UNIVERSITY OF CALGARY

Effects of Pipeline Construction on the Physical and Chemical Properties of Soils in the Pincher Creek-Crowsnest Pass Area, Southern Alberta

by

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ABSTRACT

The objectives of the study were to determine the effects of pipeline construction on the physical and chemical properties of soils and determine the topsoil reclamation suitability of the A horizon of these soils in the Pincher Creek-Crowsnest Pass area, southwestern Alberta. Both disturbed and undisturbed sites were sampled along the pipeline right-of-way. Physical properties of all soil samples were recorded and chemical analyses of all soils sampled included pH, EC, moisture content, organic matter content, $CaCO_3$ content, exchangeable cations and C.E.C.

Pipeline construction activities altered all of the chemical properties in most of the disturbed sites. The physical properties that were altered in some of the disturbed sites were structure, consistency, coarse fragments and surface stoniness. The topsoil reclamation suitability of the soils was rated as being fair, meaning there are moderate soil limitations that affect the use of the area but can be overcome by proper planning and management.

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DEDICATIONS

I would like to dedicate this thesis to my parents, Pat and Bill Hanson for all of their support and encouragement throughout my academic years.

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1.0 INTRODUCTION

Alberta has grown and prospered due to one of its main industries, oil and gas production. In order to supply consumers with this commodity, the construction of pipelines is required. At one time the main concern of this industry was to construct as many pipelines as possible to extract and transport the resource. Along with the construction were inevitable land disturbances, in effect a disruption in the previously relatively undisturbed and undamaged ecosystem.

It has been estimated that in 1988, 176,000 km of pipeline could be found throughout the province of Alberta (Bratton, 1998) and in 1996 approximately 270,000 km of pipelines were documented (Etherington, 1996). The increase in pipelines over approximately a ten year period is a realistic number due to the continual demand for oil and gas as a resource. McCoy (1986) estimates 350,000 hectares of land in Alberta were leased by the gas and oil industry for pipeline right-of-ways, plant sites and wellsites. Recently, the main concern for many industries and environmental agencies is to rectify problems which are associated with this type of construction activity, namely soil degradation and soil loss. Soil reclamation and conservation has become an important environmental concern, which is now regarded as the final activity of many construction activities.

Soil landscapes have been recognized as valuable resources that are essential for activities such as the production of food and fibre (Pedocan Land Evaluation Ltd.

(PLEL), 1993). Aside from agriculture, soil landscapes are the foundation for many vegetative communities, supporting their growth by supplying the necessary nutrients; essentially a favorable growth medium. Over time a soil-vegetation complex is established in which the soil and vegetation complement each other codependently. Any disturbance to soil landscapes can result in a deterioration of the soil and a decrease in its productivity which negatively affects vegetation and the surrounding natural ecosystem. The issue of declining soil quality became a widely recognized concern in the 1960s and 1970s and as a result numerous soil conservation initiatives, regulations and practices for soil reclamation were developed (PLEL, 1993).

Land disturbances, which are caused by the extraction and transport of resources such as oil, should be regarded as only temporary disturbances (Alberta Agriculture, 1987). It must be recognized by planners for reclamation that each individual site has its own unique characteristics (eg. soil, vegetation and topographic) and that pipelines can cause similar problems (degradation) at two different sites but in varying degrees of intensity. While one site, with its own unique characteristics, may experience only slight disturbances from a particular activity, a site that has different characteristics may experience severe damage even if it is exposed to the same activity (Alberta Agriculture, 1987). Another important need for reclamation occurs subsequent to resource extraction and transport. Many oil fields are being depleted, which leads to the eventual abandonment and reclamation of these areas (Etherington, 1996).

When reclaiming sites that have been disturbed from pipeline activities, or reclaiming an abandoned site, the goal of reclamation is the same: to return the land to use equal to or better than it was prior to disturbance. To elaborate, this statement means returning the soil in such a way that the land has the best possible productive capacity (Macyk, 1977). McNaughton and Leggett (1992) state that Alberta Environment's overall objective of reclamation and assessment at each site should be:

> "the reconstruction of contours and soil to a condition which is compatible with predisturbed and surrounding land conditions."

Although Alberta Environment does not state that the land needs to be returned to its original, undisturbed condition, there are some instances when the land should be reclaimed to its original condition or to a condition better than it was prior to disturbance. Habitat fragmentation, a common result of many land disturbances, is a situation in which reclamation efforts should concentrate on maximizing habitat quality and returning the land to a use better than it was prior to disturbance.

Once disturbances to land (soil) caused by pipeline activities are noted, and a reclamation plan is implemented, it is necessary to understand the impacts these activities can have on soil properties. Construction activities, whether pipeline or other activities that impact Alberta's soils, usually involve procedures that require some degree of excavation, grading removal and replacement of subsurface and surface material (Janz, 1992). It is important to recognize the impacts construction activities have on the chemical and physical properties of soil. Once these impacts have been noted, a proper reclamation plan can be implemented which will return the soil to a similar or better predisturbance productive capacity.

1.1 Impacts on the Physical Properties of Soil

The initial observations of the impacts on the physical properties of soil are more common and easier to recognize than the impacts on the chemical properties of the soil. When considering soil profiles, much of the degradation will occur in the soil surface, topsoil and subsoil (Janz, 1992).

The topsoil is defined as a plough depth of 15cm or the surface A horizons of the soil profile (Cloutier, 1988). This important section of the soil profile can be affected severely by construction activities. One impact is the mixing of horizons (one soil layer with another) which causes a mixture of nutrients and organic matter between the horizons. This mixing can lead to a reduction in the structural quality of the soil (aggregate loss) as well as a reduction in topsoil depth quality and organic matter content. The changes result in reduced plant growth and increased erodibility of the soil (Janz, 1992).

The subsoil, which is the soil layer underlying the topsoil, also is affected by construction activities. Common impacts are modified horizons with moderate to strong limiting characteristics (Janz, 1992). Portions of the B and C horizons of the subsoil may be replaced with compacted waste material (spoil or subsoil) which can result in impediment of the vertical movement of water through the profile, and a reduction in plant growth. Reduced infiltration, root extension, loss of horizon layers, and a degradation of subsoil structure are other impacts of construction activities (Janz, 1992).

The third important region of the soil that also is impacted negatively is the soil surface. This is the portion of the soil that is in contact with the atmosphere; degradation includes contour changes (modifications in topography) and reduced tilth quality (defined as its fitness as a seedbed and its impedance to seedling emergence and root penetration (Brady, 1990).

1.2 Impacts on the Chemical Properties of Soil

When observing impacts of activities on the chemical properties of the soil, all three regions, the topsoil, subsoil and soil surface are affected. The negative impacts include degradation of the soil by phytotoxic and non-phytotoxic contaminants from sources such as oil spills and gas leaks (Janz, 1992). These contaminants affect the chemical properties of the soil such as pH, salinity, and cation exchange capacity; the end results are reductions in plant growth, water repellency, structure of the soil and a loss of organic matter. Mixing of horizons can affect the chemical properties of the soil as well. Subsoil that may be high in calcium carbonates, salts etc. may be incorporated into the topsoil during construction and as a result will alter chemical properties of that topsoil.

Chemical properties that may be altered include pH, salinity (electrical conductivity), calcium carbonate contents and cation exchange capacity.

1.3 Conservation and Criteria for Soil Reclamation

Soil degradation has been a concern in Alberta for decades; the first Act concerning soil reclamation, known as the Soil Conservation Act was proclaimed in 1935, a result of the loss of topsoil due to drought and wind conditions (Stewart et al., 1997). In 1963, Alberta became the first province to enact necessary reclamation requirements through the introduction of the Surface Reclamation Act (Brocke and Powter, 1997). The Land Surface Conservation and Reclamation Act was proclaimed in 1973 which further solidified the need for reclamation for conserving and reclaiming disturbed areas. In 1978 a reclamation research program was established to identify the most efficient methods for achieving acceptable levels of reclamation in Alberta (Powter, 1992), and in the 1980s soil degradation became a major concern across Canada which continued to increase the knowledge of and need for reclamation (Stewart et al., 1997).

In the 1950s the pipeline industry made little effort to conserve soil capability and it was not until the 1980s that oil and gas industries pioneered the development of new procedures which required that topsoil conservation become an integral part of pipeline construction (Mutrie and Wishart, 1998). Experience gained over this time period, along with expertise in the field, has led to continued improvements in both conservation of the soil (land) and in reclamation methods and equipment used (Brocke and Powter, 1997).

In 1993, the Environmental Protection and Enhancement Act was proclaimed, which further supported the need for reclamation and required that construction activities implement the proper reclamation plans to successfully reclaim an area.

The protection of soil quality and the return of the soil to equivalent capability following soil disturbance activities, requires appropriate construction and reclamation techniques for an individual soil type, location and land use (PLEL, 1993). To ensure successful reclamation of a disturbed area, the development of an appropriate reclamation plan is necessary and should incorporate factors such as: suitable site selection, description of pre-existing and existing site conditions, determination of the final land use, soil handling, soil reconstruction and revegetation (PLEL, 1993). Once the reclamation plan has been established, certain criteria for the reclamation of pipeline activities must be followed in order for successful soil reclamation of a disturbed area.

With a continual recognition of soil degradation due to pipeline activities, expertise and experience gained in the area of soil reclamation will lead to significant improvements in reclamation planning as well as the techniques used in the area of soil reclamation. The environmentally aware public has recognized the disturbance to soils caused by pipeline activities. This recognition has led to continual research and education by industries and the public on the effects of these activities on the soils as well as reclamation techniques used and criteria needed to bring the soil back successfully to a capability level similar to its predisturbance condition.

With the growing need for reclamation, one major concern is that reclamation plans incorporate the necessary steps to successfully reclaim an area and that the reclamation plan is carried out from beginning to end in an orderly fashion. To insure successful reclamation, criteria for reclamation have been established for pipeline activities.

1.4 Previous Research

When exploring literature on the subject of impacts of pipelines on soil properties, it was found that little information was available, especially in Alberta. Research found was based on some studies done in Alberta but specifically from Ontario and Saskatchewan as well as from other countries such as the United Kingdom. There is information available on reclamation research conducted in Alberta but there is little information on the impacts of disturbances on the physical and chemical properties of soils in Alberta. There was also difficulty in finding literature on existing pipelines in Alberta and any effects they may have on the surrounding landscape (eg. soils and vegetation). Literature discussing the effects of disturbances on the physical properties of soils is also scarce; most work has concentrated on the chemical properties (Naeth et al., 1991). It must be recognized that the chemical, biological and physical properties of soils are important in the behaviour of soils found in both natural and reclaimed environments (Naeth et al., 1991). To increase the public knowledge on such areas as reclamation and impacts of disturbances such as pipelines on the properties of soils, long term studies are needed which look at the effects of such disturbances on soils over time.

1.5 Objectives

The objectives of this thesis are two-fold. The first objective is to determine the changes in the chemical and physical properties of the soils along a pipeline after construction. Emphasis is placed on the A horizons of the soils sampled since this is the section of the soil that affects revegetation efforts. The second objective is to evaluate topsoil suitability for reclamation in the study area. Soil quality criteria produced by Alberta Agriculture (1987) are used in the evaluation of the reclamation potential of the soils. This evaluation allows for a soil quality rating of good, fair, poor and unsuitable in regard to reclamation and will help determine the most suitable plants for revegetation under specific soil conditions.

2.0 STUDY AREA

2.1 Location

The Canadian 88 pipeline (Phase II) being studied is located in the Pincher Creek-Crowsnest Pass area in southwestern Alberta (Fig. 2.1 and 2.2). The specific legal description of the pipeline is from wellsite 2-24-7-2 W5M to a tie-in at 4-5-7-2 W5M (Fig. 2.3).

2.2 Physiography and Bedrock Geology

The study area is located in the Beauvais Lake Upland and Byron-Carbondale Hills subdistricts which are part of the Southern Foothills physiographic district (Walker et al., 1991) (Fig. 2.4). This physiographic district is part of the Rocky Mountain Foothills Region (Pettapiece, 1986).

2.2.1 Southern Foothills District

This district is characterized by long, low, parallel ridges with a general orientation from southeast to northwest. These ridges are made up of intricately faulted and folded rocks of the Brazeau Formation (Tertiary Period), Alberta Group (Cretaceous period) and other Mesozoic formations (Green, 1972). The landscape of the Southern Foothills District has been shaped and modified by processes such as tectonic activity (which produced the faulted and folded bedrock), weathering and erosion and deposition of glacial materials. Sandstones, which are found to be more resistant to erosive forces than shales and other fine-grained rocks, make up the ridges in the Byron-Carbondale Hills subdistrict. Valleys and benchlands along with other low-lying areas tend to be made up of shales and other

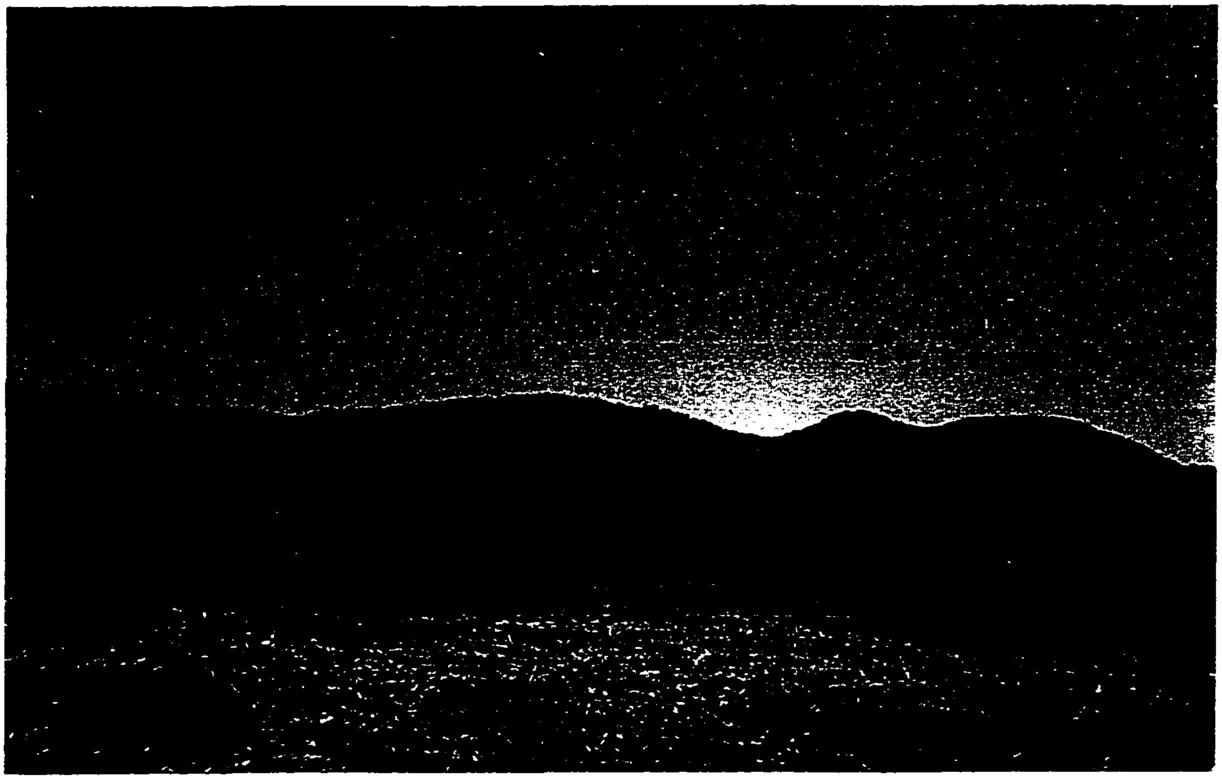


Figure 2.1: Southern Foothills landscape southwest of Pincher Creek. Notice the flat grassland area in the foreground which migrates into bushland in the background.

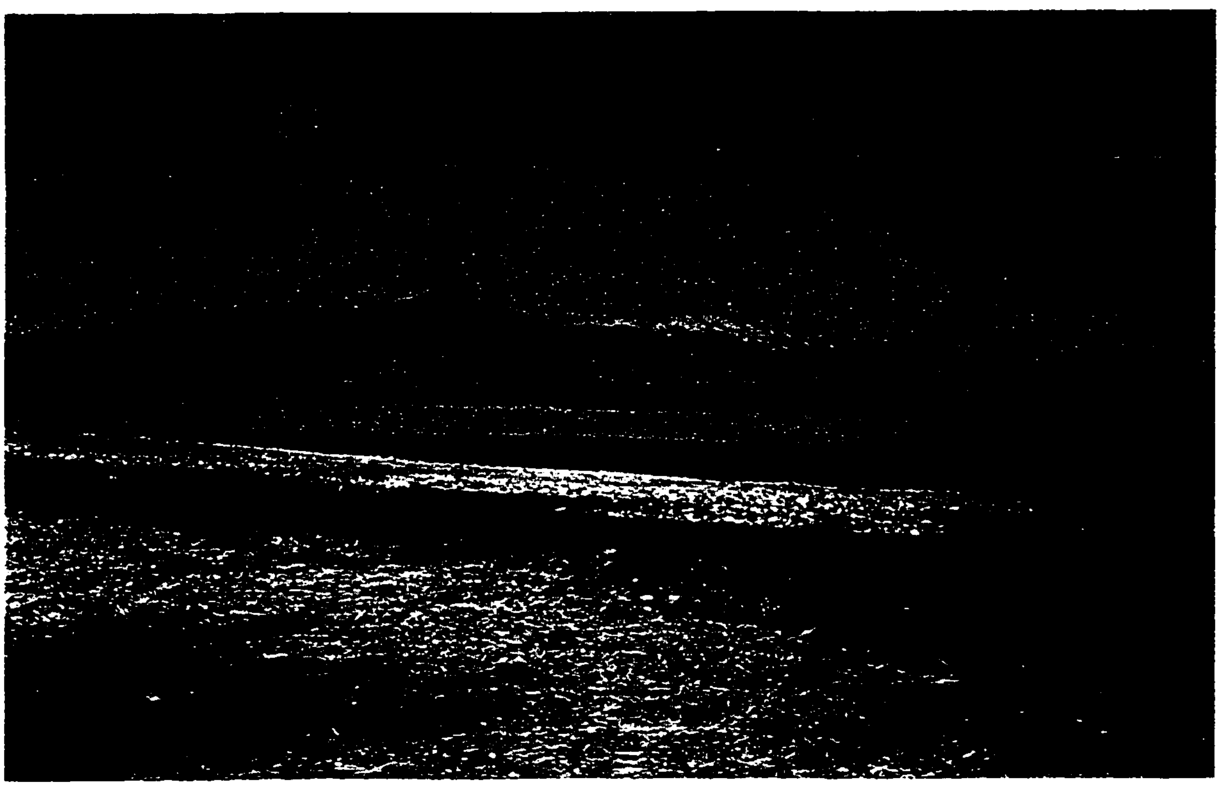


Figure 2.2: Southern Foothills landscape south of Pincher Creek. Again the foreground shows flat grassland area and the background represents ridged topography common throughout the study area.

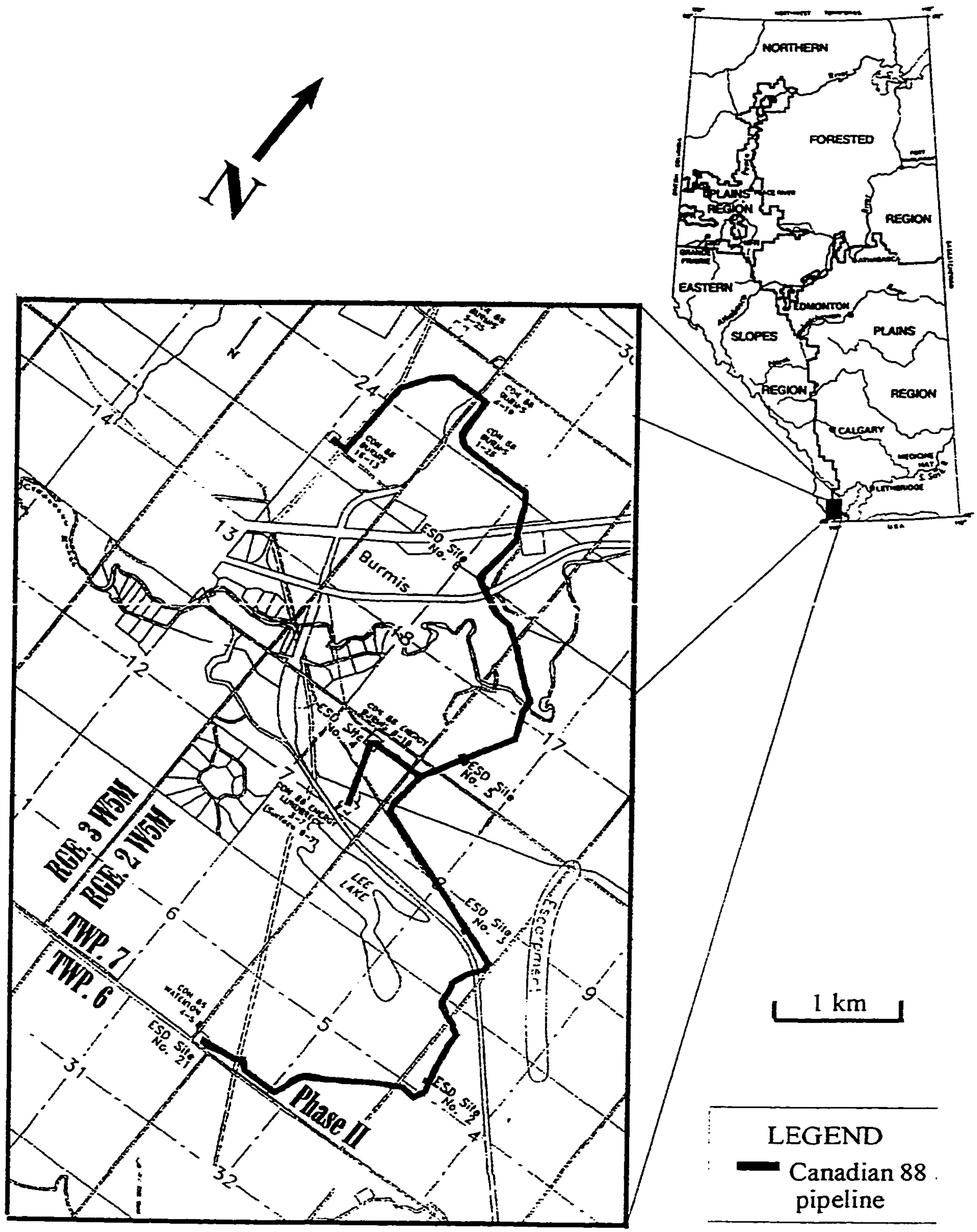


Figure 2.3: Location of the Canadian 88 pipeline in the Pincher Creek-Crowsnest Pass area (Eastern Slopes region) in southwestern Alberta. The legal land description of the pipeline is 2-24-7-2 to 4-5-7-2 W5M (Axys Environmental Consulting Ltd., 1998)

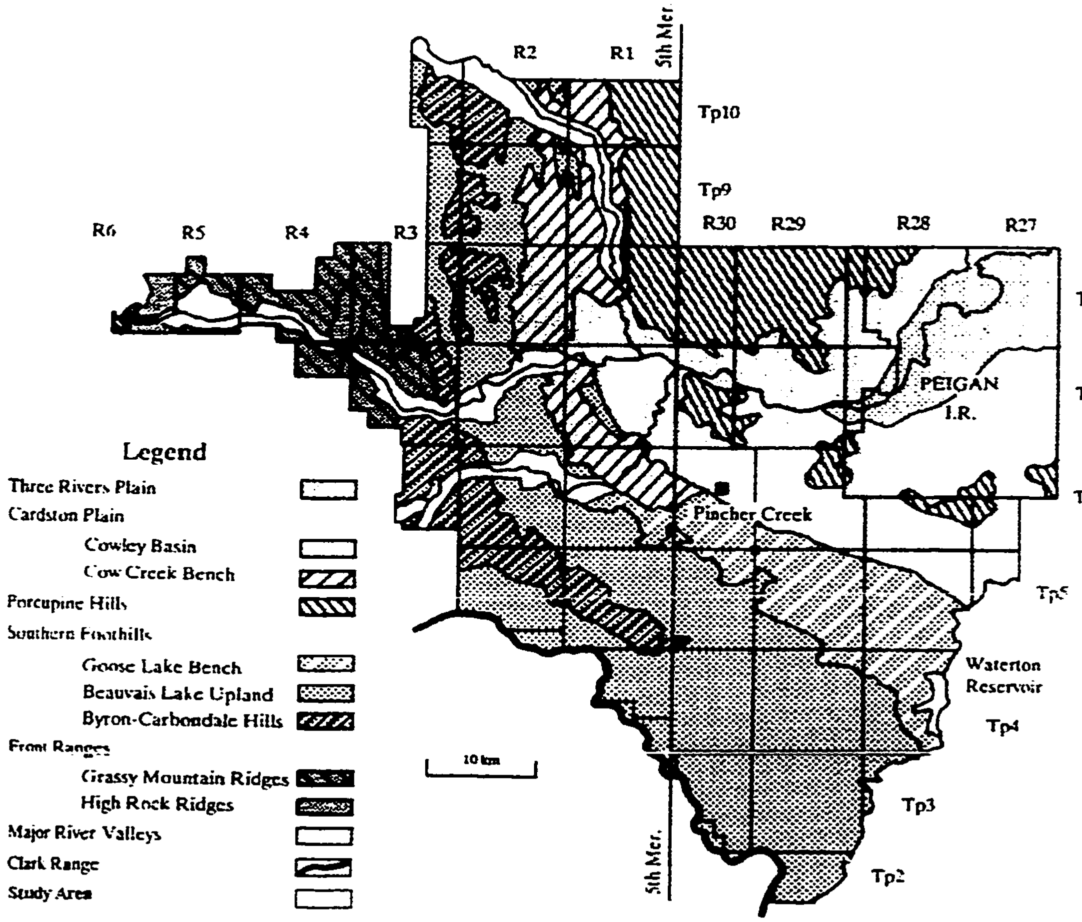


Figure 2.4: Physiographic subdivisions of the Pincher Creek-Crowsnest pass area (Walker et al., 1991) (permission to reproduce from Agriculture and Agri-Food Canada).

erosive rocks, which are modified and shaped by erosion and weathering processes, and are located in the Beauvais Lake Upland subdistrict.

2.2.2 Beauvais Lake Upland Subdistrict

The average local relief, which has been estimated from carved valley bottoms to the top of ridges and hills, is approximately 200m. Elevations range from 1250m to 1600m on some of the present ridges. Underlying bedrock tends to be overlain by deep to shallow tills of continental, mountain or mixed origin. Till-glaciolacustrine mixtures and ice contact deposits are also found in the subdistrict. Most surficial material found in this area is calcareous in nature (Walker et al., 1991).

Vegetation and soils vary within this subdistrict. The eastern edges of this area tend to be the driest and warmest and are characterized by fescue grassland underlain by Black Chernozems. Moving westward, aspen parkland appears with mixtures of Black and Dark Gray Chernozems. As conditions become cooler and moister to the west, the aspen parkland grades into aspen forest, then to mixedwood forest and eventually to lodgepole pine forest (Walker et al., 1991). Soils grade from Orthic Dark Gray Chernozems to Dark and Orthic Gray Luvisols.

2.2.3 Byron-Carbondale Hills Subdistrict

This subdistrict is considered to be the most rugged part of the Southern Foothills District. Relief is some areas of the Byron-Carbondale Hills averages from 300-400m with a maximum relief of about 520m. Elevations near the town of Maycroft range between 1842m on Byron Hill to approximately 1860m. Shallow and deep tills are mainly of mountain origin and blanket bedrock hills, ridges and the valleys. These tills range from weakly calcareous to strongly calcareous in this subdistrict (Walker et al., 1991).

2.3 Surficial Geology

Landforms are described based on surficial material, surface expression and modifying process components (Agriculture Canada Expert Committee on Soil Survey, 1987). The

Pincher Creek-Crowsnest Pass area has a wide variety of complex surficial deposits (Fig. 2.5).

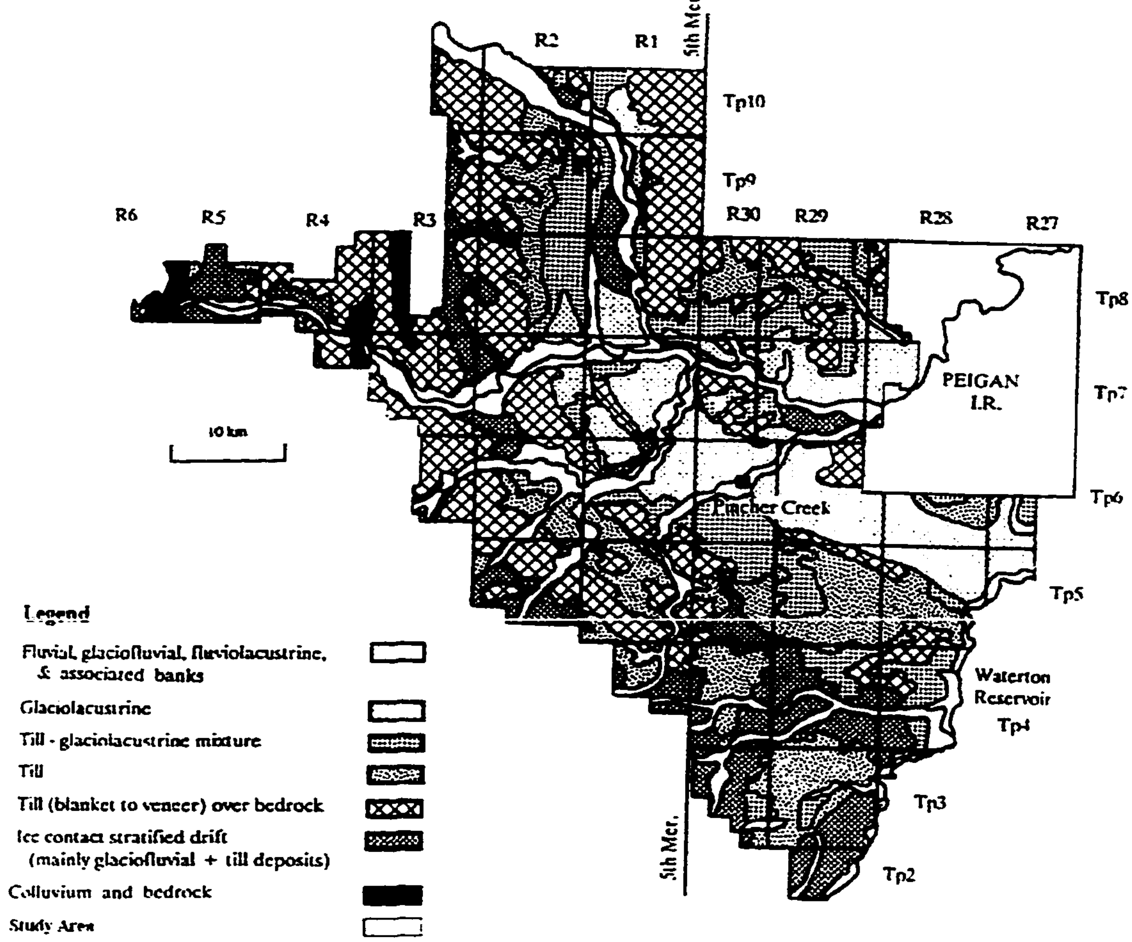


Figure 2.5: Distribution of surficial deposits in the Pincher Creek-Crowsnest Pass area (Walker et al., 1991) (permission to reproduce from Agriculture and Agri-Food Canada).

2.3.1 Tills

The Southern Foothills District is dominated by till (morainal) deposits. Two types of till can be distinguished in the study area: continental and associated mixed till and mountain tills. Continental till is uniformly heterogeneous, moderately calcareous and medium textured (clay loam-loam) with 2-15% coarse fragments. Coarse fragments are defined as rock or mineral particles larger than 2mm in diameter but smaller than bedrock and include gravels (up to 8cm in diameter), cobbles (8-25cm in diameter) and stones (>25cm in diameter) (Walker et al., 1991).

Mountain tills are characterized as having a coarse fragment content of 15-35%. Texture varies in these tills from sandy-loam to silty clay loam. Calcareousness of these tills may vary. Tills associated with the Byron Carbondale Hills tend to be non- to weakly calcareous in nature. Mountain tills located in the benchlands and in the northern portion of the Beauvais Lake Uplands are strong to very strongly calcareous.

2.3.2 Glaciolacustrine Deposits

These types of deposits are found to dominate the fringes of the Southern Foothills district (study area). Many of these deposits are fine-textured, grading from silty clay loam to clay loam near the surface and clay at depth. Coarse fragment content tends to be low in these sediments (<2%) and deposits are moderate to strongly calcareous.

2.3.3 Glaciofluvial Deposits

Small portions of the study area cross rivers or other small waterways, and here glaciofluvial deposits dominate. Most of the glaciofluvial material found in these areas tends to be gravelly and cobbly (>60% coarse fragments) and coarse textured (loamy sand to sand). A majority of these deposits are high in calcium carbonate content, rated as being moderately to very strongly calcareous.

2.4 Climate

Climate data for the Pincher Creek-Crowsnest Pass area is scarce, but selected temperature and precipitation data from ten long-term stations located in southwestern Alberta have been collected (Table 2.1 and 2.2) (Atmospheric Environment[1] in Walker et al., 1991). The climate information indicates that the Pincher Creek-Crowsnest Pass area has a continental macroclimate (short, cool summers and long, cold winters). Chinook winds, common in this area, offset the severe cold of winter resulting in the area having milder winters than locations found north and east.

Table 2.1: Selected temperature (^{0}C) and growing season data for nine long term stations in southwestern Alberta (Atmospheric Environment[1] n.d. in Walker et al., 1991)

Station and Elevation	Agroclimate[2] & Soil Zone	Mean Annual Temp.	May-Sept. Mean Temp.	EGDD[3]	FFP[4] (days)
Lethbridge A (929m)	2A, Dark Brown	5.3	15.6	1520	124
Fort Macleod (950m)	2A, Dark Brown	5.4	15.3	1483	125
Cardston (1154m)	2AH, Black	4.8	14.2	1273	111
*Pincher Creek (1155m)	2AH, Black	4.4	13.6	1231	106
*Cowley (1189m)	3H, Black	3.8	12.9	1088	83
Caldwell (1311m)	3H, Black	4.2	13.1	1079	96
Carway (135m)	4H, Black	3.9	12.7	1016	87
*Coleman (1341m)	5H, Black	3.2	11.9	730	46
Castle RS (1364m)	6H, Gray Luvisol	2.9	11.5	622	39

Notes:
1. Computer data extracted in 1985 by Alberta Energy and Natural Resources personnel
2. Agroclimatic classes as defined by A.S.A.C. (1987)
3. EGDD = effective growing degree days, defined and calculated by A.A.A.C. (1987)
4. FFP = frost free period; mean days between the last spring and first fall frosts (0C), recorded from 1951 to 1980 (Atmospheric Environment, 1982)

* Stations that are located closest to study area

A = Airport

Table 2.2: Selected precipitation data (mm) for ten long-term weather stations in southwestern Alberta (Atmospheric Environment[1] in Walker et al., 1991).

Station and Elevation	Agroclimate & Soil Zone	Mean Annual Precip.	May-Sept. Mean Precip.	P-PE[1]	% as Snow
Lethbridge A (929m)	2A, Dark Brown	423	257	-410	36
Fort Macleod (950m)	2A, Dark Brown	434	262	-400	34
Cardston (1154m)	2AH, Black	550	312	-345	42
*Pincher Creek (1155m)	2AH, Black	543	304	-362	45
*Cowley (1189m)	3H, Black	515	262	-410	39
Caldwell (1311m)	3H, Black	723	362	-250	51
*Beaver Mines (1286m)	4H, Black	645	314	-305	47
Carway (1359m)	4H, Black	515	285	-318	47
*Coleman (1341m)	5H, Black	569	265	-378	38
Castle RS (1364m)	6H, Gray Luvisol	852	325	-363	50

Notes: 1. P-PE = seasonal precipitation minus potential evapotranspiration, defined and calculated by A.A.A.C. (1987).
* Stations that are located closest to the study area
A = Airport

One well known characteristic of southern Alberta is wind. Frequent, strong, westerly winds tend to prevail in the study area. With such a strong presence of wind, soil erosion has become a major consideration especially with the disturbances in the area such as pipeline activity. Table 2.3 shows wind data from selected stations located in Alberta. It was determined that the months of October, November and December are the windiest months in southwestern Alberta (Atmospheric Environment[2] in Walker et al., 1991).

Table 2.3: Wind data (km/hr) collected from selected monitoring stations in Alberta (Atmospheric Environment[2] in Walker et al., 1991).

Station and Elevation	Mean Yearly Wind Speed	Prevailing Direction (Yr)	Maximum Hourly Speed
Lethbridge A (929m)	20.4	W	121
*Pincher Creek, old (1155m)	19.8	W	137
*Pincher Creek, new (1155m)	21.5	W	92
*Cowley A (1182m)	19.1	N	106
Medicine Hat (717m)	16.1	SW	105
Calgary Int'l A (1084m)	16.2	W	90
Edmonton Int'l A (715m)	13.4	S	87
Rocky Mountain House (1015m)	8.9	NNW	60
Banff (1397m)	7.8	SW	40

Note: * Stations located closest to study area
A = Airport

2.5 Agroclimatic Classes

Arable agriculture, defined as agricultural production that is based on cultivation practices (Walker et al., 1991), is derived from a new land capability classification system known as 'agroclimatic classes' (Alberta Soils Advisory Committee (A.S.A.C.), 1987). These classes are based on both an energy component and moisture component (Alberta Agrometeorology Advisory Committee (A.A.A.C.), 1987). The energy component is also known as 'effective growing degree days' (EGDD) and is defined by the A.A.A.C. (1987) as "accumulated growing degree days above 5^0C and ending on the average date of the first fall frost (0^0C)."

The moisture component of the classes is defined as "the growing season precipitation minus the potential evapotranspiration" also known as P-PE. In order to calculate the moisture component, the monthly potential evapotranspiration (PE) is subtracted from the monthly total precipitation (P) from May 1 to August 31 (A.A.A.C., 1987).

Areas that are surveyed for arable agricultural land fall into one of seven agroclimatic classes or subclasses, each of which indicates the degree and kind of limitations that will affect crop production. Limitations are either a result of aridity (A) or a lack of adequate heat units (H). The majority of the study area falls into agroclimatic classes 3H and 4H with only a small portion of the study area classified in class 5H (Fig 2.6) (Walker et al., 1991).

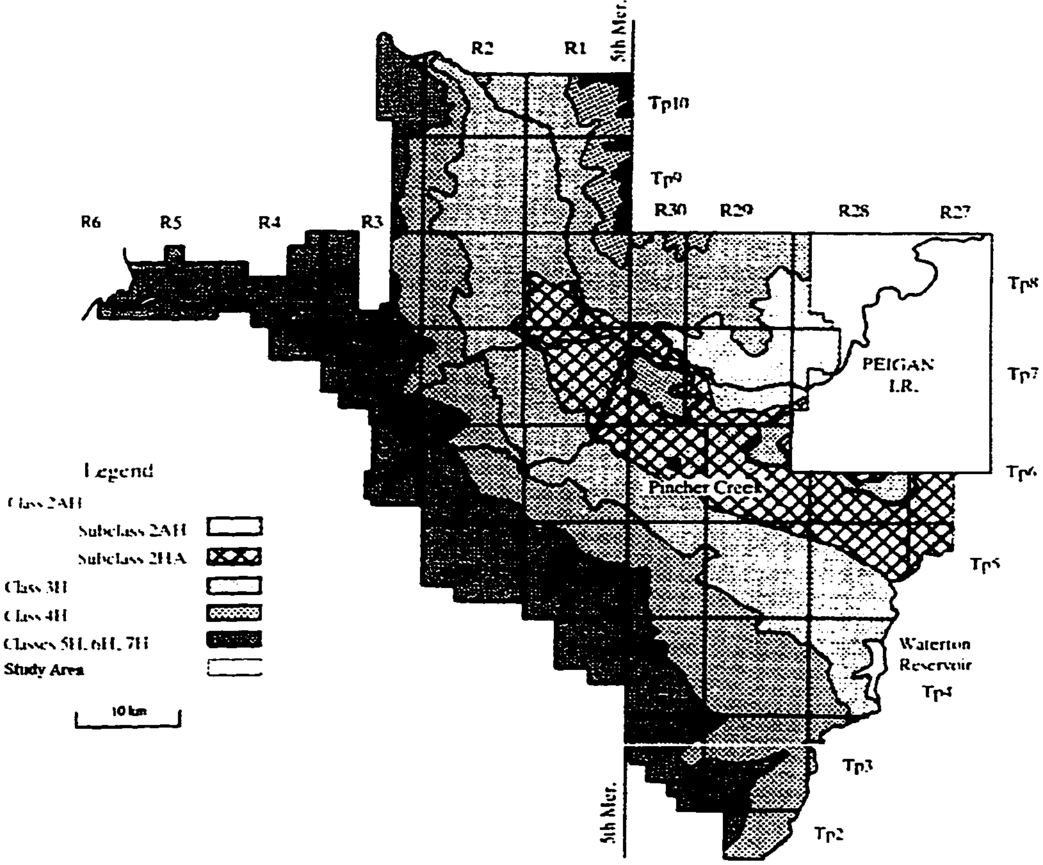


Figure 2.6: Agroclimatic classes and related subclasses for the Pincher Creek-Crowsnest Pass area (Walker et al., 1991) (permission to reproduce from Agriculture and Agri-Food Canada).

2.5.1 Agroclimatic Class 3H

This class is defined as having a moderate heat limitation and an EGDD index of 1050 to 1180 (A.A.A.C, 1987). This heat limitation tends to affect spring wheat, and includes the risk of damaging frost. Areas within this class are considered to be dry with P-PE values of –260 to –400.

2.5.2 Agroclimatic Class 4H

This class has a severe heat limitation and an EGDD index of approximately 950 to 1050. A severe heat limitation affects the range of crops that can be grown in an area. Due to this limitation most lands are used for forage production. Other uses of lands include pasture and small areas producing cereal crops such as oats and barley. The moisture index of the area (P-PE) ranges from –260 to –300 and areas are classified as dry. A portion of the study falls within this range as well as in areas that are moister than –260. This results from air masses originating in the south that provide extra precipitation in the area.

2.5.3 Agroclimatic Class 5H

Agroclimatic class 5H has a very severe heat limitation with an EGDD index of 750 to 900. Areas within this class are dominated by pasture with only a small portion being used for cultivation. Areas that are being cultivated tend to produce only forage crops. The moisture index for this class are values higher (moister) than –260 and therefore moisture is not considered to be a limiting factor in these areas.

2.6 Vegetation

2.6.1 Grassland

Grasslands found within the study area are characterized as the *Fescue Grassland Ecoregion* containing rough fescue (*Fesctuca scabrella*) with Parry oats (*Danthonia parryi*), june grass (*Koelaria cristata*) and northern wheatgrass (*Agropyron dasystachyum*) (Walker et al., 1991). Agroclimatic classes that are associated with the grassland areas in the study are 3H and 4H. This vegetation is closely associated with both thin and thick Black Chernozems which are dominant in the Beauvais Lake Upland.

2.6.2 Aspen Parkland

Within the grassland areas, narrow strips of aspen parkland occur as transition zones. These patches of vegetation are characterized by aspen (*Populus tremuloides*) on moist well drained sites and fescue grassland on warmer drier sites. Willow (*Salix spp.*) may also be found interspersed among the aspen on moister sites (Walker et al., 1991). Soils that are associated with these areas are dominantly the Black Chernozems. Agroclimatic classes associated with these areas are 4H and 5H.

2.6.3 Aspen and Mixedwood Forest

Moving westward, aspen parkland grades into aspen and mixedwood forest with stands consisting of species such as: aspen, cottonwood (*Populus trichocarpa*), balsam poplar (*Populus balsamifera*), white spruce (*Picea glauca*), lodgepole pine (*Pinus contorta*) and Douglas fir (*Pseudotsuga menziesii*) (Walker et al., 1991). Associated soils are usually Dark Gray Chernozems to Dark Gray Luvisols but the portion of the study area within this zone was found to contain Black Chernozems. The climatic class associated with this area is 5H.

2.7 Soils

The study area falls within the Black soil zone (Fig. 2.7) (Walker et al., 1991). The Black soils belong to the Chernozemic order and are distinguished from other Chernozemic great groups (eg. Brown Chernozems) by the color of the Ah or Ap horizon (determined from a Munsell Color Chart).

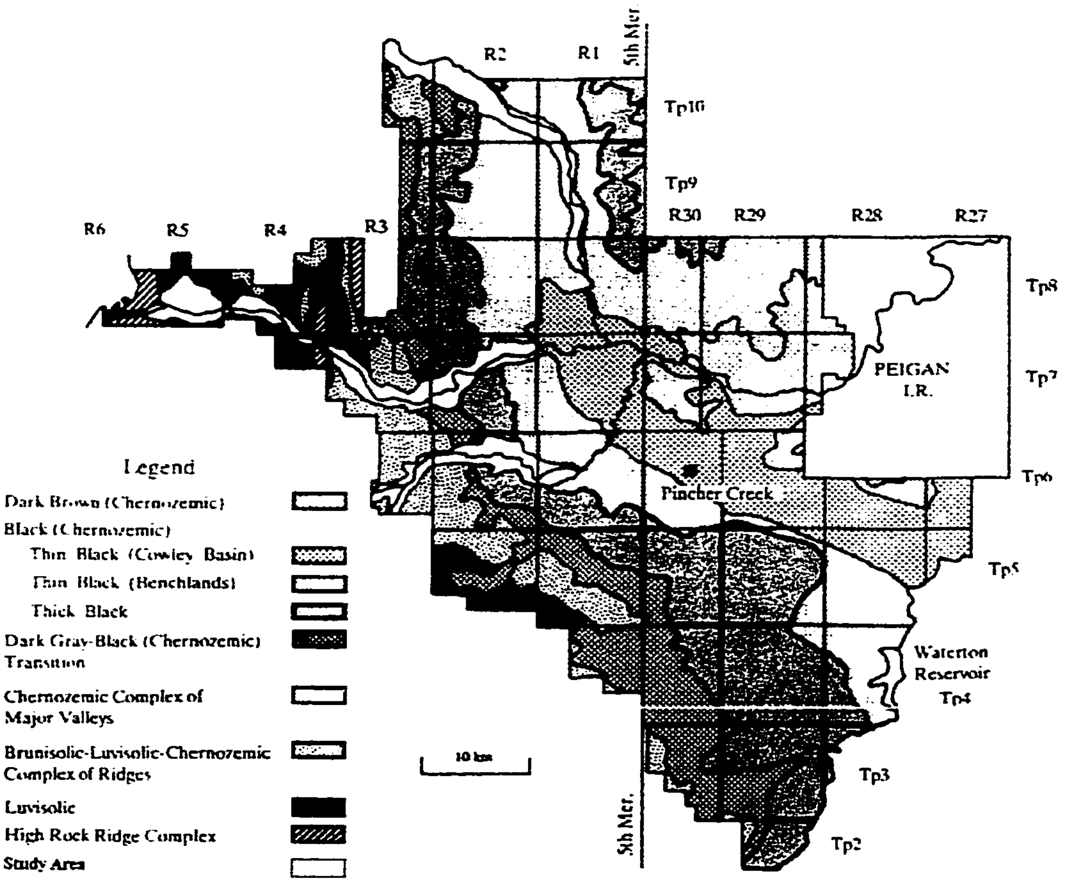


Figure 2.7: Generalized soil map of the Pincher Creek-Crowsnest Pass area (Walker et al., 1991) (permission to reproduce from Agriculture and Agri-Food Canada).

2.7.1 Thin Black Soils

Approximately half of the study area is found in the 'thin' black soil zone. These soils are found in the Fescue Grassland Ecoregion and are covered dominantly by rangeland but in a few areas where soil and topographic conditions are favourable, cultivation is practiced (Walker et al., 1991). These soils are associated with agroclimatic class 3H and soils tend to be moderately to slightly dry reflecting the lack of heat units. Topsoil depths range from 10 to 20 cm in areas where erosion or mechanical disturbance (cultivation) has occurred. Areas that have not been subjected to disturbance and are uneroded may have topsoil depths less than 50cm thick.

The dominant subgroup soils in the area are Orthic Black Chernozems, characterized by having a noncalcareous Bm horizon. Pockets of Calcareous and Rego Black Chernozems are found intermixed with the Orthic Blacks. Calcareous Black Chernozems are dominated by a calcareous B horizon (Bmk) while Rego Black Chernozems are characterized by having no B horizon and are usually shallow in nature (E.C.S.S., 1987). Till is the dominant surficial material, but areas of fine to medium textured glaciolacustrine and coarse to medium textured glaciofluvial material also can be found.

2.7.2 Thick Black Soils

The remaining half of the study area falls within the 'thick' Black soil zone. These soils also are found in the Fescue Grassland Ecoregion and extend westward into Aspen Parkland. Most of the area is dominanted by native or improved rangeland but areas that have favorable soil and topographic conditions tend to be cultivated (Walker et al., 1991) The thick black soils zone is associated with agroclimatic class 4H and is affected by a more severe heat limitation than the thin black soils. Topsoil depths generally are >15-20cm thick and the entire soil profiles tend to be >50cm. Similar to the thin soils zone, Orthic Black Chernozems are the dominant subgroup with pockets of Calcareous and Rego Black soils.

Till is the dominant surficial material, but areas of fine and medium textured glaciolacustrine deposits can also be found in these areas.

2.8 Soil Erosion Potential

Wind erosion, in the Pincher Creek-Crowsnest Pass area, is considered to be extensive. It has been approximated that 60 000ha (22% of the area) has been modified by wind erosion (Figure 2.8) (Walker et al., 1991). Of this total, 48 000ha has been catergorized as being severely eroded and the remaining 12 000ha has been moderately eroded. The

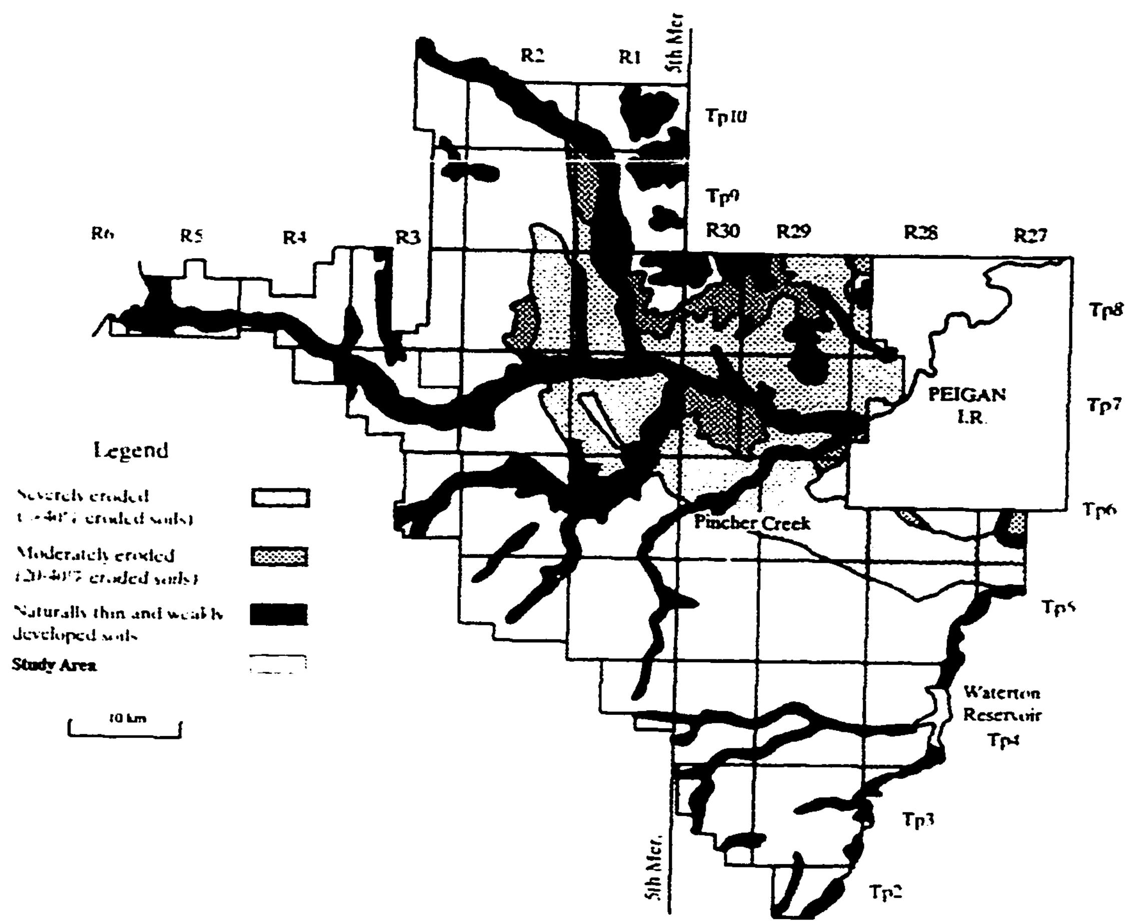


Figure 2.8: Map of erodable lands and areas with naturally thin and weakly developed soils (Walker et al., 1991) (permission to reproduce from Agriculture and Agri-Food Canada).

area being studied has a small percentage of severely and moderately eroded soils with patches of naturally thin and weakly developed soils occurring in areas located near river systems (Figure 2.8). Much of the study area has uneroded soils.

2.9 Backround Information on the Canadian 88 Pipeline

The pipeline, constructed in the Pincher Creek-Crowsnest Pass area, is approximately fourteen kilometers in length and extends from the legal land description of 16-7-7-2 W5M to 4-19-7-2 W5M. The pipeline diameter is 6 inches or 168.3 mm and is categorized as a small diameter pipeline. Pipeline right-of-ways (RoW) often associated with this size of pipeline range from 15 to 20m in width. The Canadian 88 pipeline being observed for this study has a pipeline RoW of twenty meters. Trench depths of oil pipelines usually range from 1 to 1.5 meters, and the pipeline in this study had a trench depth of 1.5 meters with 1.2 meters of average cover. The pipeline crossed two main highways, a railroad and the Crowsnest River. Crossings such as these usually are drilled directionally, which means the pipeline is drilled into an entry point on one side of the highway and exits through on the other side of the highway (pipeline is underneath highway). Extra workspace usually is required in areas where directional drilling is occurring. Due to the large amount of disturbance, no soil samples were taken in these areas. Topsoil was also salvaged along the pipeline and after construction was backfilled on top of the subsoil. Revegetation of the disturbed area (reseeding) was done immediately after construction. Straw mulch was used to prevent erosion of the bare topsoil and seeds that were spread for revegetation.

Landuse along the pipeline consisted of 36% tame pasture, 36% native grassland, 22% bush and 6% cultivated land. Two stripping techniques were employed depending on the landuse recorded prior to disturbance. The ditch plus spoil side stripping technique was used in areas consisting of tame pasture, native grassland and cultivated land (Fig. 2.9). Full right of way stripping was used in areas containing bushland (Fig. 2.10).

Ditch plus spoil stripping (Fig. 2.11) involves stripping the spoil (subsoil) side as well as the ditchline. The subsoil pile is placed on subsoil, not topsoil which results in less mixing. Topsoil is stockpiled on the working side and is either flattened to be used to weld pipe on or is spread over the working side topsoil (Mutrie and Wishart, 1988).

Full right of way stripping involves stripping the entire pipeline right-of-way and the topsoil is stockpiled in a continuous windrow along the edge of the right-of-way opposite from the spoil pile (Mutrie and Wishart, 1988) (Figure 2.11).

Table 2.4 lists the disturbed and undisturbed sites with their corresponding landuse as well as the soil stripping techniques used at each site. A map of sampling sites can be found in the methods chapter (Figure 3.1).

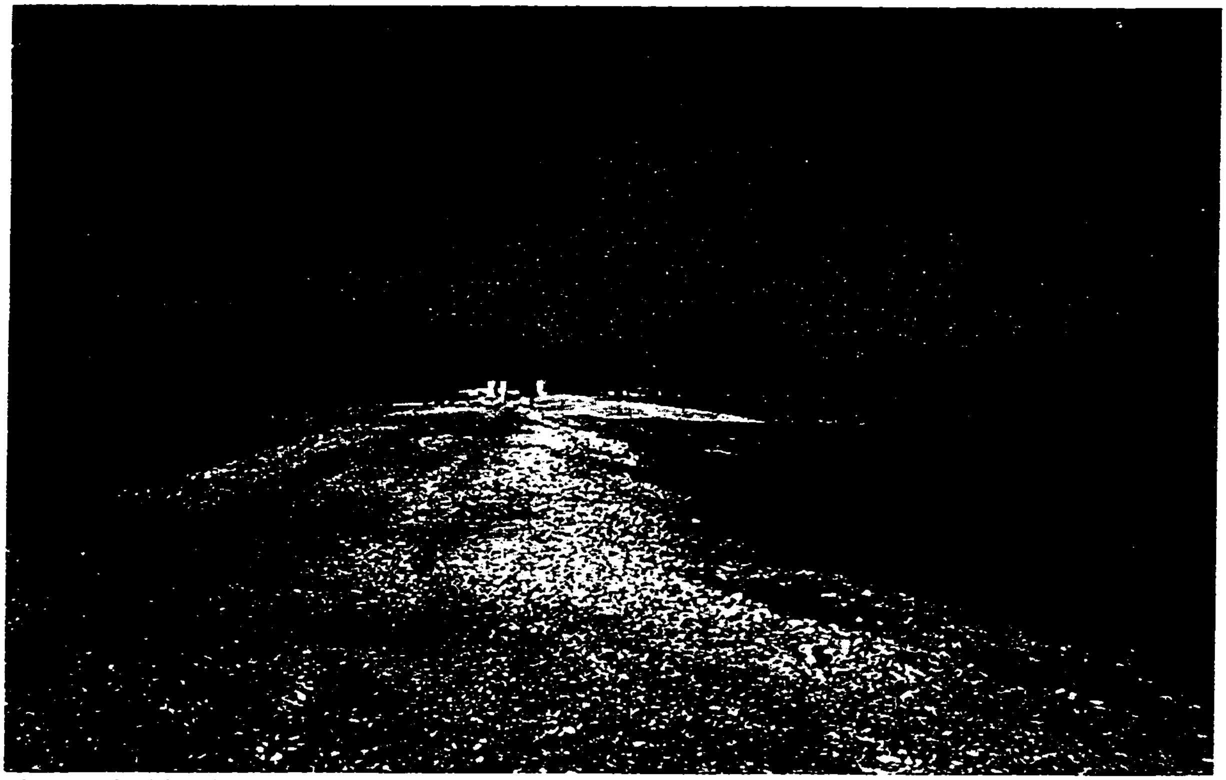
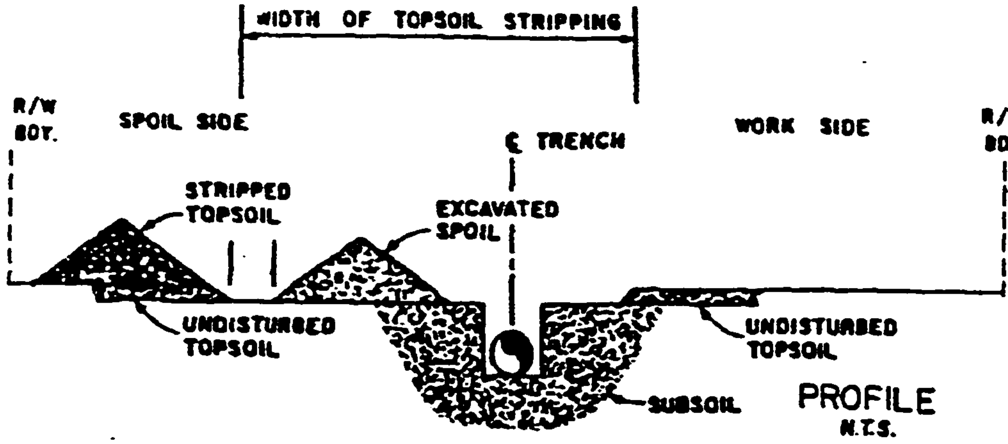
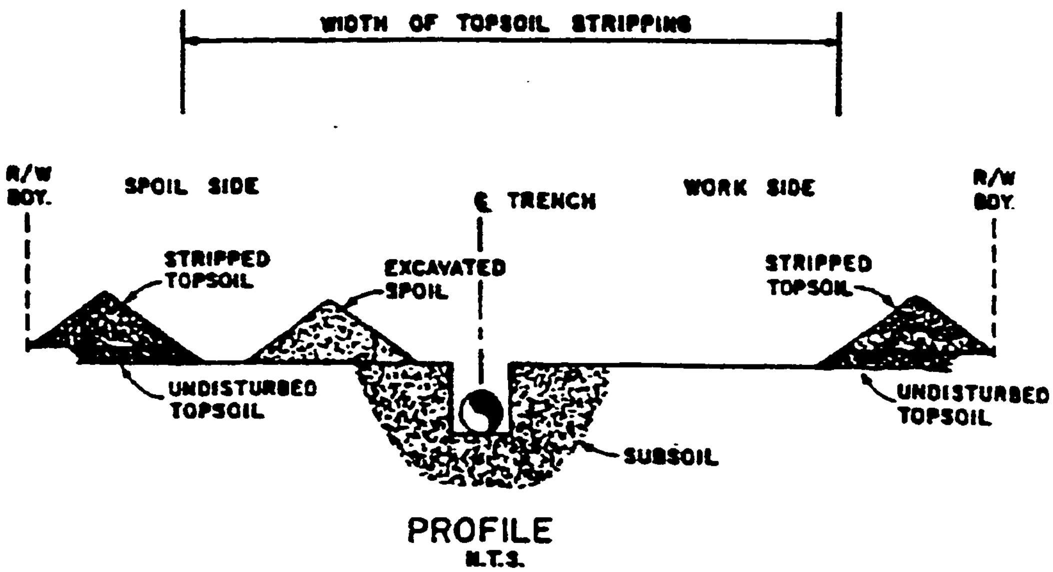


Figure 2.9: The ditch plus spoil side stripping technique used in pasture land within the study area. This technique was also used in native grassland and cultivated areas.

Figure 2.10: The full right-of-way stripping technique was used in treed areas (bushland). The entire twenty meter right-of-way is stripped in this technique.



PROCEDURE #1: Ditch Plus Spoil Side Stripping



PROCEDURE #2: Full Right-of-Way Stripping

Figure 2.11: Schematic diagram representing the two different stripping techniques used on the pipeline in this study. Both ditch plus spoil side and full right-of-way stripping were used depending on the existing vegetation/landuse (Mutrie and Wishart, 1988).

Table 2.4: Summary of sampling sites (disturbed and undisturbed), landuse and soil stripping techniques used at each site.

Sampling Sites	Landuse	[1]Soil Stripping Technique
1 D	Tame Pasture	D + S
2 U	Tame Pasture	-
3 D	Tame Pasture	D + S
4 D	Bushland	Full RoW
5 U	Bushland	-
6 U	Native Grassland	-
7 D	Native Grassland	D + S
8 D	Native Grassland	D + S
9 D	Native Grassland	D + S
10 U	Native Grassland	-
11 D	Bushland	Full RoW
12 U	Bushland	-
13 U	Tame Pasture	-
14 D	Tame Pasture	D + S
15 D	Native Grassland	D + S
16 U	Native Grassland	-
17 D	Cultivated	D + S
18 U	Cultivated	-
19 D	Tame Pasture	D + S
20 U	Tame Pasture	-
21 D	Native Grassland	D + S
22 U	Native Grassland	-
23 D	Tame Pasture	D + S
24 U	Tame Pasture	-
25 D	Native Grassland	D + S
26 U	Native Grassland	-
27 D	Native Grassland	D + S
28 U	Native Grassland	-
29 D	Bushland	Full RoW
30 U	Bushland	-
31 D	Bushland	Full RoW
32 U	Bushland	-
33 D	Tame Pasture	D + S
34 U	Tame Pasture	-
35 D	Tame Pasture	D + S
36 U	Tame Pasture	-

[1]Soil Stripping Techniques: D + S = Ditch plus spoil side stripping
Full RoW = Full Right-of-Way stripping
(soil stripping techniques only apply to disturbed sites)

D = disturbed sites U = undisturbed sites

3.0 METHODOLOGY

The Canadian 88 pipeline was constructed between the months of July 1999 and September 1999 (approximate) and was selected for this study because of timing (the pipeline was available to be studied during the first year of graduate studies) and was also recommended for study by both Axys Environmental Consulting Ltd. and Canadian 88 Energy Corporation. Information on the study area (eg. vegetation/landuse, soils) was also available prior to the study which aided in site selection and overall helped to determine the objectives for this study.

3.1 Soil Sampling

After completion of construction of the Canadian 88 pipeline in the Pincher Creek-Crowsnest Pass area, thirty-six soil sampling locations (19 disturbed sites and 17 undisturbed sites) (Figure 3.1) were chosen based on the variations in vegetation community types and soil series map units along the pipeline. Information on the changing vegetation and soil units was determined by consulting pipeline alignments sheets.

Soil pits (approximately 30cm x 30cm x 100cm) were dug at each sampling location; depths of the pits varied depending on the percent of coarse fragments at varying depths in many of the soil profiles sampled. Each soil profile was examined until the C horizon was identified or to a depth of 150cm (trench depth). Soil samples were collected from each identified horizon within each profile (55 samples total) and were sealed tightly in plastic bags and labeled with the appropriate master horizon designation and corresponding soil sampling site number. Soils were transported immediately to the

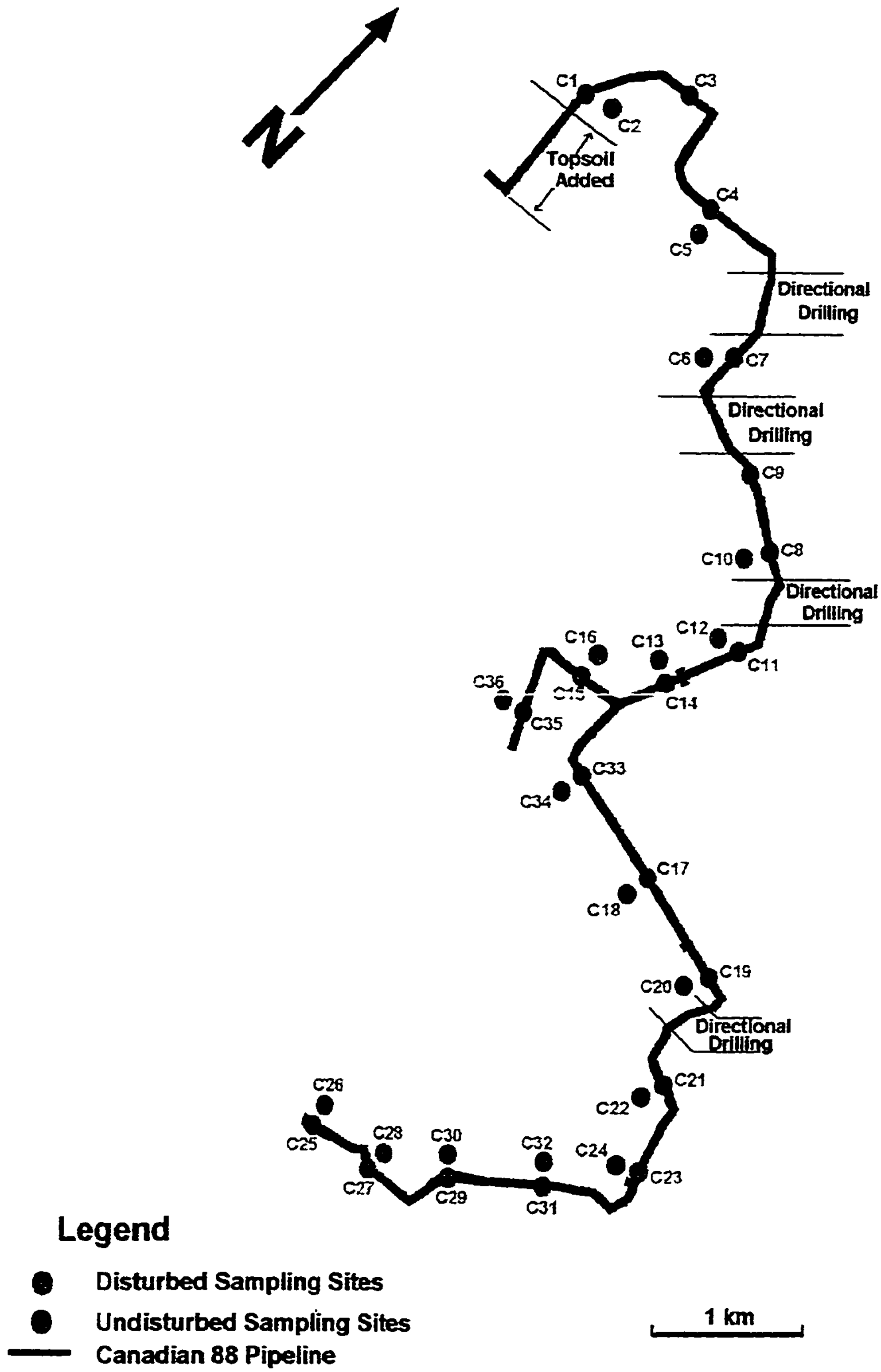


Figure 3.1: Map showing the locations of the disturbed and undisturbed sampling sites.

laboratory (University of Calgary) and were analyzed within three weeks after collection). During the three week time period, soils were stored in the refrigerator to be preserved until all laboratory analysis was complete.

3.2 Terrain Analysis

At each sampling location, the following terrain characteristics were observed and classified:

3.2.1 Aspect

Aspect is defined as the orientation of a slope (NE, NW, SW, SE, N, S, E and W) (Alberta Environmental Protection (AEP), 1994) and was determined using a compass. Compass values were recorded to the nearest degree to determine the aspect of each sampling site.

3.2.2 Slope Percent

Slope for each sampling site was determined to understand the incline and curvature of the study area. Slope percent was determined using a clinometer and readings were placed into one of the following slope classes (Table 3.1):

Table 3.1: Slope Classes (Agriculture and Agri-Food Canada, 1998)

Slope Class	Percent Slope	Approximate degrees	Terminology
1	0-0.5	0	level
2	0.5-2	0.3-1.1	nearly level
3	2-5	1.1-3	very gentle slopes
4	5-10	3-5	gentle slopes
5	10-15	5-8.5	moderate slopes

6	15-30	8.5-16.5	strong slopes
7	30-45	16.5-24	very strong slopes
8	45-70	24-35	extreme slopes
9	70-100	35-45	steep slopes
10	>100	>45	very steep slopes

3.2.3 Surface Expression

Surface expression refers to the shape of the land surface. The surface expression of each sampling site was identified and placed into one of twelve surface expression classes (Agriculture and Agri-Food Canada, 1998).

Surface Expression Categories

a	-	Apron	m	-	Rolling
b	-	Blanket	r	-	Ridged
f	-	Fan	s	-	Steep
h	-	Hummocky	t	-	Terraced
i	-	Inclined	u	-	Undulating
l	-	Level	v	-	Veneer

At each sampling site, an area of one kilometer around the soil pit was assessed and the general surface expression was determined.

3.2.4 Slope Position

The location of the sampling site on the slope (slope position, Figure 3.1) was observed by placing the site into one of seven slope position categories (AEP, 1994).

c (Crest)	- convex uppermost portion of a hill (generally has no distinct aspect).
u (Upper)	- the upper portion of the slope immediately below the crest
m (Mid-Slope)	- area of the slope between the upper and lower slope position

l (Lower-Slope)	- area towards the base of a hill (concave surface)
t (Toe of Slope)	- area at the base of a hill with a slight slope (abrupt decrease in gradient)
d (Depression)	- concave area often at the foot of a hill or in level areas
e (Level)	- an area that lacks a distinct aspect

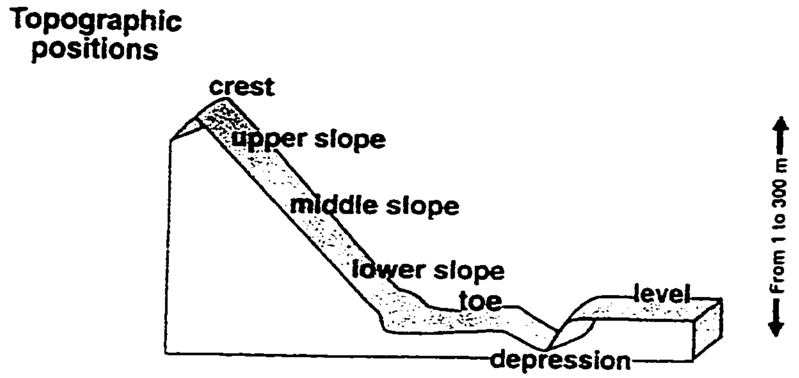


Figure 3.2: Slope Positions (AEP, 1994)

3.2.5 Substrate Percent

Identification of substrate percent includes six separate components: decaying wood, bedrock, cobbles and stones, mineral soil, organic matter and water (AEP, 1994). An estimation of each component was observed at each site based on what was exposed at the ground surface. Values were estimated to the nearest five percent and the total of each category equals 100 percent. Estimates were made in a 10 m radius plot around the soil sampling site. The following is a list of the six components of substrate percent and their definitions:

Decaying Wood	-percentage of decaying wood including fallen trees, large branches and partially buried stumps.
Bedrock	-percentage of exposed bedrock not covered by organic or mineral matter >2cm in thickness.

Cobbles and Stones	-percentage of ground cover with exposed rock fragments >7.5cm in diameter not covered by any mineral or organic matter.
Mineral Soil	-percentage of ground cover which consists of exposed unconsolidated mineral matter which includes sand, silt, clay and any rock fragments <7.5cm in diameter.
Organic Matter	-percentage of ground covered with organic matter.
Water	-percentage of ground covered by standing water.

3.2.6 Surface Stoniness

At each sampling site, surface stoniness was determined which approximates the amount of ground covered by gravel, stones, cobbles etc. Surface stoniness is defined by one of the following six classes:

S0 - nonstony
S1 - slightly stony (stones 10-30m apart)
S2 - moderately stony (stones 2-10m apart)
S3 - very stony (stones 1-2m apart)
S4 - exceedingly stony (stones .01-1m apart)
S5 - excessively stony (stones <.01m apart)

3.3 Field Data Collection – Soil Information

At each sampling site in the study area, a soil pit was dug (to a depth of 100cm or until the C horizon was reached) and specific characteristics of the soil pit were collected and identified using certain methods. The following is a list of the information collected and corresponding methods used.

3.3.1 Soil Pit Depth

The total soil pit depth was determined by measuring with a tape measure from the surface of the ground to the maximum depth of the pit recorded in cm.

3.3.2 Depth to Calcareous Zone

If calcium carbonates were detected in any of the soils sampled (HCl test) the depth of the occurrence of the carbonates was measured. Measurement in centimeters occurs from the top of the mineral soil to the first evidence of carbonates.

3.3.3 Depth to Bedrock

Any consolidated material that was encountered at the sampling locations was measured in centimeters from the top of the mineral soil to the consolidated rock.

3.3.4 Parent Material

At each sampling site the parent material was identified by observing the texture of the soils as well as consulting with surficial geology information for the study area. Parent material was identified into one of the following eight categories (AEP, 1994):

1. Moraine – materials transported by glacial ice
2. Lacustrine – sediments deposited in standing water
3. Eolian – materials moved by wind
4. Fluvial – materials developed by flowing water
5. Glacio-fluvial – materials deposited by fluvial features during glacial times
6. Organic – accumulation of plant materials

7. Residuum – materials developed by weathering of bedrock
8. Colluvium – downslope movement of materials due to gravity

3.4 Soil Profile Characteristics

The following soil profile characteristics were determined at each sampling location:

3.4.1 Soil Horizons

Soil horizons were identified by observing differences within the soil profile that included:

1. changes in the proportions of sand, silt and clay
2. changes in the amounts of coarse fragments
3. presence/absence of organic matter
4. changes in color between horizons

Soil horizon differentiation was determined by probing the side of the soil pit with a soil knife from top to bottom to determine textural differences. Changes in organic matter content and fine and coarse fragment presence also were identified. Once individual soil horizons were identified texture was determined along with percent coarse fragments and the type of coarse fragments. Classification of soils was determined after laboratory analysis to ensure proper identification.

3.4.2 Depth of Soil Horizons

Horizon depth was determined by measuring from the top of the soil surface to the bottom of the soil horizon being identified. Horizon depth was determined on all horizons found within a soil profile.

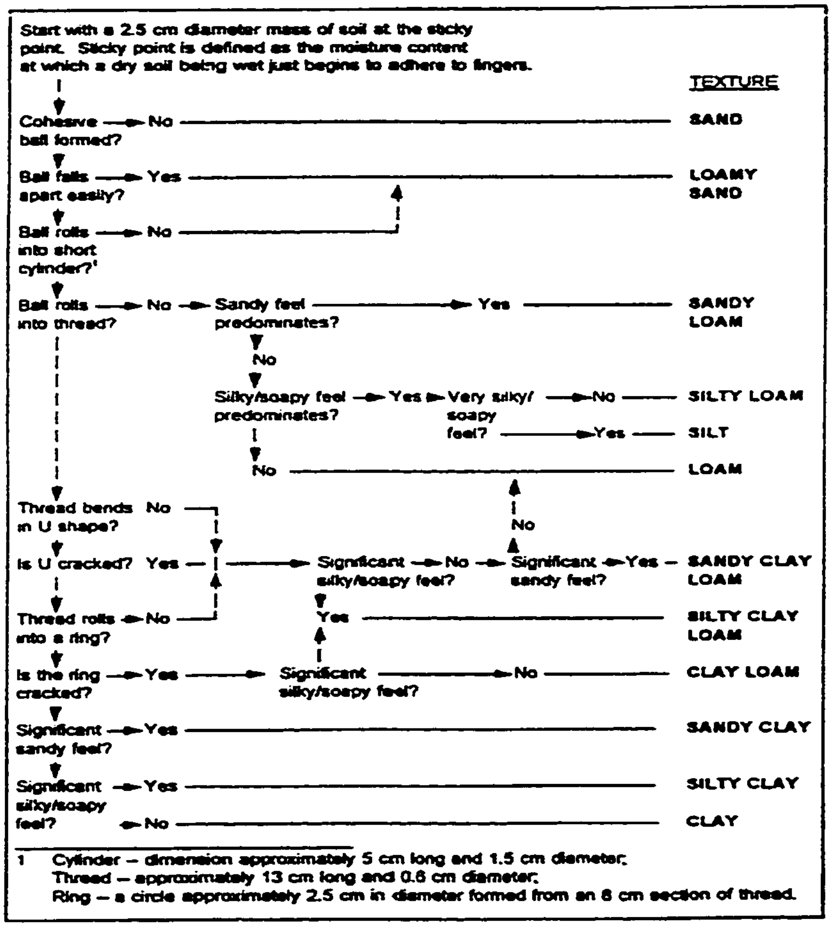
3.4.3 Color

The wet color of each horizon was determined using a Munsell color and was represented by its hue, value, chroma and common color name (eg. 10YR 3/1 = black).

3.4.4 Texture

The relative proportion of sand, silt and clay of each soil horizon was determined using hand texturing which involves a key to determine the texture (Table 3.2). Particle size anaylsis (hydrometer method) was also performed to determine texture (section 3.5.6).

Table 3.2: Key for Hand Texturing of Soils (AEP, 1994)



3.4.5 Soil Structure

Soil structure, the arrangement of soil particles into units or peds, was identified for each soil horizon. Aggregate structures were classified based on the size, shape and degree of distinctness (Table 3.3).

Table 3.3: Types and Classes of Soil Structure (Agriculture and Agri-Food Canada, 1998)

Type	Kind	Class	Size(mm)
Structureless: no observable aggregation or no definite orderly arrangement around natural lines of weakness	**Single grain structure:** loose, incoherent mass of individual particles as in sands		
	Amorphous (massive) structure: a coherent mass showing no evidence of any distinct arrangement of soil particles		
Blocklike: soil particles are arranged around a point and bounded by flat or rounded surface	**Blocky (angular blocky):** faces rectangular and flattened, vertices sharply angular	Fine blocky	<10
		Medium blocky	10-20
		Coarse blocky	20-50
		Very coarse blocky	>50
	Subangular blocky: faces subrectangular, vertices mostly oblique, or subrounded	Fine subangular blocky	<10
		Med. subangular blocky	10-20
		Coarse subangular blocky	20-50
		Very coarse subangular blocky	>50
	Granular: spheriodal and characterized by rounded vertices	Fine granular	<2
		Medium granular	2-5
		Coarse granular	5-10
Platelike: Soil particles are arranged around a horizontal plane and generally bounded by relatively flat horizontal surfaces	**Platy Structure:** horizontal planes more or less developed	Fine platy	<2
		Medium platy	2-5
		Coarse platy	5-10
Prismlike: soil particles are arranged around a vertical axis and bounded by relatively flat vertical surfaces	**Prismatic structure:** vertical faces well defined, and edges sharp	Fine prismatic	<20
		Medium prismatic	20-50
		Coarse prismatic	50-100
		Very coarse prismatic	>100
	Columnar Structure: vertical edges near top of columns not sharp: columns flat-topped, round-topped or irregular	Fine columnar	<20
		Medium columnar	20-50
		Coarse columnar	50-100
		Very coarse columnar	>100

3.4.6 Soil Consistence

Soil consistence is a term used to describe the resistance of soil at various moisture contents to mechanical stresses or manipulations (AEP, 1994). Consistency was found for all soil horizons identified and was classified using the following table:

Table 3.4: Consistency Descriptions for Soils (Brady, 1990)

Wet Soils			
Stickiness	Plasticity	Moist Soils	Dry Soils
Nonsticky	Nonplastic	Loose	Loose
Slightly sticky	Slightly plastic	Very Friable	Soft
Sticky	Plastic	Friable	Slightly hard
Very sticky	Very plastic	Firm	Hard
		Very firm	Very hard
		Extremely firm	Extremely hard

3.4.7 Drainage Class

Each soil profile was classified into a drainage class which defines the ability of water to move through a certain soil type. Each soil profile was classified into one of seven drainage classes.

1. Very Rapidly Drained - soils with coarse textured sands and gravels and are very dry (fluvial or glaciofluvial in origin).

2. Rapidly Drained – soils developed in medium to fine sands or loamy sands (fluviolacustrine or eolian in origin).

3. Well Drained – soil textures are variable but deposition is usually glacial till (coarse to fine texture).

4. Moderately Well Drained – soils that contain excess water for short periods of time. Usually a soil horizon is present that has the ability to restrict water penetration

5. Imperfectly Drained – soils with excess water for moderately long periods and have evidence of mottling and/or gleying.
6. Poorly Drained - soils developed under prolonged saturated or near saturated conditions. Gleying and/or mottling is prominent overlain by a peat layer (Gleysolic or Organic soils).
7. Very Poorly Drained – soils that have free water remaining at or within 30 cm of the ground surface most of the year. Organic and Gleysolic soils represent these conditions.

3.5 Laboratory Analyses

3.5.1 pH

All soil samples collected from the study area, were tested for pH to determine if the soils were acidic or basic in nature. In the field HCl was used to determine the approximate pH of the soils. In the laboratory, a Fisher-Scientific-Accumet pH meter was used to determine the actual pH reading. The procedure used for determining pH was the 0.01 M CaCl2 method and is considered to produce more consistent results (Scott, 1995). The method used is outlined in Scott, 1995.

3.5.2 Electrical Conductivity (EC)

Electrical conductivity was done on all soil samples to determine the total amount of dissolved salts otherwise known as the salinity (saline or non-saline) of the soil. The 1:2 extract method was used which is a common procedure. A Fisher-Scientific-Accumet pH meter was used which also identifies electrical conductivity. The method used to determine electrical conductivity is outlined in Scott, 1995.

3.5.3 Moisture Content

Moisture content was measured on all soil samples to determine their gravimetric water content which is defined as the comparison of the mass of water present in a soil to the mass of solid matter in that soil (ratio of water to solid). The gravimetry with oven drying procedure was used and is outlined in Scott, 1995.

3.5.4 Organic Matter Content

Each soil sample was tested for organic matter content using the loss on ignition method which is a common procedure and is outlined in Scott, 1995. Organic matter content testing helps to determine if the soil is nutrient rich or poor and whether or not there is sufficient organic matter present when revegetation of the study area occurs. Organic carbon percent also was determined by taking the organic matter percent and multiplying by 0.58 (McKeague, 1976).

3.5.5 Presence of Carbonates

The loss on ignition method (Scott, 1995) also was used to determine the presence of carbonates, specifically calcium carbonates in each of the soil samples and is considered to be a simple but accurate procedure. This test also helps to substantiate the values determined from pH readings (especially if the soil has been identified as slightly alkaline).

3.5.6 Particle Size Analysis

To determine the actual percentages of sand, silt and clay in each of the A horizon of the soil samples collected, particle size analysis was performed using the hydrometer method outlined in McKeague, 1976.

3.5.7 Exchangeable Cations and Cation Exchange Capacity

Exchangeable cations and cation exchange capacity were determined for all the A horizons of the soil samples by atomic absorption spectrometry as outlined in the common method by Hendershett and Duquette, 1986. Exchangeable cations measured were calcium, potassium, sodium, magnesium, manganese, iron and aluminum.

3.6 Qualitative Comparisons

The physical properties identified for the undisturbed soil samples collected were compared to the physical properties observed of the soils sampled after construction of the pipeline to determine if there were any significant changes in any or all of these properties. The physical properties recorded were: color, texture, structure and consistency.

Chemical analyses mentioned above were all performed on the off-site soil samples as well as the samples collected on the pipeline right-of-way (RoW). The results for the off-site soil chemical analyses were compared to those of the on-site samples to determine if there are any significant changes in any of the chemical properties of the on-sight soil samples (disturbed soils) as a result of pipeline construction.

After reviewing the results for the physical and chemical analyses of the RoW samples, certain chemical and physical properties (pH, organic carbon %, coarse fragment %, stoniness, texture, moist consistency and calcium carbonate content %) were selected which can be used to determine the reclamation suitability of the soils studied. These properties were selected based on the criteria used in evaluating the suitability of root zone material in the Eastern Slopes Region (Alberta Agriculture).

4.0 RESULTS

A total of thirty-six soils were sampled in the study area with nineteen soil samples collected on the pipeline right-of-way (on-site) and seventeen soil samples collected adjacent to the on-site samples in undisturbed areas (off-site). Approximately half of the total soils collected were identified as Orthic Black Chernozems with a well defined Ah (>10 cm), Bm and C/Ck horizons. The other half of the soils sampled were identified dominantly as Rego Black Chernozems with a well developed Ah (>10cm) and C/Ck horizons. There were inclusions of Orthic Regosols in areas where bedrock exposure was observed and the Ah horizons were <5 centimeters (Appendix 1). Soils in the study area often are characterized as having a shallow depth to parent materials which have a high proportion of coarse fragments or shallow depths to bedrock (Axys Environmental, 1997)

4.1 Terrain Identification

Table 4.1 identifies the terrain classification for each site sampled. Approximately fifty percent of the sites were classified as level while the other fifty percent of the sites had distinct aspects, slope percents, slope positions and surface expressions.

Table 4.1: Terrain identification for both the disturbed and undisturbed areas sampled.

Site Number	Aspect	Slope Percent	Slope Position	Surface Expression
1 D	SE 170	2-3	toe	rolling
2 U	SE 170	2-3	toe	rolling
3 D	SE 170	2-3	toe	rolling
4 D	NE 60	4-5	upper	rolling
5 U	SE 140	5	Mid	rolling
6 U	-	0	level	level
7 D	-	0	level	level
8 D	SE 130	4	upper	rolling
9 D	-	0	depression	-
10 U	-	0	depression	-

11 D	NW 340	10	lower	inclined
12 U	NW 340	10	lower	inclined
13 U	-	0	level	level
14 D	-	0	level	level
15 D	-	0	level	level
16 U	-	0	level	level
17 D	-	0	level	level
18 U	-	0	level	level
19 D	NW 280	1-2	lower	rolling
20 U	NW280	1-2	lower	rolling
21 D	SE 110	3	upper	rolling
22 U	SE 110	3	upper	rolling
23 D	-	0	level	level
24 U	-	0	level	level
25 D	NE 70	6	upper	rolling
26 U	NE 70	6	upper	rolling
27 D	NE 70	5	mid	rolling
28 U	NE 70	5	mid	rolling
29 D	NE 40	14	upper	inclined
30 U	NE 40	14	upper	inclined
31 D	NE 40	21	upper	inclined
32 U	NE 40	21	upper	inclined
33 D	-	0	level	level
34 U	-	0	level	level
35 D	-	0	level	level
36 U	-	0	level	level

D = disturbed sites U = undisturbed sites

4.1.1 Parent Material Identification

Parent material of the study area is dominantly till (mountain till) with an inclusion of continental till which occurred at the first two sites sampled in the study area. Samples collected near the Crowsnest River were identified as having a parent material of glacio-fluvial/fluvial origin and in the area of exposed bedrock, samples had a parent material identified as rock.

4.1.2 Drainage Determination

In areas where soils had textures consisting of sand and sandy loam, drainage was determined as rapidly to well drained. Areas consisting of finer textures such as very fine sandy loam, loam and clay loam, drainage were identified as being moderately well drained.

4.1.3 Substrate Percent

Substrate percent (section 3.2.5) was determined at all sampling sites. The disturbed soil had substrates consisting of approximately 60% mineral soil (due to exposed soil from disturbance) and 40% cobbles and stones (which reflects surface stoniness). The undisturbed sites had substrates consisting of approximately 50 to 60 % cobbles and stones and 40 to 50 % organic matter (litter layer).

4.1.4 Surface Stoniness

Surface stoniness was determined at each site (both disturbed and undisturbed) (Appendix 1). The surface stoniness categories of the disturbed sites and undisturbed sites ranged from S0 (non-stony) to S5 (exceedingly stony). Approximately 42 % of the disturbed sites had an increase in surface stoniness (Appendix 1). Twelve percent of these sites had an increase of one stoniness category (slight change), 18% had an increase of two stoniness classes (significant change), and 12% had an increase of three stoniness classes (very significant change). The increase in one stoniness class of disturbed sites 1 and 4 was significant but not dramatic. Surface stoniness increased from stoniness class S0 (nonstony) to stoniness class S1 (slightly stony). Disturbed sites 14 and 17, compared to the undisturbed sites had an increase in surface stoniness from class S1 to S3. The increase in surface stoniness at these two sites is more significant than at disturbed sites 1 and 4 because the surface stoniness has changed from slightly stony (S1) to very stony

(S3). Disturbed sites 7 and 35 had the highest increase in surface stoniness compared to the undisturbed sites as well as the other disturbed sites whose surface stoniness increased. Sites 7 and 35, compared to the undisturbed sites 6 and 36, had a surface stoniness increase from S1 (slightly stony) to S4 (exceedingly stony). Table 4.2 summarizes the surface stoniness of both the disturbed and undisturbed sampling sites.

Table 4.2: Surface stoniness classes for both disturbed and undisturbed sampling sites. (each disturbed site is paired with the adjacent undisturbed site in the same row).

Disturbed Sites	*Surface Stoniness Class	Undisturbed Sites	*Surface Stoniness Class
1	S1	2	S0
4	S1	5	S0
7	S4	6	S1
8	S1-S2	10	S2
11	S1	12	S1
14	S3-S4	13	S1-S2
15	S2	16	S0
17	S3	18	S1
19	S3	20	S3
21	S1	22	S1
23	S1	24	S1
25	S1	26	S1
27	S2	28	S2
29	S0	30	S
31	S4-S5	32	S4-S5
33	S1	34	S1
35	S4	36	S1

* Surface stoniness classes: S0 – nonstony; S1 – slightly stony; S2 – moderately stony; S3 – very stony
S4 – exceedingly stony; S5 – excessively stony

4.2 Soil Profile Results (Physical Properties)

For samples collected on the pipeline RoW and adjacent to the RoW, the following physical properties were determined: horizon identification, depth of horizons, color, texture, structure, consistency and percent coarse fragments (Appendix 1).

4.2.1 Depth of the A horizon

The majority of the A horizons measured for the disturbed sites had depths >15cm (range between 10 – 30cm). Only one soil sampling site (site 14) had an A horizon depth of 5cm. Undisturbed sites had mostly A horizon depths of >10cm (10 – 30cm) with two sampling sites (13 and 32) having A horizon depths of 5cm and 7cm respectively. Disturbed sites 17, 21, and 25 had increased A horizon depths compared to the corresponding undisturbed sites. Sites 17 and 21 had a 10 cm increase over their adjacent undisturbed sites and site 25 had an 8 cm increase compared to the adjacent undisturbed site. Disturbed sites 27 and 29 had a reduction in the A horizon depths compared to the undisturbed sites. Site 27 had a 13 cm decrease and site 29 had a 7 cm decrease. The remaining disturbed sites had relatively equal A horizon depths compared to the adjacent undisturbed sites. Table 4.3 summarizes the A horizon depths of both the disturbed and undisturbed sampling sites.

Table 4.3: Summary of A horizon depths for both the disturbed and undisturbed sampling sites (disturbed and undisturbed sites on the same row are paired together).

Disturbed Sites	Depth of A Horizon (cm)	Undisturbed Sites	Depth of A Horizon (cm)
1	15	2	18
4	13	5	13
7	15	6	15
8	26	10	23
11	22	12	20
14	5	13	5
15	25	16	25
17	20	18	10
19	12	20	15
21	25	22	15
23	20	24	20
25	20	26	28
27	12	28	23
29	18	30	25
31	10	32	7
33	12	34	12
35	10	36	18

4.2.2 Color

Color did not change between the disturbed and undisturbed sites and therefore is eliminated as a factor for determining effects of pipeline construction on the soils in the study area. Colors of the soils sampled varied from dark brown to black which is common in Chernozemic soils.

4.2.3 Texture

Hand texturing of the soils was done in the field to determine the approximate texture, but particle size analysis (hydrometer method) was done on all A horizon samples to determine the actual amount of sand, silt and clay as well as to allow for proper identification of the soil texture. Table 4.4 summarizes textures of the A horizon in both the disturbed and undisturbed sites sampled. Textures were similar between the disturbed and undisturbed sites and this factor was eliminated in terms of determining the effects of pipeline construction. However, texture is used to determine reclamation suitability of the soils in the study area. The majority of the textures for the soils sampled were very fine sandy loam and sandy loam. Sites 1, 2 and 3 had a clay loam texture and sites 5, 19, 22, 26, 28, 29 and 36 had a loam texture.

4.2.4 Structure

A majority of the disturbed soils sampled had granular structures comparable to the undisturbed soil structures which indicates no change of structure between these disturbed and undisturbed sites. Only at disturbed sites 4, 11 and 15 was there structure degradation of the A horizon compared to the adjacent undisturbed sites. Site 4 had an A

Table 4.4: Summary of textures of the A horizons of both the disturbed and undisturbed soils sampled (disturbed and undisturbed sites in each row are paired together).

Disturbed Sites	Texture	Undisturbed Sites	Texture
1	clay loam	2	clay loam
4	very fine sandy loam	5	loam
7	very fine sandy loam	6	sandy loam
8	sandy loam	10	very fine sandy loam
11	fine sandy loam	12	sandy loam
14	very fine sandy loam	13	very fine sandy loam
15	very fine sandy loam	16	very fine sandy loam
17	very fine sandy loam	18	sandy loam
19	loam	20	very fine sandy loam
21	very fine sandy loam	22	loam
23	very fine sandy loam	24	very fine sandy loam
25	sandy clay loam	26	loam
27	sandy loam	28	loam
29	loam	30	very fine sandy loam
31	sandy loam	32	sandy loam
33	sandy loam	34	fine sandy loam
35	sandy loam	36	loam

horizon soil structure identified as weak, fine crumb. The adjacent undisturbed site (Site 5) had a strong, medium crumb structure. Although both the A horizons had crumb structure, the size and stability of the aggregates were degraded at disturbed site 4. Disturbed site 11 had a similar degradation in soil structure compared to its corresponding undisturbed site 12. Site 11 was identified as having a soil structure of weak, fine crumb, while the undisturbed sites had a soil structure of strong, medium blocky. Again there was degradation in structure size and stability. The disturbed site 15 showed a change in structure size, stability and also structure shape. Disturbed site 15 had a single grained structure. The adjacent undisturbed site 16 had weak, medium crumb structure (similar to undisturbed sites, 5 and 12). Table 4.5 summarizes the structures determined for the A horizon of both the disturbed and adjacent undisturbed soil samples collected.

Table 4.5: Structures determined for the A horizons of both the disturbed and undisturbed sites (disturbed and undisturbed site in the same row are paired together).

Disturbed Sites	Soil Structure	Undisturbed Sites	Soil Structure
1	weak fine crumb	2	weak fine crumb
4	weak fine crumb	5	strong medium crumb
7	granular	6	weak fine crumb
8	granular	10	granular
11	weak fine crumb	12	moderate medium crumb
14	granular	13	granular
15	granular	16	weak fine crumb
17	granular	18	granular
19	granular	20	granular
21	granular	22	granular
23	granular	24	weak crumb
25	granular	26	granular
27	granular	28	granular
29	weak fine crumb	30	weak fine crumb
31	granular	32	granular
33	granular	34	granular
35	granular	36	granular

4.2.5 Consistency

Consistency is directly related to the strength of soil structure; disturbed sites 4, 11 and 15 had a degradation or reduction in the consistency of the A horizon compared to the undisturbed adjacent sites. These disturbed sites are the same sites that had a change in structure type. Sites 4 and 11 had very friable (easily manipulated) consistencies compared to friable to firm (not as easily manipulated) consistencies for the adjacent undisturbed sites (5 and 12). The disturbed site 15 had a loose consistency (characteristic of a single grained structure) while the undisturbed site 16 had a very friable consistency. The degradation of the structure of these disturbed sites resulted in a consistency change compared to the matched undisturbed sites. All other disturbed sites had similar soil consistencies compared to the undisturbed areas. Table 4.6 summarizes the consistencies determined for the A horizon of both the disturbed and undisturbed site sampled.

Table 4.6: Consistencies determined for the A horizons of both the disturbed and undisturbed sites sampled (disturbed and undisturbed sites in the same row are paired together).

Disturbed Sites	Soil Consistency	Undisturbed Sites	Soil Consistency
1	very friable	2	very friable
4	very friable	5	friable
7	loose	6	very friable
8	loose	10	loose
11	very friable	12	very friable
14	loose	13	loose
15	loose	16	very friable
17	loose	18	loose
19	loose	20	loose
21	loose	22	loose
23	loose	24	very friable
25	loose	26	loose
27	loose	28	loose
29	very friable	30	very friable
31	loose	32	loose
33	loose	34	loose
35	loose	36	loose

4.2.6 Percent Coarse Fragments

The percentage of coarse fragments of each soil profile was observed and it was determined that the disturbed sites 1, 7, 8, 11, and 31 had an increase in the amount of coarse fragments in the A horizon compared to the adjacent undisturbed sites. There was an increase in the coarse fragments of the B horizon at disturbed site 1. Coarse fragment percent increased from 10 to 20 % in the A horizons of these five disturbed sites. The remaining disturbed sites had similar percents of coarse fragments compared to the undisturbed areas. Coarse fragment content ranged from 0 to >40% in the A horizons of the soils sampled. Table 4.7 summarizes the percent coarse fragments determined for the A horizon for both the disturbed and undisturbed sites.

Table 4.7: Percent coarse fragments of the A horizons for both the disturbed and undisturbed sites (disturbed and undisturbed sites on the same row are paired together).

Disturbed Sites	Percent Coarse Fragments	Undisturbed Sites	Percent Coarse Fragments
1	20	2	<5
4	none	5	<5
7	40	6	<20
8	10	10	none
11	10-20	12	<5
14	10-20	13	<20
15	5	16	none
17	none	18	10-20
19	none	20	10-20
21	none	22	10-20
23	none	24	<5
25	5	26	none
27	5	28	none
29	none	30	none
31	40-60	32	20-40
33	20-40	34	20-40
35	10-20	36	10-20

4.3 Chemical Analyses Results

Both the disturbed and undisturbed soil samples collected were analyzed for pH, electrical conductivity, moisture content (%), organic matter content (%), calcium carbonate content (%), exchangeable cations (Ca, Na, Mg, Mn, K, Fe and Al) and cation exchange capacity (Appendix 2). The SPSS for windows statistical program was used to run the two sample difference of means test on pH, moisture content, organic matter content and calcium carbonate content between the disturbed and undisturbed sites to determine if the sites are significantly different from one another (Norusis, 1991). Results of the statistical test showed that the disturbed sites were considered to be similar to the undisturbed sites. However, looking at the results on a site specific basis (comparing each disturbed site to the adjacent undisturbed site) determined there were differences between sites. Thus, all results and subsequent discussions are based on comparing each individual disturbed site to its adjacent undisturbed site for a more meaningful comparison.

Within the results graphs have been created to represent changes in the chemical properties between the disturbed sites and undisturbed sites by pairing the sampling sites. The following table lists each paired site and the corresponding disturbed and undisturbed site that is found in each pair.

Table 4.8: Summary of each paired site and the corresponding disturbed and undisturbed site found in each pair.

Paired Site Number	Disturbed Site	Undisturbed Site
1	1	2
2	4	5
3	7	6
4	8	10
5	11	12
6	14	13
7	15	16
8	17	18
9	19	20
10	21	22
11	23	24
12	25	26
13	27	28
14	29	30
15	31	32
16	33	34
17	35	36

3.1 pH

The pH values were determined for the A horizons for both the disturbed and undisturbed sites as well as for the B horizons that were able to be sampled and tested (coarse fragments inhibited some horizons from being collected). The determination of pH is important for the A horizons because this is the zone that if affected by a change in pH due to pipeline construction will affect the outcome of reclamation (revegetation). It was found that approximately 90% of the soils sampled at disturbed sites had an increase in pH compared to the adjacent undisturbed sites. Figure 4.1 shows distribution of pH values for the A horizons of the disturbed sites and the adjacent undisturbed sites sampled. Not all sites sampled are listed on these figures (missing two sites); only the

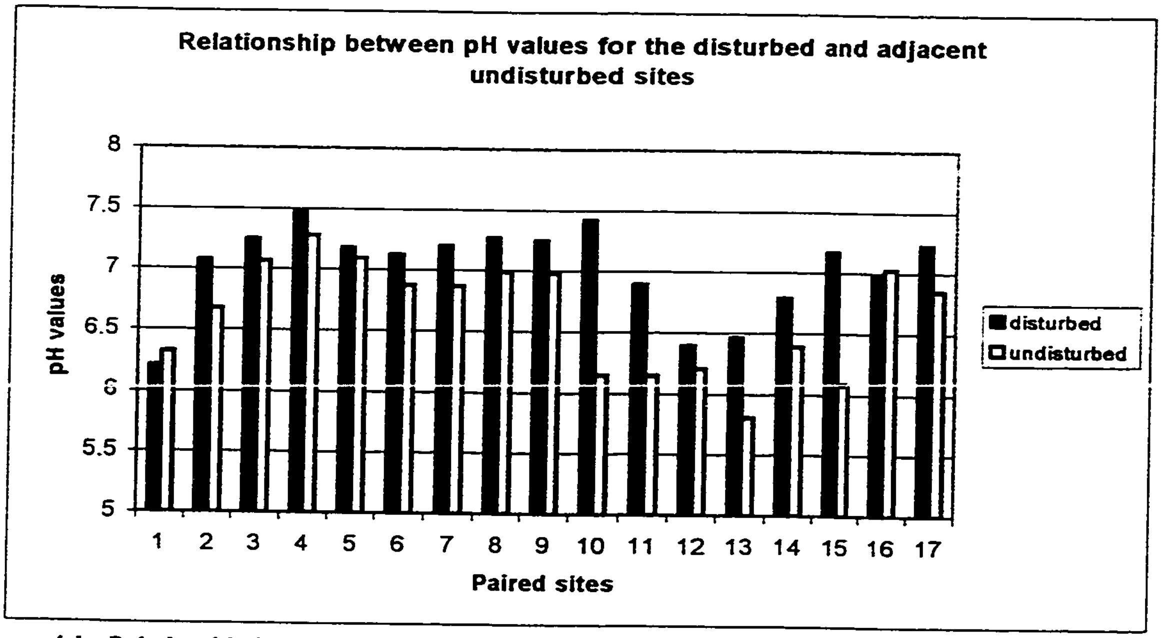


Figure 4.1: Relationship between the pH values of the A horizon for the disturbed soils sampled to the pH values determined for the corresponding undisturbed samples. Each disturbed site has a representative undisturbed site (paired sites) which are grouped together in order to distinguish differences in pH values.

disturbed sites that had adjacent undisturbed sites are shown in the corresponding figure. The paired sites 10, 11, 13 and 15 showed a noticeable increase in the disturbed sites pH levels compared to the corresponding undisturbed sites. Only paired sites 1 and 16 showed higher pH values on the undisturbed compared to the disturbed sites. The pH values also were determined for B horizons that were sampled in some of the disturbed and undisturbed sites (Appendix 2). The undisturbed B horizon samples had pH values slightly higher than the comparable disturbed sites. However, the B horizon pH levels did not show a significant change between the disturbed and undisturbed sites. Importance of pH concentration is placed on the A horizon since this is the area in which a high percentage of plant root mass is concentrated and is affected by significant changes in pH levels.

4.3.2 Electrical Conductivity

Electrical conductivity was identified for all the disturbed and undisturbed sites. Electrical conductivities of the A horizon for all samples (disturbed and undisturbed) ranged between 0.023 and 0.161 mmhos/cm. This indicates that the A horizons are non-saline in nature. The B horizons that were collected for select disturbed and undisturbed sites had electrical conductivities ranging between 0.013 and 0.093 mmhos/cm which also indicates non-saline B horizons. Electrical conductivity results allowed for identification of the soils as non-saline/sodic and the determination that salt is not a factor to be included when determining the reclamation suitability of the soils.

4.3.3 Moisture Content

Moisture content was determined for all samples and emphasis of the results is placed on the A horizons. Figure 4.2 shows the relationship between moisture content of the disturbed sites and the corresponding undisturbed sites. All of the disturbed sites except for 4, 8, 11, 13, 14 and 16 show decreased moisture content compared to the undisturbed sites. Paired sites 2, 3, 7, 10 and 17 show a more noticeable decrease in moisture content than the other paired sites.

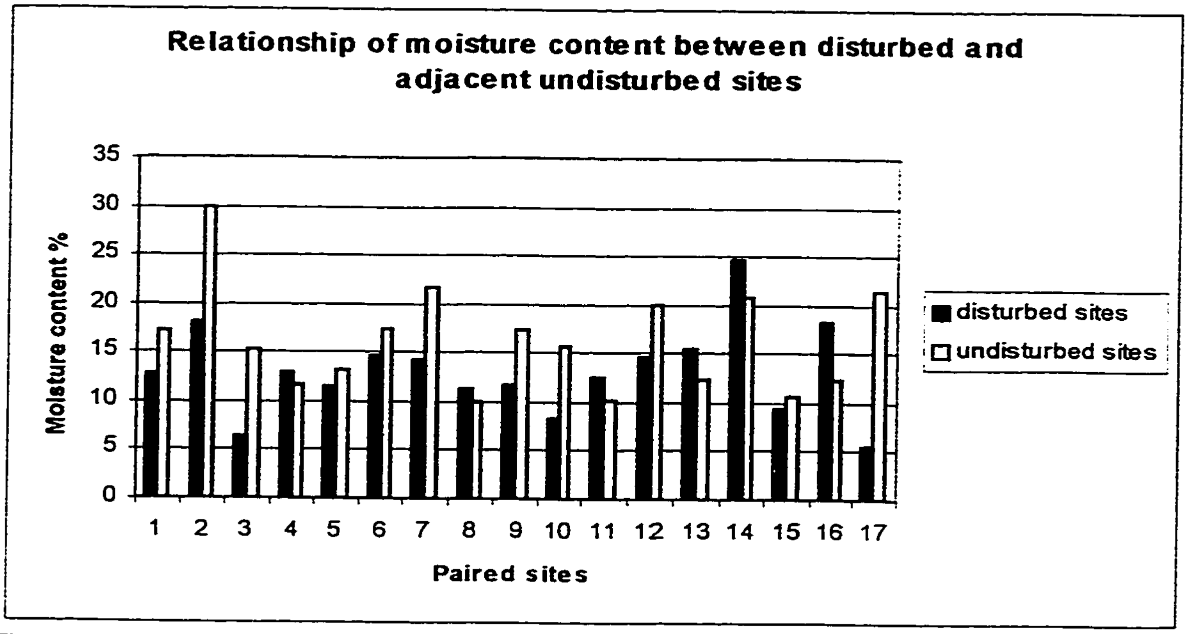


Figure 4.2: Relationship between the moisture content of the disturbed sites and the corresponding undisturbed sites. Each disturbed site has been paired with the adjacent undisturbed site and graphed to show the differences in moisture content.

4.3.4 Organic Matter Content

Organic matter content was determined on all the A horizons and sampled B horizons for both the disturbed and undisturbed sites. Although organic matter content determination is essential for the A horizon (aids plant growth), organic matter contents for the B horizons that were sampled were collected and noted as important as well. Figure 4.3 shows the relationship between organic matter contents in the A horizon of the disturbed and undisturbed sites. Seventy-six percent of the paired sites had disturbed sites with organic matter contents lower than the adjacent undisturbed sites. Only the paired sites 3, 10, 12 and 14 had higher organic matter contents than the undisturbed sites. Figure 4.4 shows the correlation between organic matter content and moisture content over the entire study area (all paired disturbed and undisturbed samples are represented). Figure

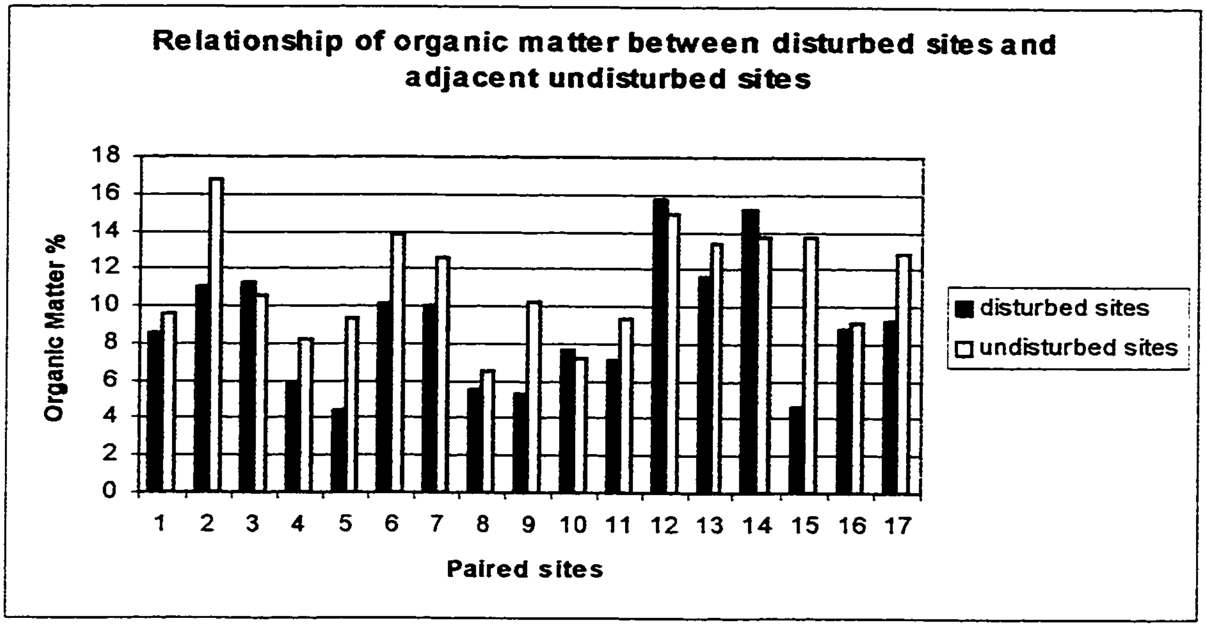


Figure 4.3: Relationship between organic matter content of the disturbed sites and corresponding undisturbed sites.

4.4 shows a trend in moisture content and organic matter content between the disturbed sites and the undisturbed sites. An increase in moisture content shows a corresponding

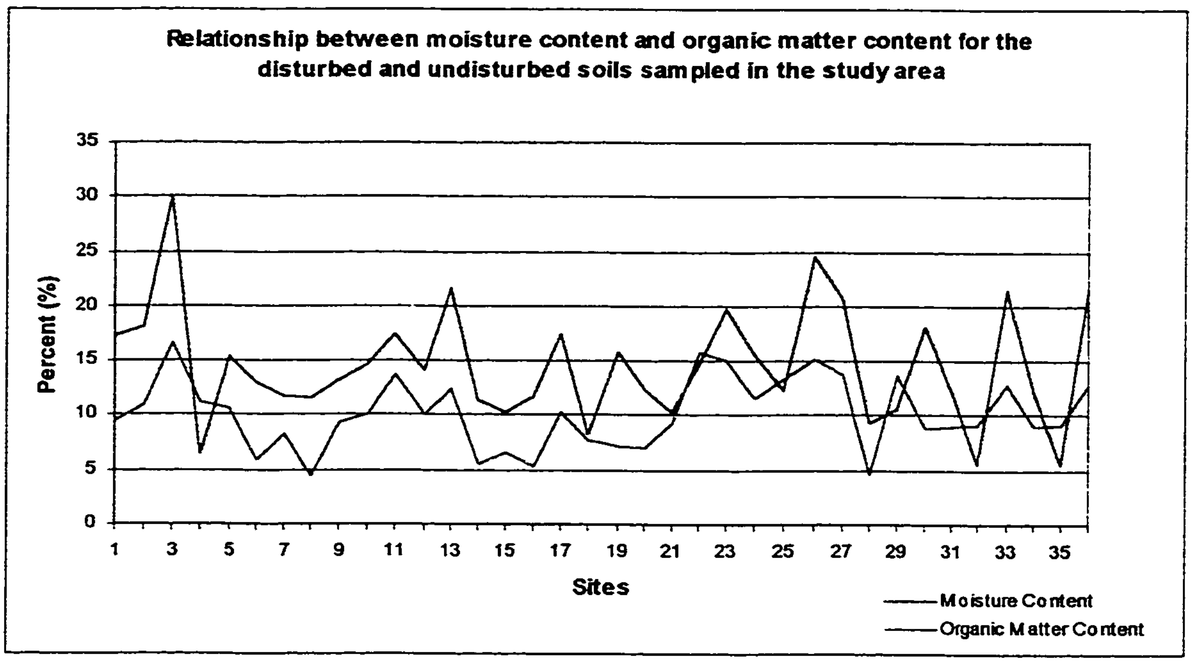


Figure 4.4: Graph showing the relationship between moisture content and organic matter between the disturbed sites and undisturbed sites.

increase in organic matter content and vice versa.

Organic carbon also was found to decrease at ~76% of the disturbed sites as compared to the adjacent undisturbed sites. Organic carbon is related to organic matter content, so the same disturbed sites that had a decrease in organic matter (Figure 4.3) also had a decrease in organic carbon.

4.3.5 Calcium Carbonate Content

Calcium carbonate ($CaCO_3$) content was determined for all soil samples collected. Figure 4.5 shows the relationship between calcium carbonate content of the disturbed sites to the adjacent undisturbed sites. These values represent the A horizon, but calcium carbonate was determined on all horizons that were collected (Appendix 2). A change in the calcium carbonate of the A horizon (increase/decrease) can affect the growth ability of plants and therefore more importance is placed on the A horizon $CaCO_3$ contents than other horizons. Results show that 71% of the disturbed sites had higher calcium carbonate contents than the adjacent undisturbed sites. Paired sites 3, 4, 5, 6, 7, 8, 9, 13, 15, 16 and 17 had noticeably higher CaCO3 contents on the disturbed sites over the undisturbed sites. Paired site 15 shows the most dramatic increase. Twenty-nine percent of the sites had higher CaCO3 contents in the undisturbed sites compared to the disturbed sites.

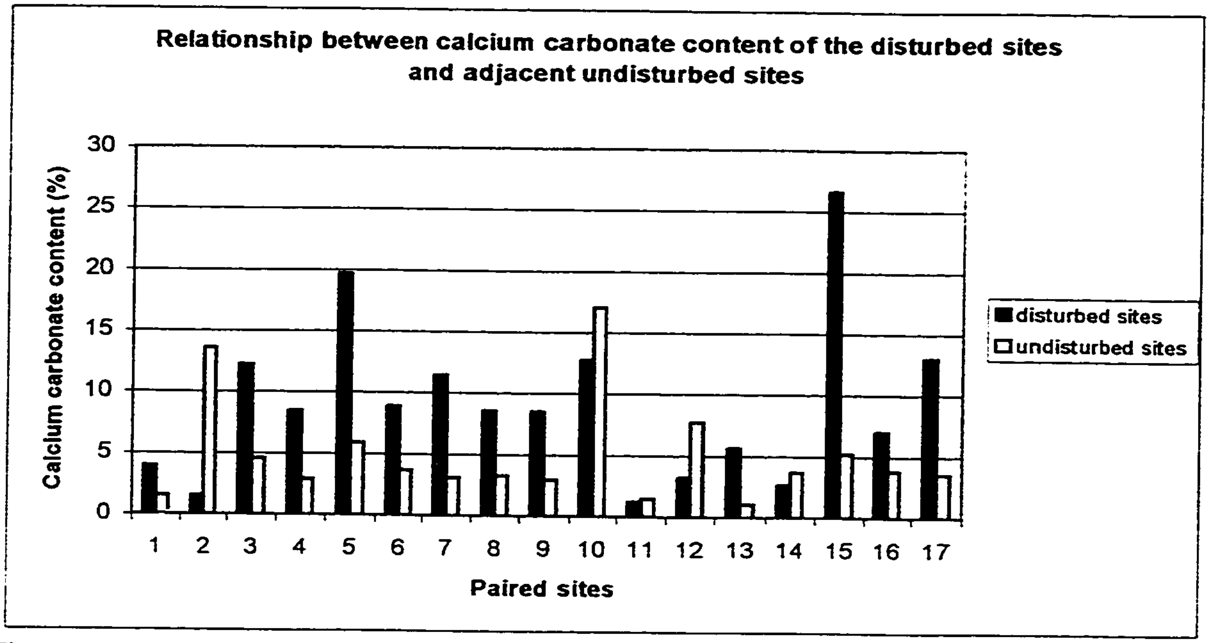


Figure 4.5: Relationship between calcium carbonate contents of the disturbed sites and corresponding undisturbed sites.

4.3.6 Exchangeable Cations and Cation Exchange Capacity

All A horizons collected (disturbed and undisturbed) were tested for the amounts of the following exchangeable cations: Ca, Na, K, Mg, Mn, Al and Fe. Table 4.9 shows the amounts of exchangeable calcium and potassium determined by using atomic absorption spectrometry. Cation exchange capacity was also determined for all the A horizons sampled. Results for the remaining exchangeable cations determinations (Na, Mg, Mn, Al and Fe) and cation exchange capacities are shown in Appendix 2. Figure 4.6 shows the relationship between exchangeable calcium and the total cation exchange capacity (sum of all exchangeable cations). It is evident that exchangeable calcium represents a large portion of the total cation exchange capacity. Exchangeable calcium is therefore the dominant cation found in the soils sampled. Figure 4.7 represents the percentage of exchangeable calcium that is found in the soils. Base saturation is the degree to which bases (%) occupy the cation exchange sites (Scott, 1995). Calcium saturation was determined by the following calculation (Scott, 1995):

$$\frac{\text{Exchangeable cation (Calcium) in meq/100g}}{\text{Total cation exchange capacity (meq/100g)}} \times 100 = \text{Base Saturation \% by Calcium}$$

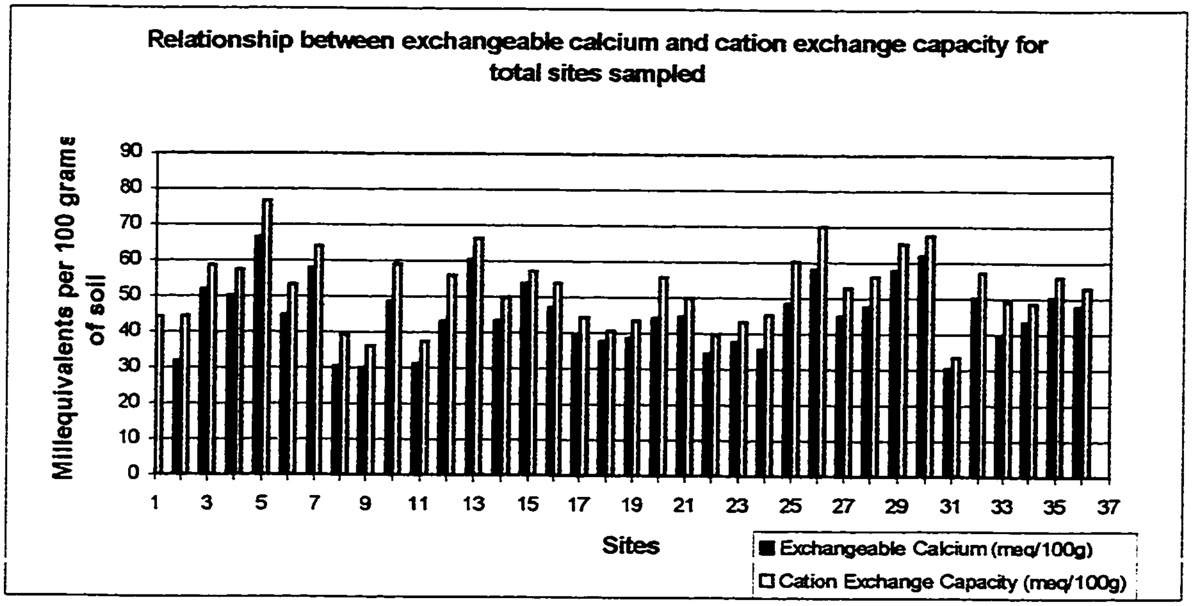


Figure 4.6: Represents the relationship between exchangeable calcium and the total cation exchange capacity of the soils sampled (disturbed and undisturbed). Results show exchangeable calcium being the dominant cation in the soils sampled.

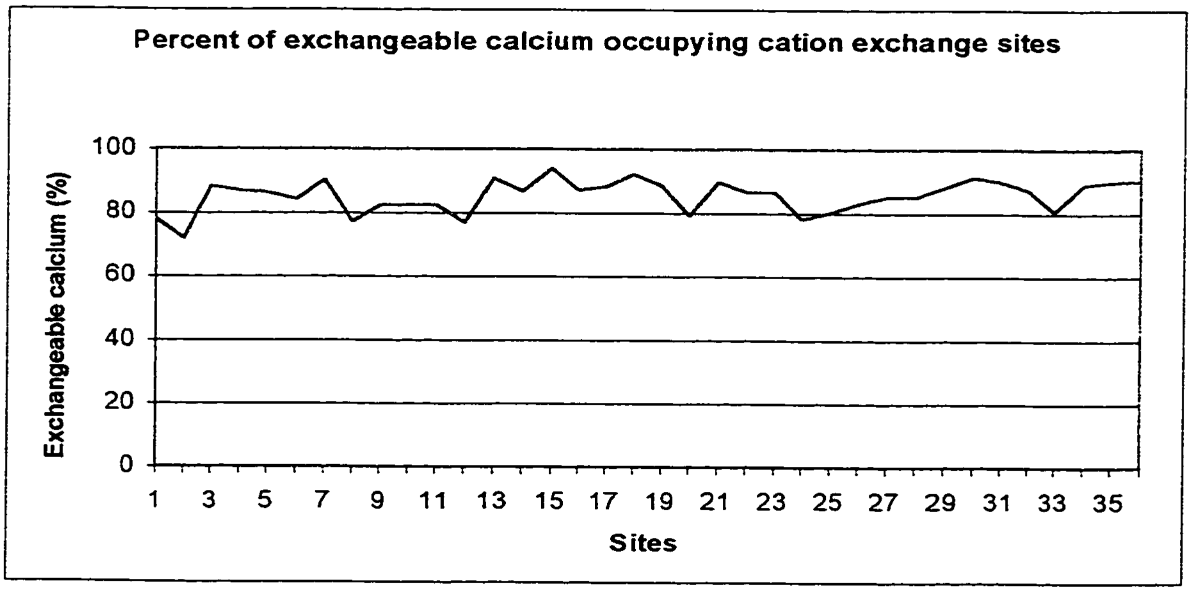


Figure 4.7: Shows the percent of exchangeable calcium which occupies the cation exchange sites of both the disturbed and undisturbed sites

Approximately 70 to 95% of the cation exchange sites found in the A horizons of the soils sampled are occupied by exchangeable calcium. The remaining 5 to 30 % of the cation exchange sites are occupied by other bases (magnesium, potassium and sodium) as well as H^+ (hydrogen ions). Potassium was found to occur in the second largest quantity; approximately 5 to 20 % of the cation exchange sites were occupied by potassium. The average exchangeable calcium on exchange sites for the samples tested was ~86% and average exchangeable potassium was ~10%. Thus, these two cations account for a total of 96% base saturation with the remaining 4% of cation exchange comprised of exchangeable Na, Mg, Mn, Al, Fe and H^+ ions. Cation exchange capacity also was found to be strongly related to organic matter content; as cation exchange capacities increased so did organic matter content (Agriculture Canada, 1981; Thurber Consultants Ltd et al., 1990). Figure 4.8 shows the relationship between organic matter content and cation exchange capacity.

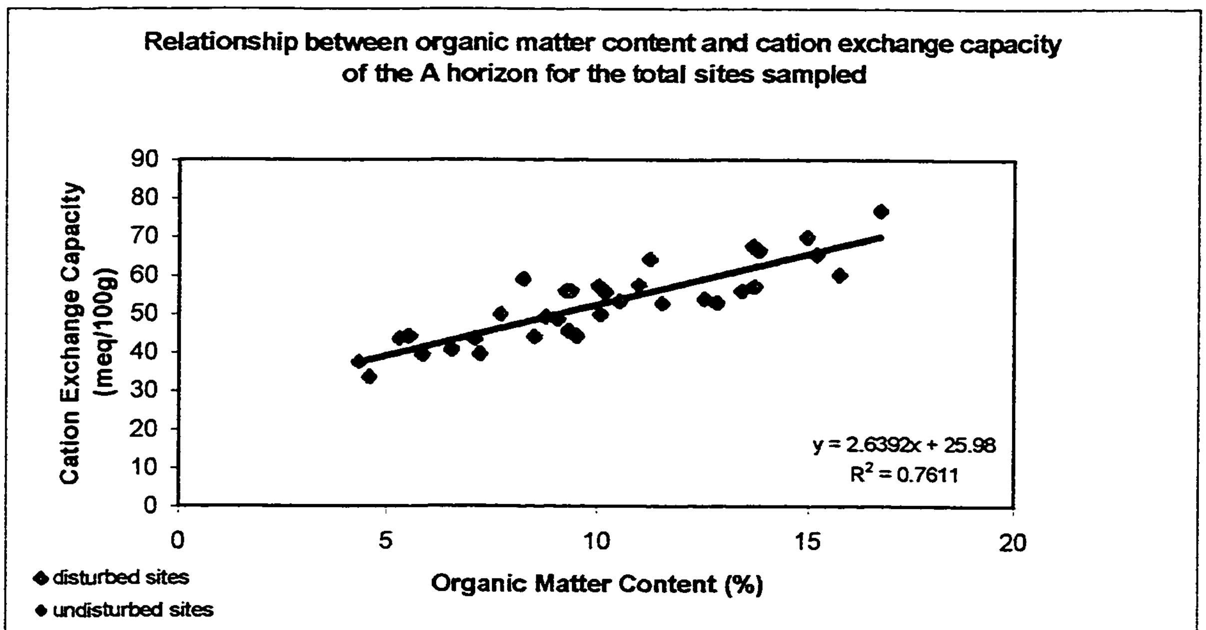


Figure 4.8: Graph showing the relationship between organic matter content (%) and cation exchange capacity (meq/100g) for the A horizons of all sites sampled (both disturbed and undisturbed).

In order to determine if organic matter is correlated with cation exchange capacity, the Pearson correlation coefficient (Norusis, 1991) was determined using an SPSS bivariate correlation test. Statistical results (Appendix 3) showed the correlation coefficient was 0.87 indicating the variables are strongly correlated. Linear regression also was run on the variables to determine the linear relationship between the two variables. Results of the linear regression (Figure 4.8 and Appendix 3) showed a regression coefficient (R^2) of 0.76, meaning 76% of the variability in cation exchange capacity can be explained by the organic matter content. Figure 4.8 also shows the equation that was determined for the regression line:

$$y = 2.6392x + 25.98$$

25.98 = intercept value   2.6392 = slope

where y = predicted cation exchange capacity (meq/100g)

and x = organic matter content (%)

Using this equation, it is possible to predict cation exchange capacity if the organic matter content is known.

Table 4.9: Amounts of exchangeable calcium (Ca), potassium (K) and cation exchange capacity (total cations = Ca, K, Na, Mg, Mn, Al and Fe) for the A horizons of all soils sampled

Sampling Site	Exchangeable Calcium (meq/100g)	Exchangeable Potassium (meq/100g)	Cation Exchange Capacity (meq/100g)
1 D	34.417	6.701	44.056
2 U	31.777	8.664	44.263
3 D	51.907	3.366	58.643
4 D	49.797	5.434	57.365
5 U	66.553	6.223	76.891
6 U	44.792	6.322	53.227
7 D	58.045	4.209	64.163
8 D	30.327	5.793	39.301
9 D	29.836	3.524	36.194
10 U	48.614	6.852	58.942
11 D	30.94	5.058	37.431
12 U	43.026	11.181	55.883
13 U	60.363	3.825	66.348
14 D	43.233	3.238	49.81
15 D	53.918	1.661	57.241
16 U	47.001	5.015	53.802
17 D	39.172	2.489	44.245
18 U	37.47	1.879	40.643
19 D	38.586	3.625	43.536
20 U	44.011	9.996	55.606
21 D	44.726	3.767	49.772
22 U	34.253	3.98	39.523
23 D	37.599	2.793	43.35
24 U	35.46	7.477	45.405
25 D	48.275	9.848	60.185
26 U	58.064	9.809	69.96
27 D	44.968	5.883	52.782
28 U	47.58	5.015	55.935
29 D	57.664	5.425	65.299
30 U	61.781	3.121	67.537
31 D	30.212	1.961	33.53
32 U	49.962	5.251	57.074
33 D	39.643	3.265	49.163
34 U	43.198	3.569	48.505
35 D	50.242	4.164	55.865
36 U	47.85	2.754	52.932

D = disturbed sites   U = undisturbed sites

5.0 DISCUSSION

The Pincher Creek-Crowsnest Pass Area has been shaped by processes such as tectonic activity, weathering and erosion and glacial forces. It has been recognized that both the Laurentide and Cordilleran glaciations are the foundation for the different types of surficial materials found in the Southern Foothills district (study area) (Walker et al., 1991).

The modification of the landscape by processes such as weathering and erosion have also produced specific landforms found in the area as well as the development of soils characteristic of the Pincher Creek-Crowsnest Pass area. The study area is dominated by Orthic Black Chernozems with Rego Black Chernozems codominating and inclusions of Calcareous Black Chernozems. The different slope percentages (eg. 5%), aspects and surface expressions determined in the study area are also a result of the modifications of the landscape over time.

5.1 Soil Physical Properties

5.1.1 Depth of A horizons

One of the first changes observed between some of the disturbed sites and adjacent undisturbed sites was A horizon depth. Disturbed sites 17, 21 and 25 had increased A horizon depths compared to the corresponding undisturbed sites. One possible reason for this increase is the addition of extra topsoil. Where topsoil depths were shallow prior to pipeline construction, additional topsoil was brought in to increase the topsoil depths which aids in better reclamation of the area. Extra topsoil in these areas may be the reason for such an increase. Disturbed sites 27 and 29 had a decrease in A horizon depths compared to the undisturbed sites. Topsoil loss from these areas may be a result of the method used to spread topsoil after pipeline installation or due to wind erosion. Soils in the Pincher Creek-Crowsnest Pass area are prone to wind erosion due to fine textures encountered in many of the soil profiles (Axys Environmental Consulting Ltd, 1997). Topsoil piles, after stripping, were tackified (stabilized) to prevent loss of topsoil but it is difficult to determine if this prohibited complete loss of topsoil to wind. Respread topsoil is also prone to wind erosion prior to reclamation techniques being employed. Another possible reason for a lack of topsoil at these sites is the incorporation of A horizon material into the subsoil. During re-spreading of the topsoil, topsoil material has a tendency to settle into the coarser subsoil matrix (Axys Environmental Consulting Ltd., 1997) and as a result topsoil depths can be reduced.

5.1.2 Soil Structure

Soil structure (soil aggregration) is defined as "a group of two or more primary particles which cohere to each other more strongly than to surrounding particles" (Black et al., 1965). Soil structure and the size and stability of the soil aggregates are important factors which affect infiltration, retention and the movement of soil water; wind and water erodibility (smaller aggregates are more prone to erosion than larger aggregates); crusting and soil aeration (Thurber Consultants Ltd. et al., 1990). One main factor in the development of the soil aggregate is organic matter content. High organic matter contents tend to improve soil structure (Scott, 1995). Degradation of soil structure (eg.

during storage) can adversely affect revegetation, plant productivity and erodibility (Thurber Consultants Ltd. et al., 1990).

Most of the disturbed areas sampled had a sandy loam texture and a structure classified as granular (single grains) which was comparable to the undisturbed samples taken. Sites 4, 11 and 15 experienced a degradation in soil structure size and stability but site 15 experienced a change in soil structure classification from weak-fine crumb to granular. It is likely that a change in soil structure shape, size and stability can adversely affect revegetation more than just a weakening or degradation of the size and stability of the soil aggregates. Organic matter contents of the disturbed sites 4, 11 and 15 were 32 to 78% lower than the undisturbed sites. The decrease in organic matter content may account for the lack of material needed to bind soil particles together. The organic materials found in humus are a major function of the binding process of soil particle (Brady, 1990).

In previous research, soil aggregates (shape, size and stability) have been known to be affected (changed) by topsoil storage (Thurber Consultants Ltd. et al., 1990; Arnal and Chevasu, 1984; Anderson et al, 1988; McQueen and Ross, 1982; Hunter and Carrie, 1956). In this study, all topsoil stripped was stored and tackified (to prevent erosion) until pipeline construction was completed and the topsoil replaced. Storage and exposure to environmental elements (example: wind, heat, etc.) may contribute to a degradation in topsoil structure. Another reason for topsoil structure degradation may be due to the effect of compaction by heavy equipment during topsoil removal and the actual construction of the stockpiles (Thurber Consultants Ltd. et al, 1990; Wishart and Hayes, 1988). Although no compaction studies were done on these soils, these possibilities cannot be ruled out. Heavy traffic in an area reduces aggregate size and as a result increases the possibility of wind and water erosion of the soil (Naeth et al., 1991). A reduction in aggregate size can also influence infiltration, retention and the movement of water through the soil (Thurber Consultants Ltd et al., 1990).

5.1.3 Soil Consistency

Soil consistency is defined as the resistance of soil at various moisture contents to mechanical stress. Consistency of soils generally is described in three conditions: wet, moist and dry (Brady, 1990). A horizon samples collected in the study area of both disturbed and undisturbed sites were either moist or dry. Thus, classification of consistence for moist and dry soils was used (Chapter 3).

The general trend for both the disturbed and undisturbed sites A horizons was a loose consistency which correlates with the granular structure that was determined. Granular structures and loose consistencies are common with sandy loam horizons; ~70 % of the disturbed sites and ~60 % of the undisturbed sites had this consistency and soil structure. All the B horizons sampled in the disturbed and undisturbed sites had similar consistencies.

The change in consistencies from the undisturbed sites to the disturbed sites may be a result of topsoil storage. Hardy Associates Ltd. (1983) found changes in topsoil consistency in three sites sampled on a pipeline right-of-way constructed in the Dark Brown Soil Zone (Chernozems). Consistency was found to have a looser, drier nature compared to their control sites.

Structure changes have been documented in topsoil storage piles and the closely related consistency may have been affected by the same elements that degraded the structure in the same disturbed sites. Activities which affect organic matter content or the chemical properties of soils have been identified as affecting consistency as well (Naeth et al., 1991). Disturbed sites 4, 11 and 15 were noted as having a 32 to 78% decrease in organic matter compared to the undisturbed site 5, 12 and 16. This organic matter decrease may have resulted in a degradation or change in the consistency of the disturbed sites A horizons.

5.1.4 Percent of Coarse Fragments and Surface Stoniness

The percent of coarse fragments refers to the amount of identifiable gravels, stones, cobbles and boulders found within different horizons of a soil profile expressed as a percent. Percent coarse fragments were determined for all collected soil horizons for each soil profile of both the disturbed and undisturbed sites. Increased coarse fragments usually results from fragments being brought to the surface during pipeline construction (Fig. 5.1) (Mutrie and Wishart, 1988; Culley et al, 1981; Hardy Associates Ltd, 1983). This is evident at disturbed site 1 where the B horizon had a high coarse fragment content and after pipeline construction the A horizon had a dramatic increase (~25%) in coarse fragments. It is likely that fragments from the B horizon were integrated into the A

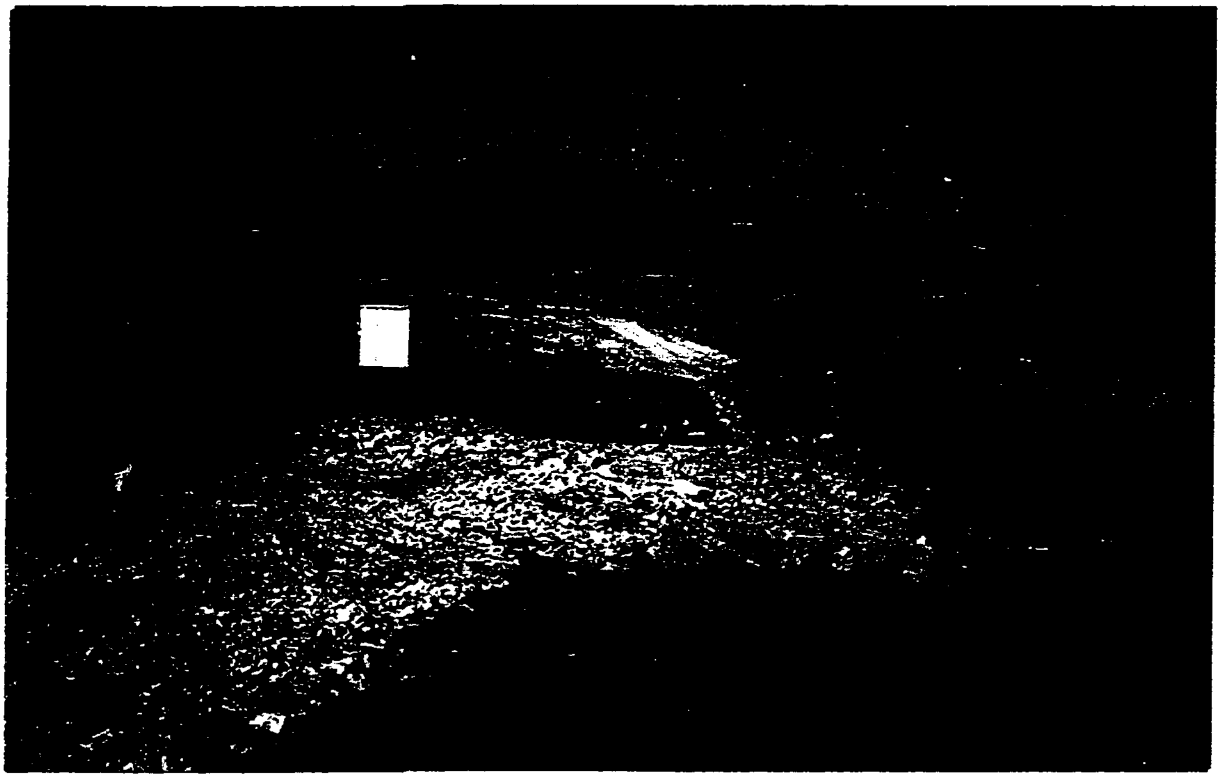


Figure 5.1: Solid bedrock, which is broken up during pipeline construction, is incorporated into the soil surface horizons during construction increasing coarse fragments percentages.

Figure 5.2: During pipeline construction, gravel, cobbles and stones are brought to the surface which inevitable increases the surface stoniness of a particular site.

horizon during construction of the pipeline. Another possible reason for increase coarse fragments occurs during re-spreading of topsoil. Topsoil materials have a tendency to settle into the coarser subsoil matrix which leaves a higher proportion of coarse fragments exposed at the soil surface (Axys Environmental Consulting Ltd., 1997). An increase in coarse fragments within the soil profile can be either a positive or negative results. Increased stones can cause a reduction in soil capability (Deloitte and Touche, 1990) which can result in unsuccessful revegetation/reclamation. Increased stone fragments in a horizon possibly can change the chemistry of the horizon overtime if the fragments are high in carbonates for example. A change in soil chemistry as a result of increased carbonates (due to increased coarse fragments) can result in a change in soil capability/productivity. Plant roots from revegetated species also may be affected adversely by an increase in coarse fragments. A large increase of fragments can result in roots not being able to penetrate the soil to retrieve necessary nutrients or soil moisture for example. It also should be stated that the presence of coarse fragments can prove to be advantageous when the land use is anything other than cultivation for certain crops. Coarse fragments help to provide sites for seed germination as well as aid in slope stabilization (Alberta Agriculture, 1987). Sites 1, 7 and 8 occur in areas of tame pasture and native grassland. Seed mixes were used to revegetate these areas and increased coarse fragments could affect their growth. Sites 11 and 35 occurred in bush areas (Aspen and Douglas Fir) and may not be as adversely affected by the increased coarse fragments. The percent of coarse fragments as well as the size (volume) will determine if the coarse fragments are helpful or restrictive to an area.

Surface stoniness is similar to coarse fragment content except it refers to the amount of stones found on the surface of the ground (not within the profile). Surface stoniness is usually classified into six stoniness categories (Chapter 3). Five disturbed sites had increased surface stoniness compared to the undisturbed sites, and the amount of increase in surface stoniness varied among the disturbed sites. The higher the increase in surface stoniness, the more the soil capability and root penetration will be affected. Similar to coarse fragments, increased surface stoniness can adversely affect the soils capability (for plant growth) (Deloitte and Touche, 1990) and impact root penetration from revegetated species. Increased surface stoniness is a result of stones being brought to the surface during pipeline construction (Fig. 5.2) and past research has shown similar problems encountered during pipeline construction (Mutrie and Wishart, 1988; Culley et al., 1981; Hardy Associates Ltd., 1983). Again, increased stoniness does not necessarily imply a negative impact to the area. Land use other than cultivation may benefit from increased surface stoniness because it aids in creating improved sites for seedbed germination (Alberta Agriculture, 1987). The surface stoniness of each site will reflect the site's ability to have a suitable soil capability for revegetation.

5.2 Soil Chemical Properties

5.2.1 pH and Electrical Conductivity

Approximately 90% of the A horizons of the disturbed sites sampled had higher pH values than the adjacent undisturbed samples collected. The pH is a direct reflection of the acidity or alkalinity of the soil. The pH values ranged from 6.1 to 7.5 over most of the study area with only one site (undisturbed) measured at a pH of 5.8. This range allows the soils to be identified as moderately acid (5.0 – 6.5) to alkaline (>7.0). The moderately acid soils have a higher base saturation than very acid soils while the alkaline soils have exchange sites dominated by mostly exchangeable calcium, magnesium and other base forming cations (Brady, 1990). An increase in pH of the A horizons of the disturbed sites compared to the undisturbed sites may be a result of a few different factors. One main reason is the possibility of incorporating subsoil into the topsoil. Soils that experience high pH normally due to large amounts of bases in the soil (such as this study area) will have high pH values and pH generally increases with depth towards the parent material, since this is the original source for basic cations. Appendix 2 shows the pH values with the corresponding horizons and it is evident that pH increased with depth.

Twenty-one percent of the disturbed sites had lower B horizon pH values than the A horizon pH values. This suggests that there may have been some mixing or incorporation of the subsoil (B horizon) into the A horizon, causing increased pH levels at these sites. Overall the disturbed sites had higher pH values than the undisturbed sites and this also indicates the possibility of mixing of horizons. Thurber Consultants Ltd. (1990) identified that extreme changes in pH are likely due to the incorporation of calcareous material into the topsoil storage piles made during construction. Abdul-Kareem and McRae (1984) and Harris and Birch (1988) found pH increased in topsoil storage heaps in the United Kingdom with depth varying from slightly acidic to nearly neutral. De Jong and Button (1973), who worked on effects of pipeline installation on soil productivity in Saskatchewan, found that certain Chernozemic soils (Weyburn Soils) had pH increases up to 1.0 on the pH scale, and was a direct result of trenching. Soil microbiological activity, plant growth and nutrient availability are affected by soil pH (Alexander, 1977; Brady, 1990). As a result a change in topsoil pH during storage may affect reclamation after re-spreading of the topsoil (Thurber Consultants Ltd. et al., 1990).

The pH also is considered to be a function of the amount of organic matter in the soil (Thurber Consultants Ltd. et al., 1990). Organic matter helps to buffer rapid changes in pH, so a lack of organic matter may cause pH to change since there is not a lot of buffering activity. Organic matter levels decreased in the disturbed sites compared to the undisturbed sites which may result in pH levels increasing in the disturbed sites due to a decrease in a buffering agent.

Electrical conductivity, which measures the amount of total dissolvable salts in the soil, was found to be low in all soils sampled. This reflects the nature of the parent material and concludes that the soils are non-saline in nature. Comparison of the disturbed sites to the undisturbed sites showed no difference between electrical conductivity values.

5.2.2 Moisture Content

Moisture content overall was lower in the disturbed sites compared to the adjacent undisturbed sites (Figure 4.2). A lack of moisture may be the result of topsoil storage; the material removed and stored is more likely to dry out due to exposure to environmental elements such as wind, solar radiation and evaporation (Thurber Consultants Ltd et al., 1990). The Pincher Creek-Crowsnest Pass area is known for high wind activity (Walker et al., 1991) and a drier environment and this is a possible reason for lower moisture contents. Moisture content also is related to the amount of organic matter present in the soil (Figure 4.4). Organic matter has the capacity to hold water and therefore more organic matter generally means more moisture in the soil (Scott, 1995). A dilution of organic matter can affect moisture content of the soil (Wishart and Hayes, 1988). Eighty-two percent of the disturbed sites had lower organic matter contents than the undisturbed sites which correlates with the lower moisture contents in the disturbed sites.

5.2.3 Organic Matter Content

Overall, organic matter decreased in the disturbed sites compared to the undisturbed sites (Fig 4.3). A mixing of subsoil with topsoil can cause a dilution of organic matter content within the A horizon (Culley et al., 1981). A few of the disturbed sites sampled (3, 23 and 27) (Appendix 2) show the B horizon having a slightly higher percentage of organic matter than the A horizon (range from 1 to 4%) which indicates possible mixing of subsoil with topsoil during trenching. Again, there is a relationship between organic matter content and moisture content as indicated in Figure 4.4. A decrease in organic matter content generally shows a decrease in moisture content. Studies have been done in the United Kingdom on the effects of topsoil storage on organic matter. Abdul-Kareem and McRae (1984) observed that stored topsoil had 32 to 85% less organic matter than similar undisturbed topsoils. Topsoil storage may also be a factor in the decrease in organic matter in the disturbed soils sampled compared to the undisturbed samples collected in this study.

Organic matter affects plant growth in a number of ways: organic matter maintains soil structure and aggregate stability, is known as a plant nutrient reservoir, acts as a buffer against changes in pH and increases the water holding capacity of the soils (Thurber Consultants Ltd. et al., 1990). If there is a reduction in the amount of organic matter (as there was on the disturbed sites compared to the undisturbed sites), the above factors for plant growth may be adversely affected. For example, pH levels were found to be higher at the disturbed sites while organic matter levels were found to be lower in the disturbed sites compared to the undisturbed sites. This again shows a decrease in the buffering capability of the soils on the disturbed sites.

Organic carbon also was determined, and it was found that 76% of the disturbed sites had a decrease in organic carbon in the A horizon compared to the undisturbed sites. A decrease in topsoil organic carbon is a good indicator that mixing of the subsoil and topsoil has occurred (Wishart and Hayes, 1988). In undisturbed sites organic carbon is highest in the A horizon and decreases with depth. In the case of the disturbed soils 76% experienced a lower topsoil organic carbon value compared to the underlying B horizon.

5.2.4 Calcium Carbonate Content

The general trend for the study showed increased calcium carbonate contents in the A horizons of the disturbed sites compared to the undisturbed sites (Figure 4.5). This indicates possible mixing of subsoil with topsoil. Generally, within a soil profile that has parent material high in calcium carbonates, the amount of calcium carbonate increases with depth. In most of the disturbed and undisturbed sites, this was the case, except for disturbed sites 3, 4 and 27 where the B horizon had less calcium carbonate than the A horizon. This shows that mixing of horizons possibly occurred to create these results. Mixing can be indicated by an increase in carbonates in the topsoil (Wishart and Hayes, 1988). One effect of increased calcium carbonates in the soil is an increase in pH (increased alkalinity) which can adversely affect soil microbiological activity, plant growth and nutrient availability (section 5.2.1) (Thurber Consultants Ltd. et al, 1990). There was no research found on the effects of topsoil storage on the levels of calcium carbonates found; probably this cannot be referenced as a possible reason for increased calcium carbonate in the A horizon of the disturbed soils. Increased coarse fragments and surface stoniness, which are due to stones being brought to the surface or near it during trenching, also may have contributed to increased calcium carbonate contents at the disturbed sites. The stones and coarse fragments at each sites were tested for carbonate content and the HCl test showed a majority of them had carbonates in them. The addition of these materials to the surface horizons in the disturbed soils will likely increase levels of calcium carbonates.

5.2.5 Exchangeable Cations and Cation Exchange Capacity

The exchangeable cation Ca (calcium) was found to be in the largest quantity, occupying approximately 70 to 95 % of the exchange sites in the all soils sampled (both disturbed and undisturbed). The remaining 5 to 30 % is occupied by the remaining exchangeable cations. Overall, the average exchangeable calcium for the disturbed sites was slightly lower than the undisturbed sites. The cation exchange capacity (sum of all exchangeable cations) also was lower on the disturbed sites (49.83 meq/100g) compared to the undisturbed sites (55.44 meq/100g). Cation exchange capacity (nutrient availability) is related directly to the amount of organic matter in the soil (Culley et al., 1981; Thurber Consultants Ltd. et al., 1990). Wishart and Hayes (1988) also state that a dilution of organic matter in the topsoil can affect nutrient holding capacities of the soil. Figure 4.8 shows the correlation between organic matter content and cation exchange capacity. Organic matter levels were found to be lower in the disturbed sites than the undisturbed 4 sites which correlates with a lower CEC in the disturbed areas. Horizon mixing was identified as a possible reason for a decrease in organic matter of the disturbed sites and may also account for the lower cation exchange capacities. Culley et al. (1981) found that cation exchange capacities were lower on the pipeline right-of-way but had higher pH levels than the adjacent undisturbed sites. Similar results were found in the present study. Thurber Consultants Ltd. (1990) indicate there is no information in the literature indicating changes in cation exchange capacity in topsoil during storage. However, they do suggest that if changes did occur, it is likely a result of changes in organic matter content and quality.

5.3 Reclamation Suitability

The study area falls into the Eastern Slopes Region closely bordering the Plains Region area in southern Alberta (Walker et al., 1991) The study area vegetation communities consist of native grassland, tame pasture, cultivation and bush (containing both deciduous and coniferous species). During construction of the pipeline, topsoil (A horizon) was salvaged and care was taken not to mix subsoil with topsoil. Once replacement of topsoil occurred after the pipeline was put into the ground reclamation of the disturbed areas was done immediately. One important consideration when reclaiming an area after pipeline disturbance is the reclamation suitability of the soils. Alberta Agriculture has created a document that rates selected criteria of soil as either good, fair, poor or unsuitable for reclamation (Alberta Agriculture, 1987). Table 5.1 shows the criteria used to rate the suitability of topsoil materials for reclamation. Table 5.2 summarizes the topsoil suitability results for reclamation of the Canadian 88 pipeline. Over the entire study area, the soils can overall be rated as fair, which means there are moderate soil limitations that affect use but which can be overcome by proper planning and good management (Alberta Agriculture, 1987).

Table 5.1: Criteria used for evaluating the suitability of root zone material in the Eastern Slopes region (Agriculture Agriculture, 1987)

Rating/Property	Good (G)	Fair (F)	Poor (P)	Unsuitable (U)
Reaction (pH)	5.0 – 6.5	4.0 – 5.0 6.5 – 7.5	3.5 – 4.0 7.5 – 9.0	<3.5 >9.0
Organic Carbon[a] (%)	>2	1 – 2	<1	
Coarse Fragments (%)	<30b <15c	30 – 50b 15 – 30c	50 – 70b 30 – 50c	>70b >50
Stoniness Class[a]	S0, S1	S2	S3, S4	S5
Texture	L, SiCL, SCL, SL, fSL	CL, SiL vfSL, SC, SiC	LS, S Si, C, HC	Consolidated Bedrock
Moist Consistency	very friable, friable	loose, firm	very firm	extremely firm
$CaCO_3$ (%)	<2	2 to 20	20 to 70	>70

a Plains Region values used
b if matrix texture finer than sandy loam
c if matrix texture sandy loam or coarse

Table 5.2: Topsoil Suitability for Reclamation on the Canadian 88 Pipeline

Disturbed Sampling Sites	pH	Organic Carbon (%)	Coarse Fragments (%)	Stoniness	Texture	Moist Consistency	$CaCO_3$
1	Good	Good	Good	Good	Fair	Fair	Fair
3	Fair	Good	Good	Good	Good	Good	Fair
4	Fair	Good	Good	Fair	Fair	Good	Good
7	Fair	Good	Fair	Poor	Fair	Fair	Fair
8	Fair	Good	Good	Fair	Poor	Fair	Fair
9	Fair	Good	Fair	Poor	Good	Good	Fair
11	Fair	Good	Good	Good	Good	Good	Fair
14	Fair	Good	Good	Poor	Fair	Good	Fair
15	Fair	Good	Good	Fair	Fair	Fair	Fair
17	Fair	Good	Good	Poor	Fair	Fair	Fair
19	Fair	Good	Good	Poor	Good	Fair	Fair
21	Fair	Good	Good	Good	Fair	Fair	Fair
23	Fair	Good	Good	Good	Fair	Fair	Good
25	Good	Good	Good	Good	Good	Fair	Fair
27	Good	Good	Good	Fair	Good	Fair	Fair
29	Fair	Good	Poor	Good	Good	Good	Fair
31	Fair	Good	Poor	Poor	Good	Fair	Poor
33	Fair	Good	Fair	Good	Good	Fair	Fair
35	Fair	Good	Fair	Poor	Good	Fair	Fair
Undisturbed Sampling Sites							
2	Good	Good	Good	Good	Fair	Good	Fair
5	Fair	Good	Good	Good	Good	Good	Fair
6	Fair	Good	Good	Good	Good	Good	Fair
10	Fair	Good	Good	Fair	Fair	Fair	Fair
12	Fair	Good	Good	Good	Good	Good	Fair
13	Fair	Good	Good	Good	Fair	Fair	Fair
16	Fair	Good	Good	Good	Fair	Good	Fair
18	Fair	Good	Good	Good	Good	Fair	Fair
20	Fair	Good	Good	Poor	Fair	Fair	Fair

Table 5.2: Continued

22	Fair	Good	Good	Good	Good	Fair	Fair
24	Good	Good	Good	Good	Fair	Good	Good
26	Good	Good	Good	Good	Good	Fair	Fair
28	Good	Good	Good	Fair	Good	Fair	Fair
30	Good	Good	Good	Good	Fair	Good	Fair
32	Good	Good	Fair	Poor	Good	Fair	Fair
34	Fair	Good	Fair	Good	Good	Fair	Fair
36	Fair	Good	Good	Good	Good	Fair	Fair

It is difficult to determine the overall suitability rating because there are seven different criteria being used in this present study to rate the soils. All of the criteria are important and recognition should be given to the ratings for each individual criterion. Some soils may have a good rating for all criteria except pH and $CaCO_3$ which have a fair rating. It is not necessarily truthful to rate the topsoil as good because pH and $CaCO_3$ are important criteria that cannot be left out. Both pH and $CaCO_3$ can greatly affect revegetation of certain species and therefore should be considered. The same applies to criteria that have been rated as poor. The question must be asked: Is this criteria not as important as others or is it one of the dominant criteria that will affect revegetation more than the other criteria? Although the soils generally have been rated as fair, it is important to note that some criteria are more important than others in terms of assessing quality and that certain management practices may overcome or compensate for some limitations (Alberta Agriculture, 1987). If a particular criterion (eg. pH) has been rated as poor and outweighs the other criteria which have been rated as good, then it may be reasonable to qualify the weighted criteria with a management practice that can be utilized to result in better soil material.

6.0 SUMMARY AND CONCLUSIONS

Pipeline construction had an effect on some of the physical and chemical properties of the soils in the Pincher Creek-Crowsnest Pass area. One area of importance is the root zone or A horizon which is of primary concern when considering revegetation. Any effects of pipeline construction on the A horizon can adversely affect plant growth.

Disturbance by pipeline construction increased or decreased the depth of the A horizon or topsoil. A decrease in topsoil is likely the result of either wind erosion during storage and re-spreading or the incorporation of topsoil into the subsoil during construction and re-spreading. Soil structure and consistency also were found to be degraded in some of the disturbed sites. Two possible reasons for the change in structure and consistency are topsoil storage and compaction by heavy equipment during the removal and construction of stockpiles. Organic matter also has been identified as a key component for soil structure formation and consistency. Organic matter contents were found to be low at the disturbed sites that had both structure and consistency degradation. The increase of coarse fragments and surface stoniness at some of the disturbed sites resulted from either stones being brought to the surface horizons during construction or the incorporation of topsoil into the subsoil which results in more coarse fragments at the surface.

Pipeline construction also had an effect on all of the chemical properties studied. Topsoil storage and the mixing of horizons were found to be the main reasons for changes in pH, organic matter content, moisture content, calcium carbonate content, exchangeable cations and cation exchange capacity between the disturbed sites and undisturbed sites.

The pH was found to be higher in most of the disturbed sites which reflects the possibility of mixing of horizons. Topsoil storage has also been found to affect pH levels (Thurber Consultants Ltd., 1990; Harris and Birch, 1988; Abdul-Kareem and McRae, 1984). Moisture content, which was lower in the disturbed sites, may be affected by topsoil storage which can dry the soils out (soils are exposed to environmental elements). Moisture content was related to the amount of organic matter present and it was determined that where organic matter contents were lower in the disturbed areas, so was moisture content. Calcium carbonate which affects pH and the amounts of calcium present in the soil were found to be higher in a majority of the disturbed sites. Mixing of horizons can be determined by an increase in carbonates, and therefore it is the main cause for higher levels of calcium carbonates at the disturbed sites. Organic matter contents were lower in the disturbed areas and similar to carbonates, indicates the mixing of horizons at the disturbed sites. Topsoil storage can affect the amounts of organic matter present (Abdul-Kareem and McRae, 1984). Exchangeable cations and cation exchange capacity were also found to be lower in the disturbed areas. Cation exchange capacity was found to be correlated with organic matter content. Lower organic matter contents in the disturbed sites correlated with lower cation exchange capacities at the same sites. Again, horizon mixing may be a possible reason for lower cation exchange capacities at the disturbed sites. Previous research has shown similar decreases in cation exchange capacities on pipeline right-of-ways compared to undisturbed areas (eg. Culley et al., 1981).

The following is a summary of the problems/areas that were identified as potential causes for changes in the chemical and physical properties during pipeline construction:

1. Mixing of horizons – subsoil is incorporated into topsoil
2. Topsoil storage
3. Compaction by heavy equipment
4. Wind erosion

The following are some suggested recommendations for minimizing the above problems/areas that can cause changes in the physical and chemical properties of the soil. One recommendation is not more important than the other and therefore all recommendations should be given the same amount of consideration.

1. Ensure that topsoil and subsoil are removed separately and stockpiled separately to prevent mixing of horizons which can affect both the physical and chemical properties of soils. Topsoil and subsoil should also be backfilled in their orginal sequence to also reduce the amount of horizon mixing.
2. When backfilling material it is necessary to maintain a sufficient amount of backfill between the topsoil and subsoil which will aid in better plant growth. This recommendation is extremely important in areas where the subsoil is high in aggregate composition (high coarse fragment content) and can adversely affect revegetation efforts if aggregates are mixed with topsoil.
3. The Pincher Creek-Crowsnest Pass area (study area) is prone to strong wind activity and as a result soil erosion potentials are high. All soil that is stockpiled or re-spread

after pipeline construction should be tackified (stabilized) to prevent a loss of soil. Mulches such as straw are useful in stabilizing bare soil as well as seeds that have been spread after pipeline construction. This type of reclamation technique is useful in preventing erosion and is one of many techniques that should be considered.

4. "Stone-picking", or the removal of stones, cobbles etc. is a common practice during pipeline construction and is useful for reclamation. During construction, excessive amounts of stones can be brought to the surface and should be removed. This will allow for reduced amounts of aggregates in the topsoil and better conditions for revegetation.
5. When removing and stockpiling topsoil it is recommended that a sufficient amount of topsoil (eg. 30cm) should be removed from above the trench. This will reduce incomplete topsoil stripping and allow for a sufficient amount of topsoil to be backfilled which will allow for better revegetation. One exception to this rule is in areas where topsoil depths are less than 30cm. In this case topsoil should be stripped to depth and in order to ensure adequate topsoil amounts for successful revegetation, additional topsoil from other sources may be required.
6. All subsoil that has been removed from the trench should be hauled away prior to the re-spreading of topsoil. This reduces the potential for horizon mixing which can affect revegetation.
7. If heavy equipment used during construction has caused compaction of the soils, it may be necessary to consider techniques such as chisel plowing and tilling which can reduce compaction problems. Severe compaction of soils can adversely affect plant growth by reducing water infiltration and nutrient availability to plants.

8. Once construction of the pipeline is completed, revegetation/reclamation should be completed as soon as possible. This helps to reduce wind and water erosion of bare soils.
9. Continual monitoring of the right-of-way after construction is important to ensure successful reclamation. Soil monitoring over a specified time period (eg. ten year period) will give insight into the effects of pipeline construction on the soils over time as well as help to determine the soils ability to recovery from such land disturbances.

Another important consideration when dealing with construction activities is determining the reclamation suitability of the soils that are going to be disturbed. In this study the soils were classified as Orthic Black Chernozems and Rego Black Chernozems. Certain criteria were selected which were evaluated to determine whether the soils were rated as good, fair, poor or unsuitable for reclamation. Considering the criteria as a whole, the soils were determined to have a fair rating, meaning there are some limitations that can be overcome with proper management. Consideration of each individual criterion and the corresponding rating for each criterion, it was determined that there are some criteria (eg. pH and calcium carbonate) that were rated as poor and may become the limiting factors in terms of reclamation suitability. It is important to realize that some criteria are more important than others when assessing quality (Alberta Agriculture, 1987). A soil can be rated good, fair, poor or unsuitable based on one particular criterion (eg. stoniness).

Soil and vegetation monitoring of the pipeline right-of-way after construction is a necessity to ensure that revegetation and reclamation techniques are successful. It is

Soil and vegetation monitoring of the pipeline right-of-way after construction is a necessity to ensure that revegetation and reclamation techniques are successful. It is important to remember that any changes in the chemical and/or physical properties of soils can adversely affect proper reclamation of a disturbed area.

6.1 Future Recommendations

As stated before, there was not a lot of information available on the impacts of pipeline construction on the physical and chemical properties of soils, especially in the province of Alberta. Most of the information found was based on studies done in Ontario, Saskatchewan and the United Kingdom. The lack of sufficient information on this subject leads to future research. It is important to understand the effects of disturbances on soil, especially if areas are to be revegetated or properly reclaimed. If soils are degraded (chemical and/or physical properties) there is a possibility that revegetation/reclamation efforts will be unsuccessful. It is recommended that more studies be conducted that look at the effects of pipelines (and other disturbances) on the physical and chemical properties of soils. In Alberta, pipelines and wellsites are a common occurrence, and need to be monitored and studied over time to determine if soil properties have been altered. Future studies can include:

1) The effects of pipeline construction on soils over time. Pipelines that were constructed years ago can be researched to determine if the pipeline has degraded the soils over the time the pipeline has been in the ground and if the pipeline has affected reclamation and revegetation efforts in any way.

2) To investigate if pipelines have altered any of the physical and/or chemical properties of soils immediately after pipeline construction prior to reclamation.

3) A third important area that needs to be studied more is the role of soil physical properties in soil disturbance related activities. Studies have been done on the chemical properties of soils and their relationship to disturbance but little has been done on the physical properties of soils which are integral to understanding the behaviour of soils in both natural and reclaimed areas (Naeth et al., 1991).

To reclaim areas to a use equal to or better than it was prior to disturbance, soils are one important aspect that must be considered in order to achieve this goal. If land disturbances are altering the physical and/or chemical properties of soils, then revegetation efforts can be unsuccessful. In order to prevent unsuccessful revegetation or reclamation efforts, continual short term and long term studies on the effects of disturbances on the properties of soils should be conducted.

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APPENDIX 1:

Soil Profile Information Collected on the Pipeline Right-of-Way and Adjacent to the Pipeline Right-of-Way

Table 1.1: Soil information collected on the pipeline right-of-way after construction

Site Number	[a]Soil Subgroup	Horizon	Depth (cm)	*Color	[b]Texture	[c]Structure	Consistency	**Carbonates	Coarse Fragment(%)	[d]Surface Stoniness
C1	O.BLC	Ah	0-15	10YR 3/2	CL	weak fine crumb	very friable	none	20	S1
		Bm	15-60	10YR 4/2	SL	weak granular	loose	none	40	
		C	60+	N/A	N/A	N/A	N/A	N/A	N/A	
C3	O.BLC	Ah	0-10	10YR 2/1	L	m-m crumb	friable	slight	5	S2
		BC	10-40+	10YR 3/1	CL	w-m sbk	friable	slight	30-40	
C4	O.BLC	Ah	0-13	10YR 2/1	vfSL	weak fine crumb	very friable	none	none	S1
		Bm	13-70	10YR 2/2	vfSL	granular	loose	none	none	
		Ck	70-100	10YR 4/2	SL	m-m sbk	friable	moderate	none	
C7	R.BLC	Ah	0-15	10YR 3/2	vfSL	granular	loose	none	40	S4
		C	15+	N/A	N/A	N/A	N/A	N/A	N/A	
C8	R.BLC	Ahk	0-26	10YR 3/2	SL	granular	loose	moderate	10	S1-S2
		Ck	26+	N/A	N/A	N/A	N/A	N/A	N/A	
C9	R.BLC	Ah	0-21	10YR 3/1	SL	granular	loose	slight	10-20	S3
		Ck	21+	N/A	N/A	N/A	N/A	N/A	N/A	
C11	R.BLC	Ahk	0-22	10YR 2/2	fSL	weak fine crumb	very friable	moderate	10-20	S1
		Ck	22+	N/A	N/A	N/A	N/A	N/A	N/A	
C14	R.BLC	Ah	0-5	10YR 2/1	vfSL	granular	loose	none	10-20	S3-S4
		C	5+	N/A	N/A	N/A	N/A	N/A	N/A	
C15	R.BLC	Ah	0-25	10YR 2/1	vfSL	granular	loose	none	5	S2
		Ck	25+	N/A	N/A	N/A	N/A	N/A	N/A	
C17	R.BLC	Ahk	0-20	10YR 2/2	vfSL	granular	loose	moderate	none	S3
		Ck	20+	N/A	N/A	massive	N/A	N/A	N/A	
C19	O.BLC	Ah	0-12	10YR 2/2	L	granular	loose	slight	none	S3
		Bm	12-60	10YR 4/2	vfSL	granular	loose	strong	none	
		Ck	60+	N/A	N/A	N/A	N/A	N/A	N/A	

Table 1.1: Continued

C21	R.BLC	Ah	0-25	10YR2/2	vfSL	granular	loose	slight	none	S1
		Ck	25+	N/A	N/A	N/A	N/A	N/A	N/A	
C23	O.BLC	Ah	0-20	10YR 2/2	vfSL	granular	loose	none	none	S1
		Bm	20-80	10YR 2/2	vfSL	w-m sbk	friable	slight	none	
		Ck	80-120	10YR 3/3	SL	granular	loose	strong	none	
C25	R.BLC	Ah	0-20	10YR 2/2	SCL	granular	loose	none	5	S1
		BC	20+	N/A	N/A	N/A	N/A	N/A	N/A	
C27	O.BLC	Ah	0-12	10YR 2/1	SL	granular	loose	none	5	S2
		Bm	12-25	10YR 2/2	vfSL	granular	loose	none	20	
		C	25+	N/A	N/A	N/A	N/A	N/A	N/A	
C29	R.BLC	Ah	0-18	10YR 2/1	L	weak fine crumb	very friable	none	none	S0
		BC	18+	10YR 3/2	SL	weak fine sbk	very friable	none	none	
C31	R.BLC	Ahk	0-10	10YR 2/2	SL	granular	loose	moderate	40-60	S4-S5
		Ck	10+	N/A	N/A	N/A	N/A	N/A	N/A	
C33	O.BLC	Ah	0-12	10YR 2/2	SL	granular	loose	none	20-40	S1
		Bm	12-25	10YR 3/2	SL	granular	loose	moderate	20-40	
		Ck	25+	N/A	N/A	N/A	N/A	N/A	N/A	
C35	O.BLC	Ah	0-10	10YR 3/2	SL	granular	loose	none	10-20	S4
		BC	10-20+	10YR 2/2	SL	granular	loose	slight	10-20	

* Color was determined in the field using a Munsell Color Chart

** Presence of carbonates was determined in the field using the HCl (hydrochloric acid) test

a Soil Subgroup distinctions: O.BLC = Orthic Black Chernozem; R.BLC = Rego Black Chernozem

b Texture categories (determined by hand texturing): CL = Clay loam; L = Loam; LS = Loamy sand; vfSL = very fine sandy loam; fSL = fine sandy loam; SL = Sandy loam; vfS = very fine sand

c Structure distinctions: sbk = subangular blocky; w-m = weak-medium; m-m = moderate-medium; s-m = strong-medium

d Surface Stoniness Classes: S0 = nonstony; S1 = slightly stony; S2 = moderately stony; S3 = very stony; S4 = exceedingly stony; S5 = excessively stony

Table 1.2: Soil information collected in undisturbed areas adjacent to the soil samples collected on the pipeline right-of way after construction

Site Number	aSoil Subgroup	Horizon	Depth (cm)	*Color	bTexture	cStructure	Consistency	**Carbonates	Coarse Fragment(%)	dSurface Stoniness	eRoW Soil Sample Sites
C2	O.BLC	Ah	0-18	10YR 2/2	CL	weak fine crumb	very friable	none	<5	S0	C1
		Bm	0-40	10YR 4/2	SL	weak fine crumb	very friable	none	<5		
		C	40+	N/A	N/A	N/A	N/A	N/A	N/A		
C5	O.BLC	Ah	0-13	10YR 2/1	L	s-m crumb	friable	none	<5	S0	C4
		Bm	13-70	10YR 2/2	vfSL	weak fine sbk	very friable	none	<5		
		C	70-100	10YR 3/2	vfSL	s-m sbk	friable	none	<5		
C6	O.BLC	Ah	0-15	10YR 2/2	SL	weak fine crumb	very friable	none	<20	S1	C7
		Bm	15-40	10YR 3/2	SL	granular	loose	none	20		
		C	40+	N/A	N/A	N/A	N/A	N/A	N/A		
C10	R.BLC	Ah	0-23	10YR 3/1	vfSL	granular	loose	none	none	S2	C8
		C	23+	N/A	N/A	N/A	N/A	N/A	N/A		
C12	R.BLC	Ah	0-20	10YR 2/2	SL	m-m crumb	very friable	none	<5	S1	C11
		BC	20+	10YR 3/2	SL	weak fine sbk	friable	moderate	20		
C13	R.BLC	Ah	0-5	10YR 2/1	vfSL	granular	loose	none	<20	S1-S2	C14
		C	5+	N/A	N/A	N/A	N/A	N/A	N/A		
C16	R.BLC	Ah	0-25	10YR 3/1	vfSL	weak fine crumb	very friable	none	none	S0	C15
		C	25+	N/A	N/A	N/A	N/A	N/A	N/A		
C18	R.BLC	Ah	0-10	10YR 2/1	SL	granular	loose	none	10-20	S1	C17
		C	10-20+	N/A	N/A	N/A	N/A	N/A	N/A		
C20	R.BLC	Ah	0-15	10YR 2/1	vfSL	granular	loose	none	10-20	S3	C19
		C	15+	N/A	N/A	N/A	N/A	N/A	N/A		
C22	R.BLC	Ah	0-15	10YR 2/2	L	granular	loose	moderate	10-20	S1	C21
		Ck	15+	N/A	N/A	N/A	N/A	N/A	N/A		

Table 1.2: Continued

C24	O.BLC	Ah Bm Ck	0-20 20-50 50-80	10YR 2/2 10YR 3/2 10YR 3/4	vfSL vfSL vfS	weak crumb granular granular	very friable loose loose	none none moderate	<5 <5 <5	S1	C23
C26	O.BLC	Ah C	0-28 37+	10YR 2/2 N/A	L N/A	granular N/A	loose N/A	none N/A	none N/A	S1	C25
C28	R.BLC	Ah C	0-23 23+	10YR 2/1 N/A	L N/A	granular N/A	loose N/A	none N/A	none >40	S2	C27
C30	R.BLC	Ah C	0-25 25+	10YR2/2 N/A	vfSL N/A	weak fine crumb N/A	very friable N/A	none N/A	none N/A	S0	C29
C32	R.BLC	Ah C	0-7 7+	10YR 2/2 N/A	SL N/A	granular N/A	loose N/A	none N/A	20-40 N/A	S4-S5	C31
C34	O.BLC	Ah Bm Ck	0-12 12-28 28+	10YR 2/2 10YR 2/2 N/A	fSL SL N/A	granular w-m granular N/A	loose N/A	none moderate N/A	20-40 20-40 N/A	S1	C33
C36	O.BLC	Ah BC	0-18 18+	10YR 2/1 N/A	L N/A	granular N/A	loose N/A	none N/A	10-20 N/A	S1	C35

* Color was determined in the field using a Munsell Color Chart

** Presence of carbonates was determined in the field using the HCl (hydrochloric acid) test

a Soil Subgroup distinctions: O.BLC = Orthic Black Chernozem; R.BLC = Rego Black Chernozem

b Texture categories (determined by hand texturing): CL = Clay loam; SL = Sandy loam; vfSL = very fine sandy loam; L = Loam; vfS = very fine sand

c Structure distinctions: sbk = subangular blocky; w-m = weak-medium; m-m = moderate-medium; s-m = strong-medium; w-f = weak-fine

d Surface Stoniness Classes: S0 = nonstony; S1 = slightly stony; S2 = moderately stony; S3 = very stony; S4 = exceedingly stony; S5 = excessively stony

e These are the soil sampling sites (Table 1) collected on the pipeline right-of-way after construction that correlate with the soil samples taken in adjacent undisturbed areas

APPENDIX 2:

Chemical Analyses Results of the Disturbed and Undisturbed Soil Samples Collected

Table 2.1: Chemical analyses of the soil samples collected on the right-of-way after pipeline construction

Site Number	Horizon	pH	Electrical Conductivity (mmhos/cm)	Moisture Content (%)	Organic Matter Content (%)	Calcium Carbonate Content (%)	Organic Carbon (%)
C1	Ah	6.21	0.055	12.75	8.50	3.93	4.93
	Bm	6.27	0.019	7.47	5.75	4.31	3.34
C3	Ah	7.17	0.052	17.56	7.57	9.55	4.39
	BC	6.7	0.074	10.63	8.16	6.73	4.73
C4	Ah	7.08	0.036	17.1	11.00	1.51	6.38
	Bm	6.77	0.053	9.98	6.38	0.94	3.7
	Ck	6.89	0.051	5.65	3.59	4.23	2.08
C7	Ah	7.25	0.082	6.38	11.26	12.22	6.53
C8	Ah	7.48	0.067	12.96	5.83	8.45	3.38
C9	Ah	6.78	0.050	6.24	5.75	2.39	3.34
C11	Ah	7.18	0.055	11.50	4.34	19.68	2.51
C14	Ah	7.13	0.102	14.61	10.29	8.36	5.97
C15	Ah	7.2	0.092	14.17	10.04	11.44	5.82
C17	Ah	7.27	0.080	11.33	5.52	8.54	3.2
C19	Ah	7.25	0.059	11.69	5.30	8.49	3.07
	Bm	7.53	0.053	5.85	4.12	18.13	2.39
C21	Ah	7.42	0.106	8.33	7.68	12.76	4.45
C23	Ah	6.90	0.039	12.43	7.05	1.19	4.09
	Bm	6.96	0.067	8.55	7.74	3.25	4.49
	Ck	7.28	0.045	8.46	2.33	18.98	1.35

Table 2.1: Continued

C25	Ah	6.40	0.079	14.69	15.75	3.19	9.14
C27	Ah	6.47	0.035	15.50	11.55	5.63	6.7
	Bm	6.29	0.030	12.32	11.79	1.52	6.83
C29	Ah	6.79	0.032	24.57	15.20	5.06	8.82
	BC	6.41	0.058	17.17	15.12	2.61	7.77
C31	Ah	7.17	0.060	9.29	4.59	26.63	2.66
C33	Ah	6.98	0.050	18.23	8.78	6.96	5.09
	Bm	7.18	0.076	11.30	4.64	19.36	2.69
C35	Ah	7.23	0.097	5.55	9.25	13.03	5.37

Table 2.2: Chemical analyses on the soil samples collected adjacent to the right-of-way after pipeline construction

Site Number	Horizon	pH	Electrical Conductivity (mmhos/cm)	Moisture Content (%)	Organic Matter Content (%)	Calcium Carbonate Content (%)	Organic Carbon (%)	aRoW Soil Sample Sites
C2	Ah	6.32	0.023	17.27	9.52	3.49	5.52	C1
	Bm	6.56	0.018	9.66	4.54	5.41	2.63	
C5	Ah	6.68	0.027	29.98	18.73	13.59	9.7	C4
	Bm	6.27	0.013	11.2	7.24	0.96	4.2	
	C	5.88	0.013	6.01	3.89	2.3	2.26	
C6	Ah	7.07	0.161	15.37	10.54	4.54	6.11	C7
	Bm	6.99	0.093	12.55	9.16	6.34	5.31	
C10	Ah	7.28	0.038	11.67	8.24	2.91	4.78	C8
C12	Ah	7.1	0.048	13.19	9.38	5.88	5.44	C11
	BC	7.22	0.060	12.02	6.03	9.93	3.5	
C13	Ah	6.88	0.103	17.33	13.8	3.69	8	C14
C16	Ah	6.87	0.128	21.61	12.55	3.12	7.28	C15
C18	Ah	6.99	0.050	10.26	6.51	3.26	3.78	C17
C20	Ah	6.98	0.133	17.41	10.19	2.92	5.91	C19
C22	Ah	7.28	0.086	15.73	7.17	17.07	9.9	C21
C24	Ah	6.15	0.042	10.28	9.32	1.46	5.41	C23
	Bm	6.48	0.027	5.5	5.16	0.95	2.99	
	Ck	7.38	0.054	3.88	3.28	11.34	1.9	
C26	Ah	6.21	0.080	19.84	14.97	7.7	8.68	C25
	Bm	6.71	0.023	9.59	8.61	2.92	4.99	
C28	Ah	5.81	0.034	12.23	13.41	1.04	7.78	C27

Table 2.2: Continued

C30	Ah	6.39	0.042	20.74	13.69	3.66	7.94	**C29**
C32	Ah	6.08	0.051	10.68	13.72	5.17	7.96	**C31**
C34	Ah	7.03	0.047	12.29	9.07	3.78	5.26	**C33**
	Bm	6.97	0.045	9.86	7.71	2.43	4.47	
C36	Ah	6.85	0.079	21.4	12.84	3.55	7.45	**C35**

a = These are the soil sampling sites (2.1) collected on the pipeline right-of-way after construction that correlate with the soil samples taken in adjacent undisturbed areas

Table 2.3: Amounts of exchangeable magnesium determined for the A horizons of all soils sampled (determined by atomic absorption spectrometry)

MODE Continuous
ELEMENT Magnesium (Mg)

DATE 10/21/98

SAMPLE ID	Site	SIGNAL Abs	CONC. mg/l	CORRECTED meq/100g
Sample 1	D	0.0791	0.467	2.303
Sample 2	U	0.0971	0.572	2.823
Sample 3	D	0.1007	0.593	2.926
Sample 4	D	0.0462	0.274	1.353
Sample 5	U	0.1254	0.737	3.638
Sample 6	U	0.0539	0.319	1.577
Sample 7	D	0.0493	0.292	1.442
Sample 8	D	0.0757	0.447	2.205
Sample 9	D	0.0811	0.478	2.362
Sample 10	U	0.099	0.583	2.876
Sample 11	D	0.0325	0.194	0.957
Sample 12	U	0.0328	0.196	0.968
Sample 13	U	0.0446	0.265	1.308
Sample 14	D	0.0918	0.541	2.67
Sample 15	D	0.035	0.209	1.032
Sample 16	U	0.043	0.255	1.261
Sample 17	D	0.0684	0.404	1.993
Sample 18	U	0.0307	0.183	0.905
Sample 19	D	0.0283	0.169	0.836
Sample 20	U	0.0346	0.207	1.02
Sample 21	D	0.0245	0.147	0.728
Sample 22	U	0.0241	0.145	0.717
Sample 23	D	0.0864	0.509	2.514
Sample 24	U	0.0597	0.353	1.744
Sample 25	D	0.0469	0.279	1.375
Sample 26	U	0.0546	0.323	1.596
Sample 27	D	0.0532	0.315	1.557
Sample 28	U	0.0935	0.551	2.719
Sample 29	D	0.054	0.32	1.578
Sample 30	U	0.0729	0.43	2.123
Sample 31	D	0.0257	0.155	0.763
Sample 32	U	0.0449	0.266	1.315
Sample 33	D	0.1959	1.149	5.671
Sample 34	U	0.0384	0.228	1.128
Sample 35	D	0.0334	0.199	0.983
Sample 36	U	0.0638	0.377	1.861

D = disturbed sites
U = undisturbed sites

Table 2.4: Amounts of exchangeable aluminum determined for the A horizons of all soils sampled (determined by atomic absorption spectrometry)

MODE Continuous
ELEMENT Aluminum (Al)

DATE 10/21/98

SAMPLE ID	Site	SIGNAL Abs	CONC. mg/l	CORRECTED meq/100g
Sample 1	D	-0.0005	0.518	0.173
Sample 2	U	0.0003	0.754	0.251
Sample 3	D	-0.001	0.399	0.133
Sample 4	D	-0.0013	0.308	0.103
Sample 5	U	-0.001	0.387	0.129
Sample 6	U	-0.0007	0.47	0.157
Sample 7	D	-0.0008	0.46	0.154
Sample 8	D	-0.0003	0.593	0.198
Sample 9	D	-0.0003	0.575	0.192
Sample 10	U	0.0002	0.728	0.243
Sample 11	D	-0.0008	0.46	0.153
Sample 12	U	-0.0005	0.533	0.178
Sample 13	U	0	0.673	0.224
Sample 14	D	0.0005	0.793	0.265
Sample 15	D	-0.001	0.383	0.128
Sample 16	U	-0.0005	0.524	0.175
Sample 17	D	-0.0001	0.644	0.215
Sample 18	U	-0.0013	0.32	0.107
Sample 19	D	-0.001	0.397	0.132
Sample 20	U	0.0003	0.736	0.246
Sample 21	D	-0.0013	0.297	0.099
Sample 22	U	-0.0005	0.53	0.177
Sample 23	D	-0.0011	0.375	0.125
Sample 24	U	-0.0007	0.462	0.154
Sample 25	D	-0.0006	0.5	0.167
Sample 26	U	-0.0005	0.52	0.173
Sample 27	D	-0.0007	0.478	0.159
Sample 28	U	-0.0004	0.546	0.182
Sample 29	D	-0.0001	0.634	0.211
Sample 30	U	-0.0004	0.564	0.188
Sample 31	D	-0.0007	0.482	0.161
Sample 32	U	0	0.669	0.223
Sample 33	D	0.0007	0.847	0.282
Sample 34	U	-0.0006	0.499	0.167
Sample 35	D	-0.0004	0.558	0.186
Sample 36	U	-0.0008	0.443	0.148

D = disturbed sites
U = undisturbed sites

Table 2.5: Amounts of exchangeable manganese determined for all the A horizons of the soils sampled (determined by atomic absorption spectrometry)

MODE Continuous
ELEMENT Manganese (Mn)

DATE 10/21/98

SAMPLE ID	Site	SIGNAL Abs	CONC. mg/l	CORRECTED meq/100g
Sample 1	D	0.0009	0.015	0.002
Sample 2	U	0.0013	0.018	0.002
Sample 3	D	-0.0002	0.009	0.001
Sample 4	D	0.0009	0.015	0.002
Sample 5	U	0.0016	0.019	0.002
Sample 6	U	-0.0002	0.008	0.001
Sample 7	D	-0.0002	0.009	0.001
Sample 8	D	-0.0001	0.009	0.001
Sample 9	D	0.0011	0.016	0.002
Sample 10	U	-0.0006	0.006	0.001
Sample 11	D	-0.0008	0.005	0.001
Sample 12	U	-0.0005	0.007	0.001
Sample 13	U	0.0017	0.02	0.002
Sample 14	D	-0.0004	0.008	0.001
Sample 15	D	-0.0006	0.006	0.001
Sample 16	U	-0.0003	0.008	0.001
Sample 17	D	0.0001	0.011	0.001
Sample 18	U	-0.0001	0.009	0.001
Sample 19	D	-0.0003	0.008	0.001
Sample 20	U	-0.0004	0.008	0.001
Sample 21	D	-0.0001	0.009	0.001
Sample 22	U	0.0001	0.011	0.001
Sample 23	D	0.0003	0.012	0.001
Sample 24	U	0.0041	0.033	0.004
Sample 25	D	0.0011	0.016	0.002
Sample 26	U	0.0023	0.023	0.003
Sample 27	D	0.0009	0.015	0.002
Sample 28	U	0.0029	0.027	0.003
Sample 29	D	0.0002	0.011	0.001
Sample 30	U	0.0004	0.012	0.001
Sample 31	D	0.0002	0.011	0.001
Sample 32	U	0.0226	0.139	0.015
Sample 33	D	0.0034	0.029	0.003
Sample 34	U	0.0009	0.015	0.002
Sample 35	D	0.0015	0.019	0.002
Sample 36	U	0.0016	0.019	0.002

D = disturbed sites
U = undisturbed sites

Table 2.6: Amounts of exchangeable sodium determined for the A horizons of all soils sampled (determined by atomic absorption spectrometry)

MODE Continuous
ELEMENT Sodium (Na)

DATE 10/21/98

SAMPLE ID	Site	SIGNAL Int	CONC. mg/l	CORRECTED meq/100g
Sample 1	D	75	3.506	0.458
Sample 2	U	113.05	5.708	0.745
Sample 3	D	52.05	2.36	0.308
Sample 4	D	79.35	3.76	0.491
Sample 5	U	57.42	2.618	0.342
Sample 6	U	62.85	2.882	0.376
Sample 7	D	44.92	2.029	0.265
Sample 8	D	123.73	6.282	0.82
Sample 9	D	46.98	2.121	0.277
Sample 10	U	59.55	2.722	0.355
Sample 11	D	54.09	2.457	0.321
Sample 12	U	84.16	4.043	0.528
Sample 13	U	96.36	4.77	0.622
Sample 14	D	66.45	3.058	0.399
Sample 15	D	80.67	3.838	0.501
Sample 16	U	58.31	2.661	0.347
Sample 17	D	62.4	2.86	0.373
Sample 18	U	47.38	2.139	0.279
Sample 19	D	59.55	2.722	0.355
Sample 20	U	55.66	2.533	0.331
Sample 21	D	73.73	3.432	0.448
Sample 22	U	65.23	2.999	0.391
Sample 23	D	53.08	2.409	0.314
Sample 24	U	88.74	4.313	0.563
Sample 25	D	82.48	3.944	0.515
Sample 26	U	52.37	2.375	0.31
Sample 27	D	35.58	1.62	0.211
Sample 28	U	71.92	3.327	0.434
Sample 29	D	69.39	3.202	0.418
Sample 30	U	53.93	2.45	0.32
Sample 31	D	71.29	3.296	0.43
Sample 32	U	51.48	2.332	0.304
Sample 33	D	50.28	2.275	0.297
Sample 34	U	72.55	3.363	0.439
Sample 35	D	48.36	2.185	0.285
Sample 36	U	53.1	2.41	0.314

D = disturbed sites
U = undisturbed sites

Table 2.7: Amounts of exchangeable iron determined for the A horizons of all soils sampled (determined by atomic absorption spectrometry)

MODE Continuous
ELEMENT Iron (Fe)

DATE 10/21/98

SAMPLE ID	Site	SIGNAL Abs	CONC. mg/l	CORRECTED meq/100g
Sample 1	D	0.0008	0.019	0.002
Sample 2	U	0.0004	0.011	0.001
Sample 3	D	0.0008	0.019	0.002
Sample 4	D	0.0014	0.032	0.003
Sample 5	U	0.0016	0.037	0.004
Sample 6	U	0.0007	0.016	0.002
Sample 7	D	0.0011	0.025	0.003
Sample 8	D	0.0004	0.01	0.001
Sample 9	D	0.0005	0.011	0.001
Sample 10	U	0.0004	0.011	0.001
Sample 11	D	0.0002	0.006	0.001
Sample 12	U	0.0006	0.013	0.001
Sample 13	U	0.0017	0.039	0.004
Sample 14	D	0.0015	0.034	0.004
Sample 15	D	-0.0001	-0.001	0
Sample 16	U	0.0007	0.017	0.002
Sample 17	D	0.0007	0.016	0.002
Sample 18	U	0.0006	0.014	0.002
Sample 19	D	0.0005	0.012	0.001
Sample 20	U	0.0004	0.01	0.001
Sample 21	D	0.0012	0.027	0.003
Sample 22	U	0.0017	0.038	0.004
Sample 23	D	0.0017	0.037	0.004
Sample 24	U	0.0014	0.032	0.003
Sample 25	D	0.0013	0.028	0.003
Sample 26	U	0.002	0.044	0.005
Sample 27	D	0.0008	0.018	0.002
Sample 28	U	0.0009	0.022	0.002
Sample 29	D	0.0008	0.019	0.002
Sample 30	U	0.0013	0.03	0.003
Sample 31	D	0.0008	0.018	0.002
Sample 32	U	0.0018	0.04	0.004
Sample 33	D	0.0007	0.017	0.002
Sample 34	U	0.0008	0.019	0.002
Sample 35	D	0.0012	0.028	0.003
Sample 36	U	0.0014	0.031	0.003

D = disturbed sites
U = undisturbed sites

Table 2.8: Summary of the amounts of exchangeable cations and cation exchange capacity for the A horizons of all soils sampled.

Soil Sampling Site	Ca (meq/100g)	K (meg/100g)	Mg (meg/100g)	Mn (meg/100g)	Na (meg/100g)	Fe (meg/100g)	Al (meg/100g)	*CEC (meg/100g)
1 D	34.417	6.701	2.303	0.002	0.458	0.002	0.173	44.056
2 U	31.777	8.664	2.823	0.002	0.745	0.001	0.251	44.263
3 D	51.907	3.366	2.926	0.001	0.308	0.002	0.133	58.643
4 D	49.979	5.434	1.353	0.002	0.491	0.003	0.103	57.365
5 U	66.553	6.223	3.638	0.002	0.342	0.004	0.129	76.891
6 U	44.792	6.322	1.577	0.001	0.376	0.002	0.157	53.227
7 D	58.045	4.209	1.442	0.001	0.265	0.003	0.198	64.163
8 D	30.327	5.793	2.205	0.001	0.82	0.001	0.154	39.301
9 D	29.836	3.524	2.362	0.002	0.277	0.001	0.192	36.194
10 U	48.614	6.852	2.876	0.001	0.355	0.001	0.243	58.942
11 D	30.94	5.058	0.957	0.001	0.321	0.001	0.153	37.431
12 U	43.026	11.181	0.968	0.001	0.528	0.001	0.178	55.883
13 U	60.363	3.825	1.308	0.002	0.622	0.004	0.224	66.348
14 D	43.233	3.238	2.67	0.001	0.399	0.004	0.265	49.81
15 D	53.918	1.661	1.032	0.001	0.501	0	0.128	57.241
16 U	47.001	5.015	1.261	0.001	0.347	0.002	0.175	53.802
17 D	39.172	2.489	1.993	0.001	0.373	0.002	0.215	44.245
18 U	37.47	1.879	0.905	0.001	0.279	0.002	0.107	40.643
19 D	38.586	3.625	0.836	0.001	0.355	0.001	0.132	43.536
20 U	44.011	9.996	1.02	0.001	0.331	0.001	0.246	55.606
21 D	44.726	3.767	0.728	0.001	0.448	0.003	0.099	49.772
22 U	34.253	3.98	0.717	0.001	0.391	0.004	0.177	39.523
23 D	37.599	2.793	2.514	0.001	0.314	0.004	0.125	43.35
24 U	35.46	7.477	1.744	0.004	0.563	0.003	0.154	45.405
25 D	48.275	9.848	1.375	0.002	0.515	0.003	0.167	60.185
26 U	58.064	9.809	1.596	0.003	0.31	0.005	0.173	69.96
27 D	44.968	5.883	1.557	0.002	0.211	0.002	0.159	52.782
28 U	47.58	5.015	2.719	0.003	0.434	0.002	0.182	55.935
29 D	57.664	5.425	1.578	0.001	0.418	0.002	0.211	65.299
30 U	61.781	3.121	2.123	0.001	0.32	0.003	0.188	67.537
31 D	30.212	1.961	0.763	0.001	0.43	0.002	0.161	33.53
32 U	49.962	5.251	1.315	0.015	0.304	0.004	0.223	57.074
33 D	39.643	3.265	5.671	0.003	0.297	0.002	0.282	49.163
34 U	43.198	3.569	1.128	0.002	0.439	0.002	0.167	48.505
35 D	50.242	4.164	0.983	0.002	0.285	0.003	0.186	55.865
36 U	47.85	2.754	1.861	0.002	0.314	0.003	0.148	52.932

* Cation exchange capacity is equal to the sum of all the exchangeable cations found in the A horizons of all soils sampled

D = disturbed sites
U = undisturbed sites

APPENDIX 3:

Statistical Results

- - Correlation Coefficients - -

	CEC	OM
CEC	1.0000	.8724
	(34)	(34)
	P= .	P= .000
OM	.8724	1.0000
	(34)	(34)
	P= .000	P= .

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

* * * * M U L T I P L E R E G R E S S I O N * * * *

Listwise Deletion of Missing Data

Equation Number 1 Dependent Variable.. CEC

Block Number 1. Method: Enter OM

Variable(s) Entered on Step Number
1.. OM

Multiple R	.87239
R Square	.76106
Adjusted R Square	.75359
Standard Error	5.01246

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	1	2560.83578	2560.83578
Residual	32	803.99358	25.12480

F = 101.92463 Signif F = .0000

------------------ Variables in the Equation ------------------

Variable	B	SE B	Beta	T	Sig T
OM	2.639222	.261419	.872387	10.096	.0000
(Constant)	25.979820	2.776595		9.357	.0000