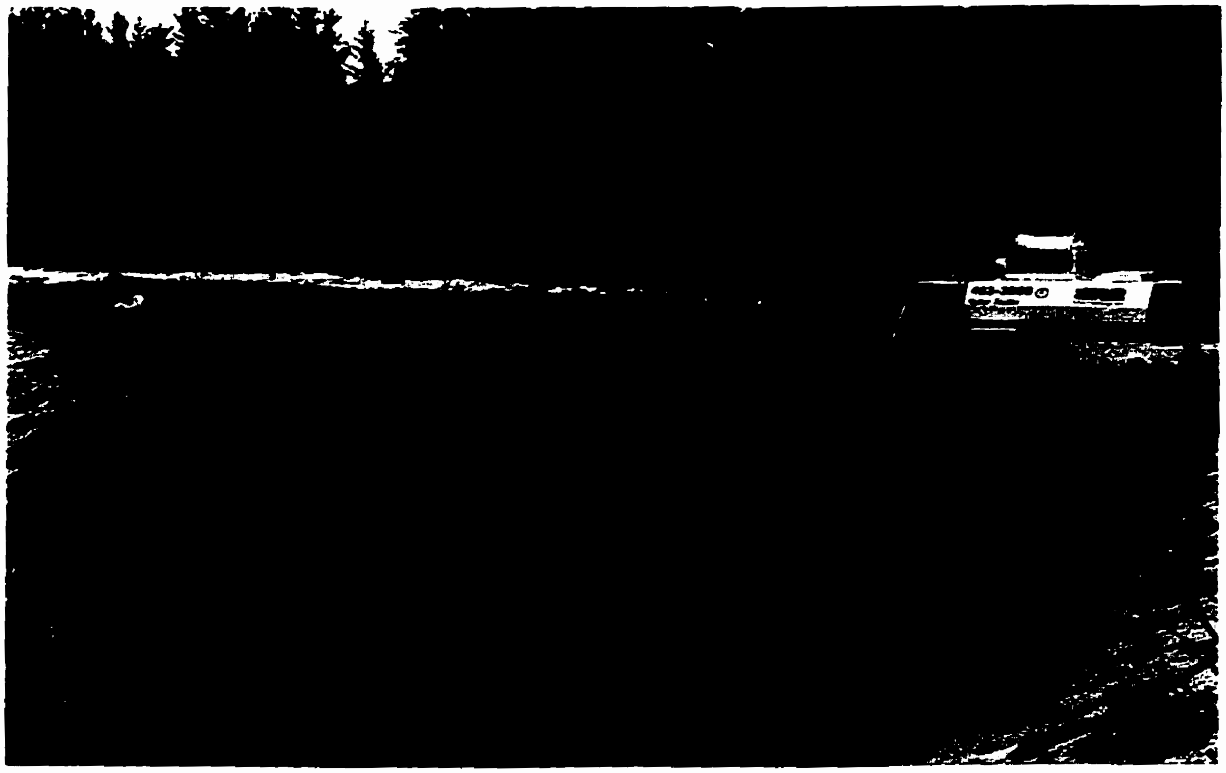


Photo 3.7: Treatment 3: Canfor's Ecofiber™ and Pickseed Canada Inc.'s "Custom Forage Mixture". Brown dye.

*Photo 3.8: Site 3: MMF Gravel Site. Applying Treatment 3, PFPC based hydro mulch with Jackpine (*Pinus banksiana*) seed. The same technique was used to apply the Treatment 2, PFPC based hydro mulch, red clover and annual rye grass at the Stead sand pit site.*

Evaluating the Performance of the Hydroseeding Products

The evaluation of the performance of the hydroseeding products included taking field notes and photographs during inspections. In addition, the following set of "subjective" criteria were used in the evaluation process, as per the practice of the hydroseeding industry (Myrowich, pers. Comm., 1996):

- The ability of the product to remain intact and viable;
- The approximate degree of weed control provided; and
- The estimated rate of germination (when applicable).

Because the criteria used to evaluate the performance of the hydroseeding products were subjective in nature, statistical tests were not performed on the data collected in this part of the project.

3.4.1.2 Part Two: Evaluation of a Paper Mill Sludge as a protective mulch for established plant material.

The practice of planting trees and shrubs in existing soil conditions and then protecting them with a layer of organic mulch is a commonly used and highly successful technique outside of Manitoba. This approach is frequently utilized in the revegetation of sand and gravel pits (Miller and Macintosh 1987, Coppin and Styles 1995, Schiechtl 1980). The source of organic mulch for this part of the trials came in the form of the paper mill sludge from the Pine Falls Paper Company (PFPC) located within the MMF area.

In June 1996, the Pine Falls Paper Company (PFPC) began to produce a biosolid, a product of its new waste treatment plant. This material, also known as paper sludge, could serve as a source of organic mulch. The sludge used for this project originated from the processing of raw timber only and as such, contained no recycled fibers. Although literature showed that paper mill sludges have been utilized as soil amendments in other jurisdictions, its use as a protective mulch was limited, and its use as a component of a hydroseeding slurry was not documented (Thacker and Macyk 1995). It was therefore decided that it would be appropriate to evaluate the sludge as a protective mulch for established plants (rather than as a soil amendment) and also as a component of a hydroseeding slurry. Laboratory analysis of the paper sludge was required as a first step. The results of the analysis appear in Appendix 2.

Therefore, Part Two of the field trials was designed to evaluate: (1) the potential of PFPC paper sludge as a protective mulch for established plants; and (2) the performance response of a variety of native plant species to the treatments. The trials were located at Site 3: MMF Gravel Site, located within the MMF area.

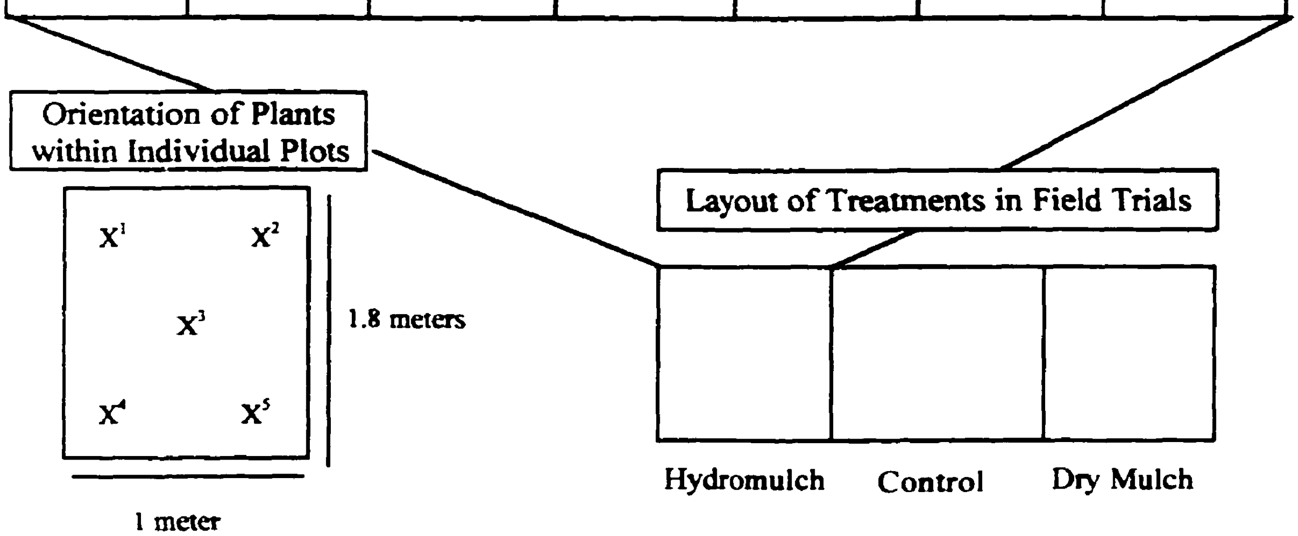
3.4.2 Tree and Shrub Field Trial Plot Design

Trees and shrubs were established in the existing soil and then protected by a variety of treatments. The treatments that tested, were (1) application of the PFPC sludge as a dry mulch (as it arrived from the mill); (2) use of the PFPC sludge as the fiber component of a hydroseeding slurry, applied as a "hydro-mulch"; and (3) a control, where no mulch was applied.

The trials consisted of the three treatments each with twenty eight (28) 1.0 meter x 1.8 meter plots per treatment, for a total of eighty four (84) plots. Each plot was cleared of any existing vegetation by hand then five plants of each species were planted within each plot. Figure 3.5, Trial Plot Layout for the Evaluation of the PFPC Sludge as a Protective Mulch illustrates how the plots appeared. To ensure statistical rigor, four replications of each plant species took place within each treatment. Twenty (20) plants were installed per treatment, for a total of sixty (60) plants per species at each of the two field sites. The total number of plants installed per treatment was n = 140, for a total number of plants installed per site being n = 420. Posting stakes on the perimeter of the plots and stretching twine to create a matrix delineated individual repetitions, or plots. Flagging tape was used to identify the separation between the two treatment types and the control, as well as to draw attention to the presence of the plots in the hope that casual users of the pits would avoid them and thus not cause damage to them.

Figure 3.5: Trial Plot Layout for the Evaluation of the PFPC Sludge as a Protective Mulch

Hawthorn	Dogwood	White Spruce	Acute Willow	Buffalo-berry	Rose	Jackpine
Acute Willow	White Spruce	Buffalo-berry	Dogwood	Hawthorn	Jackpine	Rose
Jackpine	Buffalo-berry	Rose	Acute Willow	Dogwood	White Spruce	Hawthorn
Rose	Buffalo-berry	Dogwood	White Spruce	Hawthorn	Acute Willow	Jackpine



- 'X[1]' Indicates location of plant within the plot.
- Superscript indicates plant number.

3.5 Selection of Plants

Appropriate plant species needed to be selected to evaluate the identified techniques and strategies. Literature suggested that native plants should be used in revegetative efforts whenever possible (BC Environment 1997, Gerling *et al.* 1996, Pitz pers. comm. 1997, Browning pers. comm. 1996, 1997, Gewurz 1986, Kinvig pers. comm. 1996, 1997, Andrews and Kinsman 1990, Gunn *et al.* 1992). The use of grasses and legumes was given initial consideration, however, only introduced, non-native species were available at the time of the first field season (spring 1996). To avoid the introduction of a non-native plant species into the ecosystems of the study areas, the use of commercial mixes was rejected. Wark (pers. comm. 1996) suggested that the grass varieties used by DUC would also not be appropriate for use in the MMF, as they are short and tall grass prairie species, not boreal forest species. This opinion was echoed by Dr. David Punter (pers. comm. 1996)(University of Manitoba), and Dr. Jennifer Shay (pers. comm. 1996)(University of Manitoba). The collection of seed from the local area was considered however, this was not within the scope of the project and was therefore rejected. Further discussions led to the decision that native herbaceous plant species and native tree species would be the most appropriate choice for the trials.

Recognizing that there are a number of potential end uses for disturbed sites, including forestry, recreation and wildlife habitat, a variety of plants were identified for evaluation. Input from revegetation experts, the Practicum Committee and findings from the literature review were used to create the following list of criteria to select appropriate plant species for use in the trials:

1. The plants should be native to the boreal forest ecozone found in the MMF and Manitoba:

2. The tree species should be commercially valuable to the MMF region and Manitoba as a whole;

3. To encourage succession, plants that are known as colonizers and/or nitrogen fixers should be used when possible: and

4. Species that could be used as a food source by wildlife should be selected, when possible.

By applying the above criteria and with additional input from Dr. Howe, Mr. Schroeder, and Mr. Kaczanowski, the following trees and shrubs were selected for the experimental field trials.

- Acute willow, *Salix acutifolia*,
- Buffaloberry (soapberry), *Shepherdia argentia*;
- Dogwood, *Cornus stolonifera* ;
- Hawthorn, *Crataegus arnoldiana*.
- Jackpine, *Pinus banksiana* ;
- White spruce, *Picea glauca* : and
- Wild rose, *Rosa sp.*

The Jackpine (*Pinus banksiana)* and White spruce (*Picea glauca)*, were supplied by Pine Tree Nursery, Haddishville, Manitoba, with the remaining plants being supplied by PFRA Nursery, Indian Head, Saskatchewan. The acute willow came in the form of dormant cuttings (approximately ten centimeters long), the remainder of the plant material came in the form of bare root stock. The PFRA material was one year old. The Haddishville stock was two years old, having been originally grown in "cells" for two seasons, then kept in cold storage as bare root material until needed.

3.5.1 Installation and Maintenance of the Plants

The techniques used to install and establish the plant materials are well described in literature and are an accepted practice of experts in the revegetation field (Howe pers. comm. 1996, Schroeder pers. comm. 1996). The plants were kept in cold storage until installation. All the plants were installed by hand. To prevent desiccation of the roots during installation, the plants were kept out of the wind, kept shaded and in a pail of water. Plants were watered immediately after installation, then every two to three days for approximately six weeks until established, at which time the protective mulches were applied. During the establishment period, weed control involved physical removal by hand as required. To aid the establishment of the plants, a feeding of fertilizer, 24 - 4 - 12, at a rate of 1.00 pound of nitrogen per 1000 square feet was provided at installation (prior to the first watering). Photograph 3.9 provides a visual documentation of the plant installation process.

Photo 3.9: Installing plants at Site 3, MMF Gravel Site.

3.6 Description of the Protective Mulch Treatments

A summary of the protective mulch treatments tested at each of the sites appears in Table 3.2. A photographic documentation of the process of applying the treatments appears in Photos 3.10.

Table 3.2: Summary of the Protective Mulch treatments tested at each of the sites.

Location	Treatment Applied
Site 3: MMF Gravel Site	Treatment 1: (Control) Established plant material with no protective mulch. Treatment 2: (Dry mulch) Established plant material with dry PFPC paper sludge as a protective mulch. Treatment 3: (Hydro mulch) Established plant material with PFPC sludge used as the base for a protective layer of 'hydromulch'.

Photo 3.10: Site 3, MMF Mulch/Tree and Shrub Evaluation Layout. In the foreground (from the first orange flagged stake to the second, light grey colouration) is the hydromulch treatment; next is the control (appearing as a gap of white); furthest away, the dark brown/grey patch, is the dry mulch treatment.

3.6.1 Application of the Mulch Treatments

Once the plants were well established and the PFPC paper sludge was available, the dry mulch and hydromulch treatments were applied. This took place on July 18th and 19th, 1996 respectively. Watering of the plants was discontinued and weeding of the plots was done only once in mid-August 1996. It was from this point on that the performance of the paper sludge as a protective cover for established plants was being evaluated and therefore no further inputs or maintenance were provided. The dry mulch was applied to the surface and around the established plants using wheelbarrows and spreading it with rakes to a uniform thickness of eight to ten centimeters. Mr. Mark Myrowich of Mid-Canada Hydroseeding Limited, a professional hydroseeding company, applied the hydromulch using a hydroseeding machine.

Photo 3.11: The sludge as it arrived from the PFPC mill.

Photo 3.12: Installing the dry mulch at the MMF site.

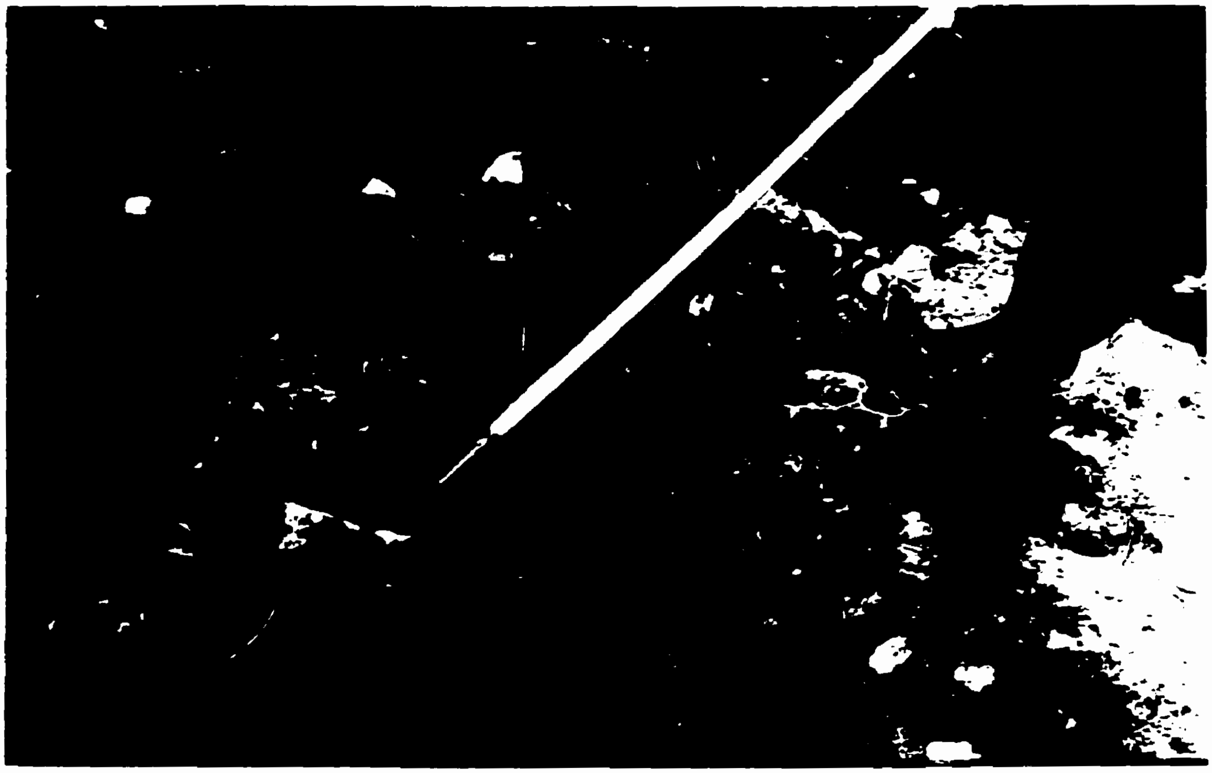


Photo 3.13: **A close-up of the dry mulch being installed at the MMF site.**


Photo 3.14: Applying the hydromulch at the MMF site with a hydroseeding machine.

Photo 3.15: Close-up of the hydromulch after installation is complete.

3.6.2 Evaluation of paper mill sludge performance as a mulch

Because of the loss of the Blumenort site, the evaluation of the paper mill sludge as a protective mulch is based entirely upon the results of the field trials located at Site 3, the Stead Gravel site.

Monitoring of the field trials came in two forms: "walk over" surveys and plant quality assessment data collection. Visits took place approximately every ten days during the two growing seasons (1996 and 1997). Data collection included field notes and photographs. The purpose of the "walk over" surveys was to document erosion, to monitor invasion by undesired plants (weeds), to document the performance of the various treatments and to evaluate and document performance of the plants.

Two criteria were used to evaluate the effect of the mulches on plant performance: (1) over-wintering success rates, and (2) overall plant quality. These two evaluation criteria are an accepted method of measuring or evaluating treatment effects on plant performance (Howe pers. comm. 1996, Schroeder pers. Comm. 1996). The quality assessment of the plants took place in June 1997.

3.6.2.1 Over-wintering Success Rates

The first criterion used to evaluate the effects of the treatments on plant performance was that of the over-wintering success rate or mortality. To determine the over-wintering success rate, a tally of the total number of plants that were viable was taken in the early fall of 1996, while the deciduous plants still retained their leaves. In the spring of 1997, after leaves emerged and new growth was observed on the conifers, another tally was taken. The results were used to determine the percentage of plants that survived the winter, also known as the over-wintering success rate.

3.6.2.2 Evaluating Plant Quality

The second criterion used to evaluate the effects of the mulches on plant performance involved an assessment of overall plant quality. The plants at the MMF Stead site were assessed for overall quality using the criteria that appear in Table 3.3, Plant Quality Ranking and Assessment Criteria. These criteria were an adaptation of those often used in the evaluation of similar techniques (Kennedy 1984, Larson *et al.* 1993).

Table 3.3: Plant Quality Ranking and Assessment Criteria

Rank	Description	Criteria
4	Very Good Health	• All leaves exhibit good colour and rigor. • Branches full and normally developed. • New growth exhibited. • Superior specimen
3	Good Health	• No dead leaves on entire stem. • Branches full and developed. • New growth evident.
2	Moderate Health	• 25 % or less dead leaves on entire stem.
1	Poor Health	• 75% or greater dead leaves on entire stem

(Adapted from Kennedy 1984, Larson *et. al.* 1993)

The assessment of plant quality took place in June 1997, approximately one year after the installation of the plant materials and after the deciduous plants had fully developed their leaves and the conifers showed new growth (as indicated by the development of candles).

The average plant quality for each species within the control and mulch treatments was then calculated using the following method (See example, Figure 3.6).

(1) All the plants were evaluated using the plant quality evaluation criteria as appears in Table 3.2;

(2) Step ①: For each species, the average plant quality ranking of the viable plants in each of the repetitions, within each treatment, was calculated.

Step ②: The *average plant quality value* for each species, within each treatment was then calculated.

Figure 3.6: Example of calculating average plant quality.

Stead Site

Treatment: **Hydromulch**

Hawthorn

Rep	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	① Average
1	4	4	4	4	4	4
2	3	4	4	3	3	3.4
3	3	1	4	4	3	3
4	X	2	4	2	4	3
				Average Plant Quality Rating		②3.35

"X" represents the absence of a plant and therefore no available data.

3.7 Statistical Analysis

Statistical tests were performed to determine whether or not the difference in plant quality between the treatments was significant. The tests included an Analysis of Variance (ANOVA), T-test and F-test. A summary of these tests is found in Appendix 3, with a summary of the findings appearing in the next chapter.

Chapter 4 Revegetation Trials

4.0 Introduction

Numerous techniques and strategies involved in the revegetation of drastically disturbed lands were considered for evaluation. Although it was apparent that in Manitoba some techniques have been practiced to a greater extent than others, it was equally evident that the evaluation of any of the techniques identified would be unique and valuable. In Manitoba, the revegetation of exhausted borrow pits and quarries is not a statutory or regulatory requirement and these sites need only be appropriately sloped and graded when being decommissioned (Bailey, pers. comm. 1996.) As a result, there has been a limited opportunity to evaluate the performance of many revegetation techniques or strategies.

The techniques of (1) hydroseeding, and (2) using a paper mill sludge as protective mulches for tree and shrub plantings were selected for evaluation by field trials. The results of the trials appear in this chapter.

4.1 Results of the Revegetation Trials

4.1.1 Part 1: The Hydroseeding Treatments

Site 1: Birds Hill

The only source of water was precipitation and it was limited in the first growing season (1996) and normal in the second growing season (1997) (Environment Canada 1998).

- *The ability of the product to remain intact and viable.*

The Soil Guard™ hydroseeding material was observed to wash off of the "crests" of the rills and accumulate in the bottom of the rills. After two growing seasons, 1996 and 1997, the accumulated materials were observed to be intact and resisting erosive forces. There was little erosion of the aggregate beneath the hydroseeding materials observed.

- *Approximate degree of weed control provided.*

Undesired plants (weeds) were not seen to be growing through the Soil Guard™ product, only along its exposed edges.

- *The estimated germination rate.*

The germination rate was estimated to be approximately 50% and confined to the bottom of the rills. During the remainder of the first growing season (1996) it was found that the seeds that had germinated earlier had developed into viable plants. A visit one year later (June 1997) found that up to 80% of what had germinated in 1996 was still growing and additional volunteer plant species were observed.

Site 2: Stead Sand Pit

Precipitation was an absent for the first three weeks that followed the applications. Below normal precipitation was recorded for the remainder of the first growing season (Environment Canada 1998). Presoaking of the seed prior to it being applied to the site had taken place.

- *The ability of the product to remain intact and viable.*

All three treatments Mat, Inc. Soil Guard™, Canfor's Ecoaegis™ , and Canfor's Ecofiber™ performed equally well. During the 1996 growing season they all remained intact and viable with no erosion of the aggregate beneath being notified. A site visit one year after installation, in June 1997, found that all the materials had begun to break down (decompose).

- *Approximate degree of weed control provided.*

No weed growth was observed in either growing season (1996 and 1997) in any of the treatments.

- *The estimated germination rate.*

No germination of the seed applied was observed in any of the treatments.

Site 3: MMF Gravel Site

Recorded precipitation was below normal the first year (1996) and normal the second year (1997) (Environment Canada 1998).

Treatment 1, Mat Inc. Soil Guard™:

- *The ability of the product to remain intact and viable.*

The product adhered very well to the surface, remained intact and viable with little or no erosion observed.

- *Approximate degree of weed control provided.*

There was a lack of weed growth during the two growing seasons, 1996 and 1997.

- *The estimated germination rate.*

Germination rates of approximately 60-80% were recorded on the Soil Guard™ product. The higher germination rate (80%) was confined to the bottom of the rills. The lower rate (60%) took place on the crests and flatter parts of the slope. Both red clover and annual rye grasses were present during the entire first growing season. Red clover was persistent in the second season, the annual rye grass was absent (1997)(Photo 4.1, Treatment 1, Soil Guard). The product was applied without any dyes. It adhered very well with some limited erosion observed in the rills. Germination was in the 60-80% range.

Photo 4.1: Treatment 1, Soil Guard. The product was applied without any dyes. It adhered very well and resisted erosion, except in the rills. Germination was in the 60-80% range.

Treatment 2, PFPC based hydro mulch:

- *The ability of the product to remain intact and viable.*

It was found that as the PFPC material dried, it shrank into "patties", but did remain in place. These patties were approximately ten to twenty centimeters across with gaps of one to three centimeters in between them. Otherwise, the material adhered well appearing to mold itself to the contours of the surface. There was no discernible erosion of the treatment area observed in the first year (1996) and a limited amount was recorded in the second year (1997). Overall, the product remained intact and viable.

- *Approximate degree of weed control provided.*

Weed growth during the first two growing season was minimal, with coverage estimated to be less than 10% in the first growing year (1996) and approximately 10 to 20% in the second year (1997). It appeared that volunteer plants were only able to establish themselves within the gaps between the patties, not through the patties themselves.

- *The estimated germination rate.*

A germination rate of 60-80% was recorded. The higher rate (80%) was observed in the bottom of the rills and the lower rate (60%) was observed on the crests of the rills and on the flatter areas of the treatment site. All of the germinated material died off within three to five weeks in 1996 (Photo 4.2. Treatment Two, PFPC based hydro mulch).

Photo 4.2: Treatment Two, PFPC based hydro mulch. This treatment exhibited excellent adherence to the surface and a corresponding resistance to erosion, as well as a 60-80% germination rate and a resistance to weed infestation.

Treatment 3: Jackpine Seed in PFPC based hydro mulch:

- *The ability of the product to remain intact and viable.*

As in the previous treatment, it was observed that as the PFPC material dried, it shrank into "patties", but did remain in place. The patties were approximately ten to twenty centimeters across with gaps of one to three centimeters in between them. The material adhered well appearing to mold itself to the contours of the surface. There was no obvious erosion of the treatment area observed in the first year (1996) with a limited amount observed in the second year (1997). The product remained intact and viable.

- *Approximate degree of weed control provided.*

There was little weed growth observed in the first growing season, with coverage estimated to be less than 10% in the first growing year (1996) and approximately 10 to 20% in the second year (1997). It was only within the gaps between the "patties" that undesired plants were able to establish themselves.

- *The estimated germination rate.*

No germination of the Jackpine seed was observed to take place.

4.1.2 Part Two: Evaluation of a Paper Mill Sludge as a protective mulch

Part Two was designed to evaluate: (1) the potential of PFPC paper sludge as a protective mulch for established plants; and (2) the performance response of a variety of native plant species to the treatments.

The effect that the mulches had on plant performance were evaluated by measuring the following: (1) over-wintering success rates of the plants, and (2) overall plant quality. Both the over-wintering counts and the assessment of overall plant quality were conducted in June 1997.

4.1.2.1 Over-wintering Success Rates

The first criterion used to evaluate the effects of the mulch treatments on plant performance was that of the over-wintering success rate or mortality. Table 4.1, Over-wintering Success Rates, provides a summary of the observed results. A descriptive of the observations is included in the table follows.

Table 4.1: Over-wintering Success Rates

Species	Viable plants (fall 1996)			Viable Plants (spring 1997)			Survival Rate (%)		
	Hydro	Control	Dry	Hydro	Control	Dry	Hydro	Control	Dry
Hawthorn *Crataegus arnoldiana*	20	17	20	19	17	19	95	100	95
Dogwood *Cornus stolonifera*	17	20	20	16	20	20	94	100	100
White Spruce *Picea glauca*	20	20	20	20	20	20	100	100	100
Acute Willow *Salix acutifolia*	15	13	4	15	13	4	100	100	100
Buffaloberry *Shepherdia argentia*	18	17	19	18	15	19	100	88	100
Rose *Rosa sp.*	19	20	20	19	20	20	100	100	100
Jackpine *Pinus banksiana*	20	16	14	20	16	14	100	100	100

From Table 4.1, it can be seen that for all species and under all treatments the survival rates ranged from 94% to 100%, except for the control treatment of the buffaloberry in which only 88% of the plants in the control survived. Total survival rates for all treatments, including the control, were excellent. The anomaly in the results is the number of acute willow that were still alive in the fall of 1996. The willow did not establish well, with only four specimens being available to test the effects of the mulch treatments. This fact is reiterated in the results of the plant quality evaluation that follows. It should be noted that from the point at which the application of the treatments was made, which was after the plants had become established, no other plants were lost.

The results suggest that the treatments had little to no effect on the ability of the plants to over-winter.

4.1.2.2 Assessment of Plant Quality

The results of the assessment appear in Table 4.2, A Summary of the Average Plant Quality Values for MMF Stead Site. To facilitate a comparison of the performance of the quality of the plants between species as related to treatments, the average plant quality values were arranged in descending order. The treatment with the plants evaluated with the highest plant quality ranking appears first, and the treatment with those plants with the lowest plant quality ranking appears last. The results of this process appear in Table 4.3, Ranking of Treatments.

Table 4.2: A Summary of the Average Plant Quality Values for MMF Stead Site

Plant name	Treatment		
	Hydromulch	Control	Dry mulch
Hawthorn	3.35	2.27	2.18
Dogwood	3.87	2.08	3.20
White Spruce	3.35	1.90	2.60
Acute Willow	3.88	1.69	3.00
Buffaloberry	2.78	1.60	2.26
Rose	3.43	2.25	3.35
Jackpine	3.15	1.99	1.93

Table 4.3: Ranking of Treatments (based upon overall plant performance).

Plant	Ranking of Treatments (from highest assessed quality to lowest)		
Hawthorn	Hydromulch (3.35)	Control (2.27)	Dry mulch (2.18)
Dogwood	Hydromulch (3.87)	Dry mulch (3.20)	Control (2.08)
White Spruce	Hydromulch (3.35)	Dry mulch (2.60)	Control (1.90)
Acute Willow	Hydromulch (3.88)	Dry mulch (3.00)	Control (1.69)
Buffaloberry	Hydromulch (2.78)	Dry mulch (2.26)	Control (1.60)
Rose	Hydromulch (3.43)	Dry mulch (3.35)	Control (2.25)
Jackpine	Hydromulch (3.15)	Control (1.99)	Dry mulch (1.93)

From Tables 4.2 and 4.3, it can be seen that the highest quality plants for all species were those associated with the hydromulch treatment. The plant quality of the hydromulch treatment ranged from a low of 2.78 (buffaloberry) to a high of 3.88 (acute willow). The most striking difference between the treatments was in the size of the plants. In some cases growth by the hydromulched plants was observed to be double that of those in the dry and control treatments and was characterized by extensive branching and large, dark green leaves in the deciduous species, and extensive leader growth and needle production in the coniferous species. The plants in the hydromulch treatment were from 20% (dogwood) to 200% (rose) larger than those in the control treatment. The plants of the remaining species in the hydromulch treatment were observed to be between 20% and 100% larger than those in the control. When comparing the plants in the hydromulch versus those in the dry mulch, it is seen that those in the former treatment ranged from having no discernible size difference (Jackpine), to being 100% larger (rose). Chlorosis was absent in the plants of the hydromulch treatment.

The quality of the plants in the dry mulch ranged from a low of 1.93 (Jackpine) to a high of 3.35 (rose). Five of the species produced better quality plants in the dry mulch treatment versus those in the control, with hawthorn and Jackpine being the exceptions. New growth was also observed on the plants of the dry mulch treatment. The plants of the dry mulch treatments exhibited excellent colour versus the plants in the control. Some chlorosis was exhibited on the plants of the dry mulch treatment, however this was limited to four or five plants and was not associated with any one species in particular.

The plants in the control had plant quality values as low as 1.60 (buffaloberry) to a high of 2.27 (hawthorn). The plants in the control were observed to be smaller than those of the mulch treatments, they exhibited chlorosis and were devoid of substantial vegetation. Photographs 4.3, 4.4 and 4.5 provide a visual account of the performance of the plants in the various treatments.

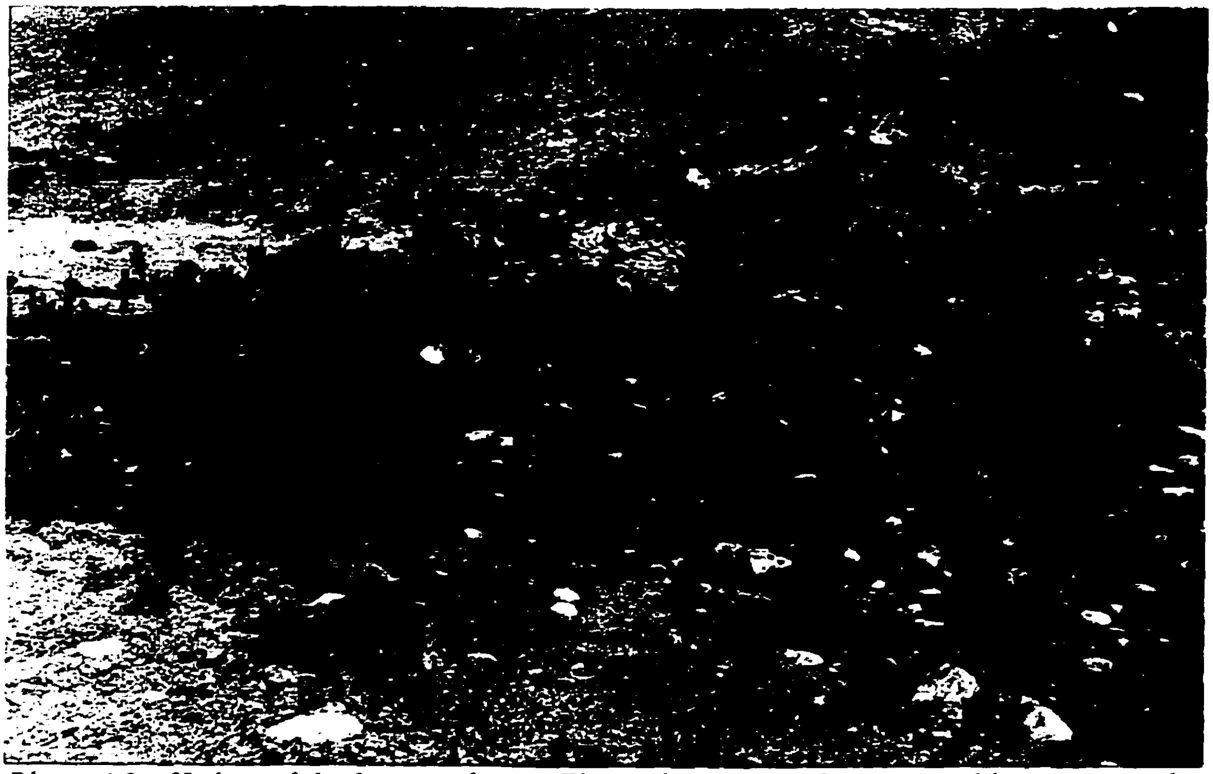


Photo 4.3: Hydromulch plant condition. These plants were characterized by new growth, a lack of chlorosis and high vigor. They scored highest in the evaluation.

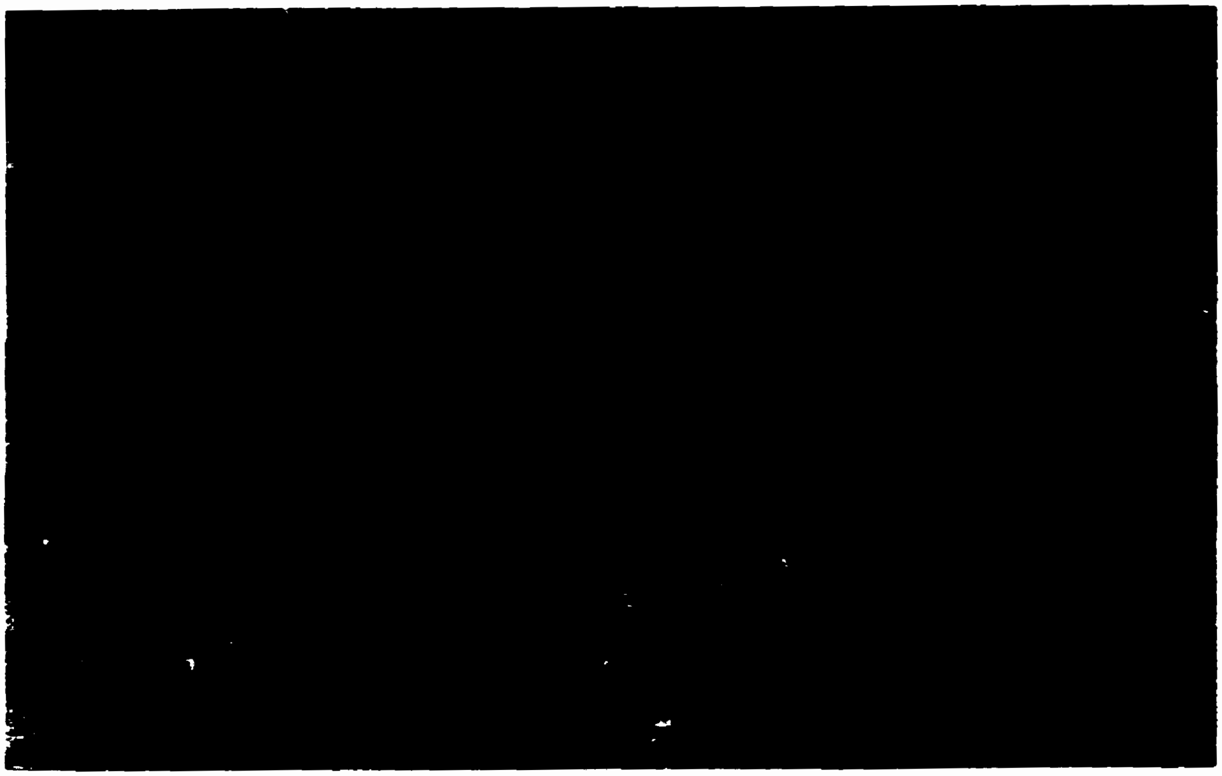


Photo 4.4: Control Treatment plant condition. The photograph clearly shows the poor condition of these plants, especially when compared to the other treatments. They exhibited chlorosis, had very little new growth and poor foliar development.

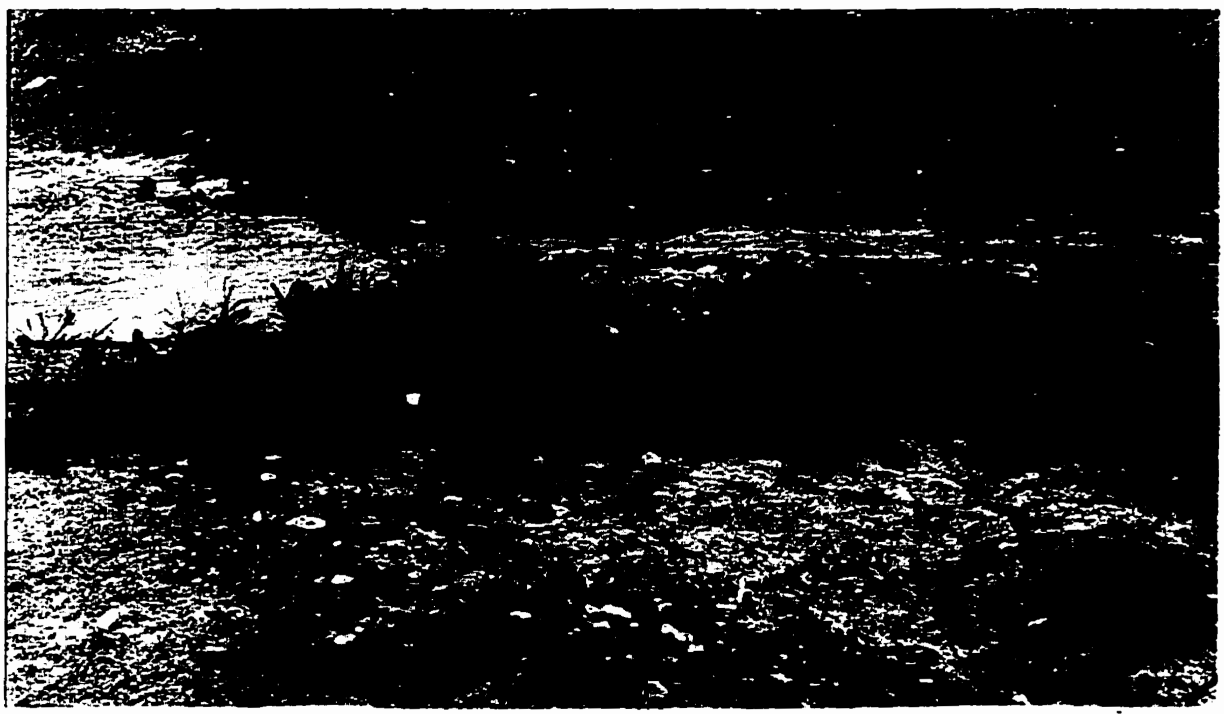


Photo 4.5: Dry Mulch Treatment plant condition. These plants were very vigorous, exhibited new growth, and did not exhibit chlorosis. Their quality was not as high as those of the hydromulch, but they did outperform the control. The vegetation in the right hand corner of the plot is actually an infestation of weeds that were thriving in the accumulated mulch that had washed down by rainfall.

4.2 Statistical Analysis of Results

Statistical tests were performed to determine whether or not the difference in plant quality between the treatments was significant. The tests included an Analysis of Variance (ANOVA), T-test and F-test (p>/= .05). A summary of these tests is found in the Appendix 3, with a summary of the findings appearing in Table 4.4, Statistical Significance Between Treatments.

Table 4.4: Statistical Significance Between Treatments

Plant	Statistical Significance between Treatments (as determined by t-test)		
	Hydro vs. Control	Hydro vs. Dry	Dry vs. Control
Hawthorn	yes	yes	no
Dogwood	yes	◃yes/no	◃yes/no
White Spruce	yes	yes	yes
Acute Willow	yes	no*	no*
Buffaloberry	yes	no	no
Rose	yes	yes	yes
Jackpine	yes	no	yes

Table 4.4 Explanation

yes: There is a statistically significant difference between variances of the treatments compared.

no: There is a lack of statistical difference between variances of the treatments compared.

◃yes/no: There is a statistical difference between variances, however it is "marginal".

no*: Low sample size, results may be inconclusive.

In general, the findings of the statistical analysis support the observations and conclusions offered, that is that the plants in the hydromulch treatment are of better quality than those of the control treatment. The difference between the hydromulch and the dry mulch is statistically significant in four of the seven species and the difference between the dry mulch and the control is statistically significant in only three of the seven species. The overall conclusion is that the plants in the hydromulch treatment benefited from the treatment versus those that received no treatment (control), with less difference between the dry and hydro mulches and less again between the dry and control treatments.

The overall performance of the seven species used in the field trials is summarized in Table 4.5, Species Performance Summary.

Table 4.5: Species Performance Summary

Plant	Performance
Hawthorn *Crataegus arnoldiana*	• Performed best in the hydromulch treatment (3.35 ranking). • Plants of the hydromulch treatment exhibited excellent new leaf and branch development, and no chlorosis observed. • Plants in the control (2.27) performed better versus those of the dry mulch (2.18)
Dogwood *Cornus stolonifera*	• Plants in the hydromulch treatment performed the best (3.87). • Large leafy stems and branches, and an absence of chlorosis characterized these plants. • Plants of the dry mulch were of very good quality (3.02), however they showed less new growth as compared to the hydromulched plants. • The plants of the control exhibiting poorest quality (2.08), with growth confined to the original stalk and leaves being of smaller sizes.
White Spruce *Picea glauca*	• Performed best in the hydromulch treatment, with a deep dark green colouration, substantive leader growth (up to 6 cms), and good lateral growth of branches (up to 5 cms). • Plants of the dry mulch had good growth of leaders (up to 4 cms) and lateral branches (up to 2.5 cms). • Chlorosis was absent. • Specimens of the control treatment ranged from poor to moderate health, averaging a 1.90 value. • The plants in the control were characterized by chlorosis in all specimens, a lack of lateral growth (maximum observed 1.5 cms) and little leader growth (maximum observed 2 cms).
Acute Willow *Salix acutifolia*	• The plants in the hydromulch treatment performed best (3.88). • They had excellent new branching, averaging 15 cms for longest branches, to a maximum of 40 cms, and no chlorosis. • The plants in the dry mulch treatment faired well (3.00) with maximum lateral growth reaching 24 cms, chlorosis was absent. • The control plants were very chlorotic, showed little new growth, and if it did occur averaged 10 cms.

Buffaloberry (soapberry) *Shepherdia argentia*	• Performed best in the hydromulch treatment (2.78), however the dry mulched plants also had good performance (2.26). • New growth in the hydromulched plants reached 10 cms, and no chlorosis was observed. • The plants of the dry mulch treatment showed smaller leaves and shorter branch lengths, however no chlorosis was observed. • The control treatment (1.60) produced the poorest plants of all the species. They exhibited chlorosis, had poor leaf development and little growth of the branches (less than 5 cms)
Rose *Rosa sp.*	• Performed best in the hydromulch treatment (3.43) • This plant performed extremely well developing maximum branch lengths of up to 40 cms in many specimens and green, lush leaves with no chlorosis detected. (Branching resulted in large "bushes" by season's end). • The plants of the dry mulch performed almost as well as those of the hydromulch ranking 3.35, they exhibited many of the characteristics as those of the hydromulch treatment. • The control plants did not perform as well as those that were mulched (2.25), which is almost an entire ranking lower than those of the mulches. • These plants exhibited poor leaf and branch development and were chlorotic.
Jackpine *Pinus banksiana*	• The plants in the hydromulch treatment were characterized by dark green needles, excellent leader development (averaging 4.5 cms, with a maximum of 7.5 cms) and good lateral growth (averaging 4.5 cms). • The plants in the dry mulch did less well (1.93), with many exhibiting "browning off" and poor leader development (averaging 4.5 cms), however, chlorosis was not evident. • The control treatment plants performed as well as those in the dry mulch size-wise, however these did exhibit chlorosis.

4.3 Other observations at the MMF Gravel Site

The hydromulch treatment area showed little surface erosion as evidenced by a lack of rilling and downward movement of mulch and aggregate materials during the 1996 and 1997 growing seasons. Erosive forces were able to carry sand materials onto the treatment area from an area upslope of the plots, however, there was little transport of the materials observed both within and from the treatment area downslope.

The hydromulch area showed little infestation by weeds. The maximum amount of infestation over the two growing seasons (1996, 1997) was approximately 10% by the end of 1997 (October). Weeds were only able to establish themselves within the cracks and crevices that had formed as the hydromulch dried into "patties". This compared to the dry mulch treatment which had up to approximately 50% of the area covered by weeds in the 1996 and 1997 seasons, and up to 100% coverage by the end of 1997 (October). The control had weed coverage of up to approximately 10% in 1996 and 1997.

The dry mulch appeared to support the establishment of weeds, with up to 100% ground coverage observed by the end of the 1997 growing season. Even an area where a small amount of the sludge was spilled during its installation was soon overgrown by volunteer plants.

Photo 4.6: A close-up of the hydromulch. The mat that was formed, although broken up while drying, was able to remain intact and provide protection from erosion and act as a weed barrier.

4.4 Post Study Monitoring

Objective Five of this project requires that guidelines for "post-study" monitoring and analysis of the field trials be developed. The techniques chosen, (1) the hydroseeding and (2) performance of the PFPC and a protective mulch, were evaluated in a very rudimentary way. This was a reflection of the time and cost limitations associated with the project. Where time and money less of a concern, then a more extensive evaluation of the techniques could take place. The following section describes possible long term, post-study monitoring techniques.

4.4.1 Post Study Evaluation of the Hydroseeding Products

Professionals who use hydroseeding as a revegetation technique evaluate existing and potential products on a number of performance characteristics. They are: (1) the ability of the product to remain intact and viable; (2) the approximate degree of weed control provided; and (3) the estimated rate of germination (when applicable) (Myrowich pers. comm. 1996).

Therefore, for long term monitoring and analysis the following criteria should be used to evaluated hydroseeding products:

(1) The rate of decomposition should be monitored, with a desired breakdown of the product beginning in the first growing season and the product remaining viable long enough for the desired plants to become established. Breakdown or decomposition of the product should take place in the second or third growing season to promote natural regeneration. Monitoring could be done through photographs, videos and a progressive series of lab analysis of the material to determine its rate of decomposition.

(2) Determine the product's ability to provide erosion control by monitoring the rate of soil loss from the plots. The monitoring program would remain in place as long as the product remained viable. Photographic evidence of material movement could be used. Erosion research plots that collect the soil that runs off could be constructed to quantify the amount of erosion taking place (Lal 1994).

(3) The amount of weed control provided by the products could be more accurately determined by calculating the percentage cover using a grid or quadrat system. The rate and speed of the natural revegetative process that takes place could be determined and how the product impacts on this process could be observed.

(4) The identification and documentation of the plant species that establish themselves should take place. The pioneer and ruderal species involved in the natural succession pattern could be identified for each of the sites. Future revegetation efforts could then consider the use of these species, possibly enhancing the plant succession process.

(5) An analysis of the soil could be undertaken to monitor the biological and chemical composition changes that take place over time. An attempt at providing the optimal chemical and biological conditions required that support the rapid regeneration of plants could then be made, enhancing revegetation efforts.

4.4.2 Post Study Evaluation of the Performance of the PFPC Mulch

Criteria to measure the effectiveness of the mulch should be designed based upon plant performance.

(1) Measuring Plant Performance: To measure the performance of plants the following criteria could be considered: Overall plant vigor (Kennedy 1984, Larson *et al.*. 1993); biomass production (Schroeder pers. comm. 1996, 1997); growth rates as determined by total height, leader growth or diameter breast height (dbh) (Adamson 1984, Keenan pers. comm. 1997); and mortality rates, including over-wintering success (Keenan pers. comm. 1997; Schroeder pers. comm. 1996, 1997: Staniforth pers. comm. 1996).

(2) Ability of the mulch to resist erosion: It is the important for a mulch to remain intact around desired plants for the period during which they are establishing themselves which is at least one growing season. Therefore, an evaluation of the ability of any mulch to resist erosion should be part of the monitoring program. This monitoring could be as

simple as using field notes and photographs, or as sophisticated as setting up traps to capture the amount of mulch lost to wind and water erosion (Lal 1994).

(3) Weed suppression: The ability to suppress weeds can be monitored through field notes, photographs and quadrat evaluations. The frequency of monitoring should correspond with the weed's growing season for the region. This would be spring (June) and fall (September) in the MMF region.

(4) Identifying the Successional Process: Given that the goal of this project is to identify techniques that may enhance or serve to "kickstart" plant succession on drastically disturbed sites, identifying and documenting the plant species that encroach on the site of the trials would be a good beginning. This could be accomplished by conducting plant surveys of the area on a seasonal basis, using field notes, photographs, and a quadrat evaluation, easily done because of the design of the plots. In addition, the volunteer plants that had begun to establish themselves on the dry mulch plots could be identified and recorded. Parameters such as diversity of plants, rate of invasion and identification of successful species should be considered.

(5) Soil and Mulch Analysis: Monitoring the types and levels of soil nutrients present as the mulch decomposes would be helpful as the mulch itself may be providing nutrients as it breaks down. Long-term analytical tests could serve to determine whether or not this is occurring, or if there is some other chemical component of the mulch or the soil providing benefit to the plants.

(6) Plant tissue Analysis: In conjunction with the soil and mulch analysis, plant tissue analysis could be performed to monitor the changes in health and structure of the plants over time. This type of analytical evaluation may serve to identify the substances or

nutrients that are providing a benefit to the plants and whether these substances originate with the mulch or the soil.

(7) A general comparison between sites: A comparison of the revegetation rates of the treatment plot versus that of the surrounding landscape would be helpful. This would serve to establish if the inputs of the trials had any influence at all on the revegetation effort, i.e. would revegetation take place anyway?

The long term monitoring of the field trials may be limited to Part Two of this project because the hydroseeding materials will have decomposed within two to four years. The duration of the effects of the mulch on the trees and shrubs could be determined through long term monitoring. Such a program should continue to be based upon the evaluation of plant vigor within the treatments, but could also be expanded to include parameters such as biomass production, growth rates as determined by total height, leader growth or diameter breast height (dbh), and mortality rates, including over-wintering success. Analytical testing of the soil, mulch and plants could help determine whether the mulch has any chemical or biological effect on the plants, and in turn, their performance.

Chapter 5 Conclusions and Recommendations

5.0 Introduction

This project originated with the Manitoba Model Forest Program (MMF) which identified drastically disturbed lands, such as sand and gravel pits, as sites which require revegetation in order to provide for the sustainable use of forests. This project was initiated to begin to address that requirement. The Manitoba Model Forest Program (MMF) is mandated to develop forestry practices that will lead to the sustainable use of forest resources.

The techniques and strategies that were identified can be applied to the sustainable development and management of other resources as well as to other sectors, and to the revegetation of drastically disturbed lands outside of the MMF area.

The purpose of this study was to identify and evaluate revegetation strategies and techniques that may serve to "kick start" plant succession on drastically disturbed lands within the MMF region. The objectives identified to meet that purpose were:

(1) To identify and review the revegetation strategies and techniques currently being used by various agencies;
(2) To assess the identified revegetation strategies and techniques for use in Manitoba;
(3) To evaluate the chosen revegetation strategies and techniques through field trials;
(4) To make recommendations for the revegetation of drastically disturbed lands based upon the review of strategies and techniques, and the results of field studies; and
(5) To develop guidelines for "post-study" monitoring and analysis of field studies.

5.1 Evaluating Revegetation Techniques

The selection of the hydroseeding technique and of the PFPC sludge as a protective mulch was as a result of the literature reviewed, interviews with revegetation practitioners and most importantly, the application of selection criteria as identified through the completion of this process and with the input of the Practicum Committee.

The evaluation of the performance of the plants, and associated observations. suggest that these two techniques may be useful tools for the revegetation of drastically disturbed lands under certain conditions.

5.1.1 Hydroseeding

The results indicate that hydroseeding is a viable and versatile technique for the revegetation of drastically disturbed lands. All of the hydroseeding fiber products tested formed stable mats on a variety of soil surfaces and under a variety of conditions. In doing so, they provided erosion control, weed suppression and provided for the establishment of desirable plant species. Even under extremely harsh conditions, such as slopes of 1:1, and on areas characterized by severe rilling, the vegetation became established with no further inputs being necessary.

The use of the Pine Falls Paper Company paper sludge as a component of a hydroseeding slurry has also proved to be promising. It was able to form a relatively stable mat on both flat and sloped conditions and remained intact for two growing seasons. It adhered well to variety of surfaces. thus resisting erosion, and exhibited the ability to support germination rates of 60 - 80%, which is considered exceptional. The lack of germination by the Jackpine seed might be attributed to a lack of seed stratification

(Kaczanowski pers. comm. 1997). The failure of the clover and annual rye grasses after they germinated was most likely due to desiccation, as there was a lack of precipitation at a critical period of time in the establishment of these new plants. This is supported by the fact that even the commercially proven hydroseeding fiber products only continued to support plant growth in the rills where both the product and much needed moisture accumulated. These results underscore the importance of timing the use of hydroseeding to coincide with periods and seasons of precipitation and low ambient air temperatures. The results of the pre-soaked seeds are inconclusive.

The results suggest that the method of hydroseeding is likely to be an effective approach in the revegetation of drastically disturbed sites. The use of the PFPC paper sludge as a component of a hydroseeding slurry was also promising, as it performed well within the parameters used to evaluate other established hydroseeding products. The PFPC-based slurry was able to form a stable mat, provide good erosion control, act as an effective weed barrier and break down with time. All are important characteristics of any good hydroseeding material.

5.1.2 PFPC Mill Sludge as a Protective Mulch

The results of the over-wintering success assessment were inconclusive. The lack of difference in plant mortality rates between the treatments shed no light on whether or not there is any value of the mulch to the plants for their survival over the winter. The only species that showed that it might benefit from the mulches was the buffaloberry, which had a survival rate of 88% without mulching as compared to 100% with mulching. The reason for the extraordinary ability of the plants to over-winter may be related to a number of factors. First, the plants were very well established in 1996 having been planted in June and regularly watered until the application of the treatments, some six weeks later. Second, the 1996 - 1997 winter was characterized by some of the highest accumulations of snow in the last century (Anderson pers. comm. 1998). The exceptional amount of snowfall would have provided an excellent insulating layer protecting the plants from the extremely cold temperatures that also characterized the 1996 - 1997 winter season. The thicker snow layer would have also provided protection from browsers. The higher than normal accumulation of snow would have been followed by a higher than normal spring runoff in 1997, thus providing the plants with an excellent start in the spring. These climatic factors, coupled with the fact that the plants were well established the previous growing season, may have contributed to the high survival rates observed.

In contrast, the results of the plant quality assessment suggest that plants were able to derive benefit from the use of the paper sludge as a protective mulch, both as a dry mulch and as a "hydromulch". Large, green leaves, a lack of chlorosis and the presence of new and vigorous growth characterized all seven species under the hydromulch treatment. Both the tree and herbaceous species benefited. Literature reviewed lists the benefits of mulches as being moisture and nutrient retention and better plant quality as a result of reduced competition from weeds. Both mulch treatments provided these benefits, with the hydromulch being particularly effective. It was able to form a durable and stable mat that adhered itself to the contours of the surface and on a variety of materials from sandy to gravel/sand soils. As a result, there was little erosion of the surface covered by the hydromulch on slopes with gradients of up to 3:1 with no rilling of these areas being observed. The material remained viable and intact for two growing seasons. The hydromulch also provided excellent weed control with the establishment of undesired plant species never exceeding 20% of the plot area. As a result, the competition for limited nutrients and moisture was eliminated, allowing the desired plants to flourish.

The dry mulch treatment produced plants somewhat poorer in quality than those of the hydromulch, however, they were still superior to those of the control. This can most likely be attributed to the lack of ability of the dry mulch to suppress undesired plants in establishing themselves. Infestation rates approached 100% by the end of the second growing season and the presence of these plants resulted in competition between the desired trees and shrubs and the undesired species for the limited nutrients and moisture present on the sites. What is important however, is that ruderals were able to establish themselves quite easily on the dry mulch material. It appeared that the dry mulch provided the necessary conditions for the re-establishment of pioneer species and the process of natural revegetation of the drastically disturbed site was enhanced.

One drawback of the dry mulch was that it very susceptible to both wind and water erosion and over the two growing seasons it accumulated at the bottom of rills and was transported up to two feet down hill of the plots. The material lacked the ability to form a resilient and erosion resistant mat. The use of this material may therefore be limited to areas with little or no slope and where erosion would not be a concern.

As has been noted, all seven plant species performed best in the hydromulch treatments. Only the Jackpine and Hawthorn failed to draw any apparent benefit from the dry mulch. All plants in the control exhibited chlorosis, while the plants in the two mulch treatments exhibited no chlorosis. The most resilient plant was the rose. It was observed as a pioneer species at the site and was observed to be establishing itself along the periphery of the borrow pit. The surprise of the group was the acute willow. Once established, it flourished under the mulch treatments, particularly the hydromulch. However, the need for protection during the delicate establishment period could limit its usefulness. The performance of buffaloberry was surprisingly disappointing. Although it is capable of fixing nitrogen, its performance was the poorest of all the plants in the control treatment and it also received the lowest quality ranking in the hydromulch treatment. It usefulness in revegetation may therefore be limited. Although the hawthorn benefited from the hydromulch, it was able to grow satisfactorily under the control conditions as well. This suggests that it could be useful as a pioneer species where mulching is not possible, and would thrive in circumstances where mulching was possible. The dogwood appeared to benefit greatly from the mulches and would most likely require such protection if it were to be used under similar conditions. The Jackpine responded very well to the hydromulch treatment and poorest in the dry mulch treatment. If planting of this species were to take place on sites with slopes then the use of the hydromulch would increase its success rate. It appears that on areas with little or no slope, this species draws little benefit from the use of mulches. Conversely, the white spruce responded very well to both mulches and therefore use of a protective mulch when using this species could be beneficial.

5.2 Summary

In conclusion, the benefits of the hydromulch appear to be related to: (1) its ability to suppress the growth of undesired plants, thus reducing or eliminating competition for nutrients and moisture; (2) its capacity to control erosion, thus providing for a stable growing medium, and (3) its ability to retain moisture either by reducing movement of water across its surface and thereby allowing for its infiltration and/or by reducing its loss through evaporation.

The dry mulch material supported the establishment of ruderals. It appears to possess the necessary qualities that provide for the re-establishment of pioneer species, thus the natural revegetation process was greatly enhanced.

Overall, the PFPC paper sludge exhibited the characteristics important to be an effective and protective mulch and as such should be considered in revegetation approaches for drastically disturbed sites. It could prove to be of benefit on sites such as ditches, rights of way, temporary logging and access roads, and borrow pits including sand and gravel pits. In situations where the goal is to revegetate with desired species, then the use of the hydromulch would be appropriate. The results of this project suggest that hydroseeding and protective mulches would be excellent techniques in efforts to "kickstart" the natural revegetation of drastically disturbed lands within Manitoba and the Manitoba Model Forest region.

5.3 Recommendations

As a result of the excellent performance of the hydroseeding and of using the PFPC paper mill sludge as a protective mulches for established plants, the following recommendations are made:

1. Given the success of the hydroseeding and mulching techniques, it is recommended that they be considered as viable options in the revegetation of drastically disturbed lands.
2. It is recommended that further study of using the Pine Falls Paper Company biosolid as a hydroseeding component or as a protective mulch be undertaken. Using the biosolid would provide for the sustainable use of the forest resource, central to the efforts of the MMF Program. The use of the material in the Manitoba Model Forest region could be cost effective and represents a reliable source of fiber. Its use as a component of these techniques is only limited by the uncertainty of its chemical make-up. The original material used in this project was derived from the processing of virgin wood, with no recycled materials present at the time. With the introduction of recycled newspapers into the paper making process comes the potential introduction of bleaches and inks, and possibly heavy metals. An analysis of the sludge, both initially and on a regular basis, would serve to determine and monitor the levels of these substances, and establish the appropriateness of using it in revegetation efforts. If the chemical composition of the sludge is determined to be acceptable by Manitoba Conservation, then its use in the revegetation of a variety of drastically disturbed lands within the MMF and beyond, is recommended. PFPC should be encouraged to undertake such a practice as a member of the MMF.

3. Given the mandate and purpose of the MMF Program, it is recommended that it lead by example and promote the revegetation of drastically disturbed lands within its boundaries. The presence of disturbed sites is ever-increasing in the area as more access roads and construction takes place and associated borrow pits are created. The apparent lack of a policy for the revegetation or rehabilitation of such sites back to

productive lands is not sustainable and is contrary to the principles and goals of the MMF Program, and the province as a whole. Failure to develop such a policy will result in the loss of productive land for years and create pressure to expand Forest Management Areas (FMAs), which is also not sustainable. Development of strong revegetation policies, whether for borrow pits, rights of ways, road allowances, or work sites would provide for a more sustainable forest resource, here and in other Model Forests throughout Canada. Such policies and their implementation could also assist in the development of "sustainable forest practices" and contribute to the development of certification criteria.

4. Further research should take place on the use of PFPC paper sludge in the following areas:

(a) As a hydroseeding component. The goals of such research would be to develop optimal mix rates of the PFPC sludge for use in a variety of conditions, on various soil types, on different slopes and with a variety of seed mixes including native species;

(b) Determine the chemical composition of the PFPC sludge so that it can be considered for other uses, other than landfilling or incineration.

(c) Evaluate its effect on the performance of other plant species native to Manitoba and the MMF.

(d) Evaluate its value as a soil amendment, fertilizer or as organic matter.

5. A botanical survey should take place to document the succession patterns and associated species on drastically disturbed lands within the MMF.

6. Research should take place into the use of other soil amendment materials, including the use of mycorrhizal inoculation on sites within the MMF.

7. The slope gradient of 4:1 should be promoted when rehabilitating sand and gravel pits in the MMF. This would provide better conditions for revegetation efforts, provide for improved public safety and greater end use options for sites.

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APPENDIX 1

Shrubs suitable for planting in Northern Ontario

Acer pensylvanicum (Striped maple. Moosewood)
Acer spicatum (Mountain maple)
Amelanchier alnifolia (Saskatoon serviceberry)
Amelanchier canadensis (Shadblow serviceberry)
Cornus alternifolia (Pagoda dogwood)
Cornus racemosa (Grey dogwood)
Cornus sericea (Red osier dogwood)
Hamamelis virginiana (Witch hazel)
Priunus pensylvanica (Pin cherry)
Prunus virginiana (Choke cherry)
Rhus typhina (Staghorn sumac)
Rosa rubrifolia (Redleaf rose)
Salix caprea (Pussy willow)
Salix purpurea (Arctic willow)
Symphoricarpos albus (Snowberry)
Verbinum lantana (Wayfaringtree)
Viburnum lentago (Nannyberry)

(Miller and MacIntosh 1987)

APPENDIX 2

Laboratory analysis of the Pine Falls Paper Mill sludge.

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SOILS AND SEDIMENTS ANALYSIS REPORT

SAMPLE		10447
ORGANIC MATTER		
TOT ORG CARBON	%	53.4
ORGANIC MATT %	%	95.0
C:N RATIO		18.4
NITROGEN	%	2.90
PG FERTILITY MJR		
NITRATE-N	ug/gm	<1.0
PHOSPHATE	ug/gm	1040
POTASSIUM	ug/gm	2170

APPENDIX 3: Example of the Plant Assessment Rankings and Related Statistical Analysis

Hawthorne

Hydro Mulch

Rep	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Average
1	4	4	4	4	4	4.00
2	3	4	4	3	3	3.40
3	3	1	4	4	3	3.00
4	X	2	4	2	4	3.00
		Average Plant Quality Rating				3.35

Control

Rep	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Average
1	1	3	3	3	3	2.60
2	2	2	2	2	0	2.00
3	0	0	2	2	4	2.67
4	2	1	2	2	2	1.80
		Average Plant Quality Rating				2.27

Dry Mulch

Rep	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Average
1	X	1	2	1	2	1.50
2	2	2	1	2	2	1.80
3	2	2	3	3	4	2.80
4	2	2	3	3	3	2.60
		Average Plant Quality Rating				2.18

Summary

Rep	Hydro	Control	Dry
1	4.00	2.60	1.50
2	3.40	2.00	1.80
3	3.00	2.67	2.80
4	3.00	1.80	2.60
Average	3.35	2.27	2.18

ANOVA: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Hydro	4	13.4	3.35	0.223
Control	4	9.07	2.27	0.188
Dry	4	8.7	2.18	0.389

Step 1 **ANOVA**

Source of Variation	*SS*	*df*	*F*	*P-value*
Between Groups	3.41465	2	6.40200194	0.01864997
Within Groups	2.400175	9		
Total	5.814825	11		

Step 2 **F-Test Two-Sample for Variances**

	Hydro vs. Control		Hydro vs. Dry		Dry vs. Control	
	Hydro	*Control*	*Hydro*	*Dry*	*Dry*	*Control*
Mean	3.35	2.27	3.35	2.18	2.175	2.2675
Variance	0.22333333	0.18755833	0.22333333	0.38916667	0.38916667	0.18755833
Observations	4	4	4	4	4	4
df	3	3	3	3	3	3
F	1.19074066		0.5738758		2.07491003	
P(F>=f) one-tail	0.4446417		0.67023409		0.28207353	
F Critical one-tail	9.27661858		0.10779821		9.27661858	

Sample Variances: • are not statistically different • are statistically different • are statistically different

Step 3 Two-Sample t-Test:

	Assuming Equal Variances		Assuming Unequal Variances		Assuming Unequal Variances	
	Hydro	*Control*	*Hydro*	*Dry*	*Dry*	*Control*
Mean	3.35	2.27	3.35	2.18	2.175	2.2675
Variance	0.22333333	0.18755833	0.22333333	0.38916667	0.38916667	0.18755833
Observations	4	4	4	4	4	4
df	6		6		5	
t Stat	3.37749126		3.00271986		-0.2436056	
P(T>=t) two-tail	0.01490389		0.02392409		0.81721562	
t Critical two-tail	2.44691364		2.44691364		2.57057764	