NATURAL REVEGETATION OF MINING DISTURBANCES IN THE KLONDIKE
AREA, YUKON TERRITORY

by

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ABSTRACT

Placer mining has taken place continuously since 1896 in the Klondike area of the Yukon Territory. Excavation of lower slopes and creek bottoms for mining has resulted in extensive areas of disturbed land. The purpose of this study is to identify and describe the spatial and temporal factors which influence successional trends in the natural revegetation of these areas. The study concentrates on identifying these factors and determining the degree to which each of them influences both total vegetation cover and dominant tree species.

Plant communities ranging from 2 to 80 years in age are described on 67 sites disturbed by placer mining. Principal Components Analysis, a gradient analysis technique, is used to transform site environmental variables into single component scores. A series of regression analyses are then used to isolate the factors influencing vegetation patterns. Predicted and residual scores represent the influence of site age, site conditions, solar radiation, and other unidentified factors on vegetation abundance.

Results show that the influence of environmental conditions at a site accounts for 48.8% of the variation in total vegetation cover. Local climate, represented by solar radiation values, explains another 9.8%. Only 9.2% of the variation is explained by site age, leaving 32.2% of the variation to be accounted for by unidentified factors which might include seed supply from adjacent vegetated areas, soil instability due to erosion, sampling error, and chance.

Once the effects of site age and the residual factors are accounted for, vegetation cover and site conditions are significantly correlated. Soil drainage, soil macropore space and slope angle comprise the major environmental factors influencing vegetation development on disturbed land.
This information is used to help define conditions in which present mining areas should be left, in order to promote optimal natural revegetation.
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Chapter 1

INTRODUCTION

Placer mining has taken place continuously since 1896 in the Klondike area of the Yukon Territory. Excavation of lower slopes and creek bottoms for mining has resulted in extensive areas of disturbed land. Different mining techniques used in particular situations and at different times are reflected in the wide range of site conditions contained within these disturbed lands. However, despite the fact that mining equipment and methods have changed, site conditions produced today are similar to those produced by past mining.

To date, the mining industry has not been required to treat disturbed lands. Consequently, areas have been left to stabilize and revegetate naturally and the vegetation now occurring on these sites shows a wide range of natural recolonization and establishment. Elsewhere in northern areas, variation in both the amount and type of vegetation on disturbed land has been observed by Hernandez (1973), Hardy and Associates (1978), Naldrett (1982), Holmes (1982), and Durst (1982). Some mined lands support vegetation communities with characteristics similar to those of adjacent unmined areas, whereas other disturbances maintain vegetation quite distinct from that of the surrounding area.

Environmental features which have been disturbed by mining activity are also components of other environmental resources presently considered valuable by the people of Yukon (Fox, Eyre and Mair 1983; Placer Guidelines Review Committee 1983). Specifically, three types of resource uses are being adversely affected by mining: fishing, terrestrial wildlife, and recreation. In order to maintain features of the environment in a condition such that these other resource values may be realized, treatment of mined...
land is necessary. Revegetation is perhaps one of the most critical components of any surface mining land management procedure (Banks, Nickel, and Blome 1981). In this respect vegetation helps:

- Stabilize soil, thus slowing erosion and sediment discharge,
- Enhance wildlife habitat, and
- Improve the aesthetic quality of a site, thus making it more attractive for recreation.

This study is concerned with identifying and describing the spatial and temporal factors that influence the successional trends in the natural revegetation of land disturbed by mining in the Klondike. It will concentrate on identifying these factors and determining the degree which each of them influences both total vegetation cover and the cover of dominant tree species. Specific questions to be answered include:

1. To what extent is total vegetation cover along a successional gradient determined by site characteristics?
2. To what extent does the correlation between tree species distribution and the examined environmental factors change along the successional gradient? i.e., Does the variation in tree species habitat width change with different site age classes?

The analysis and results presented address relationships between:

1. Vegetation cover and environmental factors of mined land.
The amount of vegetation cover on disturbed land is generally considered to be a measure of the ability of that land to resist soil erosion (Rutter 1967). Cover reduces the impact of rainfall on soil, increases adsorption, checks the speed of flowing water, and binds the soil (Agric. Canada 1961).

2. Tree species distribution and environmental factors of mined land in the Klondike.

Individual species considerations are related to the enhancement of wildlife habitat and aesthetic qualities of the site for recreation purposes.

The results of this study aid in the prediction of natural revegetation patterns on present day disturbances. In addition, the better understanding obtained of disturbance conditions amenable to natural revegetation aids in determining the extent to which assisted revegetation is required to satisfy other resource values. This report suggests environmental management practices which involve the use of ecological information pertaining to the sensitivity and/or resiliency of a disturbed ecosystem. Rather than predicting potential impacts to the environment using only accumulated inventory-type baseline information, an experimental/monitoring approach allows for greater flexibility in the definition of significant impacts to a dynamic system. This form of environmental management has been recognized by others (Hollings 1978, Beanlands 1983).

Several advantages accrue to the choice of the Klondike as a study area. First, a well documented history of soil and vegetation destruction with respect to mining is available (Green 1977, Bostock 1957, Debicki 1983, etc). Secondly, the dates of mining disturbance are available either through historical records or verbally from some of the older miners in the area.
Thirdly, although many of the old mining sites have been redisturbed, it is possible to locate numerous disturbances that have been left untouched since abandonment. Fourthly, comprehensive aerial photography coverage exists for the area since 1949. Using photos it is possible to delineate those areas affected by mining and to confirm the date of abandonment of some of the more recent mining operations. Also they can be used to illustrate the degree of vegetation recovery. Finally, records of climate, soil and vegetation information exist, dating back to 1898. This data, combined with knowledge of the site characteristics resulting from different mining methods, is required to assess the uniformity of environmental conditions in the study area during the revegetation period.

1.1 **NATURAL REVEGETATION RESEARCH IN THE NORTH**

Considerable research has been completed in the field of applied mined-land revegetation in the North (Johnson and VanCleve 1976; Peterson and Peterson 1977). However, few studies are concerned with natural revegetation. Errington (1975) and Meidinger (1979) in British Columbia, and Hernandez (1973) in the Northwest Territories, have studied natural revegetation on abandoned roads and mining disturbances. Hardy Associates (1980) in Yukon, and Rutherford and Meyer (1981), Durst (1981) and Holmes (1982) in Alaska, recently completed studies of natural revegetation on dredge tailings and associated disturbances. These studies are generally descriptive rather than causal in nature, and in particular the variation in vegetation composition and abundance has not been related to the combined effects of:

- Site Age (revegetation period),
- Site Conditions (slope, texture, drainage, etc.), and
Unexplained or Residual Factors (chance, seed source, climate, etc.)

An understanding of the proportion of influence that each of these factors has on disturbed land aids in the identification of optimal conditions for revegetation of present-day mining sites. Specifically, the degree of manipulation of site features such as slope angle, material compaction, percentage of fine material, and water supply, which will promote vegetation, can be quantified.

1.2 CONCEPTUAL FRAMEWORK FOR REVEGETATION

In order to relate plants to mined land, those morphologic and developmental traits advantageous for revegetation must first be identified. According to Noble and Slayter (1980), most phenomena of revegetation can be understood as consequences of differential colonizing ability, the growth and survival of species adapted to grow in different environments. Thus, revegetation patterns on mined land reflect an inevitable consequence of the relative availability of a range of species and their life-history characteristics.

In addition, the characteristics of land disturbed by mining which directly or indirectly determine its suitability as a growth medium for invading plants are usually numerous and complexly interrelated. Physical and chemical properties of the substrate material, as well as characteristics of the site such as the size of the disturbance and climate are important factors limiting plant growth (Holmes 1982). Goodman and Bray (1975), in their review of factors inhibiting successful revegetation of mine spoil, list 13 possible chemical and physical properties of spoil substrates which act to inhibit vegetation recovery. These include:

1. substrate instability
2. spontaneous combustion of waste
3. steep slopes
4. periodic flooding and water stress
5. high concentrations of toxic elements
6. substrate compaction and cementation
7. temperature extremes
8. wind turbulence and sand-blasting
9. nutrient poor substrates
10. excessive stoniness and absence of fine materials
11. uneven surfaces
12. sheet and gully erosion
13. absence of soil microorganisms.

Holmes (1982) found insufficient water availability was limiting to plant growth on dredge tailings near Fox, Alaska. She concluded that moisture was especially critical to plant survival on the porous coarse materials with low water holding capacity.

Moisture availability is affected by a number of other site variables including fine material content, texture, macropore space, slope, aspect, position on slope and soil depth. These measurable factors may be thought of as representational gradients which are readily measured in the field. However, they are indirect environmental gradients and do not take into account the impact of either environmental or physiological processes on the correlation between environment and vegetation. The factors are abstractions from the known physiological and environmental complexity and are used to make inferences about the availability of resources and environmental factors to plants (eg. water, temperature, light, and nutrients) (Austin, Cunningham and Fleming 1984).
Figure 1 is a flow diagram illustrating the relationship of various environmental variables and the site features which they incorporate that can be used to represent their effects on plant growth (modified from Austin et al 1984).
Figure 1. Schematic diagram of the relationship of various environmental variables, types of gradients and the site features they incorporate which can be used to represent their effects on plant growth.

Driving forces (A) supply plants with environmental and resource factors (B). Availability of these factors is modified by site conditions (C). Plant growth (E) is directly dependant upon the availability of environment and resource factors (B) and propagule dissemination (D). Site conditions (C) are used to indirectly observe the relationships between the direct environmental and resource factors (B) and plant growth (E).
Chapter 2

DESCRIPTION OF STUDY SITE

2.1 LOCATION

The study was conducted on abandoned placer mining sites located on lower slopes and valley bottoms of drainages between 1 and 40 km south of Dawson City, Yukon Territory (64°3'N, 139°26'W) (Figure 2). The area of investigation included the following drainages:

1. Bonanza Creek
2. Klondike River
3. Hunker Creek
4. Gold Bottom Creek
5. Gold Run Creek
6. Sulphur Creek

Mining disturbances on these creeks range in elevation between 335 and 600 meters above sea level.

2.2 GEOLOGY AND PHYSIOGRAPHY

Discussions of the geology and physiography of the Klondike area have been presented by McConnel (1901, 1906), Tyrell (1917), Bostock (1948), Vernon and Hughes (1966), Hughes (1972), Templeman-Kluit (1980), Milner (1976), Naldrett (1982), and others.

The study area is located within the Klondike Plateau portion of the Western Yukon Plateau (Bostock 1948). During the glacial period, due to a rainshadow effect from the St. Elias mountains to the west, ice extended out from the South Ogilvie Range only short distances leaving the Klondike unaffected by glaciers (Vernon and Hughes 1966). The region is
Figure 2. Location of the study area.
characterized by the narrow, deeply dissected "V" shaped valleys that are associated with unglaciated terrain.

The Plateau is developed mainly on Paleozoic metamorphic rocks with extensive areas of Tertiary age basalts, shales and sandstones. According to McConnel (1906), the Klondike district is underlain by a complex of rock formations of a wide range of ages and extreme variety in structure and composition. The region has repeatedly been broken through by igneous intrusions and subjected to enormous pressures from earth movement. This associated metamorphic process has caused major alteration in the character of the rock.

Valleys contain high level gravel benches over bedrock terraces and varying depths of creek gravels over the valley floors (McConnel 1906). The Klondike gold fields are the result of long since eroded gold bearing quartz veins. In situ weathering of the mineralized rock and concentration of this mineral during the course of erosion have formed the famous placer gold deposits.

The character of the various types of gravels deposited varies widely depending on factors such as rate of deposition, distance from origin and the degree of leaching that has taken place. This difference in composition and texture may influence subsequent soil formation over the gravels (I.S.S.S. 1978). The white, gold bearing gravels consist of a compact matrix of little worn, sharply angular grains of quartz, thickly packed with rounded quartz pebbles and shist, and quartz boulders. In contrast, the overlying yellow gravels are made up of unleached bedrock clasts lying loosely in a coarse sandy matrix (McConnel 1906; Milner 1980).

The gravels found within the Klondike Plateau have been classified by age, the youngest deposition located on the bottom level of the valleys.
Figure 3 illustrates the distribution of valley, creek and terrace gravels, and Table 1 presents a classification scheme of these gravels according to deposition age (McConnel 1906).

Overlying these gravels are large deposits of eolian and colluvial silt. This silt layer, referred to as "muck" by placer miners, varies in thickness from a few centimeters to 60 meters. Depths are dependant upon elevation, amount of exposure and distance from the material source. These deposits probably developed by aggradation on a vegetated surface during erosion of higher slopes (Milner 1976). Slopewash, solifluction and fluvial processes are believed to be responsible for the retransportation of silt to lower slopes and valley bottoms (Sellman 1967). In addition, Muck may also contain reworked and primary loess.

2.3 SOILS

Little information exists pertaining to soils of the Klondike. To date, no detailed soil surveys have been completed. However, the International Society of Soil Science (1978) and Hardy Associates (1980) have recorded brief observations of soil features within the Klondike Plateau.

The original soils in the study areas have been removed by mining activity. It is assumed that the soils of the adjacent unmined areas are probably similar to those once overlying the disturbances and these will be discussed below.

The lower slopes and valley bottoms are dominated by soils of the Brunisolic and Cryosolic orders (I.S.S.S. 1978; Hardy Associates 1980). Since much of the area was not glaciated, it is thought that some of the upland surfaces contain soils with deeply weathered, well developed Bt horizons.
CREEK GRAVEL CLASSIFICATION

1. LOW LEVEL GRAVELS:
   a. Gulch Gravels
   b. Creek Gravels
   c. River Gravels

2. GRAVEL AT INTERMEDIATE LEVELS:
   a. Terrace Gravels

3. HIGH LEVEL GRAVELS:
   a. White Gravels
   b. Yellow Gravels

Table 1. McConnel's (1906) Classification of Klondike Valley Gravels by age of deposition.

Figure 3. Distribution of valley, creek and terrace gravels in a typical Klondike Valley (after Naldrett, 1982).
These Luvisols are capped with loess and silt in which the Brunisolic soil has developed (I.S.S.S, 1978). The order is characterized by a B horizon of variable composition at least 5 cm thick. Both Turbic and Organic Cryosols are found throughout the plateau. Turbic Cryosols have developed mainly in mineral material and are commonly found on lower elevation, north facing slopes. Organic Cryosols have developed principally from organic material and are associated with peat plateaus in the area. Thick organic accumulations are not common in this area of the Yukon due to well developed drainage systems associated with the unglaciated terrain (I.S.S.S. 1978).

2.4 CLIMATE

The climate of the Klondike is subarctic continental, characterized by long cold winters and short hot summers. Climatological information for the study area is from two Dawson City weather stations. One located at 320 m above sea level (64°3'N, 139°26'W), and the other at 369 m a.s.l. (64°3'N, 139°8'W). The first station, referred to as "Dawson", has been in existence for 80 years, the second station, "Dawson A", for 5 years.

In general the climate is cold with wide ranges in temperature and low amounts of precipitation. Mean annual temperature is -5.1°C, with extremes of -29.1°C in January, and 15.5°C in July (Environment Canada 1982). Mean maxima for June and July is greater than 20°C with maxima up to 35°C. Temperature variations are extreme, and frost may occur in any month. The last frost of spring occurs towards the end of May and the first autumnal frost towards the latter half of August. The average frost free period (1941-70) is 92 days with 910 degree-days over 5°C (Burns 1973).
The mean annual precipitation ranges between 306 and 350 mm over much of the low elevation terrain, but increases with elevation. Snow covers the ground from mid-October until mid-May and annual snowfall averages 132 cm. Average precipitation between June and August is 141 mm with maximum rainfall occurring in late summer. The greatest rainfall in 24 hours is recorded in July, the maximum being 52.8 mm (Environment Canada 1982).

2.4.1 TEMPORAL VARIATION

Climate normals are available for the past 80 years (Environment Canada 1982). This time period coincides with the maximum revegetation periods on the oldest mined sites and the climate information is of value in determining the temporal variation in climate. In order to compare past and present revegetation processes, an evaluation such as this is necessary.

The mean annual temperature (-5.1±1.3°C) does not appear to have changed significantly over the past 80 years. However, mean annual precipitation has changed from 319.1±59.4 mm to 306.1±66.9. Considering the large standard deviation from the normal, no significant difference in precipitation rates is apparent. However, although no major changes in climate have occurred over the past 80 years, precipitation rates fluctuate widely from year to year, ranging from 240 mm to 370 mm.

2.4.2 SPATIAL VARIATION

Orographical effects within the Klondike Plateau can modify both precipitation and temperature normals. Mountainous areas receive more
snow, and both freezing and thawing indices decrease with increasing elevation. Thus, climatic information for Dawson City may not necessarily be characteristic of the Klondike Plateau as a whole (Milner 1976). This phenomenon is illustrated by the differences recorded by the two Dawson stations (Environment Canada 1982). Although no climatic data exists for the specific study area, located between 1 and 40 km from Dawson City, it can be assumed that the range between climatic values presented from the two stations represent the general macroclimate of the study area. Both climate stations and study sites are located in valley bottoms.

2.5 PERMAFROST

The Yukon Plateau lies within the discontinuous permafrost zone (Brown 1978). In general, vegetated valley flats and north facing slopes have permafrost. It is usually lacking on south facing slopes, under valley floors of large streams, and in recent alluvium. Premafrost thickness is highly variable and may reach depths of 60 m depending upon host material, slope configuration, aspect, and vegetation. The depth of thaw during summer months may also be quite variable. On steep, moss covered, north facing slopes, the active layer may be as little as 25 cm. While on south facing slopes, if present, it may be 2 to 3 m or more thick.

Many permafrost areas are in a delicate balance with the environment and are maintained only because of the insulating effects of thick blankets of moss (French and Heginbottom 1983). Ground temperatures vary between $-2^\circ$ and $-1^\circ$C.
Fire plays an important role in influencing permafrost characteristics of the Klondike. Thickening of the active layer and sudden release of water, as a result of fire, can cause significant debris-flow activity. This can add large volumes of colluvium to the valley fill, increasing permafrost thicknesses in the valley floors by burying frozen sediments (French and Heginbottom 1983).

Finer soils, including the loessal "muck" deposits which cover the valley and creek gravels, often contain massive ice structures (Naldrett 1982). Figure 4 illustrates a permafrost section exposed in a Klondike mining operation. The ice content and cryotextures of these muck and ice rich silts are listed in table 2. Water has been incorporated as wedges or lenses of pure ice. This may account for as much as 40 to 50% of the substrate by volume. In many areas of coarser soils, permafrost contains little or no ice, and because the moisture content of this material is relatively low, it may thaw rapidly and remain intact (Naldrett 1982).

2.6 VEGETATION

The vegetational landscape of Alaska and Yukon Territory has been studied since 1848 (Hultén 1940, 1968). However, other than agricultural records from the early part of this century, little detailed information is available on the vegetation of the Klondike area. Hardy Associates (1980) provide perhaps the most detailed description of major community types in their report on Fish and Wildlife Habitat Recovery in Placer Mined areas. In addition, more detailed vegetation studies have been completed in areas close to the study site. Kojima (1973) has classified and described vegetation to the level of association in the North Klondike River valley, northeast of the Klondike area. He attempted to correlate environmental
Figure 4. Massive ice permafrost section exposed in a Klondike mining operation, Hunker Creek (after Naldrett 1982). (see Table 2 for sample locations).

factors with the associations and to elucidate the circumstances under which the associations develop. Stanek, Alexander and Simmons (1981) and Stanek (1982) have performed a reconnaissance of vegetation and soils along the Dempster highway. They were concerned with revegetation aspects of soils and vegetation along a proposed pipeline route. Orloci and Stanek (1979) completed a vegetation survey of the Alaska highway, located south of the study area. Their objective was to typify the vegetation of their survey area and to search for compositional gradients on an objective basis. Neiland and Viereck (1977) provide generalized descriptions of forest types and successional patterns of the boreal forest region which includes the Klondike. They discuss community types in bottomland and lowland spruce-hardwood forests, low brush-muskeg-bog, and upland
Table 2. Ice content and cryotextures in a permafrost section exposed in a Klondike mining operation, Hunker Creek, 1980 (Naldrett 1982). (See Figure 4 for sample locations).

At a more generalized level, I.S.S.S. (1978), Milner (1976), Naldrett (1982), and French and Heginbottom (1983) have described the vegetation of the Klondike as incidental to their primary research.

The regional aspects of vegetational and environmental variations are well documented from the Yukon (Rowe 1972, Oswald and Senyk 1977). The major vegetation gradients are in part conditioned by climatic changes from
east to west, north to south and low to high altitudes, and in part by regional trends in edaphic changes (Orloci and Stanek 1979). Rowe (1972) includes the Klondike study area in the Dawson section of the Boreal Forest Region. The chief forest habitat in this section includes valley slopes supporting stands of white spruce (*Picea glauca*) commonly mixed with paper birch (*Betula papyrifera*). On the valley floors, stunted stands of black spruce (*Picea mariana*) and white spruce are common. The representation of these trees in the stands, however, depends largely on local conditions and stand history. Clearly marked local gradients from sedge to shrub to forest are typical on wetlands, and from conifers to aspen to grassland on the steep south-facing slopes of the gravel benches and other similar habitats.

Much of the vegetation of the Klondike is in a state of secondary succession following fires and extensive lumber and fuelwood harvesting by miners. As a result of fire, stands older than 200 years are difficult to find on upland sites in Alaska and Yukon (Zasada 1976). Milner (1980) provides some documentation of fire history in the Klondike area and briefly describes the location of fires that occurred in 1967, 1950, 1920, and prior to 1910. Regional studies on the effects of fire have been conducted in the Mackenzie River valley (Rowe, Bergstein, Padbury, and Hermesh 1974). Relevant to Klondike vegetation are their conclusions that:

1. Fire recurrence intervals vary from about 25 years for well-drained, seasonally frozen sites to about 100 years in areas of permafrost.
2. North-facing slopes tend to have crown fires while south-facing slopes commonly have groundfires.
3. The type of burn varies with maturity and uniformity of vegetation, storm tracks and relief.
Lutz (1956) and Viereck (1973) discuss relationships of vegetation types to fire disturbance conditions in interior Alaska. Due to the close proximity of the Klondike to the U.S. border (approximately 70 km), much of the information in these Alaskan studies is applicable. Burn frequency, size and intensity contribute to a highly complex pattern of vegetation types representing, to a great extent, varying stages of post burn recovery (Holmes 1982).

2.6.1 VEGETATION COMMUNITY TYPES

The following descriptions provide a summary of principal vegetation types which occur repeatedly in those topographic positions where most mining activity has taken place (Hardy Associates 1980). Consequently, these descriptions emphasize the vegetation on the lower slopes and valley floors in the Klondike area.

1) Black spruce-Feathermoss Woodland

Location:
- upland, lowland and bottomland of northerly (N, NW, NE) facing slopes
- lowland and bottomland of some southerly facing slopes

Major Species:
- *Picea mariana*
- *Betula papyrifera*
- *Salix glauca*
- *Alnus crispa*
- *Ledum palustre*
- *Vaccinium vitus-idaea*
- *Hylocomnium splendens*
- *Pleurozium scheberii*

Permafrost: present

Moisture: hydric, recieving seepage

2) **Aspen-Bearberry Forest**

Location:
- south-facing slopes of major valleys
- well drained sites of other slopes
- ridge tops

Major Species:
- *Populus tremuloides*
- *Picea glauca*
- *Viburnum edule*
- *Rosa acicularis*
- *Arctostaphylos uva-ursi*
- *Festuca altaica*
- *Calamagrostis purpureascens*

Permafrost: absent
Moisture: xeric-mesic, well drained

3) **White Spruce-Paper Birch-Labrador Tea Forest**

Location:
- near base of south, west and southeast facing slopes
- occupies zone below drier aspen-bearberry forest and above wetter black spruce community

Major Species:
- *Picea glauca*
- *Betula papyrifera*
- *Picea mariana*
- *Salix glauca*
- *Alnus crispa*
- *Ledum palustre*
- *Rosa acicularis*
- *Hylocomium splendens*

Permafrost: none near-surface

Moisture: mesic, some runoff and seepage from upslope

4) **White Spruce-Buffalo berry Forest**
location:
- south and west facing above base of slopes

Major Species:
- *Picea glauca*
- *Populus tremuloides*
- *Betula papyrifera*
- *Populus balsamifera*
- *Shepherdia canadensis*
- *Salix sp.*
- *Rosa acicularis*
- *Potentilla fruticosa*

Permafrost: absent near surface

Moisture: mesic, well drained

5) **Black Spruce-Sphagnum Muskeg**

Location:
- valley floors and lower valley slopes

Major Species:
- *Picea mariana*
- *Salix Glauca*
- *Betula nana*
- *Betula glandulosa*
- *Vaccinium uliginosum*
- *Ledum palustre*
- *Empetrum nigrum*
- *Calamagrostis canadensis*
- *Eriophorum vaginatum*
- *Sphagnum sp.*

Permafrost: often within 30 cm of the surface

Moisture: hydric, water table frequently near surface

6) **White Spruce–Alder Riperian Forest**

Location:
- along principal stream courses

Major Species:
- *Picea glauca*
- *Populus balsamifera*
- *Salix sp.*
- *Alnus tenuifolia*
- *Alnus crispa*
- *Ledum palustre*
- *Rosa acicularis*
- *Carex sp.*
- *Calamagrostis canadensis*
- *Pleurozium schreberi*
- *Hylocomium splendens*
Permafrost: seldom occurs within 1 m of soil surface

Moisture: mesic to hydric, moderately well to imperfectly drained alluvium

7) Riperian Willow Shrub

Location:
- valley bottoms
- along small to moderate streams

Major Species:
- Salix sp.
- Calamagrostis sp.
- Carex sp.
- Sphagnum

Permafrost: usually within 1 m of soil surface

Moisture: hydric
8) **Riparian Alder Scrub**

Location:
- narrow fringe along many stream courses

Major Species:
- *Alnus tenuifolia*
- *Alnus crispa*
- *Salix alaxensis*
- *Salix glauca*
- *Picea glauca*

Permafrost: near surface

Moisture: hydric, flooding

### 2.7 MINING HISTORY

As early as 1874, restless men advancing from northern British Columbia and the lower Yukon River area had been testing the creeks of Yukon and Alaska for placer gold. It was not until August of 1896 that George Carmack’s party found coarse gold in Rabbit Creek (now Bonanza Creek), marking the beginning of the famous Klondike gold rush. By the summer of 1898, Dawson City had a population of over 25,000 people.

Initially, the rich gold deposits were extracted by underground drift mining. Although the hand mining methods used by the early miners seem primitive today, gold poured in from the creeks. By 1898 the output had reached an estimated $10 million, increasing to a peak of $24 million in 1900.
In addition to the creeks, gold was also discovered at the base of gravel deposits that were found on the hillsides 150 to 300 ft above the creeks. These bench and hillside workings presented different mining problems. Little water was available at higher elevations, and attempts to pump water from the main creeks failed due to high operating costs. It was not until June of 1909 that large quantities of water were brought to the hillsides under pressure and the gravels, often up to 150 ft thick, were washed down by hydraulic monitors. These large hydraulic operations were abandoned by the mid 1930's when maintenance of the water supply ditches became too costly (Bostock 1957).

By the turn of the century gold mining in the Klondike rapidly changed in character. The mining out of the richest portions of gravel by individuals and small companies made further small scale excavations unprofitable and ownership of the gold-bearing ground was consolidated by larger outfits. Individual mining was superseded by large scale operations, with such engineering and mechanical aids as electrical power, mechanical lifts, dredges, and water led in from a distance, etc. Large, electrically operated bucket-wheel dredges were put into operation in the Klondike by 1905 (Bostock 1957). Dredging continued until 1966 when all major Klondike creek beds had been overturned and washed for their gold at least once. In the period 1932 to 1966, some 205 million cubic yards of gravel had been treated and $59 million in gold produced (Green 1977).

A new method of open cut mining, using bulldozers to push the gravel into the sluice boxes, had been developed in the late 1930's. It was particularly suited to small areas missed by, or inaccessible to, the dredges. This "Cat Mining" is presently the most common mining method in the Klondike. Recently, using large excavation equipment, large-scale
open-cut operations have been initiated over entire valley bottoms.

Although the present population of the Klondike is very low compared to that of the gold rush era, and most of the rich deposits have been exhausted, the area is still active and will probably remain so for years to come.

2.8 MINING METHODS AND LANDFORMS PRODUCED

Mining methods determine the nature of the disturbed terrain found in the Klondike. Some familiarity with certain aspects of the different mining processes used over the past 85 years is required to understand the origin and composition of the resultant terrain. In addition, knowledge of these processes is necessary in order to determine what aspects might be modified to facilitate revegetation.

Generally, four mining techniques have been used. These include, in a semi-chronological order:

1. Hand Mining
   a. Underground Drift Mining
   b. Open Cut Mining
2. Hydraulic Mining
3. Dredging
4. Bulldozer Mining

The decision to use each of the methods is primarily based upon three factors. First, the historical time period of the activity. Prior to 1901, mechanized methods had not been developed and underground drift or open cut hand mining were the sole techniques available to excavate gold bearing gravels. Second, the landscape position of the placer deposit. Bench and terrace gravels require different mining techniques than creek gravels.
located in the valley bottoms. Third, gold concentrations in the gravels of interest necessitate specific methods in order that the operation remain economically viable. An example being the large dredging operations. Dredges can process large volumes of low grade creek and river gravels cheaply enough to remain profitable.

In the following discussion each method will be briefly explained and associated landforms illustrated. Emphasis is placed on the location, size, material composition, and characteristic topography of each disturbance type.

2.8.1 HAND MINING

Although large-scale handmining lasted three or four years, underground drifts and open cuts yielded the largest annual gold values of any of the mining methods used in the Klondike. These labour-intensive methods were concentrated in areas where gold values were high. Early photographs show entire valley bottoms and lower slopes of the major creeks strewn with shafts, overburden piles and coarse-rock tailings piles. Much evidence of these old handworkings has been removed by subsequent dredging and hydraulicking operations. It is possible however, to find old workings on some of the lesser developed creeks throughout the Klondike. Handmining is characterized by large 1 m high piles of coarse rock (8 to 25 cm in diameter), a caved in shaft or pit, and washed tailings piles, usually difficult to distinguish because of revegetation. Figure 5 illustrates the remains of an old handmining operation.

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¹Yukon Archives Photo collection, Whitehorse, Yukon Territory.
Figure 5. Revegetated tailings and overburden of an old mine.

2.8.2 HYDRAULIC MINING

Water, under high pressure, was used to erode the gold bearing bench and terrace gravels along Bonanza and Hunker Creeks, and their main tributaries. As a result of this accelerated erosion process, unique topographical features were produced.

First, a steep face (up to $50^\circ$) sometimes 50 m in height is created by the actively eroded gravel benches (refer to Figure 3). Material stability on these faces is highly variable. Where permafrost is close to the surface above the cuts, sloughing occurs continuously due to excess moisture from the annually degrading active layer (based on field observations by Brady, 1983).
Second, the receding gravel benches expose underlying bedrock terraces, often referred to as benches. These may reach 150 m in depth from the face to the forward edge, and extend over 1 km in length along the valley sides. Bedrock benches typically consist of a variety of rock types in various stages of decomposition (refer to section 2.2 for a discussion of local geology). Dendritic patterns of deep (up to 10 m), steep-sloped rock drains often extend over the entire bench surface. These drains were used to direct hydraulicked gravels into sluiceboxes located at the forward edge of the benches. Interdrain areas are characterized by level, decomposing bedrock surfaces, intermixed with stone piles up to 1 m in height.

Third, alluvial fans of washed gravel tailings have accumulated below each bedrock bench from hydraulicking and sluicing operations above. These fans of gravel may flow 500 to 1000 m down the lower slopes, often spreading into stream channels. The widest part of the fan, usually in the valley bottom, may extend over 1 km in width. A description of the gravel composition is provided in section 2.2. Deposited by flowing water, the surfaces of these gravel fans are smooth, lying at a maximum slope angle of 15–20°. Figure 6 illustrates the features of a large hydraulic operation.

2.8.3 DREDGING

In 1905 the first bucket-line dredge was started at the mouth of Bear Creek. Between then and 1966, all major creeks of the Klondike have been dredged at least once. The large dredges could be found digging their way up towards the headwaters of creeks such as Hunker Creek, where the valley bottom narrows to 40 m in width.
Figure 6. A large hydraulic operation consisting of a steep eroded face, a bedrock bench and large fan of washed gravel tailings.

Conversely, very large expanses of tailings (approx. 5 to 10 km$^2$) can be found in both the Klondike and Indian River valleys. Figure 7 illustrates some large expanses of tailings left by the dredges.

Viewed from a distance, the dredge tailings appear to be of uniform composition. On closer inspection however, a wide variety of surface materials can be identified, both between different mounds and within the same mound. Gravel size ranges from 2–25 cm in diameter and may contain sizeable lenses of silt and sand (field observations, Brady 1983). Composition varies according to the local bedrock and consists of either quartz mica schist, chlorite schist, phyllite, gneiss quartz, slate, quartzite, and igneous rocks (McConnel 1906, Templeman-Kluit 1980, and Milner 1976. These gravels are similar in composition to tailings gravels described by Holmes (1982) at Fox, Alaska.
Upon closer examination of the tailings piles, a wide variation in fine material content (<2 mm) was noted. Some very coarse textured piles often contain 0 to 5% fine material at a depth of 0 to 0.5 m, while other tailings piles contain up to 30% fine material within 10 cm of the surface (field observations, Brady 1983).

In addition to the fine particles present throughout the surface matrix, there are often homogeneous "clumps" of mineral soil material. These vary in size, composition (clay to sand), and colour, and appear to be at different stages of decomposition into the coarse gravel matrix supporting them. These tailings often contain up to 25% macropore void-space, providing a porous surface for this fine material to wash through.

The mineral soil clumps are thought to originate from a variety of sources. These include:
1. Partially decomposed bedrock from the upper layer of bedrock dredged with the gravels. Due to its fine texture, some of this material may have remained frozen during the thawing process (Holmes 1982). When dredged, aggregates of the decomposed bedrock failed to break down, and passed through the sluicing operation straight onto the tailings piles.

2. The most likely source of the coarser-textured silt and sand clumps appears to be from silt and sand lenses found in and on top of the pre-dredged gravel deposits (Holmes 1982; Milner 1980). Portions of the larger lenses may have resisted thawing and passed through the washing process onto the tailings (Art Fry, miner, Dawson City, personal communication 1983).

3. A majority of the earlier dredge tailings piles (1905-1920) contain considerable amounts of fine material; ranging between 20 and 50% at the surface. This may be a result of either: 1) subsequent flooding and silt deposition on tailings by upstream operations, 2) inadequate thawing and stripping of overburden and "muck" due to inefficient thawing techniques, or 3) transporting the dredge through poor ground and depositing the tailings unwashed.

The repetitive, lateral sweeping motion of the tailings stacker, depositing coarse gravel from the rear of the dredge, combined with the forward moving stepping procedure, results in long, narrow tailings mounds with undulating ridges across the mound tops. Mounds vary in width from 30 to 45 m, and range in height from 1 to 15 m. The shallow furrows or undulation ridges extending across the mound tops are between 1 and 3 m apart and up to 1.5 m in depth. The distance between the parallel rows of tailings mounds is variable. If close
together, intermound areas are usually dry. Between widely spaced mounds, ponds, often silt laden, are frequently found. These ponds are common in the Indian and Klondike River dredge tailings. Figure 8 illustrates the pattern of long, narrow tailings mounds with undulation ridges across the tops.

2.8.4 BULLDOZER MINING

A new method of open-cut mining, using bulldozers to push gravel into the sluiceboxes, had been developed by the late 1930's (Green 1977). The bulldozer first strips off the overburden, piling plant material, top soil and surface gravel to the side. It then pushes the paygravel into the top end of the sluice-box and an appropriate amount of water is supplied by a pump to wash the gold from the gravel. Waste gravel is ejected from the bottom end of the box and hauled away by the dozer, or a loader or dragline.

Bulldozer mining is frequently used to mine small areas missed by, or inaccessible to, the dredges. Many narrow creeks, either above the uppermost dredged areas, or tributaries too narrow for the dredges, have been mined using this method. Typically, the dozer will push both washed gravel tailings and overburden up the valley slopes in order to make room for the sluicing operation, paygravel excavation, or water ponds. Tailings and overburden piles often reach heights of 10 m and may extend along the creeks 1 to 2 km (as seen in Gold Bottom Creek). As a result of this disturbance, creek beds usually become wide and shallow (upper Bonanza Creek) (EPA 1979). Seasonal fluctuations in streamflow lead to considerable bank erosion of both tailings and overburden piles preventing rapid
In contrast to narrow valley mining, large scale mining of wide valley deposits has been attempted recently. The channel deposits were either missed by the dredges, or too shallow or deep to accommodate them. In addition to the bulldozers, large scrapers and dumptrucks have been used in these operations. This type of mining is characterized by a series of large pits, often paralleled by extensive gravel tailings piles. Dimensions of these landforms vary from operation to operation. A recent, large-scale bulldozer operation on Sulphur Creek is illustrated in figure 10.

For a more detailed and technical account of mining methods used in the Klondike, Green (1977) provides an extensive list of published works. In addition, technical information is available from;
Figure 9. Typical narrow valley bulldozer operation characterized by tailings and overburden piles pushed up slope.

the Yukon Archives in Whitehorse, Yukon Territory; the City Archives in Vancouver, B.C.; and the Public Archives of Canada, Ottawa, Ontario.

2.8.5 LANDFORMS PRODUCED BY MINING

For the purposes of this study, the term "landform" refers to any large-scale anthropogenic feature resulting from mining activity. Mining landforms are generally distinguished by unique topographical configurations and parent material properties as discussed above. In summary, the following are major landforms produced by mining in the Klondike, and sampled during the revegetation study.
MINING LANDFORMS

1. Landforms Associated With Hydraulic Mining:
   a. Hydraulic Face
   b. Hydraulic Bench
   c. Hydraulic Tailings Fan

2. Landforms Associated with Dredging:
   a. Dredge Tailings Mounds
   b. Dredge Tailings Intermounds

3. Landforms Associated With Bulldozer Mining:
a. Cat Mining Tailings Piles  
b. Dragline Tailings Piles  
c. Worked Areas–Creeks  
d. Cleared Areas  
e. Overburden Piles  

4. Landforms Associated With General Mining Activity:  
a. Worked Areas–Valley Slopes  
b. Settling Ponds  
c. Abandoned Roads  
d. Abandoned Water Ditches
3.1 FIELD METHODS

3.1.1 SITE SELECTION

Soil, vegetation and site conditions were examined at 67 sites disturbed by mining between 1898 and 1981. Field work was completed during the summer of 1983. Sites were located within the heavily disturbed lower slopes and valley bottoms of the Klondike drainages close to Dawson City, Yukon territory. Sites were selected to illustrate the variation in vegetation occurring over a gradient of environmental conditions produced by mining (spatial variation) and a range of site ages since abandonment (temporal variation).

As a result of research completed by Holmes (1982) on dredge tailings in Alaska, a gradient of moisture supply has been identified as being the limiting factor controlling vegetation distribution. In order to accurately estimate species’ ecological breadth and distribution parameters, sampling should favour conditions in which the phenomenon under investigation is most variable (Cochran 1963). According to Mohler (1983), much is gained and little is lost when community sampling favours extreme conditions. Sampling gradient extremes improves accuracy in estimating the shape and position of most species distributions. Therefore, the sampling program was based on a direct gradient analysis in which sampling favoured the extremes of moisture supply to vegetation.
Due to the limited availability of areas that had not been redisturbed since original mining in the Klondike, sites were subjectively selected. The resulting unavoidable lack of randomness and replication in the experimental design limits the extent to which the results may be interpreted to that of inductive pattern analysis rather than revegetation pattern prediction.

The locations and ages of the mining lands sampled was identified using various sources of information. These include the Dawson Mining Recorder ledgers, Yukon Archives in Whitehorse, local publications (Bostock 1957, Green 1977, and Debicki 1982), and a heavy reliance on information provided by a few of the more experienced miners in the area. Information provided by miners was cross referenced with other sources. The age since disturbance, on sites older than 40 years since abandonment, is accurate to within five years. Appendix A lists sample sites according to creek location, local name, mining landform type, and age since abandonment.

3.1.2 SAMPLING PROCEDURES

Sample areas within the disturbed sites were selected to represent the dominant revegetation pattern occuring over the largest portion of the site. These areas are characterized first by relatively homogeneous vegetation cover and composition. Stands were considered homogeneous if the following structural components appeared relatively constant:

- Dominant lifeforms
- Total cover of vegetation
- Height of vegetation
Secondly, sampling areas were delineated by having relatively uniform micro-environmental conditions including:
- Soil texture
- Coarse fragment content
- Slope angle and position
- Moisture supply

In addition, site selection was based on the degree of redisturbance after site abandonment. Mined land that has since been flooded or where active soil movement is evident was not selected. It should be recognized that the sample stands chosen for this study probably do not represent the entire array of vegetation types present on mining disturbances in the Klondike area.

The designated minimum dimensions of these sample areas was 3000 m$^2$. A detailed description of the conditions of the sample area was recorded and environmental features were described according to the Manual for Describing Soils in the Field (CanSIS 1980) and recorded on modified Yukon Ecological Land Survey data sheets (Morison 1981).

3.1.3 VEGETATION SAMPLING

Ten sample points were randomly located within each sample area, and vegetation and soil information was recorded.

3.1.3.1 VEGETATION COVER

The Point-Intercept method (Goodall 1952, Mueller-Dombois and Ellenburg 1974, Larson 1980, Chambers and Brown 1983) was used to obtain estimates of total vegetative cover, cover by species by strata, surface stoniness, litter cover, and exposed bare areas. A 15 m
transect tape marked with 25 evenly spaced points was extended from each sample point. The direction each transect was laid in was dependent upon the most prominent environmental feature within each sample area. For example, where slope position was regarded as a dominant site feature, transects were placed along the contour of the disturbed area to ensure that all transect points remain within the same slope position. At each transect point, a 2 m plumb-bob with a 0.5 mm diameter point was lowered through the vegetation from a height of 2 m. "Hits" were recorded when the point of the plumb-bob touched leaves and stems of different species at different strata levels below 2 m. As well, hits of litter, rock, bare soil, and water were recorded at each point. Above 2 m, a survey staff was held pointing upwards to ensure the accuracy of the vertical projection of the transect point into the tree strata.

This method, originally designed for grassland measurements, was selected for use in this study due to the abundance of low shrubs (< 2 m) and small trees (few over 8–10 m) that are characteristic of the disturbed sites. In addition, precise cover estimates were required for the subsequent data analysis in which a gradient of site cover values is compared with environmental features. According to Larson's review of sampling techniques (1980), the Point method of estimating cover, if used properly, will yield the most consistent estimates of absolute ground cover.

3.1.3.2 TREE DENSITY AND DOMINANCE

The Point-Centred Quarter method (Cottam and Curtis 1956; Meuller-Dombois and Ellenburg 1974) was used to estimate total and individual species density and dominance values of trees and tall
shrubs with a basal diameter of greater than 4.5 cm and above 3 m in height.

Four quarters were established at each of the 10 sample points through a cross formed by 2 lines. One line is the transect tape and the second runs perpendicular to the transect through the first sample point. The distance to the midpoint of the nearest tree from the sampling point was measured in each quarter. In addition, diameter at breast height (DBH), tree height and species was recorded for each tree. Diameters of those trees prominently forked below breast height (1.3 m) were measured immediately below the fork. Tall shrubs with more than one emergent stem were assigned a diameter by measuring the largest stem in the clump. Parameters obtained using this method include:

- Species composition
- Density (from mean distance - stems per m²)
- Diameter (and therefore basal area and dominance - cm² per 100 m²)
- Frequency (the occurrence of a species at a sampling point)

Relative values of these parameters were used in the analysis to identify the overall importance of each species in each sample area.

Four to six of the largest trees in the sample area were identified. Increment cores were taken as near the base as possible and kept in plastic straws until ages could be determined.

3.1.4 SPECIES COLLECTION

Specimens of all species encountered during the sampling program were collected, identified and preserved. Lichen and Bryophyte
voucher specimens are deposited with the University of British Columbia herbarium. Vascular species were retained by the author.

3.1.5 TAXONOMIC PROBLEMS AND SPECIES GROUPINGS

Nomenclature of the vascular species follows that of Hultén (1969), except for the genera *Salix* and *Alnus* which follows that of Viereck and Little (1972). The non-flowering state of some groups of vascular plants made identification to the species level difficult. This led to the grouping of some plants at the genus level.

Three *Salix* species were easily distinguishable in the field. These include *S. bebbiana*, *S. arbusculoides*, and *S. alaxensis*. Possibly due to species hybridization, other *Salix* species were difficult to identify to the species level. A *Salix* sp. grouping was formed which probably contained *S. monticola*, *S. glauca*, *S. planifolia*, and *S. barclayi*, but remain unidentified.

Three species of *Alnus* were identified; *A. crispa*, *A. sinuata*, and *A. tenuifolia*, however *A. sinuata* was grouped with *A. crispa* due to difficulty in distinguishing them as separate species during the sampling program. These species intergrade with each other, and some authors regard *A. sinuata* as a variety or subspecies of *A. crispa* (Viereck and Little 1972).

Two subspecies of *Ledum* are recognized; *L. decumbens* and *L. groenlandicum*. However, during the sampling program they were referred to as *L. palustre* L. (Hult.).

During fieldwork, all grasses were combined into separate groupings at the genus level. Later, most were identified to the species level.
Nomenclature of the bryophytes is that of Schofield (1969) and Crum, Steere, and Anderson (1973). Voucher specimens were verified by Dr. W.B. Schofield of the University of British Columbia. Failure to distinguish *Polytrichum juniperinum*, *P. piliferum*, and *P. commune* in the sampling program led to a major grouping of *Polytrichum*. By midsummer, these species were identified, however the grouping was retained for the entire program. *Dicranum angustum* and *Aulacomnium palustre* were inadvertently combined. Later identification revealed that most were *D. angustum* but exact proportions are unknown.

Nomenclature of lichens follows that of Hale and Culberson (1970). Although many lichen species could be identified in the field, several problems were encountered in distinguishing some species. Individuals of *Cladina*, *Cladonia*, and *Stereocaulon* were separated, but many required chemical or microchemical tests for accurate taxonomic separation. Voucher specimens were later identified by Dr. G. Otto of the University of British Columbia, (refer to appendix B for the complete species list). In general, species were grouped according to genus when poor or scanty material prevented species determination.

3.1.6 SOIL SAMPLING

As a result of mining, all original soil has been washed downstream (to St. Michaels according to Art Fry !), or pushed into overburden piles, sometimes lining the edge of the disturbance. The remaining surface material has become the medium for any subsequent soil development. Various degrees of horizon differentiation may be observed in the proto-soils left since 1898. In recognizing this wide variation in soil development during the revegetation period, all surface
material supporting vegetation, regardless of composition or profile development, will be referred to as "soil".

Estimates of soil texture and percentage (by volume) of fine material (<2mm diam.), coarse material (>2mm diam.) and macropore void space were recorded at ten small (15 cm in depth) pits, each dug at the first sample point of each transect. The precision of these field estimates was periodically evaluated. Soil texture classes were calibrated with sample standards carried in the field. Later particle size analysis was performed on soil samples in the laboratory.

Estimates of percent volume of coarse material were not calibrated in the field. Due to the reliance on visual estimations, the coarse fragment data was probably not precise. However, I felt that the estimates were accurate and consistent due to the large number of replications (10) for each sample area, and the systematic procedures applied in the estimation of each sample. Using a shovel, soil was removed from the top 15 cm of mineral material in the small pit. The contents were visually divided into size classes which included:

1. < 2 mm in diameter
2. > 2 mm in diameter;
   a. 2 mm – 8 cm in diameter – gravel
   b. 8 cm – 25 cm in diameter – cobble
   c. > 25 cm in diameter – stones

A major soil pit (up to 1 m in depth) was excavated at a point determined to be representative of the general soil conditions of each sample area. Most often this involved expanding one of the ten
small pits previously dug. The soil profile was described and
comments pertaining to soil development were recorded. Horizon
boundaries were measured and soil structure, texture and consistancy
were described. Estimates of porosity, drainage class, and available
water storage capacity are used to describe the presumed average
moisture conditions of the site.

Samples from the top 15 cm of mineral material of three of
the small pits were removed for chemical and physical analysis. The
samples were taken from as diverse substrate material as could be
found supporting vegetation within the sample area. This was done in
order to identify the variation in soil conditions on disturbed lands.
The samples were dried, then sieved through a 2 mm screen and
retained in plastic bags until they were analysed. Soil analysis was
performed at the Pedology laboratory at the University of British
Columbia. Each sample was analysed for concentrations (PPM) of the
macro-nutrients;

1. available calcium, magnesium, potassium (Morgans) (Greweling and
   Peech 1965)
2. available phosphorus (Bray P)
3. total nitrogen (%)
4. soil acidity (in water)

Particle size analysis was performed on the Sedigraph 5000 Particle
Size Analyzer at the National Water Research Institute, Vancouver, BC.

3.1.7 SITE DESCRIPTION

A detailed description was made of the site conditions. This
included; slope angle and configuration, aspect, topographic position,
parent materials and modifying processes (washed gravel). Also, depth to water table, presence of permafrost and evidence of erosion were recorded for each sample area (CanSIS 1982). Details of each site were photographed to illustrate revegetation and site conditions.

3.1.8 DESCRIPTION OF ADJACENT VEGETATED AREAS

A brief description was made of the characteristics of vegetated unmined areas surrounding the disturbed sites. Cover values of dominant trees, shrubs, herbs, moss, and lichen were estimated, as well as the approximate distance of each stand to the disturbed land.

3.1.9 OBSERVATIONS ON SUCCESSION

Once soil and vegetation features of each site had been sampled, comments were then made pertaining to the unique revegetation processes occurring within each sample area. These include observations on species propagation, micro-topographical influences, vigour of the dominant species, and any observable influence of the adjacent unmined areas. In general, an attempt was made to understand the revegetation process unique to each disturbance by combining knowledge of the vegetation, site conditions, and possible influence of the adjacent vegetated areas. This exercise was found to be a valuable component of the field program.
3.2 ANALYTICAL METHODS

3.2.1 VEGETATION COVER ANALYSIS

In order to explore the relationships between vegetation abundance and habitat features of the disturbed land it is necessary to segregate the sources of variation in vegetation cover into both spatial and temporal determinants (Yarranton 1969, Austin 1971, Carleton 1984, Johnson 1981). Such a partitioning process is of value when attempting to identify the amount of variation in vegetation accounted for by:

- The age of the site since disturbance.
- Site environment conditions.
- Local climate, as expressed by solar radiation.
- Unidentified residual factors which may include:
  a. The influence of adjacent vegetated areas to supply seed,
  b. Substrate instability, preventing establishment,
  c. Variability in soil nutrients,
  d. Chance.

Johnson (1981) and Johnson and Jasieniuk (1982) used a partitioning technique to segregate the sources of spatial and temporal variation in vegetation subject to fire disturbance. Using regression models they were able to isolate separate habitat and successional ordinations from a single vegetation data set representing spruce-lichen woodland stands in northern Canada. The advantage of this approach is that alternative hypotheses of the importance of different combinations of environmental measures can be tested for their relationship with vegetation abundance (Carleton 1984). However,
unlike fire disturbances, land disturbed by mining is initially sterile, devoid of seed and vegetative material. As a result of this primary successional condition, at least initially revegetation of these sites is dependant upon seed coming from adjacent stands (Holmes 1982). In contrast, the burned sites contain variable amounts of seed, roots and other vegetation which may survive fire and contribute to the revegetation process (Rowe 1983, Viereck 1983). In addition, organic matter overlying soil is seldom completely consumed by fire in northern areas (Viereck 1983). This organic material provides a more equitable micro-environment for establishment of vegetation than does the bare, gravelly material produced by placer mining.

As a result of the differences between conditions produced by fire and those by mining, a further partitioning may be performed, segregating the influence of habitat conditions on mined land from the influence of adjacent stands to provide seed to the sterile site. The rational supporting this distinction is based on the presence of continually abundant, highly dispersive "invader" species characteristic to the North and available to all sites, regardless of their location and size (Rowe 1983, Hernandez 1973). Once settled on the disturbed land, subsequent growth of the wind-disseminated propagules is dependant upon the microsite and environmental conditions of the particular site. In general, most disturbed sites are exposed to an abundant seed rain of a variety of species. Although seed from species in adjacent areas may influence species composition, my field observations indicate that vegetation abundance is not influenced by the relative proximity of the adjacent vegetated areas to the disturbed sites. In addition, all sites possess sterile conditions initially.
Therefore, for the purposes of this study, it is assumed that the relative influence of site environment conditions may be partialled out from the seed availability conditions of the disturbed sites. This allows for a further partitioning of the variation explained by separate spatial determinants of vegetation abundance.

The vegetation-cover analysis consists of two major steps:

1. An ordering of all sample sites along gradients representing:
   a. the age of each site,
   b. the principal environmental components identified at each site, and
   c. the amount of solar radiation received at each site.

2. A partitioning of the sources of spatial and temporal variation in vegetation cover.

3.2.1.1 ENVIRONMENTAL GRADIENTS

1) Site Substrate Conditions

A synthetic gradient representing the principal substrate conditions of disturbed land is produced.

First, principal components are selected from the environmental variables recorded at each site. These variables include:
- soil drainage class
- % macropore void space
- slope angle
- topographic position
- soil texture
- soil perviousness
- soil available water storage capacity
A Multivariate Sample Size Analysis Program (MSS) is used to select those environmental variables that account for the highest amount of variation in the site conditions (Scagel, R.K.; Y.A. El-Kassaby, and J. Emanuel 1984, Emanuel 1984, Orloci 1973, 1975). The program consists of Ranked Dispersion and Specific Variance analyses, which are combined to produce variable selection. Both algorithms use a correlation matrix as their starting point.

Ranked Dispersion Analysis measures the contribution to the total dispersion of variables for each variable. Those with the highest dispersion (sum of squares) are considered the best candidates for variable selection. Specific Variance Analysis also uses a correlation matrix to measure "redundancy"; the information shared between each variable individually against all other variables. Those with the lowest redundancy provide the most information.

The analysis revealed that soil drainage, % macropore space, and slope angle respectively, account for the highest amount of variation in site data, and are best used to describe the substrate conditions of each site.

Principal Components Analysis (correlation matrix), a multivariate gradient analysis technique, was used to transform the combined values of the three independant site variables into single component scores for each site. These scores (eigenvalues of the first axis) numerically represent the environmental conditions of the sample sites. Gittins (1969) and Pimentel (1979) provide thorough explanations of the Principal Component Analysis technique.
Soil macronutrient and acidity values, although recorded, were not considered in the analysis. As a result of taking three soil samples from as diverse material as could be found supporting vegetation at each site, high within-site variability of soil nutrient values restrict the use of the information for any quantitative analysis. In order to estimate mean nutrient values with a high degree of confidence, many more samples would be required per site. Courtin, Feller, and Klinka (1983) for example, propose that in some cases, over 100 samples would be required to assess some soil properties of disturbed soils in B.C. In addition, the large amount of inert coarse material, characteristic of placer mining landforms, may have a dilution effect on nutrients contained in the finer material. Thus, nutrient data in areas of heterogeneous substrate conditions may be of limited usefulness (Berg 1978).

2) Local Climate - Solar Radiation Gradient

In addition to physical conditions of the site substrate, variation in vegetation abundance may also be attributable to topographic differences in climate. Based on a review of literature on vegetation ecology of the Klondike area, it is possible to anticipate certain relationships between the components of local climate and plant distribution (Hardy Associates 1980, I.S.S.S. 1978, French and Hegginbottom 1983).

According to Loucks (1962), the effects of slope and aspect cause the greatest differences in the amount of radiation reaching a
surface in hilly terrain. Temperatures of natural or man-made surfaces and rates of evaporation, heating and cooling, photosynthesis, and snowmelt are usually a response to solar radiation input (Hay 1979). For the purposes of this study, the influence of local climate on vegetation abundance will be expressed by the amount of radiation reaching a particular surface. However, it must be understood that an examination of such relationships needs to be restricted to a small region of essentially uniform macroclimate such as the valley bottoms of the Klondike.

Measured values of short wave radiation input for various slopes aspects in the Klondike do not exist. Instead, measurements of total short-wave radiation on a horizontal surface from Whitehorse were used. Despite the differences in latitude between the two areas (3° 60'), slope radiation calculations produced from the Whitehorse measurements were used. These observations take into account the effects of local cloudiness in diffusing direct solar radiation. Although data on cloud cover is not available for the Klondike, generally the cloud cover periods of the two areas are similar. The advantages of using actual radiation data to produce a radiation index outweigh the use of theoretical radiation models, even when programmed for a specific latitude of interest. These models require that cloud cover data be available for the specific area.

For this study, mean July values of daily shortwave radiation on inclined surfaces and different aspects are used to represent

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*Personal communication, Dr. J.E. Hay, Dept. of Geography, University of British Columbia, Vancouver, Canada, 1984.*
climate scalar values because maximum daily temperatures occur in July, and are associated with maximum radiation outputs (Environment Canada 1982). Figure 11 illustrates the local climate gradient, combining topography and aspect. Values range from 20.1 MJ m⁻² day⁻¹ for a south facing 30° slope, to 12.3 MJ m⁻² day⁻¹ on a north facing 40° slope (Hay 1979). Each site is assigned a shortwave radiation value based on its compass direction and slope angle (declination adjusted 31°).

3.2.1.2 FACTOR PARTITIONING ANALYSIS

A successive series of Stepwise Regression Analyses were used to examine the relationships between vegetation cover and additive combinations of temporal and habitat factors. The regression model was built to explain the distribution of vegetation in terms of a set of predictor variables (Carleton 1984). In addition, the difference between observed and predicted values which represents the residual or unexplained component was also identified.

The method first involved partialling out variation in vegetation abundance accounted for by the ages of the disturbed sites. Thus age and habitat features constitute linearly independent and additive components of the basic predictor set. Second, using residual scores from the first regression, the influence of site habitat conditions was further partitioned into the relative influences of site substrate conditions and local climate at each site.

Expressed numerically, the data consists of a set of vegetation cover values represented by $y$, and $x_1, x_2, x_3$ are the explanatory variables consisting of site age, site substrate conditions and local climate conditions respectively. The linear model is:
Figure 11 Local climate gradient representing the relative amount solar radiation received on different slopes and aspects in the Klondike.

\[ Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 \]

and the datum is split into:

\[ y = Y + e \]

where \( Y \) is the estimated value and \( e \) is the residual (Austin et al. 1984). The equation implies that the relationship between vegetation abundance and the predictor variables is linear, yet this is not usually the case (Johnson 1981). However, both higher and lower order equations did not improve the fit enough to justify their use (i.e., regression coefficients did not increase). Figure 12 outlines the major steps of the vegetation cover analysis.
The results of the successive regressions conveys a clear indication of the relative importance of the temporal and various spatial factors in influencing vegetation abundance. In brief summary, the features of disturbed land in the Klondike can be placed into a revegetation model of the following dimensions:

Vegetation Abundance = f (site age, substrate conditions, local climate, and unexplained residual factors)

The partitioning method emphasizes the estimation of relationships between a response and a set of explanatory variables. Due to limited number of sites sampled (67), and a lack of randomness and replication in the site selection program, the data does not fully meet the requirements of regression analysis when used for confirmatory purposes (Steel and Torrie 1980). Rather the method is used as an exploratory technique to aid in hypothesis generation of revegetation theory (Kempthorne 1978).

3.2.2 TREE SPECIES DISTRIBUTION ANALYSIS

The distributions of seven tree species, commonly occurring on the revegetating mine sites, were analyzed to determine the extent to which their composition along a successional gradient is accounted for by site characteristics rather than by chance factors, such as seed
Figure 12. Major steps of the vegetation-cover analysis.

The species and number of sites in which they occur include:

1. *Picea glauca*—44 sites
2. *Populus balsamifera*—41 sites
3. *Populus tremuloides*-38 sites
4. *Betula papyrifera*-45 sites
5. *Alnus crispa*-19 sites
6. *Salix arbusculoides*-44 sites
7. *Salix alaxensis*-43 sites

3.2.2.1 FACTOR PARTITIONING

The methodology that was used in this first section of the tree species analysis is similar to that used in the vegetation cover analysis (sec. 3.2.1). Cover values of the seven tree species were used in the successive regression analysis process. This partitioning process was used to identify the amount of variation in tree cover explained by site age and various spatial features of the disturbed sites. Figure 13 outlines the major steps of the tree species distribution analysis.

3.2.2.2 AGE CLASS ANALYSIS

In addition to examining the influences of the temporal and various spatial determinants of tree species distribution, this section of the analysis also addressed the response of trees to mined land conditions at different time periods since disturbance.

Margalef (1963, 1968) suggests that the distribution of plants in pioneer communities is determined by chance arrival during the initial period of colonization when competition is low. Over time, increasing competition should result in decreasing niche breadth and increasing species fidelity to site conditions. Control of species co-existence within stands will pass from external physical factors to internal biological interactions as time since disturbance increases (Woods 1984). Thus, species distribution should become increasingly predictable.
Figure 13. Major steps of the tree species distribution analysis, as succession proceeds (Christensen and Peet 1984). This view of successional divergence is in contrast to the highly deterministic composition of pioneer communities postulated by Clements (1916, 1928). Early successional composition was considered to be highly deterministic and the "Clementsian" model made little allowance for
chance effects such as spatial and temporal variation in seed availability or between yearly climatic variation (Christensen and Peet 1984).

A univariate 1-way Analysis of Variance (ANOVA) was performed on the cover values of each tree species to determine whether the species distribution could be divided into distinct age-cover classes. For the ANOVA, each of the seven species was grouped into three age classes based on site ages. Growth ring counts of the largest trees on each site ranged between 2 and 5 years less than the age of the site since it’s abandonment. The three age class boundaries were based on two gaps found in the site ages. One is 12 and the other 5 years. The classes include; (i) 1-18 year old sites, (ii) 30-53 year old sites, and (iii) 58-83 year old sites.

The ANOVA program was used to partition the variation in species abundance into that proportion of variation accounted for by between age class cover values or the effect of site age, and that accounted for by within age class cover values or the range of variation within each age class.

Hence: \[ SS(\text{total}) = SS(\text{between}) + SS(\text{within}) \]

and: \[ SS(\text{within}) = SS(\text{age class 1}) + SS(\text{age class 2}) + SS(\text{age class 3}) \]

Those species that showed significantly distinct (p < 0.01) ranges of cover values within each age class were then analyzed for their compositional predictability over time. For a particular age class, the
more randomly species are distributed relative to the site condition (PCA) and solar radiation gradients, the greater should be the species habitat breadth along these gradients. Thus, habitat breadth can be viewed as a measure of the randomness of tree species distribution (Christensen and Peet 1984).

As a result of the small sample sizes in each age class, the relationships between vegetation cover and the two environmental gradients could not be analyzed quantitatively. The analysis was limited to a qualitative description of scatter diagrams which showed the variation in habitat requirements of each species over time. For those species which did not show distinct age class boundaries, a scatter diagram was produced for that age class which accounted for the highest amount of variation in cover.

3.2.2.3 SITE CLASSIFICATION

Once the relative proportions of influence of the temporal and various spatial factors characteristic of disturbed land were identified, the variation in vegetation abundance accounted for by site substrate conditions was further utilized. Given that site substrate conditions do influence vegetation distribution to some identified degree, and that environmental management during mining is limited to modifying the physical features of a site (substrate conditions), it is of value to describe the range of vegetation along the site substrate condition gradient.

Site were classified according to their groupings of Principal Component scores (section 3.2.1.1). Once grouped, Sites were then ranked by age within each class. A Vegetation Table Processor program (VTAB)(Emanuel 1984) was used to facilitate the classification
procedure. Species composition, and cover and importance values were listed by strata height for each site within the substrate condition classes (see the summary table in Appendix D).

A descriptive evaluation was produced for each of the classes with emphasis placed on describing the variation in species distributions. In addition, species presence and absence within each class was related to the descriptions of the vegetated areas adjacent to the sites. These descriptions provide insight into the nature of the unexplained portion of variation in vegetation cover.
Chapter 4

RESULTS AND DISCUSSION—VEGETATION COVER ANALYSIS

4.1 SITE SUBSTRATE CONDITION GRADIENT

Results from the Multivariate Sample Size Analysis showed that of the eight site condition variables used to describe the substrate conditions; Soil drainage, %fine material, macropore void space, and slope angle respectively, are those variables which best describe the conditions of each of the 67 sample areas. They accounted for the highest percentage of variation in the site data (67.4% of the total sum of squares).

The first axis produced by the Principal Component Analysis (PCA) accounted for 49.4% of the variance in the site data. The analysis revealed significantly high eigenvector values for both the percentage of soil macropore space and soil drainage (0.69 and -0.70 respectively). This indicates that these two variables are best used to distinguish site substrate conditions of mined land. The slope angle eigenvector element was 0.19 indicating that slope is of less importance in differentiating site characteristics. The remaining PCA axes are not considered in this discussion as they individually accounted for small portions of the explained variance.

The PCA transformation procedure produced a component score for each site ranging from 0.0 to 5.5 units. These scores were ranked along a gradient representing the first PCA axis. Figure 14 illustrates the scalar ranges of the environmental variables that comprise the gradient of this principal component.

The Environmental gradient presented in figure 13 summarizes major trends in substrate composition and moisture supply. Gradient boundaries
Figure 14. Scalar ranges of four environmental variables representing site substrate composition and moisture supply along divisions of the principal component gradient.

were not distinguished using quantitative methods due to small sample sizes for each of the site condition classes found on disturbed land. Instead, scatter diagrams of the PCA scores against the individual variables were overlaid and the boundaries visually delineated.

The upper half of the gradient (2.8 - 5.5) represents very well drained soil conditions, characterized by a range of 0 - 16% fine material, 0 - 63% slope angles and 8 - 27% soil macropore space. Soils in this drainage class have very low available water storage capacity (usually less than 2.5 cm) within the control section, and are usually coarse textured, or shallow, or both (CanSIS 1982). Water source is primarily precipitation.

The lowest portion of the gradient (0.0 - 0.3), classed as poorly drained, was characterized by ranges of 70 - 100% fine soil material, 0 - 8% slope angles and 0 - 2% soil macropore spaces. Water is removed from the soil sufficiently slowly, in relation to supply, such that the soil remained moist for a significant part of the growing seasons (CanSIS 1982). Subsurface flow or groundwater flow, or both, in addition to precipitation, are the main water sources in poorly drained areas. These soils exhibited a wide range of available water supply, texture and depth.
Thus, the wide range of some of the scalar values (e.g., 0 – 63% slope angles) may have been a result of variability in water supply to each sample area.

The middle portion of the gradient (0.3 – 2.8) is represented by substrate conditions characterized by a wide variation in drainage capacity, 0–6% macropore space, 16–100% fine material and 0–95% slope angles. Sites within this range of the gradient possessed a much wider variety of conditions compared to those at the extremes of the gradient. It was noted during the sampling program that these mid-gradient sites usually contained a high variation in within-site substrate conditions. For example, considerable deviation from the mean percentage of fine material estimated, was observed at these sites.

4.2 FACTOR PARTITIONING

The first linear regression was performed using total vascular cover values against age since disturbance of each sample site. The amount of deviation between the site cover values and the cover over age regression line were referred to as residual scores. These scores were used in the second regression.

The regression coefficient indicated that 9.2% of the variability in vegetation cover was associated linearly with variation in site age. This weak association appears reasonable considering the variability in habitat conditions between sample areas. For example, several mined areas, abandoned two years previous to the study (1981), contain up to 80% vegetation cover. Conversely, some areas dredged up to 70 years ago were observed to have less than 5% ground cover. The small variation related to site age, may be partially explained by the extremely wide range of man
made conditions produced by mining activity. For example, settling ponds
often contained 100% fine material (silt loam), whereas dredge tailings may
have contained no fine material and up to 27% macropore void-space.

Factors other than site age accounted for 90.8% of the variation in
vegetation cover. Thus, site conditions and adjacent vegetated areas had a
much greater influence on vegetation growth than did the time period since
abandonment. Holmes (1982) also found that factors other than site age
control rates of revegetation on dredge tailings in Alaska.

The second regression was performed to further partition the
determinants of vegetation cover into effects due to site conditions and
those due to other factors on and off the site. Residual scores from
regression I (vegetation cover values with the influence of site age
removed) represented the dependant values. While scores along the gradient
of the principal environmental component (section 3.2.1.1) represented the
dependant values.

The second regression line, representing the influence of site
conditions, accounted for 48.8% of the variation in vegetation abundance.
This percentage indicated that vegetation–environment relationships were
moderately correlated. This finding is in agreement with Holmes (1982), who
found that total woody cover was definitely related to substrate conditions;
particularly fine particle concentration.

In order to identify factors confounding this relationship it was
necessary to examine the variation in vegetation distribution and abundance
within ranges of environmental conditions. This classification and description
procedure was performed in section 5.4.

In view of the knowledge that 48.8% of the variation in vegetation
abundance was associated with variation in the substrate conditions of
mined land, materials handling techniques used by mine operators can have only partial influence in promoting a desired level of natural revegetation.

The final regression revealed that 9.8% of the variability in vegetation cover is associated linearly with variation in local climate as expressed by solar radiation values on specific slopes and aspects. This low degree of influence may have been a result of the location of the disturbed sites. Most dramatic effects of the influence of solar radiation are usually seen on upper valley slopes in the Klondike (I.S.S.S., 1978, Larsen 1982). Differences in moisture supply and permafrost may be more pronounced at these higher elevation. In contrast, flatter slopes and moisture receiving conditions characteristics of lower slopes may reduce the influence of differences in solar radiation intensity on plant growth (Milner 1977). Generally, higher cover values were associated with steeper, north facing sites where evaporation rates and daytime temperatures may be moderate. Flatter sites of all aspects contained a wide range of cover values, while sites on slopes steeper than 30° tended to have lower values indicating that the influence of local climate was most pronounced at the topographical extremes.

The remaining 32.2% of the variability in vegetation cover represented the influence from all factors affecting vegetation growth that were not measured at each sample area. As such, it represented that portion of the data that remains unexplained following the identification of the influence of site condition and age. Figure 15 illustrates the proportion of influence of each of the four determinants of vegetation cover over the disturbed sites.

The residual factors may represent the influence of unmeasured variables such as wind direction, soil nutrients, sampling error, the effects
Figure 15. The proportion of influence of spatial and temporal factors on vegetation abundance was partitioned into: 1) site age, 2) site substrate conditions, 3) local climate, and 4) unidentified residual factors.

In general, soil movement may inhibit plant propagation. However, due to low rainfall in the Klondike (320 mm/year) and the coarse textured soils exposed by mining, little evidence of erosion was observed on uphill sites, except where degrading permafrost provides a continual source of water. However, considerable bank erosion was observed in valley bottoms where stream levels fluctuate continually. The resultant unstable substrate
conditions do not provide a medium for revegetation.

In addition to on-site conditions, the influence of adjacent vegetated areas surrounding the disturbances must be considered. These areas provide a source of seed for the revegetating sites. However, there is some variability in the capacity of adjacent areas to provide both quality and quantity of seed. Wind direction, tree age and seed production, dispersal periods of seed, and dispersal distance are factors influencing seed availability from adjacent areas to disturbed sites (Zasada 1971). They require consideration when assessing the revegetation potential of any site.

Although aspects of seed source availability are factors to be considered, it is important to note that as a result of the frequent fire regime and extreme seasonal temperatures characteristic to the North, many plant species have developed wide tolerance ranges to environmental conditions and in general, are capable of rapid recolonization in many disturbed areas (Viereck, 1983, Rowe 1983). Preliminary field observations indicated that the influence of adjacent vegetated areas are most prominent on mesic-type sites and mainly evident in understory species composition. Generally, many more species were found on these mesic sites. Most tree species were found throughout the range of site conditions, and their cover and density values did not appear to be affected by the proximity of adjacent stands. This subject is further discussed in section 5.4.

4.3 VEGETATION - ENVIRONMENT RELATIONSHIPS

Figure 16 illustrates the relationship between vegetation cover and environmental conditions of mined land in the Klondike. The influences of both site age and unidentified residual factors (adjacent vegetated areas, soil nutrients, climate, etc.) were removed so as not to confound this
relationship.

The range of vegetation cover associated with portions of the site condition gradient illustrate the variation in vegetation response to the mined sites. For example, comparatively narrow ranges of cover values were found at the extremes of the gradient, while wider ranges occur in the central portion. This suggests that vegetation response is more predictable at extremes of the gradient of site conditions. This phenomenon is discussed further in section 5.4.

A range of 70-100% cover values were most often found in moist areas which are characterized by substrate conditions of; poor drainage, 0-2% macropore space, 70-100% fine material and slope angles of less than 8%. Generally, landforms containing these wet to moist conditions included: settling ponds, abandoned roads, cleared areas, and some overburden piles and valley slopes. The vertical heights of the surface micro- and meso-topography in these areas appeared to be slightly less than in the drier areas. This condition is accentuated by the filling in of the surface depressions with litter to the point that on some densely forested sites, the landform patterns were barely recognizable. Most of the older sites (> 30 years) supported an almost continuous layer of litter with average depths ranging from 5 to 23 cm.

Soil textures on these wet sites ranged from sand to clay with the majority of sites containing silt loam. Most soils were identified as Regosols, usually gleyed, humic or cumulic. Frequent flooding and moisture supplied from degrading adjacent permafrost areas resulted in most of the soils being saturated for some portion of each year, as evidenced by the presence of mottles in all horizons.
Figure 16. A graph illustrating the relationship between vegetation cover and the range of site conditions (gradient of principal environmental variables) found on land disturbed by mining in the Klondike. Hatched areas represent the range of both vegetation cover and site conditions.

Moist sites supported a limited number of species. These include plants capable of rapid colonization and growth. Willows, alders, grasses (*Calamagrostis* sp.), and Horsetails (*Equisetum* sp.) are commonly found in wetter areas.

Cover values of 0–5% were found in areas characterized by very rapidly drained substrate conditions. Often these surfaces contained 6–27% macropore space, 0–16% fine material and slope angles of up to 63%.
Dredge tailings mounds are the only landform type which appeared to maintain these dry conditions. The surface layers of these tailings mounds contained a much greater proportion of larger sized mineral fragments than the material in the moist sites. Although pockets of fine grained material were present, they were much less abundant than in moister areas. Vertical heights of the micro- and meso-surface undulations were extreme on the dredge tailings, and are accentuated by the lack of any litter material accumulation.

Very dry sites supported few plant species. These included: lichens (*Cladina*, *Stereocaulon*), mosses (*Polytrichum*), small shrubs (*Rubus*, *Salix*), and trees (*Betula*, *Populus*). The degree to which these species may alter their environment is limited as a result of their ability to colonize only in those areas of the tailing that contained clumps of fine material on the surface. Often these clumps were widely separated, preventing any degree of cover or canopy closure, thus inhibiting litter accumulation and succession. For example, many older tailings (40–60 years) contained sparse, even aged 50 year old birch stands. Often there were few, if any younger trees growing beneath the older birch indicating that the stands were not regenerating as of yet.

Medium sites contained a wide range of site conditions, and vegetation response was highly variable. Generally, landforms containing mesic to dry conditions included: cat mining mounds, overburden piles, dredge tailings intermounds, hydraulic tailings fans and benches, some dredge tailings mounds, and cleared areas. It was within these intermediate areas where adjacent vegetated areas may have had the most influence on vegetative composition. Interactions between colonizing plant species become increasingly complex as site age increases. Eventually, the
vegetation begins to modify the site, producing a more favorable medium for growth.
5.1 FACTOR PARTITIONING

Results of the partitioning process for each of the seven tree species are illustrated in figure 17.

The proportions of influence of the four partitions was quite variable, with none resembling the distribution determined for that of total vegetation cover (section 4.2). Of the spatial and temporal factors partitioned, the influence of site age appeared to be most variable between the seven species. At one extreme, 51.7% of the variability in alder (*Alnus crispa*) cover was associated linearly with variation in site age. This may be a result of the relatively narrow range of site conditions in which alder was found compared to other trees. Also, alder is a rapid colonizer, often growing to maturity within the 85 year site age range. At the other extreme, site age has little influence on the abundance of many of the tree species. Results for feltleaf willow (*Salix alaxensis*), little tree willow (*Salix arbusculoides*), paper birch (*Betula papyrifera*), white spruce (*Picea glauca*), and cottonwood (*Populus balsamifera*) indicated that 0.8 to 3.1% of the variation in their cover was associated with variation in site age. Individual tree species characteristics are discussed in section 5.2 and 5.3.

Site environmental factors including substrate conditions and local climate appear to have little influence on the variation in tree species cover. Substrate conditions accounted for a maximum of 5.9% (little tree willow) of tree cover variation. This insignificant correlation may be due to the wide range of site conditions in which these species were found. The analysis also revealed that white spruce is somewhat influenced by local
Figure 17. Factor partitioning for 7 major tree species on mined land. In a clockwise direction, the partitions represent: 1) The influence of site age, 2) The influence of site substrate conditions, 3) The influence of local climate, and 4) The influence of unmeasured factors. The relative diameter of each pie chart represents the maximum cover value of each tree species as indicated in the parentheses.
climate (20% explained variation). Unlike other species, spruce did not appear on sites which sloped steeply towards the north.

The proportion of variation in tree cover values explained by unmeasured factors was relatively high for all species, ranging from 44.7% (alder) to 97.1% (birch). Insight into the nature of the unidentified factors may be gained by considering qualitative information recorded during the sampling program. These observations relate to the vegetative composition of areas adjacent to the site, evidence of active erosion, and variability in soil chemical conditions both within and between sites.

Little more information may be derived from the partitioning process. However, the analysis does indicate that management of mined land using materials handling techniques to modify site conditions, may have little influence on site tree species composition (0.4 to 5.9% variation explained), unlike the influence on total vegetation cover (48.8% variation explained). Using additional analyses, section 5.3 and 5.4 discuss this issue in more detail.

5.2 AGE CLASS ANALYSIS

Figure 18 illustrates the results of the Analysis of Variance for the age-cover groupings of the seven tree species.

The analysis revealed that alder was the only species in which cover values could be grouped within distinct age class boundaries. 70.2% of the variation in alder cover was accounted for by between age class cover values, or by the effect of site age. These results are in general agreement with the factor partitioning analysis (section 5.1) which showed that 51.7% of the variation in alder cover is associated with variation in site age.
Figure 18. An analysis of within and between variance of cover values for 3 age classes of 7 tree species. The first partition to the right represents the influence of between differences in site age classes. The remaining 3 partitions represent the proportions of influence accounted for by each age class (within variation). The relative diameter of each pie chart represents the maximum cover value of each tree species as indicated in the parentheses.
Aspen also showed a relatively high proportion of between-age class variation (30.1%). However, only the late age class may be considered significantly distinct ($p < 0.01$).

Analysis of the remaining five tree species showed no age class differentiation. This analysis confirms the conclusions drawn from the results of the factor partitioning process, indicating that tree growth cannot be related to site age of mined land. This finding dispels the commonly held notion that vegetation will eventually return to any disturbed site if left for a period of time (up to 85 years!).

Despite the lack of age class distinction, further analyses of the distribution characteristics of the seven tree species was performed. Scatter diagrams were described for age classes, although not distinct, that account for the highest percentage of variation in cover.

### 5.3 SPECIES DISTRIBUTIONS

Scatter diagrams were produced for the selected age classes of each of the seven tree species. Each graph illustrates the relationship between tree cover and gradients of site substrate conditions (section 4.1) and solar radiation (section 3.2.1.1).

#### 5.3.1 ALDER

The scatter diagrams in Figure 19 include all three age classes as alder was the sole tree species which showed any correlation between site age and tree growth. Both graphs showed a clear pattern of increasing cover between each successive age class. Alder reached a maximum cover value of 69% in the oldest class.
Figure 19. Graphs illustrating the relationships between alder cover and gradients of site conditions (defined in section 4.1) and solar radiation (defined in section 3.2.1.1) for three age classes.

The distribution of alder over the environmental gradients does not appear to change significantly between the site age classes. Minor
shifts are visible, however more samples are required to make statements with any degree of confidence.

Generally, alder grew within a moderate range of conditions. Usually they could be found on sites containing greater than 16% fine material, up to 6% macropore spaces, and in imperfectly to rapidly drained conditions. Alder was observed on slopes ranging from 0 to 95%. Local climate appeared to have little influence on alder growth as the species was found on most slopes and aspects. However, alder was not common on steep, south facing slopes.

Field observations indicated that alder may occur in slightly wetter conditions on early age class sites compared to the mid-age sites. Being a rapid colonizer, the species is abundant and establishes quickly (Neiland and Viereck 1977). However, in time other moist environment species such as willows, sedges and grasses may eventually dominate the site, eliminating alder.

Mid-age class sites supporting alder also appeared to contain a slightly narrower range of substrate conditions. It was noted that most of the hydraulic tailings fans were dominated by alder. On these particular sites, fine material content varied between 16 and 40%, with most sites being sandy textured and rapidly drained. Figure 20 shows a typical hydraulic tailings fan dominated by dense alder growth. Other researchers have observed that alder requires a mineral soil seedbed and can develop rapidly on moist sites (Viereck and Little 1972).

Maximum cover values occurred in areas that received a constant supply of moisture. Reaching 4.8 m in height, with density values of 6.0 stems/100m² and dominance values of 236.0 cm²/100 m², the largest growth of alder was recorded at the toe of a hydraulic face
Figure 20. Hydraulic tailings fan dominated by alder growth. abandoned 58 years ago. Also, it grows on soils too sterile for other trees. These characteristics may provide insight as to why hydraulic tailings fans are dominated by alder. These sites contain perhaps the most thoroughly washed material of any of the mining landforms. The washed gravel is devoid of organic matter and probably nutrient poor.

In addition, alder acts as a nurse tree, improving soil conditions, and adding organic matter and nitrogen. As a result, white spruce is appearing through the alder cover on many of the mid to late age sites.

5.3.2 ASPEN

Mid and late age class sites accounted for 68.9% of the variation in aspen cover. Cover values within these two age classes were considered distinct from each other, and the early age class was
The scatter diagrams in Figure 21 indicate that the relationship between aspen cover and site conditions shifted to some degree between the two age classes. Aspen distribution in the mid-age class is concentrated between 1.5 and 3.5 on the site condition gradient. Conditions ranged from well drained to very rapid drainage, 0–13% macropore space, and 10–50% fine material content. Cover values were low in this age class, seldom reaching 15%.

Conversely, aspen distribution in the late age class appeared to shift towards moister conditions. This shift was associated with higher cover values, reaching a maximum of 61%. The distribution was concentrated between 0.5 and 2 on the site condition gradient. This indicated that surviving aspen stands are most often found on imperfectly to well drained soil containing 50–100% fine material and 0–2% macropore spaces.

Often, older sites contained dense, pure stands as aspen frequently propagated by suckers from roots. Figure 22 demonstrates the ability of aspen to form stands on tailings piles. This particular site contained the highest concentration of aspen found on any of the disturbed sites. Stand density was 44.6 trees/100 m², and dominance reached 4204.3 cm²/100 m². The average aspen height was 7.3 meters.

Aspen is considered an invader species, and it's success as an early arriver is due to the copious production of short lived, wind disseminated propagules (Rowe 1983). Once established, they usually flower and fruit rapidly or spread vegetatively.

Variation in aspen distribution over the local climate gradient was not apparent between age classes. The species was common on
Figure 21. Graphs illustrating distributions of aspen cover over gradients of site substrate conditions and local climate as expressed by solar radiation intensities. Distributions within two age classes are scattered.

most slopes and aspects. However, aspen was uncommon on moderate
to steep north facing slopes. Aspen is thought to be an edaphic
Figure 22. A dense, pure stand of aspen has colonized this tailings pile on Whiskey Hill.

climax species on the steeper, south facing slopes of central Yukon (Stanek et al 1981).

5.3.3 PAPER BIRCH

Paper birch occurred over a wide range of site conditions. Figure 23 illustrates the width of birch distribution on gradients of site substrate conditions and local climate. Mid-age class sites (30–53 yrs.) were used in the scatter diagrams. Despite the small proportion of variation in birch cover associated with variation in site age, species distribution or habitat breadth was most predictable on mid-age class sites.

Birch is also an early arriver on disturbed land due to the copious production of short lived, wind-disseminated propagules. On undisturbed sites, it is best developed on warm slopes with porous
Figure 23. Graphs illustrate the distribution of birch over site substrate conditions and a gradient of local climate.

soils, but is also common on cold, north slopes (Viereck et al 1972).

As well, it may grow on rocky soil and even on organic soil
associated with peat (Eulert and Hernandez 1980).

On sites disturbed by mining, birch was found within a wide range of conditions, extending from 0.1 to 5 on the site condition gradient. Conditions range from poor to very rapid drainage, 0 to 22% macropore space and 30 to 100% fine material content. Birch was found on most slopes and aspects, although steeper, south facing slopes usually contained lower cover values.

Maximum cover (53%) was found on rapidly drained, coarse textured sites. Figure 24 shows a dense stand of birch growing on a site disturbed by mining at the turn of the century. The average height of birch on this site was 12.8 meters, stand density was 6.1 trees/100 m², and dominance was estimated to be 2273.9 cm²/100 m².

Increasing macropore space appeared to inhibit birch growth at the high end of the substrate condition gradient. For example, large increases in growth were observed on those dredge tailings where roads had been placed upon the mound tops. The compacted tailings resulting from road construction contained macropore spaces of 5 to 8% compared to the uncompacted portions which often contained up to 27% macropore space.

At the wetter end of the condition gradient, competition from other species may have inhibited birch distribution. Paper birch has been rated as a species very intolerant to competition, although it may be slightly more tolerant than aspen (Eulert et al 1980). When overhead light is available, birch grows rapidly. Eventually, only those dominant individuals that make up the canopy layer survive.

Even aged stands were observed on many dredge tailings. Very few young birch appeared under the mature canopies, perhaps as a
Figure 24. A mature stand of birch growing on an old handmining area of Temperance Hill.

result of shade intolerance or possibly due to the lack of appropriate microsites for germination. Upon closer examination of birch growing in coarse textured dredge tailings, it was noted that trees were found only in those portions of the coarse material that contained clumps of finer soil on the surface. The frequency of these soil clumps appeared to dictate the density of birch stands on the tailings. Figure 25 shows a sparse stand of birch on coarse textured dredge tailings. Subsequent observations on litter accumulation under birch revealed
Figure 25. A sparse stand of birch on coarse textured dredge tailings. Stand density appears to be controlled by macropore void space size, that stand density may influence the quantity of organic matter accumulating over the tailings. Thus, no litter was found on spoil material supporting sparse stands of birch. This suggests that the current vegetation on these particularly coarse sites is not self-perpetuating. Few young trees were found under the 40 to 60 year old birch stands, indicating that succession is not taking place.

5.3.4 WHITE SPRUCE

Although white spruce is a major component of the boreal forest, it is not a dominant tree species on mined land in the Klondike to date. The graphs in Figure 26 confirm this, showing average cover values of 4 to 5%, with one site containing 40% spruce cover.
Spruce is not particularly well-suited as a "pioneer" species for several reasons. Often, they require prior modification of the ecosystem either by organic matter accumulation or shading, before they can invade by propagules and maintain themselves (Rowe 1983). In addition, maximum seed crop periodicity ranges from 10 to 12 years and the small winged seeds usually fall within 100 meters of the parent tree, although they can be carried up to 300 meters by wind (Zasada 1971).

On older sites, white spruce often appeared in; 1) the understory of cottonwood (*Populus balsamifera*) located in low, moist areas, 2) interspersed throughout alder thickets dominating the hydraulic tailings fans, and 3) invading the open forests of birch and aspen on tailings piles and cleared areas. Thus, spruce distribution was most predictable on the late age class sites where other species had modified the conditions. Figure 27 shows white spruce growing in the understory of an aspen stand. The area had been cleared and mined in 1930.

Spruce distribution over the site condition gradient was limited to the moist to mesic portion. They were found in poor to well drained soils, characterized by 0 to 4% macropore space and 30 to 100% fine material content. The best developed stands occurred on low, alluvial plains along major drainageways. Spruce stands, 60 to 70 years old, were found in areas cleared for dredging in the Klondike River valley. Trees on these sites reached heights of 25 m and D.B.H. of up to 70 cm. On old handmining sites upslope from the valley bottoms, spruce reached maximum density values of 3.9 trees/100 m², and dominance values of 787.5 m²/100 m². Few spruce were found on
Figure 26. Graphs illustrating the distribution of white spruce over environmental gradients of site substrate conditions and local climate, steeper north facing and drier south facing slopes.
5.3.5 COTTONWOOD

Cottonwood is also considered to be a pioneer species in the boreal forest (Rowe 1970). Great quantities of seed are produced almost every year and may be carried long distances by wind (Lutz 1956). Seed appears to germinate immediately after dispersal, dying if seedbed conditions are unfavorable. Lutz (1956) reported that cottonwood seedlings were abundant wherever mineral soil has been exposed and a seed source is present. It is a rapidly growing tree,
outgrowing aspen and birch on mesic to wet lowland sites, but often
gives way to aspen and paper birch on many upland sites where they
are better adapted (Eulert et al 1980). On upper slopes, young
cottonwood was observed on early and some mid aged tailings piles.
However, few late age sites in similar locations, supported the species
to any extent.

Cottonwood seedlings require continuous moisture. These
conditions occurred most frequently on lowlands with recent overflow.
Figure 28 shows a mature cottonwood stand located on an alluvial silt
deposit overlying dredge tailings. Perhaps the largest trees in all the
klondike can be found on these silt deposits. Cottonwood stand
densities of 8.6 trees/100 m² and dominance of 3847.7 cm³/100 m²
were measured on these sites. The largest trees grew to 50cm D.B.H.
and over 22m in height.

It was noted that the stands of large cottonwood were located
in areas where annual flooding and silt deposition has taken place.
However, species did not appear in areas where continual flooding
occurs, Salix species tend to dominate these poorly drained flood
sites. Figure 29 shows the distribution of cottonwood on environmental
gradients. It is evident that the species occurs over a wide range of
site conditions. The highest cover values were associated with
imperfectly drained soils which contained a high percentage of fine
material (the only major species associated with clay soils). Soil
textural class though, did not appear to be as important as an
abundant supply of moisture. The low relief, coarse textured dredge
tailings shown in Figure 30 are dominated by cottonwood. Conversely,
the species was virtually absent on tailings of higher relief, as depth
5.3.6 **WILLOW**

Of the eight willow species encountered on disturbed sites, feltleaf and little tree willow provided the highest percentage of cover (45 and 37% respectively). Figures 31 and 32 illustrate the extremely wide distributions characteristic to both these species on mid-age class sites. Willows were found on sites ranging across the entire

Figure 28. A mature stand of cottonwood growing in silt, deposited over dredge tailings.

to water supply was much greater.
Figure 29. Graphs illustrating the distribution of cottonwood along gradients of site substrate conditions and local climate.

substrate condition gradient.
Figure 30. Coarse textured tailings of low relief supporting cottonwood.

Highest cover values were associated with mesic to moist conditions. As well, both species exhibited a wide distribution along the local climate gradient. However, few willows were found on steep south facing slopes.

The largest willows were observed on slopes of dredge tailings-intermound areas where standing water was present. Ponds with fluctuating water levels and high silt content usually provided highly fertile conditions along the water line for willow. In addition, these areas also appeared to be prime sites for cottonwood establishment. However, continual flooding as evidenced by thick horsetail (*Equisetum*) ground cover and gleyed soil conditions probably inhibits their establishment.

Stand densities of 13.9 stems/100 m² and dominance estimates of 1647.9 cm²/100 m² were recorded for feltleaf willow on these
Figure 31. Distribution of feltleaf willow along gradients of site substrate conditions and local climate.

sites. Slightly lower values were estimated for little tree willow on the same site types. Some trees grew to over 27cm D.B.H. and 9m in
Figure 32. Distribution of little tree willow along gradients of site substrate conditions and local climate.

height, exceeding the dimensions observed by others in the boreal

(Viereck and Little 1972). The fast growing willows attained this size
in 25 to 30 years. A large amount of deadfall was observed on the
40 to 50 year old sites, indicating that the willows mature rapidly,
then die within this time period. Figure 33 illustrates the dense cover
provided by willows at the dredge tailings-interface.

Willow was also observed to grow rapidly in areas where
permafrost disturbances have occurred. The degrading permafrost
provides a continual supply of moisture, and supports vigorous growth.
However, long term willow establishment on permafrost disturbances
does not necessarily signify a reestablishment of thermal equilibrium
and associated soil stability. Figure 34 shows a recent slope failure
(1983) occurring on a permafrost site disturbed by mining in 1950. A
dense cover of 15 to 20 year old willows had little effect in
stabilizing the slope. Regardless of rooting depths and the amount of
thermal insulation the willow could provide, the slide was most likely
a result of water seepage from above the disturbance.

5.4 SITE CLASSIFICATION AND DESCRIPTION

The classification procedure was based on groupings of sites which
contained similar substrate conditions. Classes were distinguished by
identifying major gaps within the ranked 67 PCA scores. Six classes were
delineated, each containing the following dimensions (units refer to PCA
gradient scores):
- Class 1: wet (0.00 to 0.02) – 3 sites
- Class 2: moist (0.43 to 0.63) – 9 sites
- Class 3: mesic (0.88 to 1.52) – 15 sites
- Class 4: mesic to dry (1.66 to 2.50) – 29 sites
- Class 5: dry (2.95 to 3.97) – 6 sites
Figure 33. Fluctuating water levels causing silt accumulation on the coarse tailings, provide a fertile environment for willow growth.

- Class 6: very dry (4.41 to 5.50) - 5 sites

Appendix D is a summary table listing all species found on disturbed land (105), and their presence and mean cover values for each site class.

Species which had high presence values in all classes included the following:

1. Trees
   a. *Salix arbusculoides*
   b. *S. alaxensis*
   c. *S. bebbiana*
   d. *Betula papyrifera*

2. Shrubs
   a. *Rosa acicularis*

3. Herbs
   a. *Epilobium angustifolium*
Figure 34. Dense willow cover provided little long term protection from failure on this permafrost disturbance.

b. *Calamagrostis* sp.

4. Mosses
   a. *Hylocomnium splendens*
   b. *Polyblastia tristicula*

5. Lichen
   a. *Peltigera* sp.
   b. *Stereocaulon* sp.
   c. *Cetraria* sp.
   d. *Cladonia* sp.

These species were common on disturbed areas and thus, their presence did not appear to be influenced by: 1) the proximity of adjacent areas, and 2) The composition of the adjacent vegetation.
As discussed in the tree distribution analysis, birch and willow had wide distributions and were common to most disturbed sites. Both species were observed to recolonize areas rapidly. However, when it appeared that site conditions were not optimal and when other species from adjacent vegetated areas also arrived on site at an early period, birch and willow were unable to compete. Few older sites contained pure stands of either of these species.

5.4.1 **CLASS 1 - WET**

Class 1 contains three sites and a total of 52 species were identified. No species were entirely unique to class 1, however the following contained predominantly higher cover values within these wet site conditions:

- *Cornus canadensis*
- *Empetrum nigrum*
- *Equisetum sylvaticum*
- *Ledum palustre*
- *Vaccinium uliginosum*
- *Vaccinium vitis-idaea*
- *Salix glauca*
- *Clamagrostis canadensis*
- *Equisetum arvense*
- *Hylocomium splendens*

All sites were subjected to comparatively light disturbance activities, mainly clearing and overbunden stockpiling. Each is located within permafrost, thus the continual supply of moisture. Despite the abundance of moisture, no evidence of soil erosion was observed on
these fine textured sites. Adjacent vegetated areas surrounding all three sites consisted of a black spruce - moss - lichen association, which is commonly found in frozen areas.

The youngest (3 years) contained 48±20% cover, while the two older sites (33 and 38 years) had 85±11% and 100% respectively, indicating that on these wet sites high cover values are attained within 38 years.

5.4.2 CLASS 2 - MOIST

Class 2 contains 9 sites and a total of 63 species were identified. Again, no species were entirely unique to this class, although the following contained predominantly higher cover values within the moist site conditions:

1. Trees
   a. *Picea glauca*

2. Shrubs
   a. *Linnaea borealis*
   b. *Shepherdia canadensis*

3. Moss
   a. *Ceratodon purpureus*

The significance of these species shifted over time. The high cover values of *Ceratodon purpureus* appeared to decrease between the 2 and 3 year old sites and sites over 30 years. Conversely, *Linnaea borealis* and *Shepherdia canadensis* cover increased with site age, reaching maximum values on the oldest sites.

Adjacent vegetated areas were highly variable, with no sites surrounded by any distinct vegetation association. Many valley slopes
in the Klondike had been cleared or burned during the early part of this century. The resulting regrowth after 70 or 80 years consists of a highly complex mosaic of different associations.

In some cases, vegetated areas surrounding a site were dominated by species completely different from what had colonized the disturbed area. For example, overburden piles left on Gold Bottom Creek in 1950 contain a dense, pure stand of 27 to 30 year old aspen. However, the slopes of this narrow valley were dominated by black spruce, moss and lichen. This confirms observations made by Zasada (1971) who found that the long silky hairs attached to aspen seed allow dispersal over long distances. Conversely, other sites located long distances from vegetated areas were dominated by species whose seed dispersal distances are thought to be short. For example, the centre of the Klondike River valley contains areas disturbed by dredging activity at the turn of the century (1905). Small pockets or "islands" of white spruce were located, perhaps 500 to 600 meters from the valley slopes. These dense stands contained white spruce up to 75 years of age, measuring 60 cm D.B.H. and 24 meters in height. Zasada (1971), in a review of literature, found that 50 to 90% of the seed dispersed from the top of a 60-foot-tall spruce landed 90 and 210 feet, respectively, and only 2% travelled more than 300 feet. Seeds may have also arrived on site by floodwater as the Klondike river was redirected several times, or by animal or human means. These examples illustrate the complexities involved in attempting to identify the influences of adjacent vegetated areas in determining the vegetative composition of disturbed land. Rowe (1983) emphasizes the point that succession can never be successfully
predicted and modelled on the basis of autecological information alone, he stresses that:

Succession must be more than an autogenic process, for ecosystems are not closed.

and

each landscape ecosystem has an ecology that comprise the web of relationship with the ecosystems that surround it, as well as an internal physiology.

5.4.3 **CLASS 3 AND 4 - MESIC AND MESIC TO DRY**

These classes contained the majority of sites. Fifteen sites were grouped into class 3 and 29 into class 4. The classes contained a total of 71 and 91 species respectively.

Those species that predominantly occurred in class 3 include aspen and cottonwood. Alder and *Stereocaulon* sp. contained high importance values in class 4. The characteristics and distributions of these tree species have been discussed in section 5.3.

As discussed in the class 2 description, the influence of adjacent vegetated areas is highly complex. Factors that must be considered, pertaining to seed supply from adjacent areas, include the following (Zasada 1971):

1. tree age and seed production
2. ripening and dispersal of seed
3. quantity, quality, and dispersal distance of seed
4. periodicity of seed years
5. viable seed to seedling ratio
6. seedbed requirements
Considering the complexity of these factors once combined, it appears that chance plays a large role in determining what particular species initially colonizes a disturbed site, particularly on these mesis-type sites where many species are capable of germination and growth. The Tree Species Distribution analysis (section 5.3 and 5.4) was performed in order to identify changes in the habitat requirements of the seven tree species in the time period since site disturbance. Changes in distribution or habitat width over time confirm this notion of species randomness during the initial recolonization period. However, the analysis revealed that of the 7 species, only alder contained distinct age class groupings of cover values. Little change in alder habitat width was detected between the age classes. Further analysis will require an increased number of sites and older aged disturbances.

5.4.4 CLASS 5 - DRY

Class 5 contained 6 sites and a total of 39 species were identified. Differences in substrate conditions between site 4 and 5 were the largest of any of the classes. Conditions became much drier, with a large increase in macropore space and coarse fragment content. Sites included in this class were on coarse dredge tailings piles.

Birch is the only species that contained predominantly higher cover values in this class compared to others. Its characteristics are discussed in section 5.3. The influence of adjacent vegetated areas on these sites compared to sites in the mesic classes, is thought to be minimal. All dredged sites were located in valley bottoms, between 400 and 1000m from the valley slopes. Dispersal distances of birch seed are unknown, although Zasada (1971) states that considerable
quantities of seed may be carried further than two tree heights in strong winds. Aspen and cottonwood are also capable of travelling long distances, although they were not major species on these dry sites. It appeared that conditions within these extreme sites may be strongly dictating species composition regardless of species availability.

5.4.5 CLASS 6 - VERY DRY

Class 6 contained 5 sites and a total of 17 species were identified. Differences in substrate conditions between class 5 and class 6 were a result of increasing macropore space to between 13 and 22%, and decreasing fine material content to less than 5%.

Predominant species on sites in this class included Cladonia sp. and Cladina sp. Netleaf willow and birch could also be found on these sites. Their wide distributions are discussed in section 5.3.

Similar to class 5, the influence of adjacent vegetated areas appeared to be minimal on these extreme sites. Again, all are dredge tailings and are located in wide valley bottoms.
SUMMARY

Substrate conditions of the disturbed sites are best characterized by differences in soil drainage, the volume of soil macropore space, and slope angle. These variables reflect a gradient of both soil water holding capacity, and moisture supply. The influence of site conditions accounts for 48.8% of the variation in vegetation cover on the mined sites. Another 9.2% of this variation is a function of site age, and 9.8% is accounted for by local climatic conditions. The remaining 32.2% is due to unmeasured factors. These may include:

1. The ability of the adjacent vegetated areas to supply viable seed
2. The stability of substrate material as a result of wind or water erosion
3. The chemical composition of the substrate
4. Chance and Sampling error

Revegetation trends appeared to be more predictable at the extremes of the gradient representing mined site conditions. With site age partitioned, 70-100% vegetative cover was found over moist sites and 0-5% cover over the driest sites. Intermediate sites were observed to exhibit a wide range of cover values; between 5 and 80%.

The distribution of 7 major tree species appeared to be controlled by factors other than site age, substrate conditions and local climate. The influence of adjacent vegetated areas to provide seed appeared to be strongest in mesic-type sites where many species can germinate and grow.

The study area includes all major streams in the Klondike, extending south to the Indian River. Observations were also made in the Clear Creek area east of Dawson. Revegetation conditions here appeared similar to those found in the Klondike. However, further east towards Mayo, an
increase in precipitation rates may alter the natural revegetation potential from that of the Klondike. Further observations are required to determine the geographical extent to which the results of this study may be extrapolated.
REVEGETATION OBJECTIVES

Most northern revegetation research has been directed towards selecting species and fertilizer combinations to provide a relatively rapid cover of agronomic grasses (Peterson and Peterson 1977; Johnson and VanCleve 1976). However, according to Younkin (1976):

"This research has shown that revegetation alone can not prevent or significantly retard thermal erosion after destruction of the natural insulative mat, and also that a dense cover of agronomic grasses on disturbed areas can inhibit the reestablishment of a better adapted and more ecologically desirable native vegetation."

This study has shown that rehabilitation objectives can be more effectively identified if an understanding is gained of the natural recovery processes of any disturbed area.

Results indicate that land disturbed by mining can be abandoned in conditions that will promote high levels of natural revegetation and soil stability. Adjacent areas are capable of providing seed to the disturbed sites and these sites, if left within an identified range of conditions, may support up to 100% vegetation cover. Therefore active seeding and fertilizing programs are not necessarily required for revegetation of mine spoil in the Klondike. The study has shown that although many unrevegetated disturbances remain visible in the Klondike, these represent the harshest conditions created by mining activities. There is a large proportion of disturbed land that has revegetated and is no longer recognizable from a distance.
MANAGEMENT INTERPRETATIONS

Based on the information derived from the preceding analysis, the following management considerations are suggested. These refer to the conditions which present mining operations should be left in, to promote optimal natural revegetation.

In addition, Appendix C provides a management guide for the identification of mined land rehabilitation objectives appropriate for post mining resource uses in the Klondike area. This framework may be used to determine rehabilitation objectives providing it is supplemented with site specific information pertaining to:

1. the nature and extent of the disturbance,
2. the designated post mining land use, and
3. the characteristics of the environmental features affected by mining.

A) SITE AGE CONSIDERATIONS

Site age has little influence on the amount of vegetation over disturbed land in the Klondike. However, older sites with little vegetative cover are generally coarse textured. They do not appear to contribute to soil loss and water quality problems. Revegetation of these coarse textured sites will require specific treatment to meet desired land-use goals.

B) SITE CONDITION CONSIDERATIONS

1.

Improvement in substrate moisture holding capacity may increase the revegetation potential of placer mined land. This can be accomplished by compacting coarse material; reducing macropore
void-space to 5% or lower. Also, slope surfaces should be recontoured to a minimum angle, preferably less than 30%, and fine material content (% fine sand, silt and clay) should be 50%, or greater.

2.

Revegetation of disturbed land is also dependent upon the amount of moisture supplied by precipitation, or more importantly (due to low rainfall rates), subsurface seepage and groundwater. Improved moisture supply may be promoted by controlled flooding of coarse textured material in valley bottoms. This procedure promotes siltation and accumulation of fine material, which will improve substrate moisture holding capacity. In addition, mounds of coarse material may be levelled and recontoured to reduce the depth to water supply for plant roots.

C) OTHER CONSIDERATIONS

1.

Generally, adjacent vegetated areas are capable of providing seed to mined land in the Klondike. Thus, active seeding and fertilizing programs are not necessarily required for revegetation of these areas. This high degree of vegetation resiliency is unique to northern areas and cannot be related to that of southern Canada. It is believed that the increase in fire frequency associated with northern areas is the reason for this phenomenon. Carleton and Maycock (1978), in a study on the effects of fire, observed that deforested sites in northern regions become reforested more rapidly and extensively than those in southern forest regions. Shafi and Yarranton (1973) suggest that
evolutionary pressures in a repeatedly disturbed environment have resulted in species adapted for rapid growth and reproduction. Considering these differences in natural revegetation potential, vegetation management of mined land in the Klondike should not necessarily be based on criteria used for southern mining situations.

2.

Soil movement may reduce the revegetation potential of disturbed sites. Two types of soil instability problems were observed to inhibit plant propagation and growth:

a. Degrading permafrost in excavations can provide excessive moisture on slopes, and promote sliding of soil material. Where permanently frozen ground has been disturbed, slope angles should be reduced to enable moisture to penetrate the surface. Adequate drainage pathways may also be required to drain water from the thawed material.

b. Fluctuating stream levels appear to contribute to instability problems in valley bottoms where spoil material has not been recontoured and sufficient channel stabilization established. Stream bank erosion inhibits vegetation establishment and may often contribute sediment to the stream. In contrast, on uphill sites sheet and gully erosion does not appear to cause significant substrate instability problems. Low precipitation rates, in combination with the well drained alluvial material associated with the mining areas, promote little surface overland flow of water.
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List of sample sites according to creek location, local name, mining landform type and age since abandonment.

Key to mining landform abbreviations:

<table>
<thead>
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<th>LANDFORM</th>
<th>ABBREVIATION</th>
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Lists of vascular, bryophyte and lichen taxa growing on mined land.

**BOTANICAL NAMES**

**VASCULAR TAXA:**

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<th>Common Name</th>
<th>Botanical Name</th>
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<td>Achillea borealis Bong. Achillea lanulosa Nutt.</td>
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<td>Agropyron subsecundum (Link) Hitchc. Agropyron violaceum (Hornem.) Lange</td>
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<td>Agrostis scabra Willd.</td>
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<td>Alnus crispa (Ait.) Pursh.</td>
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<td>Alnus sinuata (Reg.) Rydb.</td>
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<td>Thinleaf Alder</td>
<td>Alnus tenuifolia Nutt.</td>
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<td>Antennaria rosea Greene Ted.</td>
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<td>Artemisia tilesii Ledeb. subsp. elatior (Torr. &amp; Gray) Hult.</td>
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<td>Astragalus alpinus subsp. alpinus L.</td>
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<td>Beckmannia eruciformis (L.) Host subsp. baicalensis (Kuzn.) Hult.</td>
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<td>Betula glandulosa Michx.</td>
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<td>Calamagrostis canadensis subsp. langsdorffi (Link) Hult. (Michx.) Beauv.</td>
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<td>Strawberry Blite</td>
<td>Carex rhynchophyssa C.A. Mey</td>
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<td>Fireweed</td>
<td>Crepis elegans Hook.</td>
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<td>River Beauty</td>
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<td>Deschampsia caespitosa (L.) Beauv.</td>
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<td>Dryas octopetala L.</td>
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<td>Dryopteris fragrans L. Schott</td>
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<td>Galium trifidum L.</td>
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BOTANICAL NAMES

Populus balsamifera L.
Populus tremuloides Michx.
Potentilla fruticosa L.

Pyrola asarifolia Michx. var. purpurea (Bunge) Fern.

Ribes glandulosum Grauer
Rorippa hispida (Desu.) Britt.
Rosa acicularis Lindl.
Rubus arcticus L. subsp. acaulis (Michx.) Focke
Rubus chamaemorus L.
Rubus idaeus L. subsp. melanolasius (Dieck) Focke
Salix alaxensis (Anderss.) Cov.
Salix arbusculoides Anderss.

Salix barclayi Anderss.
Salix bebbiana Sarg.
Salix glauca L.
Salix monticola Bebb
Salix planifolia Pursh subsp. pulchra (Cham.) Argus

Salix scouleriana Barratt
Saxifraga tricuspidata Rottb.
Sheperdia canadensis (L.) Nutt.
Solidago decumbens Greene var. orephila (Rydb.) Fern.
Spiraea beauverdiana Schneid.
Stellaria longipes Goldie
Taraxacum ceratophorum (Ledeb.) DC.
Trifolium hybridum L.
Trisetum spicatum (L.) Richter
Vaccinium uliginosum L. subsp. alpinum (Bigel.) Hult.
Vaccinium vitis-idaea L. subsp. minus (Lodd.) Hult
Viburnum edule (Michx.) Raf.

BRYOPHYTES:

Aulacomnium palustre (Hedw.) Schwaegr.
Aulacomnium turgidum (Wahlenb.) Schwaegr.
Brachythecium albinans (Hedw.) B.S.G.
Ceratodon purpureus (Hedw.) Brid.
Dicranum angustum Lindb.
Dicranum muehlenbeckii B.S.G.
Drepanocladus uncinatus (Hedw.) Warnst.
Funaria hygrometrica Hedw.
Hylocomium splendens (Hedw.) B.S.G.
Hylocomium splendens (Hedw.) B.S.G. var. splendens
Leptobryum pyriforme (Hedw.) Wils.
Mnium rugicum Laur.
Pleurozium schreberi (Brid.) Mitt.
Polytrichum commune Hedw.
Polytrichum piliferum Hedw.
Polytrichum strictum Brid.
Ptilium crista-castrensis (Hedw.) De Not.

COMMON

Balsam Poplar
Quaking Aspen
Shrubby
Cinquefoil
Liverleaf
Wintergreen
Skunk Currant
Yellow Cress
Prickly Rose

Cloudberry
Raspberry
Feltleaf Willow
Little Tree
Willow
Barclay Willow
Bebb Willow
Grayleaf Willow
Park Willow
Diamondleaf Willow
Scouler Willow
Prickly Saxifrage
Soapberry
Goldenrod
Alaska Spiraea
Chickweed
Dandelion
Alski Clover

Alpine Blueberry
Lingonberry
High Bush
Cranberry

Step moss
Feather moss
Hair-cap moss

Knight’s plume
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MINED LAND REHABILITATION OBJECTIVES FOR THE KLONDIKE AREA

A MANAGEMENT FRAMEWORK
INTRODUCTION

Existing legislative framework in Yukon Territory gives placer mining clear priority in any conflict over the use of a particular parcel of land. The Placer Mining Act and the Territorial Lands Act enable land and water resources to be freely open to placer mining. In conflicts over the use of particular rivers or streams of Yukon, reliance has primarily been placed on the Canada Fisheries Act to protect the associated land, water and biological resources. However, due to a priority given this single purpose environmental resource use, stabilization and rehabilitation of mined land for other resource considerations, beyond broad fisheries concerns, has not been required to date (Fox, Eyre and Mair 1983).

Placer mining activity generally involves the direct disturbance of four main environmental features. These include soil, vegetation, water and stream channels (Hardy Associates 1978; EPA 1979). These features are also components of other environmental resources now considered valuable by the people of Yukon and Canada (Placer Guidelines Review Committee 1983). Specifically, three types of resource uses are being affected by placer mining; terrestrial wildlife, fishing, and recreation.

Achievement of post mining use of environmental resources in Yukon requires that mined areas be considered for resource values other than, or in addition to placer gold content. The significance of the effects of mining on these other resource values varies from situation to situation, depending on the size and nature of the fish and wildlife affected, the importance of the recreation values, and the degree of impact of the mining activity. As a result of recognizing post mining resource uses in mining areas, mined land rehabilitation techniques must be developed that will maintain features of the environment in a condition such that other resource values may be considered.

The purpose of this appendix is to provide a management framework for the identification of mined land rehabilitation objectives appropriate for the post mining resource uses in the Klondike area. This analysis provides a working framework for mining companies to determine rehabilitation goals which are to be included in the premining development plan (Placer Guidelines Review Committee 1983). It also aids regulatory agencies in identifying rehabilitation requirements, based on resource values, for specific situations.

Land management technologies, in areas of erosion control, revegetation, streamside stabilization and wastewater treatment, have been sufficiently developed and are readily available for northern areas (Peterson and Peterson 1978; Johnson and Vancleve 1976). However, techniques alone are not enough. The best techniques, unless guided by a clear understanding of the environmental and political context under which they are to be applied can turn solutions into larger problems (Beanlands and Duinker 1983).

First, this paper identifies the physical, chemical and biotic components that are directly affected by placer mining activities and establishes their environmental significance. Secondly, rehabilitation goals are stated in the context of maintaining each environmental factor in a condition such that post mining resource values are considered. At this point in the analysis, environmental issues related to land rehabilitation in the Klondike area are clearly identified. Thirdly, terminology used to state rehabilitation goals is defined. These terms include both the structural and functional aspects of each environmental factor. Finally, using these
definitions, rehabilitation goals are translated into specific rehabilitation objectives appropriate to the Klondike. Figure A illustrates the steps followed in developing this management framework for rehabilitation. It should be noted that these objectives require further specification at the site specific level.

Prior to discussing the framework used to identify rehabilitation objectives, the meaning of the term rehabilitation must be clearly defined. The definition suggested by the National Academy of Sciences (N.A.S. 1974) in their estimation of rehabilitation potential of western United States coal lands is adopted for the context of this framework.

"Mined land rehabilitation means that the disturbed site will be returned to a form and level of productivity that conforms with a prior post mining land use plan. It implies that a stable ecological state will be established that will not deteriorate substantially with the projected land use. It also suggests that the area does not contribute to environmental deterioration and that it must be consistent with surrounding aesthetic values. This view of mined land rehabilitation allows the disturbed landscape to be altered for land uses other than the one that was in effect prior to disturbance."
MANAGEMENT FRAMEWORK

PRIMARY REHABILITATION OBJECTIVES

Scope and definition of goals for placer mining disturbances in the Klondike area.

REHABILITATION GOALS

Rehabilitation for post mining land use.

DISTURBED ENVIRONMENTAL COMPONENTS: SOIL, VEGETATION, WATER, STREAM CHANNELS

Includes context features

DISTURBED NATURAL ENVIRONMENT

Viewed within a context

MINED LAND REHABILITATION

Necessitates

MINING DISTURBANCES

Figure A. Steps in the development of a management framework used to identify rehabilitation objectives for the Klondike area.
ENVIRONMENTAL COMPONENTS AFFECTED BY MINING

Viewed from an ecological perspective, placer mining activities directly alter specific structural components of the affected ecosystem. As a result of the geologic nature and location of placer mining in Yukon, these components include; 1) soil (and overburden material), 2) vegetation, 3) water, and 4) stream channels. The addition, removal or redistribution of these features may result directly or indirectly in a net loss or gain of their value as a resource.

Identification of the nature and extent of the impacts resulting from placer mining activity aids in determining those environmental components requiring consideration in the rehabilitation process. Table A. summarizes rationale for the establishment of each environmental component.

The significance of the changes in these environmental components may be considered in various ways. First, ecosystem components may be regarded as having no intrinsic value. Thus, they are only ascribed value to the degree that they are required by man. For example, terrestrial wildlife, fishing and recreation are other resources or resource uses that are recognized as having value in Yukon. These resources are also composed of environmental features affected by mining processes. Secondly, the ecological significance of mining activity to the loss or alteration of ecosystem components must be considered in terms of specified temporal and spatial boundaries. This includes the duration of the impact, and the size and location of the areas affected. The estimation of impact significance will not be considered in this discussion.
EFFECT OF MINING ACTIVITY ON ENVIRONMENTAL COMPONENTS

1) SOIL COMPONENT:
- Soil and overburden material are removed and redistributed.
- Fine soil is washed out of gold bearing material.

2) VEGETATION COMPONENT:
- Vegetation is destroyed where terrain is cleared and excavated.

3) WATER COMPONENT:
- Mining activity occurs in, or in close proximity to water courses.
- Water flows through disturbed areas from a non-point source.
- Water is discharged from point sources: sluicing and settling ponds.

4) STREAM CHANNELS:
- Mining activity occurs in, or in close proximity to water courses.
- Stream beds and banks may be mined or disturbed.
- Stream channel condition may influence non-point source effluent standards (water quality).

Table A. Identification of the nature of the impacts resulting from placer mining activity on components of the environment.
REHABILITATION GOALS

When benefits of placer mining are compared to the benefits of competing resource uses and values, rehabilitation goals must be considered in the context of maintaining environmental features in a condition such that post mining resource values may be considered. Each environmental component directly affected by mining is viewed as a resource with post mining values. Potential rehabilitation goals for the maintenance of these values are stated below. Underlined terms in each of the stated goals are discussed to provide scope and definition to the rehabilitation activities.

1) SOIL RESOURCE

Goal-1: To produce soil conditions which provide protection against soil erosion equivalent to, or better than premine conditions.

Soil conditions are defined as the chemical and physical properties of soil. These include texture, coarse fragment content, drainage characteristics etc. Erosion refers to the wearing away of the land surface by detachment and transport of soil and rock materials caused by the action of moving water, ice, wind, and other geological agents. The amount of erosion that may occur is expressed as a percentage of the surface soil eroded, ranging from less than twenty-five percent (slight erosion) to greater than seventy-five (severely gullied) (CanSIS 1982). The level of protection against erosional forces and soil loss is expressed in terms of the erodability potential of a given soil material.

Soil loss from gully, rill or sheet erosion can affect the water quality in downhill watercourses, decrease the aesthetic value of the area and prevent other land use activities from taking place due to unstable conditions.

Goal-2: To produce soil conditions which support the desired vegetation structure

Vegetation structure refers to the organization, in space, of the individuals that form a stand and may be expressed in terms of lifeform (physiological class), biomass (kg/m-sq.) and floristic structure (species composition).

Vegetation composition and cover values are important considerations for wildlife habitat, prevention of soil loss and the aesthetic quality of the post mining area.

2) VEGETATION RESOURCE

Goal-1: To establish a level of vegetative ground cover which provides protection from soil erosion equivalent to, or better than premine conditions.

Vegetative ground cover is defined as the vertical projection of the crown or the shoot area of a species to the ground surface expressed as a fraction or percentage of a reference area.

Vegetation cover protects soil from rainsplash impact, and reduces soil loss by absorbing overland flow. As well, plant roots bind soil together.

Goal-2: To maintain vegetation which is capable of regeneration under natural conditions prevailing at the site.
Regeneration refers to plant reproduction and is measured in terms of production (kg/m²) or ground cover (%/area). Natural conditions refer to the unaltered and unmaintained conditions of a mined area upon abandonment.

Achievement of this goal will reduce site maintenance costs, prevent land degradation and ensure post mining land use objectives. As well, productive wildlife habitat may be considered.

Goal-3: To promote the establishment of a vegetation structure which is compatible with the designated post mine land use.

Post mining land use refers to the predetermined use of environmental features of the mined area after mining activity has ceased. The selection of a post mining land use is a critical element in the evaluation of rehabilitation success.

3) WATER RESOURCE

Goal-1: To maintain a desired standard of water quality flowing from disturbed areas.

Standard of water quality refers to the allowable amount (mg/l) of suspended solids (as measured over the background levels found in the stream, upstream of mining activity). In addition, temperature (°c), turbidity (JTU's), dissolved oxygen (mg/l), and arsenic (mg/l) levels may also be considered (EPA 1979).

Goal-2: To maintain a desired quantity of water in disturbed stream channels.

Water quantity refers to the volume or depth of water at any given point along a stream course and is measured as discharge (m³/sec) or by the wetted perimeter of the stream. The continuous or intermittent nature of flow regimes in snowmelt areas requires additional consideration.

Maintaining both water quality and quantity standards are important considerations in the rehabilitation process due to their effects on; the fisheries resource, supply for human consumption, flooding, and recreation use. These two goals are currently the most important rehabilitation concerns due to the impact of placer mining in valley bottoms and the value placed on the local fishery resource (Placer Mining Guidelines Review Committee 1983).

4) STREAM CHANNEL RESOURCE

Goal-1: To maintain the physical stability of disturbed stream channels during expected peak stream flow events.

Substrate stability is defined as the equilibrium state between bed and bank material texture, structure and chemical nature, and the average flow velocity. It is measured by changes in water quality, and stream width and depth. Peak stream flow events refer to those periods when discharge rates are at a maximum. This occurs during high runoff periods as a result of snow melt or high precipitation rates.

Maintaining stream channel stability ensures desired water quality, flood prevention, stable fish habitat and promotion of the aesthetic qualities of a given stream course.
3) REHABILITATION OBJECTIVES

To ensure that stated rehabilitation goals for placer mining are achieved, specific objectives must be developed, based on the unique environmental conditions of the Klondike area. Consideration of these conditions enable general rehabilitation goals to be translated into specific rehabilitation objectives appropriate for the area and its associated resource uses.

Each rehabilitation goal for soil, vegetation, water and stream channel resources is translated into a hierarchical series of objectives. These are sequenced in order of required completion and are referred to as; 1) description objectives, 2) standards objectives, and 3) prescription objectives.

1) Description Objectives:
   - The Characterization of each environmental component as it relates to mining impacts and the scope of associated rehabilitation goals. Specific relationships unique to the Klondike are identified.

2) Standards Objectives:
   - Based on characteristics of each of the environmental components that have been identified and the designated post mining land use of the area being disturbed. Rehabilitation standards and levels for each impact parameter are established.

3) Prescription Objectives:
   - Based on rehabilitation standards and levels. Specific rehabilitation methods are developed for the Klondike area.

Completion of this hierarchical series of objectives is necessary in order to identify the specific requirements for local rehabilitation activity. However, due to their site specific nature, each of the objectives cannot be fully defined in operational terms in this appendix.
1) SOIL RESOURCE

Goal-1 To produce soil conditions which provide protection against soil erosion equivalent to, or better than premine conditions.

1-1) DESCRIPTION OBJECTIVE: To study characteristics of soil which relate to erosion potential (surficial geology, texture, structure).

1-2) STANDARDS OBJECTIVE: To determine the extent of soil loss from erosion of different types of soil material and different site conditions (e.g., under premine conditions).

1-3) PRESCRIPTIVE OBJECTIVE: To determine rehabilitation activities which will provide the desired level of protection from erosion in each mining situation.

Goal-2 To produce soil conditions which will support desired vegetation structure.

2-1) DESCRIPTION OBJECTIVE: To study undisturbed vegetation and soil-vegetation relationships in the Klondike area.

2-2) STANDARDS OBJECTIVE: To determine soil conditions which best support desirable vegetation structure.

2-3) PRESCRIPTION OBJECTIVE: To determine rehabilitation methods which will provide desirable soil conditions.

2) VEGETATION RESOURCE

Goal-1 To establish a level of ground cover which provides protection from soil erosion equivalent to, or better than premine conditions.

1-1) DESCRIPTION OBJECTIVE: To study characteristics of vegetation which relate to rainfall interception and ground cover qualities.

1-2) STANDARDS OBJECTIVE: To determine the amount of
vegetative cover and/or biomass required to protect different soil types from wind and water erosion.

1-3) PRESCRIPTION OBJECTIVE: To determine revegetation methods (assisted or unassisted) which will provide desirable erosion protection.

Goal-2 To maintain vegetation which is capable of regenerating under natural conditions prevailing at the site.

2-1) DESCRIPTION OBJECTIVE: To study soil-vegetation relationships in disturbed areas.

2-2) STANDARDS OBJECTIVE: To determine on and off site conditions which may promote desirable vegetation.

2-3) PRESCRIPTION OBJECTIVE: To determine rehabilitation methods which will help establish stable vegetation cover.

Goal-3 To promote the establishment of a vegetative structure which is compatible with the post mining land use.

3-1) DESCRIPTION OBJECTIVE: To identify vegetation structure and composition associated with land uses in the Klondike.

3-2) STANDARDS OBJECTIVES: To determine the class of lifeform, amount of biomass, and diversity of species required for each type of land use.

3-3) PRESCRIPTION OBJECTIVE: To determine revegetation methods for the establishment of the desired vegetation structure.
3) WATER RESOURCE

Goal-1 To maintain a desired standard of water quality flowing from or through land disturbed by mining.

1-1) DESCRIPTION OBJECTIVE: To classify streams according to their use (e.g., fish, recreation, human consumption, etc.).

1-2) STANDARD OBJECTIVE: To determine the standard of water quality required to maintain each stream type.

1-3) PRESCRIPTION OBJECTIVE: To develop rehabilitation methods which can be used to maintain the required water quality standards.

Goal-2 To maintain a desired quantity of water in stream channels disturbed by mining.

2-1) DESCRIPTION OBJECTIVE: To classify streams based on use.

2-2) STANDARDS OBJECTIVE: To determine the quantity of water (stream depth or flow rate) required for each stream use.

2-3) PRESCRIPTION OBJECTIVE: To determine rehabilitation methods which can be used to maintain the desired quantity of water in streams disturbed by mining.

4) STREAM CHANNEL RESOURCE

Goal-1 To maintain the physical stability of disturbed stream channels during expected peak flow periods.

1-1) DESCRIPTION OBJECTIVE: To study characteristics of the watershed related to runoff/flowrate relationships, and the texture, structure and chemical nature of stream bed and bank material.

1-2) STANDARDS OBJECTIVE: To determine the level of stream bed
and bank stability for the watershed of concern.

1-3) PRESCRIPTION OBJECTIVE: To identify stream channel rehabilitation methods which can be used to maintain the desired channel stability.
CONCLUSIONS

The preceding framework of rehabilitation objectives has been developed in order to help both the mining industry and concerned regulatory agencies in the Klondike to identify appropriate management activities. It is grounded within the definition of rehabilitation which implies that land disturbed by mining must be managed to the degree that it possesses potential for future use similar to that of the undisturbed land surrounding it. This type of framework may be used to determine rehabilitation requirements, providing it is supplemented with site specific information pertaining to:

1) the nature and extent of the disturbance,
2) the designated post mining land use, and
3) the characteristics of the environmental features affected by mining.

This appendix has been presented to illustrate the efficiency in recognizing that rehabilitation objectives vary from region to region throughout mining areas in Canada. This distinction may help promote more effective planning of natural resource use.
SITE CONDITION CLASSIFICATION

The 67 sites are classified into 6 groupings of similar site substrate conditions. Presence class and mean cover values are presented for species within each grouping (presence classes range from 1 to 5, with 5 indicating occurrence of the species in all groupings. Cover values range from 1 to 100%).
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