THE LONG-TERM IMPACT OF PIPELINE CONSTRUCTION ON SOLONETZIC MIXED PRAIRIE

Prepared
For
NOVA Corporation of Alberta

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1993

EXECUTIVE SUMMARY

In 1981, a study was initiated near Princess, Alberta to evaluate single-lift pipeline construction impacts on Solonetzic mixed prairie rangeland. In August 1991, a further evaluation of the study sites was conducted to determine the longevity of the changes that took place on the 1981 right-of-way from using 1981 construction techniques. The study concentrated on the well-documented 1981 right-of-way, and compared it to the oldest trench, installed in 1957, and to the undisturbed adjacent mixed prairie.

It was still evident in August 1991, that single-lift pipeline construction in Solonetzic mixed prairie had significant effects on soil chemical, soil physical, hydrologic, and vegetative parameters of the ecosystem. Effects were similar to those documented in 1983. As in the first study, these effects and their changes over time were in turn affected by both the grazing regime imposed on the rangeland and the different construction activities at the time of pipeline installation, with trenching having the most significant impact. However, there was a distinct trend towards predisturbed conditions evident in many vegetation and soil chemical and physical parameters.

In August 1991, on the 1981 right-of-way vs the undisturbed prairie there was still increased surface bulk density and surface water; increased organic carbon, pH and sodium adsorption ratio to depths of 15 cm, and electrical conductivity to depths of 45 cm. Calcium, magnesium, sodium, sulphate, and chloride were decreased to 45 cm, and potassium below 5 cm. Soil bulk density with depth decreased in trench treatments and increased on work and stockpile treatments. In the trench, penetration resistance and depth to maximum penetration resistance decreased and soil water with depth increased. Bare ground, the number of introduced and pioneer (weedy) species, and cover of little club moss increased; species diversity and number of native species decreased.

A trend towards predisturbed conditions was evident on the rights-of-way from 1983 to 1991, although the magnitude of change was often small and not always statistically significant. The trend was characterized by decreased bare ground, increased species diversity and native species, and decreased native pioneer species. Downward salt movement in the 1981 trench and 1981 stockpile treatments was evidenced by decreases in electrical conductivity, sodium, sulphate, and sodium adsorption ratio to 15 cm and increases in these parameters below 15 cm. Soil bulk density at the surface and with depth decreased; there was a slight increase in organic carbon.

Grazing regime continued to impact the revegetated pipeline rights-of-way by increasing *Elymus angustus* under early season grazing and increasing *Agropyron pectiniforme* under late season grazing.

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I. BACKGROUND

The re-establishment of a successful vegetative cover after industrial disturbance is dependent on soil-plant-water dynamics. On rangelands, grazing impacts are also critical. Grazing regimes, particularly heavy intensity, early season grazing, can reduce litter and soil organic matter (Naeth 1991a) and compact the soil surface (Naeth et al. 1990a). This in turn can affect infiltration rates (Naeth et al 1990b; Naeth et al. 1991b), water holding capacity (Naeth et al. 1991c), and soil water status (Naeth et al. 1991d). The longevity of re-established plant cover after any land disturbance such as pipeline construction is particularly important in grazed ecosystems, since grazing rangeland with much bare ground can contribute to a further decline in range condition and increase erosion hazards on the right-of-way (RoW). Thus, when selecting plant species for revegetation, not only ability to withstand grazing, but effect of season of defoliation must be considered.

Revegetating native rangelands after linear disturbances creates a specific problem. Cattle are attracted to the RoW with lush growth that is often more palatable and productive than native range, particularly if fertilized (Naeth 1985). RoW species generally mature later and are more palatable when native species have set seed. Rangeland cattle move onto the RoW when they first enter the field each spring. This attraction leads to excessive defoliation which can reduce plant cover if young seedlings are grazed heavily before they develop a sufficient root system or carbohydrate reserves to survive grazing. Cattle overuse of the RoW is associated with trampling and soil surface compaction which can lead to crusting and sealing, reduced infiltration, and associated runoff and erosion. Litter is often removed during pipeline construction and does not build up for years if the RoW is heavily grazed. It is important to identify potentially detrimental grazing regimes so revegetation strategies can be adapted to the grazing regime or the grazing regime may need to be altered until a suitable ground cover has been established.

In 1981, a study was initiated near Princess, Alberta, to evaluate pipeline construction impacts on Solonetzic mixed prairie rangeland. Four sites were selected within a natural gas pipeline corridor containing lines installed in 1957, 1963, 1968, 1972, and 1981. Two sites were early season grazed from May through July, and two were late season grazed from August through November. From fall 1981 through fall 1983, selected soil physical (bulk density) and chemical (electrical conductivity, salt concentration, sodium adsorption ratio, pH) parameters and vegetation characteristics (ground cover, species composition, plant density) were evaluated on all the pipeline RoW and compared to adjacent undisturbed mixed prairie. The 1981 and older RoW were compared to determine return towards predisturbed conditions with time The study was completed in 1984 (Naeth 1985, 1986, 1989, 1990; Naeth and Bailey 1984; Naeth et al. 1987, 1988). Although the ecosystem was severely altered by pipeline disturbance, the changes were often not detrimental to plant growth. Trenching caused the most extensive disruption of the ecosystem, whereas grading and compaction by heavy equipment were less disruptive.

From this earlier study the following parameters were quantified. In the 1981 trench, clay content, total profile water, soil surface temperature in the summer, winter temperature with depth, surface bulk density, and total soil surface soluble salts increased; water retention became more uniform with depth, and bulk density with depth decreased. Winter soil surface temperature and soil surface organic carbon content decreased with trenching. Soil surface bulk density increased in the pipelay, work, and stockpile treatments. Changes in bulk density were altered relatively little by time following pipeline construction. However, there was a distinct trend towards predisturbed conditions for soil water and soil chemical changes, especially in the older trenches.

RoW botanical composition was dramatically altered by pipeline construction. Following disturbance, pioneer and introduced species dominated the RoW, particularly over the trench. In 1983, after 26 years, succession towards undisturbed mixed prairie vegetation on the 1957 RoW was evident, with increased native species and reduced introduced species from the seed mix.

Changes in vegetative factors from pipeline construction were compounded by the grazing regime on the rangeland. Late season grazing resulted in a slower return to predisturbed conditions by favouring the establishment and dominance of introduced species such as *Agropyron pectiniforme* and pioneer species such as *Descurainia sophia*. Early season grazing reduced the dominance of pioneer and introduced species but resulted in more bare ground over the RoW for a longer period of time. *Selaginella densa*, which occupied over 50% of the ground area in the undisturbed prairie, was virtually eliminated by disturbance and has not reinvaded even the oldest RoW.

The success of newly established vegetation is contingent on soil properties after disturbance and on its fitting into the grazing environment. Soil chemical properties such as pH, soluble cations and anions, and electrical conductivity need to be evaluated over time in an effort to monitor salt movement which may have an impact on the establishment and longevity of vegetation. This is of particular importance over the trench where salts brought up to the surface of Solonetzic soils may have a negative impact on vegetative growth. The re-establishment of pre-disturbance organic matter levels will have a major impact on soil-plant-water interactions in the pipeline environment. Soil compaction has been identified as a problem in many reclamation efforts, particularly in clay-dominated soils (Naeth et al. 1991e). This compaction, in turn, affects soil water dynamics. Together they impact heavily on the success of revegetation efforts. These factors must then be assessed to determine the potential success of reclamation efforts after pipeline construction in native rangeland ecosystems.

II. OBJECTIVES

Ten years have elapsed since construction of the 1981 line and eight years elapsed between the data collection from the first study and this study on this pipeline corridor. To determine the longevity of the changes that took place on the 1981 RoW after pipeline construction, soil and vegetative characteristics were re-evaluated in August 1991. The study concentrated on the well documented 1981 RoW, comparing it to the oldest line, which was installed in 1957, and to the undisturbed mixed prairie.

Specific Objectives:

To document the longevity of selected vegetation and soil responses to single-lift pipeline construction in Solonetzic mixed prairie using 1981 construction techniques. Specifically:

1. To examine the effects of pipeline construction on vegetation: specifically on ground cover and plant species composition.
2. To examine the effects of pipeline construction on soil chemical properties, specifically pH, soluble cations and anions, and electrical conductivity.
3. To examine the effects of pipeline construction on soil physical properties, specifically bulk density, penetration resistance, and soil water content.
4. To examine the effects of pipeline construction on soil organic carbon.
5. To examine the foregoing within different zones of construction activity and on two different aged pipeline rights-of-way.
6. To compare the disturbed areas to the undisturbed native prairie.
7. To examine the effects of late and early season grazing on the above vegetative parameters.

III. METHODS

A. STUDY SITES

The study area was located approximately 225 km east of Calgary, Alberta, and 10 km east of Princess, Alberta (51°N latitude and 112°W longitude). The area has a continental climate and a semiarid moisture regime. Mean annual precipitation is 355 mm; mean annual temperature is 4°C with a July mean of 19°C and a January mean of -13°C. Elevation ranges from 730 to 760 m and slopes are less than 2%. The most common surficial materials are till and fluvial-lacustrine deposits. Undisturbed soils are 25% Brown Solod and 75% Brown Solodized Solonetz (Norwest Soil Research Ltd. 1981; Kjearsgaard et al. 1982). In a recent survey, soils were identified as predominantly Brown Solods with some Brown Solodized Solonetz areas and Orthic Brown Chernozemic profiles overlying buried Solonetzic horizons (Finlayson 1992). Eroded pits (blowouts), with the A horizon removed, are common. Undisturbed prairie soil to a 7.6 cm depth was silt loam to loam textured (Naeth 1985). Soil texture to 45 cm in the 1981 trench was clay loam and in all other treatments was loam. Soil texture below 45 cm in all treatments was clay loam. Finlayson (1992) found hand-textured samples were loam to fine sandy loam.

Vegetation is dominated by blue grama (*Bouteloua gracilis*), spear grass (*Stipa comata*), and western and northern wheatgrasses (*Agropyron smithii* and *A. dasystachyum*). Pasture sage (*Artemisia frigida*) and little club-moss (*Selaginella densa*) are common forbs. A short grass disclimax dominated by blue grama is common as a result of the heavy long-term grazing.

The study area, used for extensively managed beef cattle production, had never been cultivated. Sites from the original study were monitored in August 1991. The two early season grazed sites, grazed May through July, were in NW and NE 16-20-11-4 and the two late season grazed sites, grazed August through November, were in NW and NE 15-20-11-4 of a community pasture established in 1964. The 0.9 AUM ha^{-1} stocking rate was considered heavy for the area.

Each of four sites, located within 4 km of each other, was 100 by 135 m, spanning five natural gas pipeline RoWs with an undisturbed reference (control) on either side (Figure 1). The lines had been installed in 1957, 1963, 1968, 1972, and 1981 and had diameters of 86, 86, 91, 107, and 107 cm, respectively. Construction procedures were similar for all lines with grading prior to pipe installation but no topsoil salvage due to the small amount of topsoil present (Naeth 1985). Trenching was done with a ditcher and then backfilled. The trench was approximately 30 to 60 cm larger than the pipe. At least 0.8 m of soil was placed over the 1981 and 1972 trenches; soil depths over the older lines were at least 0.5 m. The 1981, 1972, and 1968 RoW were seeded to mixtures of: *Agropyron pectiniforme* (crested wheatgrass), *Elymus junceus* (Russian wildrye), *Agropyron riparium* (streambank wheatgrass), *Agropyron trachycaulum* (slender wheatgrass), *Agropyron elongatum* (tall wheatgrass), *Agropyron trichophorum* (pubescent wheatgrass), *Elymus angustus* (Altai wildrye), *Medicago* species (alfalfa), *Onobrychis vicaefolia* (sainfoin), and *Astragalus cicer* (cicer milk-vetch). The 1957 and 1963 RoW were not seeded, but left to revegetate naturally.

The sites were divided into east-west treatments representing areas of pipeline construction activity and ages of pipeline RoW. The 1981 RoW was 30 m wide and comprised the stockpile; the trench; the pipelay, approximately 3 m from the center of the 1981 trench, where pipe was strung until installation; and the work area, approximately 10 m from the center of the 1981 trench, over which most vehicular movement occurred. The area corresponding to work, pipelay, and stockpile treatments of the older RoW was referred to as the between trenches treatment. Soil chemical and physical evaluations were made on three sites and vegetation analyses on four sites (the impact of grazing was not significant on soil factors and therefore three sites were sufficient for soil data collection). For the 1991 study, treatments in the 1981 RoW (trench, work, and stockpile areas), the 1957 trench, and an adjacent undisturbed control were studied.

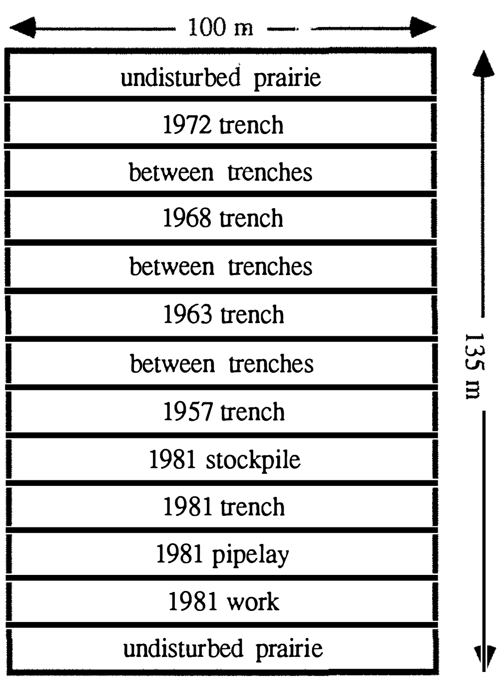

Figure 1. Site treatment layout.

B. SOIL CHEMICAL PROPERTIES

Soil was sampled at three locations per treatment in depth increments of 0-5, 5-15, 15-30, 30-45, 45-60, and 60+ cm. Sampling was by coring truck in non-trench locations and by hand auger over the trench. Samples were air dried and ground to pass a 2-mm sieve, then analyzed by Norwest Labs for organic carbon, pH, soluble anions and cations, and electrical conductivity. Soil pH was determined on a 1:1 soil-water suspension (Day 1965). Soluble cations, anions, and electrical conductivity were determined by the saturation paste method (McKeague 1978). Total carbon was determined by dry oxidation on a Leco automatic carbon analyzer, with whole soil carbonates determined by acid neutralization and back titration to pH 8.2 (Black 1965).

C. SOIL PHYSICAL PROPERTIES

Bulk density and soil water were measured using a Campbell Pacific Nuclear 501 moisture/density depth probe in access tubes from the original study (three per treatment; five on the 1981 trench). Measurements were in 10 cm intervals starting at 15 cm. Measurement depths ranged from 45 to 135 cm with two 16-s counts for each of soil water and bulk density at each depth. Penetration resistance was measured with a Centre Cone Penetrometer, using the small cone (area 0.2 in^2). Because of extremely high penetration resistances (PR), only maximum PR and depth of maximum PR were measured at each of ten locations per treatment. Surface (0-7.5 cm) soil water and bulk density were measured near each PR measurement location using an MC1 surface moisture/density gauge at ten locations per treatment. All probes had been calibrated within the year.

D. VEGETATION PROPERTIES

Twenty 0.1 m^2 quadrats (20 by 50 cm) were read in each treatment for species composition and ground cover. Ground cover categories consisted of live vegetation, litter, manure, rocks, and bare ground. Quadrats were randomly located in each of the treatments.

E. STATISTICAL ANALYSES

Data for the split block design were tested for homogeneity of variance using Cochran's test for homogeneity. Parameters were analyzed with an SPSS analysis of variance program. Parameters with significant F values were further analyzed using Student-Newman-Keul's (SNK) test at the 5% level of significance (Steel and Torrie 1980).

IV. RESULTS AND DISCUSSION

A. SOIL CHEMICAL PROPERTIES

1. Soil pH

Soil pH in all treatments at all depths was between 5.6 and 8.3 (Figure 2), posing no potential problems for plant growth, particularly for native mixed prairie species. Statistically significant treatment differences occurred in the upper 15 cm, with undisturbed prairie pH lower than pH for other treatments. With depth, pH increased in undisturbed prairie, decreased in the 1957 trench, and was relatively unchanged in the 1981 trench. The 1981 line construction increased pH levels to those found in undisturbed blowouts above 15 cm depths.

2. Saturation Percentage

Saturation percentage generally increased with depth (Figure 3). Values above 5 cm in blowouts were significantly lower than in all other treatments and higher than in all other treatments below 5 cm. Disturbance lowered values, but not statistically. Values in the 1957 trench were higher than in the 1981 trench to 5 cm, after which the opposite occurred, particularly at 15-30, 30-45, and 45-60 cm. No values in any disturbed treatments indicated a major shift from undisturbed prairie.

3. Electrical Conductivity

Electrical conductivity (EC) increased with depth, being lowest in undisturbed prairie to 45 cm and highest in the 1981 trench at all depths (Figure 4). With disturbance, EC in the upper 15 cm was more similar to blowouts than undisturbed prairie. To a depth of 45 cm, EC in the 1957 trench was significantly lower than EC in the 1981 trench, and statistically similar to EC in undisturbed prairie. EC was low (< 2 dS m^{-1}) to a depth of 5 cm, but high (4.5 to 8.5 dS m^{-1}) in the 1981 trench below 5 cm.

4. Cations

Cations increased with depth (Figures 5 to 8, inclusive). At 0-5 cm, Ca, Mg, and Na were lowest in undisturbed prairie and highest in the 1981 trench. The 1957 trench cation levels resembled undisturbed prairie more than the 1981 trench.

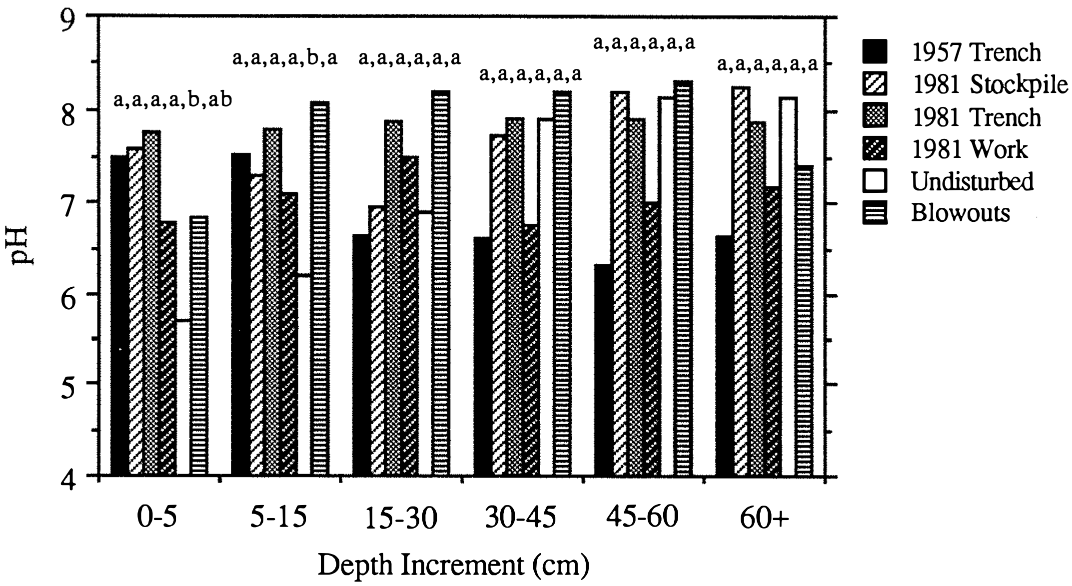

Figure 2. Soil pH site-averaged profile for August 1991. Means within a given depth increment with the same letters are not significantly different at the 5% level of significance.

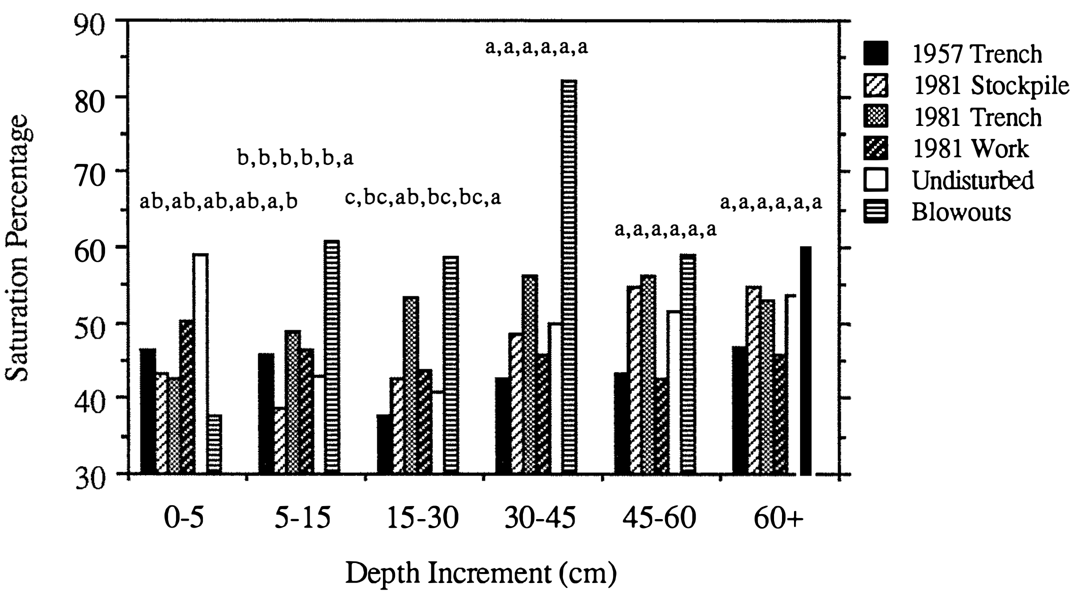

Figure 3. Saturation percentage site-averaged profile for August 1991. Means within a given depth increment with the same letters are not significantly different at the 5% level of significance.

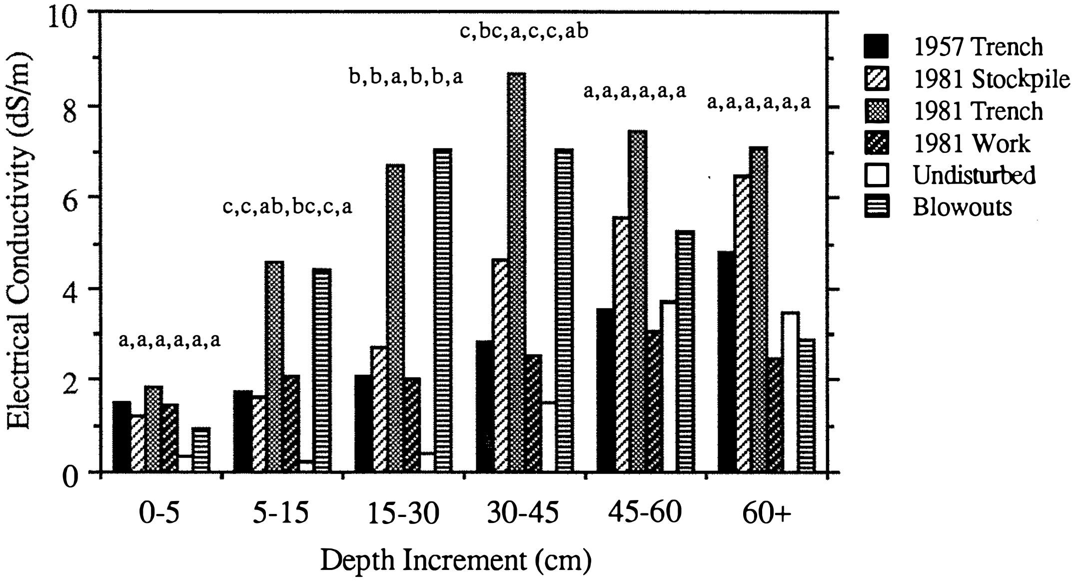

Figure 4. Electrical conductivity site-averaged profile for August 1991. Means within a given depth increment with the same letters are not significantly different at the 5% level of significance.

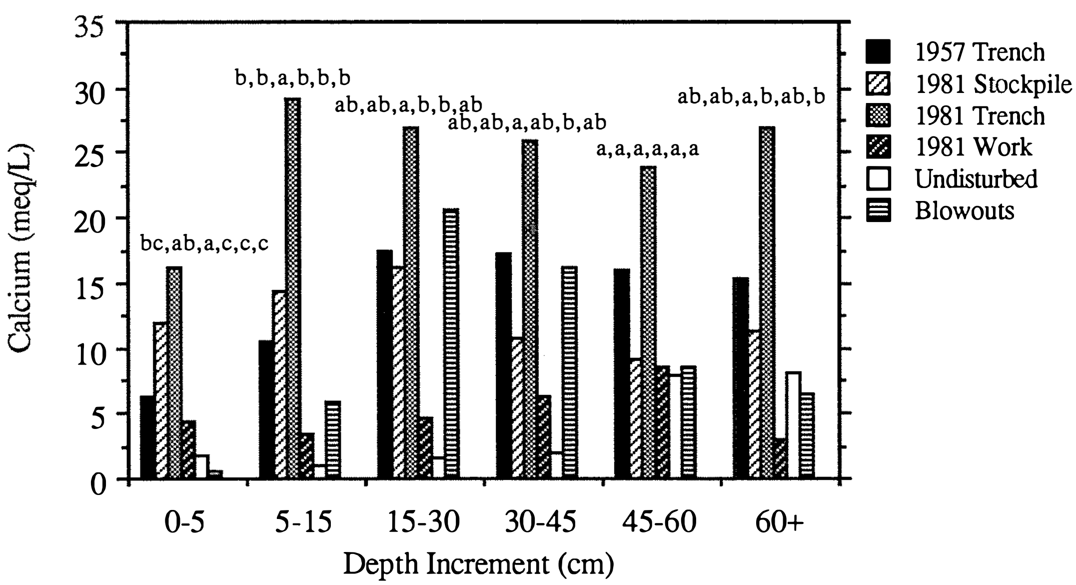

Figure 5. Calcium site-averaged profile for August 1991. Means within a given depth increment with the same letters are not significantly different at the 5% level of significance.

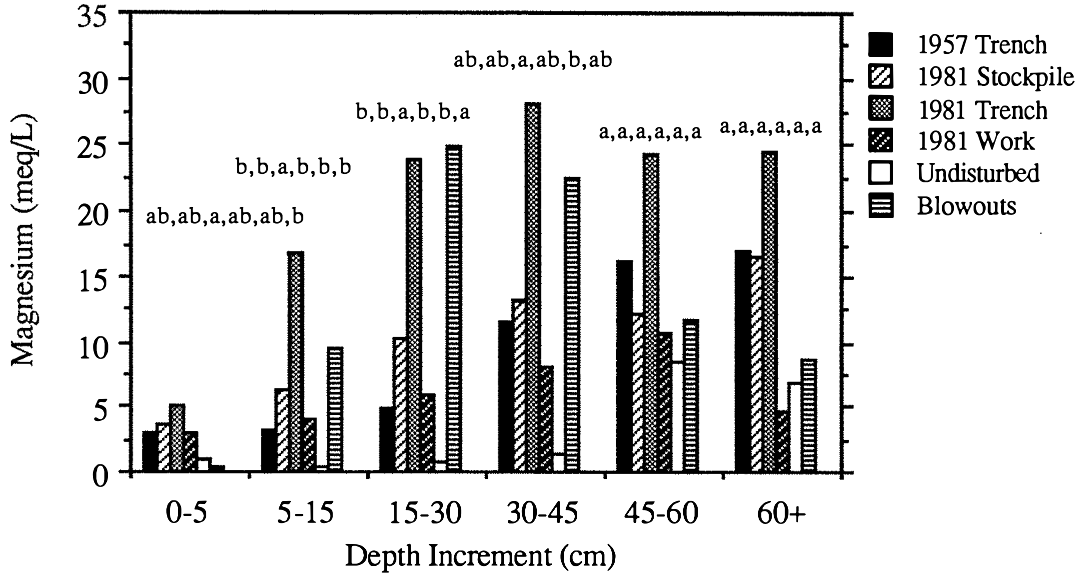

Figure 6. Magnesium site-averaged profile for August 1991. Means within a given depth increment with the same letters are not significantly different at the 5% level of significance.

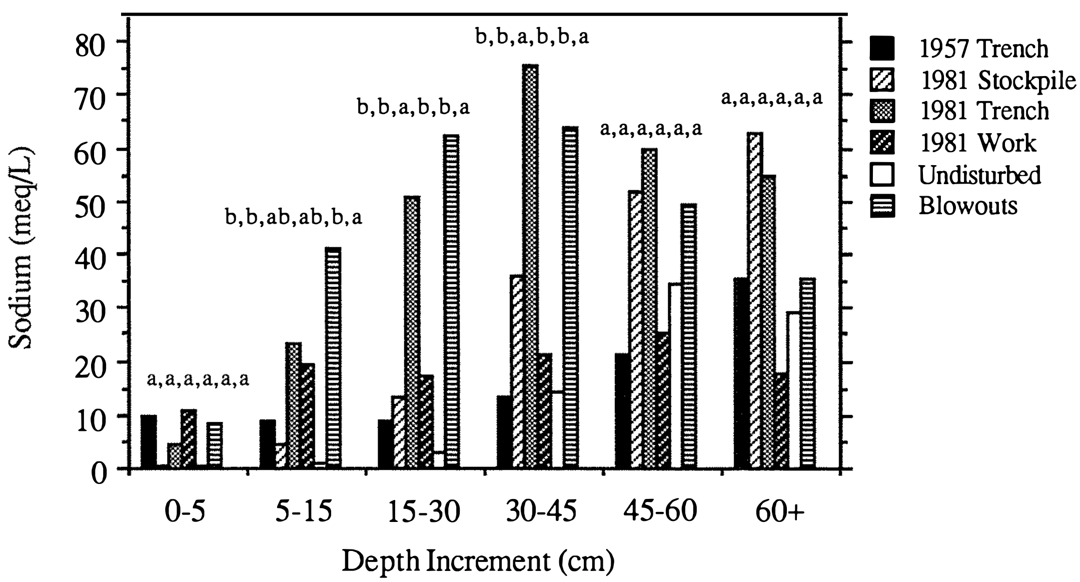

Figure 7. Sodium site-averaged profile for August 1991. Means within a given depth increment with the same letters are not significantly different at the 5% level of significance.

5. Anions

Anions increased with depth (Figures 9 to 12, inclusive). Statistically significant treatment differences for sulphate sulphur occurred in the 5-15, 15-30 and 30-45 cm depth increments where values were higher in the 1981 trench than in undisturbed prairie. 1957 trench values were less than those in the 1981 trench; although the differences were not statistically significant, actual values were at least twice those in undisturbed prairie. Treatment differences for chloride were not statistically significant for any depth interval. Although to 30 cm, there was a physical trend to higher values in the 1957 trench than in the 1981 trench or the undisturbed prairie; below 30 cm, the trend reversed. Bicarbonates were higher in the 1957 than in the 1981 trench at all depths but were similar to those in undisturbed prairie. Nitrate and nitrite varied inconsistently with depth and treatment, being highest at 15-30 cm.

6. Sodium Adsorption Ratio

Sodium adsorption ratio (SAR) generally increased with depth (Figure 13). Values were lower in the 1981 trench than in the 1957 trench to 15 cm, after which the opposite trend occurred. For the 1981 RoW treatments, at depths greater than 15 cm, disturbed treatment SAR was not statistically greater than that in undisturbed prairie. In undisturbed blowouts, SARs were always greater than 8, which could pose problems for sensitive plant growth. SARs were greater than 8 to depths of 30 cm in work and blowout treatments, from 30-60 cm in the 1957 trench, and at 60 cm in all treatments. In general, disturbed treatment SARs in the upper 30 cm would not likely limit most plant growth. Below 30 cm, values increased, but were not statistically different than in undisturbed prairie, indicating an inherent soils problem, not a pipeline activity problem.

7. Total Alkalinity

There were few statistically significant differences with treatment (Figure 14). Total alkalinity was lower in the 1981 trench relative to the 1957 trench; values in the 1957 trench were closer to the undisturbed prairie than those in the 1981 trench.

8. Theoretical Gypsum Requirement (TGR)

There were few statistically significant differences with treatment (Figure 15). TGR was higher for the 1981 trench than the 1957 trench to a depth of 30 cm, after which the reverse occurred. Values in the undisturbed prairie were closer to those in the 1957 trench than in the 1981 trench.

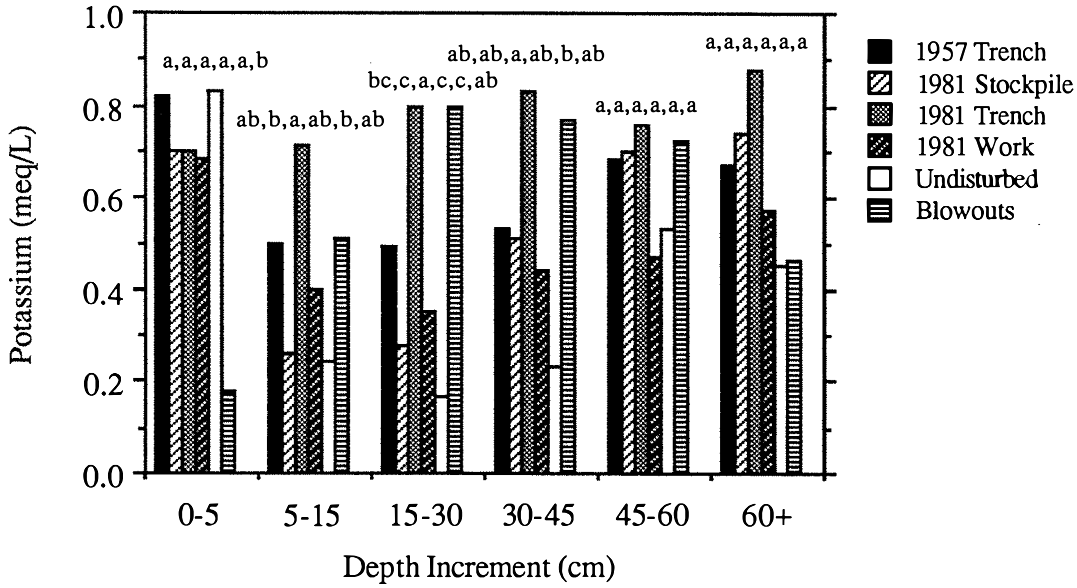

Figure 8. Potassium site-averaged profile for August 1991. Means within a given depth increment with the same letters are not significantly different at the 5% level of significance.

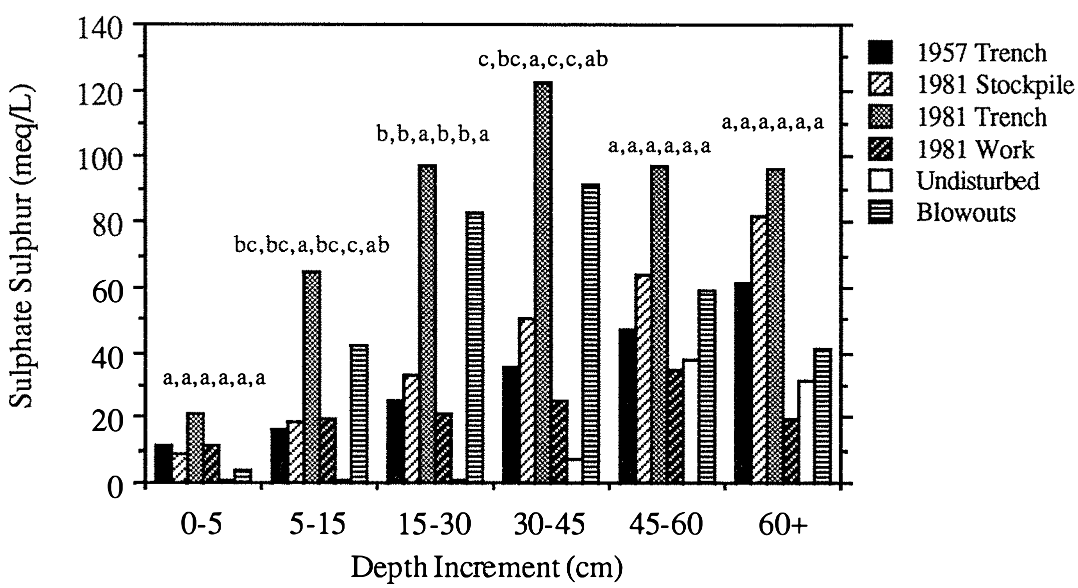

Figure 9. Sulphate sulphur site-averaged profile for August 1991. Means within a given depth increment with the same letters are not significantly different at the 5% level of significance.

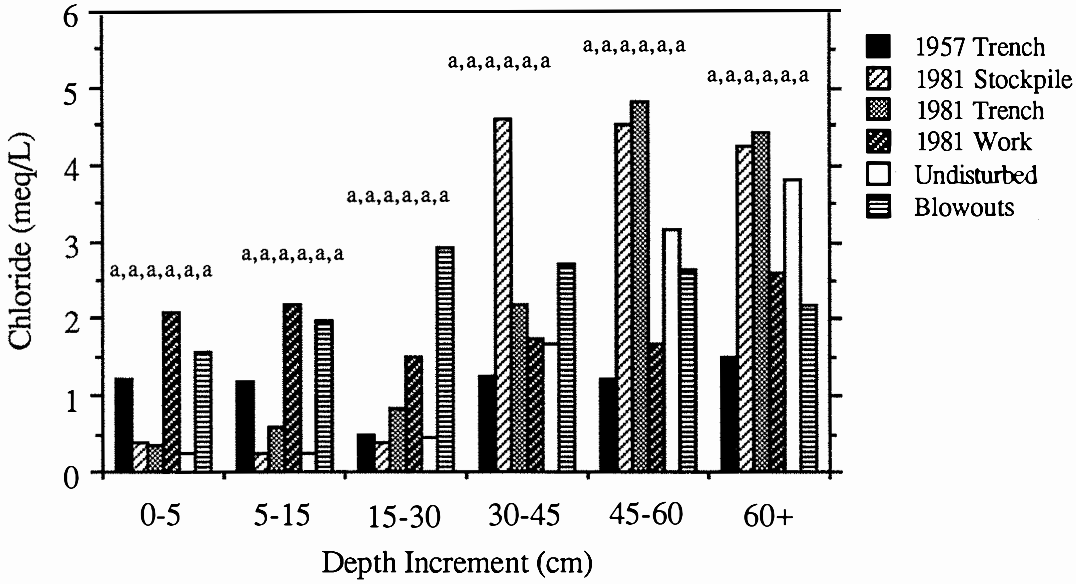

Figure 10. Chloride site-averaged profile for August 1991. Means within a given depth increment with the same letters are not significantly different at the 5% level of significance.

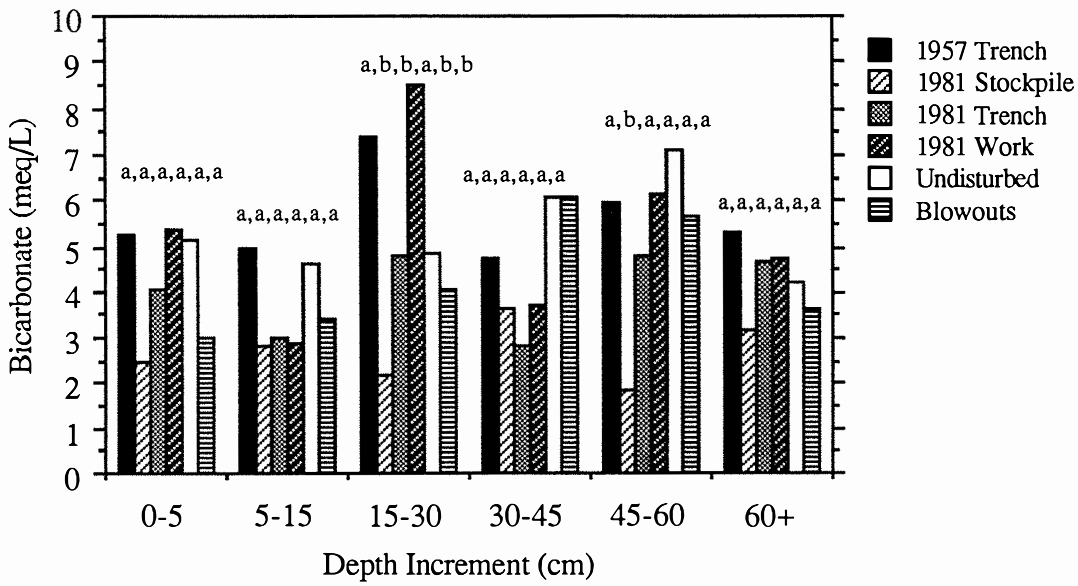

Figure 11. Bicarbonate site-averaged profile for August 1991. Means within a given depth increment with the same letters are not significantly different at the 5% level of significance.

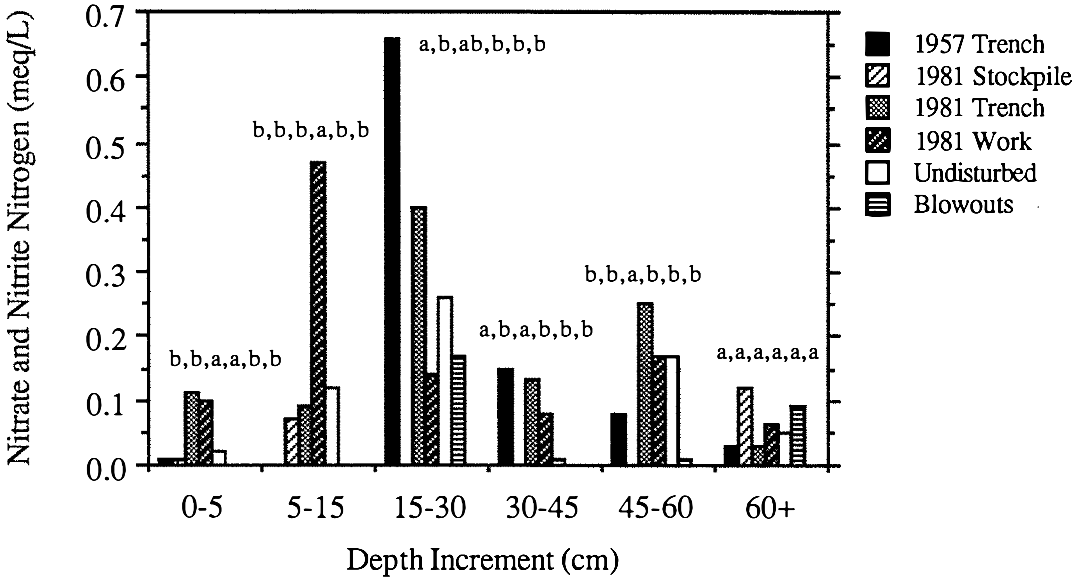

Figure 12. Nitrate and nitrite nitrogen site-averaged profile for August 1991. Means within a given depth increment with the same letters are not significantly different at the 5% level of significance.

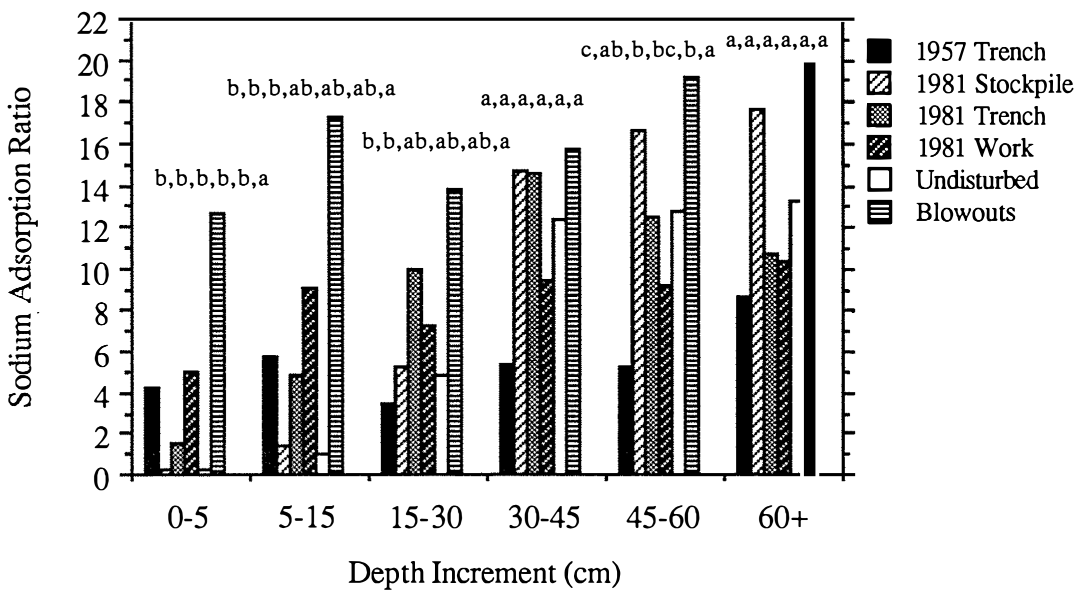

Figure 13. Sodium adsorption ratio site-averaged profile for August 1991. Means within a given depth increment with the same letters are not significantly different at the 5% level of significance.

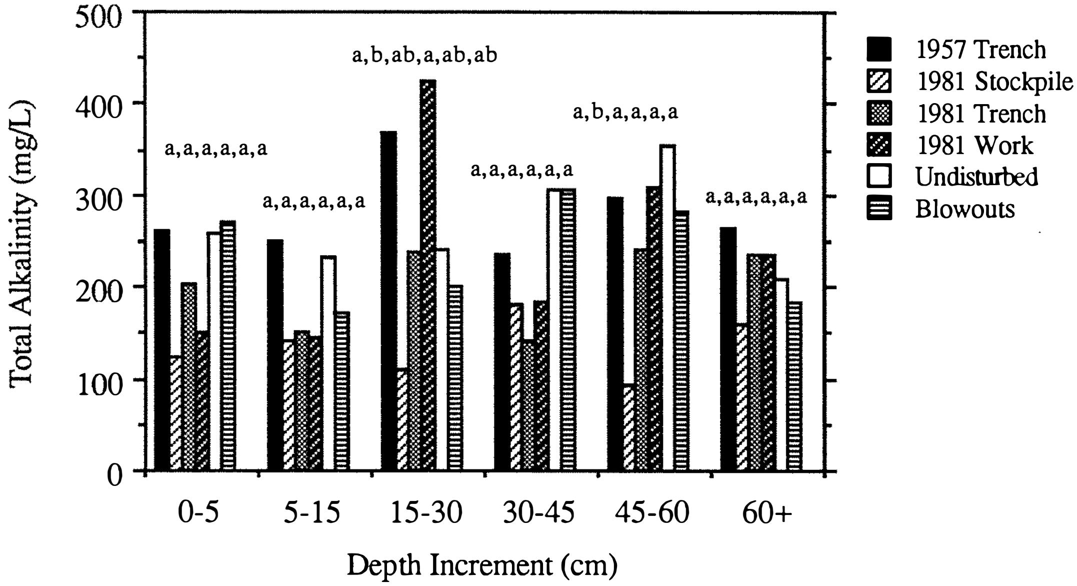

Figure 14. Total alkalinity site-averaged profile for August 1991. Means within a given depth increment with the same letters are not significantly different at the 5% level of significance.

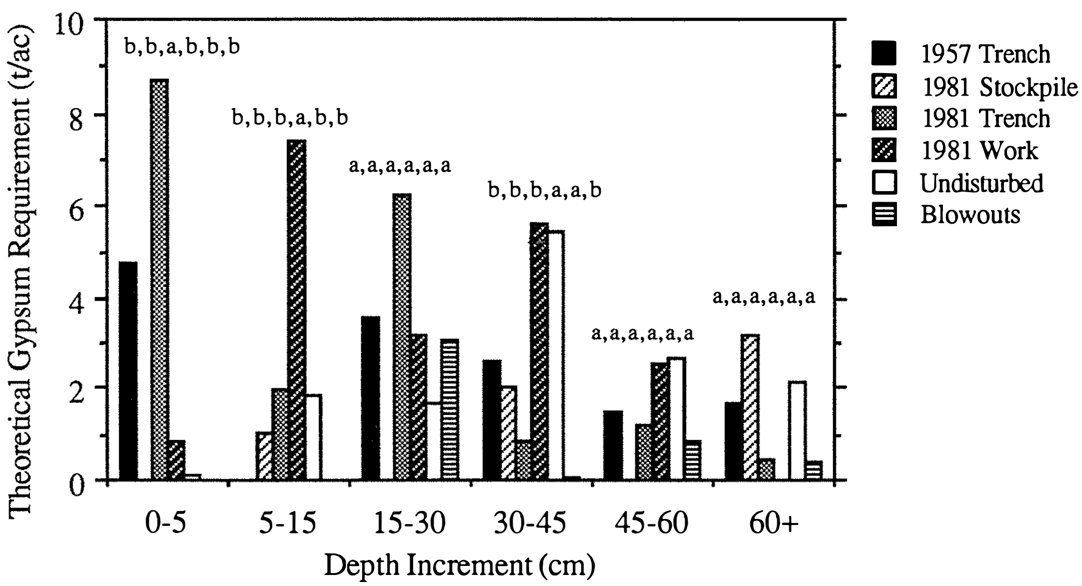

Figure 15. Theoretical gypsum requirement site-averaged profile for August 1991. Means within a given depth increment with the same letters are not significantly different at the 5% level of significance.

9. Organic Carbon

Organic carbon generally decreased with disturbance in the 0-5 cm depth increment relative to the undisturbed prairie (Figure 16). Although the differences were not statistically significant, the higher values in the 1957 trench compared to the 1981 trench may indicate a trend towards increases of organic carbon with time after trenching. The changes are very slow, however, indicating the long period of time to build up organic material in a relatively arid ecosystem. Organic carbon in these two trenches and the stockpile were similar to the undisturbed blowouts. The lower values in the stockpile compared to the work treatment is likely due to the scraping to refill the trench; the work treatment was driven on, creating less surficial disturbance. For the 5-15 cm depth increment, only values in the 1957 trench were significantly lower than undisturbed prairie. This is inconsistent in that organic carbon would be expected to increase in that trench due to the length of time from disturbance relative to the 1981 RoW treatments.

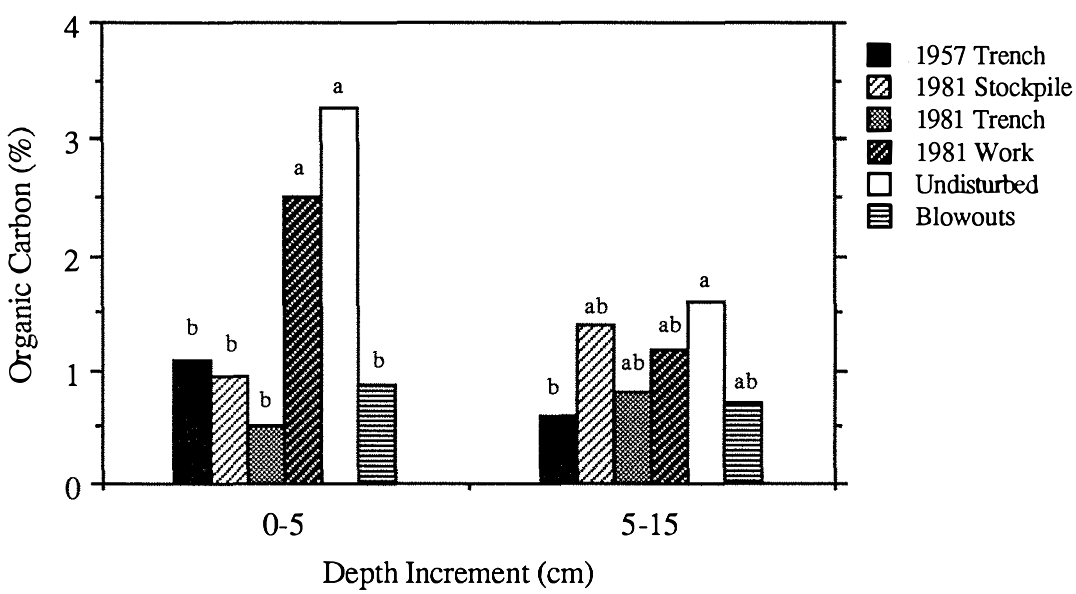

Figure 16. Organic carbon site-averaged profile for August 1991. Means within a given depth increment with the same letters are not significantly different at the 5% level of significance.

B. SOIL PHYSICAL PROPERTIES

1. Surface Bulk Density

Surface bulk density for a given treatment differed slightly among sites (Figure 17). Site-averaged highest values were in the 1981 trench, followed by 1957 trench, 1981 stockpile, 1981 work, and undisturbed prairie treatments (Figure 18). On the work treatment, where most traffic occurred, values were lowest of all disturbed treatments. Values would not limit most plant growth.

2. Bulk Density

Bulk density in the undisturbed prairie increased with depth at all three sites: from approximately 1.25 Mg m^{-3} at a depth of 15 cm to 1.70 Mg m^{-3} at 115 cm (Figure 19). Bulk density in the 1981 trench, at all three sites, generally decreased with depth, although the pattern was not linear (Figure 20). Thus the pattern for bulk density change with depth was diametrically opposite for the undisturbed prairie and the 1981 trench (Figures 19 and 20); bulk density values were higher with depth in the undisturbed prairie than in the trench. Bulk density at 95 cm in the 1981 trench was 0.57 Mg m^{-3} lower than in the undisturbed prairie at the same depth.

In 1981 pipelay and work treatments, site-averaged bulk density increased with depth (Figure 21). The trend for the pipelay and undisturbed prairie was identical and values equal in magnitude. The pattern for the work area was similar to these two treatments although bulk density was generally higher in the work area than in either the pipelay or the undisturbed prairie, most noticeably for depths between 25 and 65 cm. This was likely due to compaction during construction.

Bulk density in Site 2 trench treatments followed patterns of bulk density increase with depth (Figure 22). Values for the 1972 trench were significantly higher than for other trenches; less than 1.60 Mg m^{-3} below 60 cm. Being near the road may account for the higher values. Bulk densities in other trenches had not increased to predisturbed levels. Lower values in the 20 to 30 than the 0 to 20 cm or lower depths may be due to pipeline construction and plant rooting.

3. Penetration Resistance

Site-averaged penetration resistance (PR) did not differ significantly among treatments (Table 1). However, there was a trend to higher values in the work treatment and lower values in trenches. In all cases, PR was very high, indicative of dry and/or dense soils. Depth of maximum resistance was highest in undisturbed prairie and lowest in the 1981 trench. Values in the 1957 trench were similar to that of undisturbed prairie. In all cases, maximum PR occurred at shallow depths.

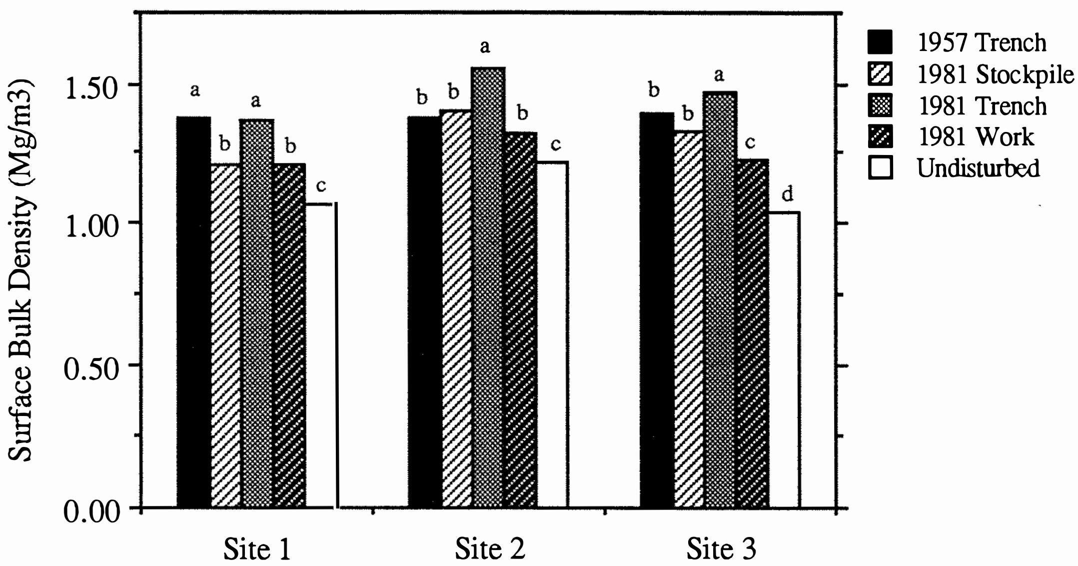

Figure 17. Surface bulk density at Sites 1, 2, and 3 for August 1991. Means within a given site with the same letters are not significantly different at the 5% level of significance.

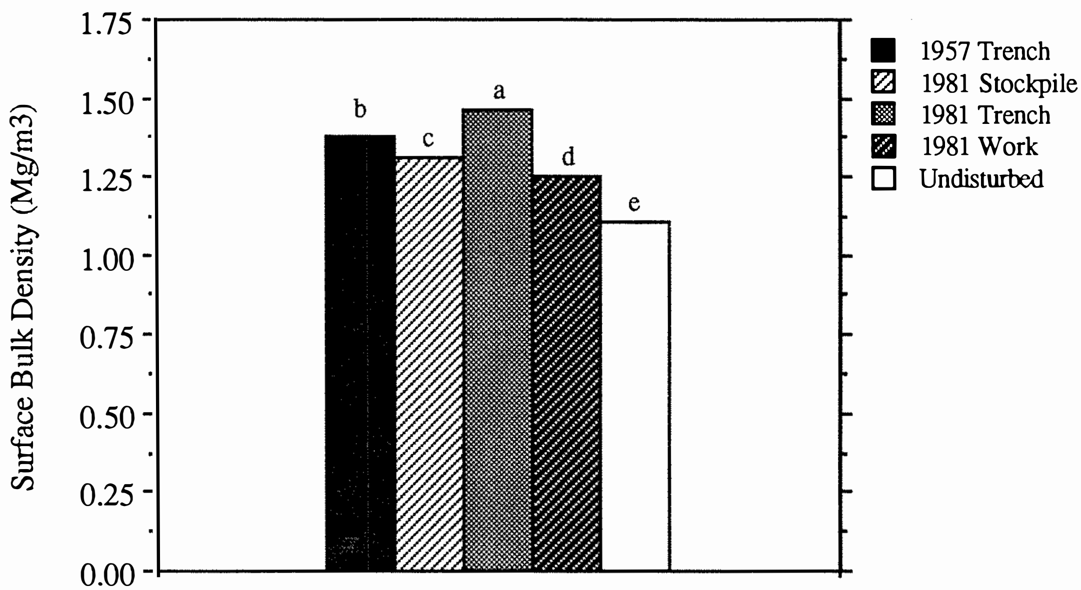

Figure 18. Site-averaged surface bulk density for August 1991. Means with the same letters are not significantly different at the 5% level of significance.

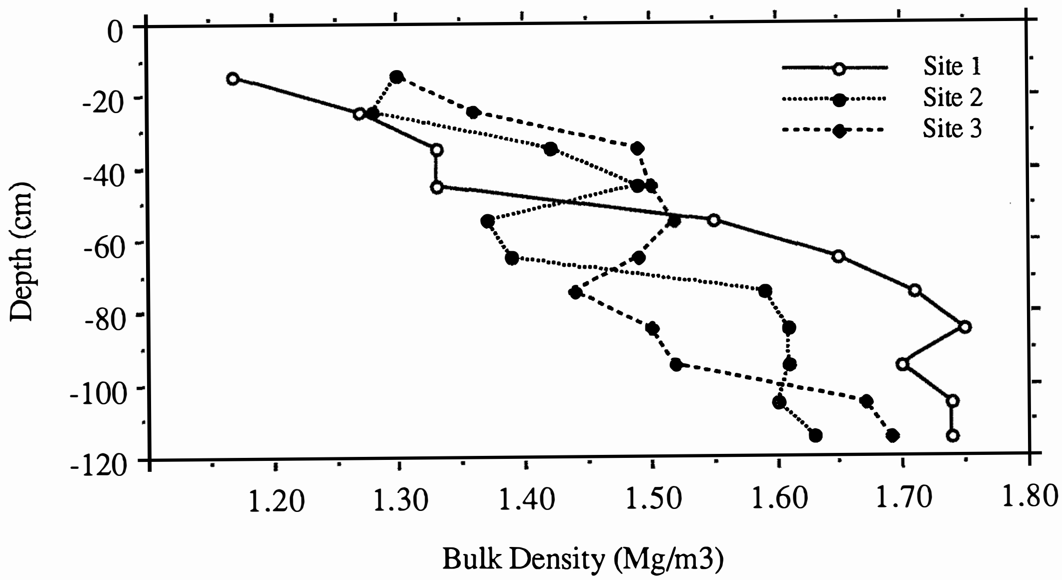

Figure 19. Bulk density in the undisturbed prairie at Sites 1, 2, and 3 for August 1991.

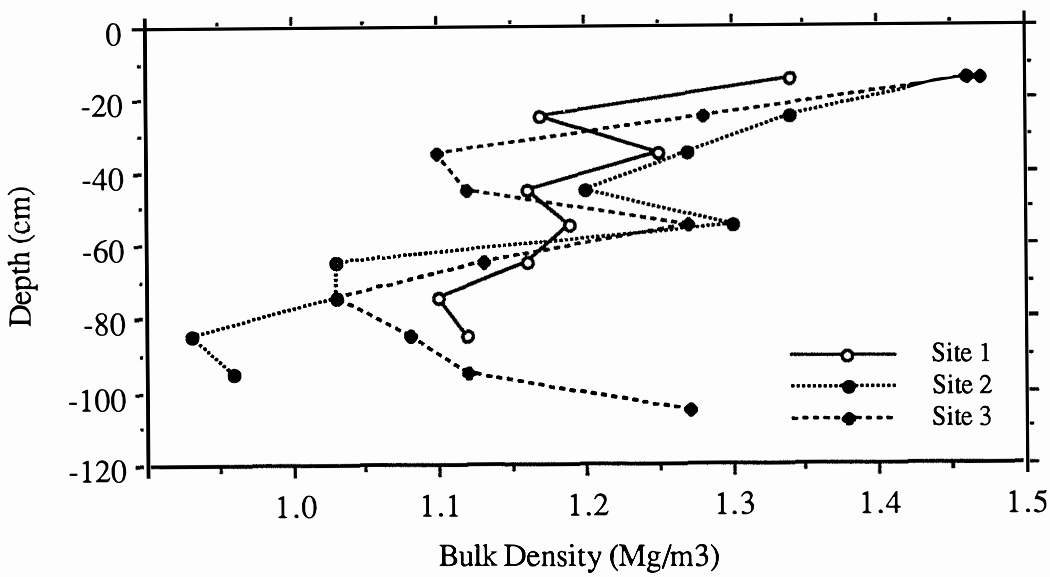

Figure 20. In-trench bulk density at Sites 1, 2, and 3 for August 1991.

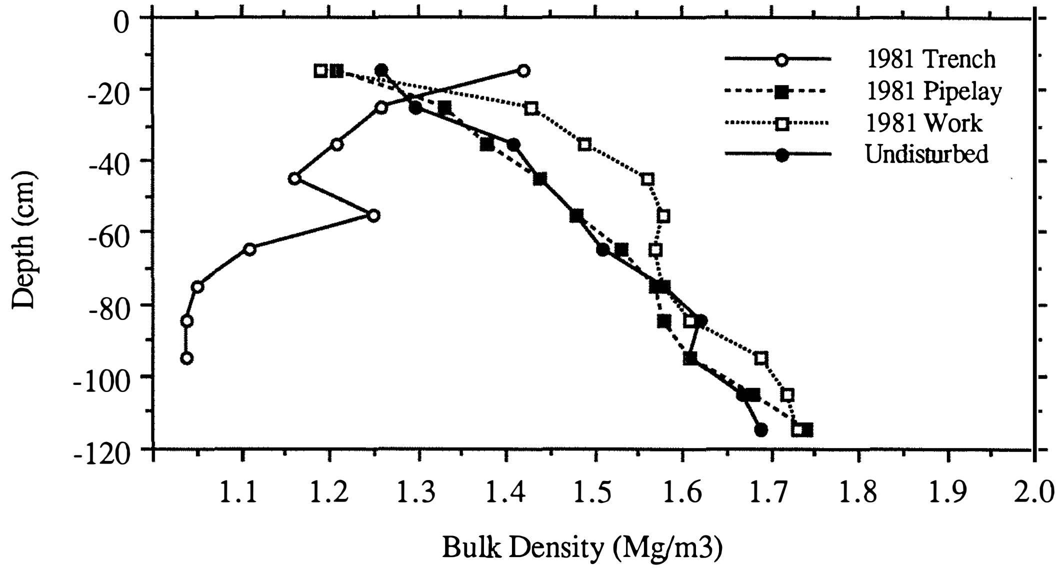

Figure 21. Site-averaged bulk density on the 1981 RoW and for the undisturbed prairie for August 1991.

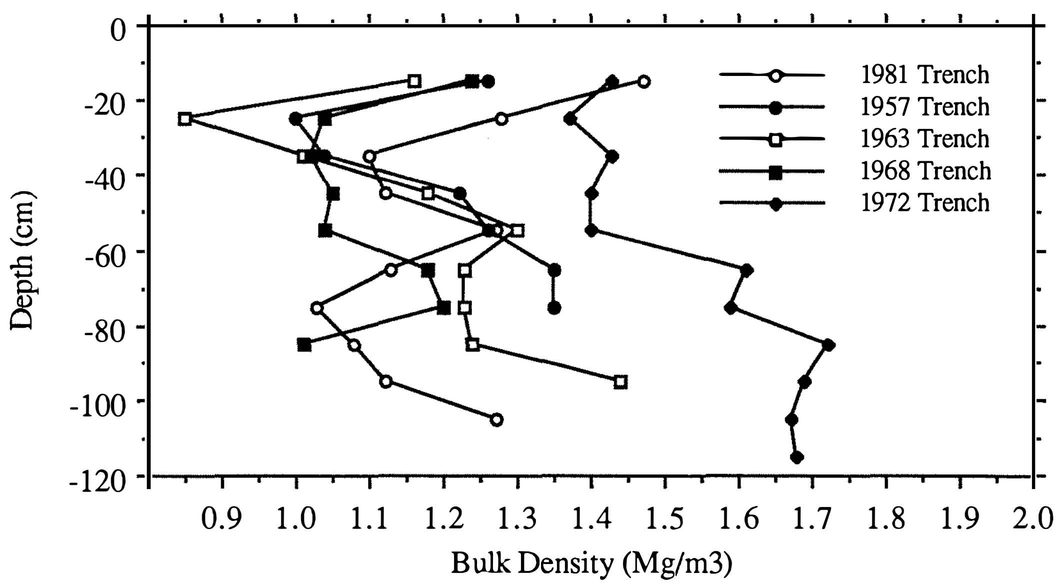

Figure 22. In-trench bulk density at Site 2 for August 1991.

Table 1. Site-averaged maximum penetration resistance and depth of maximum penetration resistance for August 1991.

	Penetration Resistance (MPa)	Depth of maximum Penetration Resistance (cm)
1957 Trench	9.2	14
1981 Stockpile	9.3	11
1981 Trench	8.3	8
1981 Work	10.4	10
Undisturbed Prairie	9.0	16

4. Surface Soil Water

Surface soil water was similar among sites for a given treatment (Figure 23). Site-averaged surface soil water was highest in the 1981 trench and lowest in the undisturbed prairie (Figure 24). Surface soil water was low, especially in the undisturbed prairie (approximately 4 $cm^2\ cm^{-2}$ x 100)

5. Soil Water

Soil water generally increased with depth in the undisturbed prairie at all three sites, from approximately 4% at 15 cm to 20% at 115 cm (Figure 25). Soil water in the 1981 trench had a different trend at each of the three sites: relatively constant with depth at Site 1; generally increasing with depth at Site 2; and remaining constant from depths of 25 to 45 cm, then declining at Site 3 (Figure 26). Soil water magnitudes ranged from 11% at 15 cm to a maximum value of 24% at 85 cm at Site 2. Soil water patterns with depth are characteristic of poorly vegetated areas, with the trend at Site 2 apparently indicating the greatest amount of vegetative use of soil water.

Soil water in the 1981 RoW and the undisturbed prairie followed similar trends, except for the pipelay treatment where maximum soil water occurred at 65 cm (Figure 27). The lowest soil water was in the work treatment at depths between 35 and 95 cm, as might be expected from its high bulk densities (and likely attendant poor percolation). The trends in soil water were similar in both the undisturbed prairie and the 1981 trench with values generally ranging from 14 to 20%.

In-trench soil water at Site 2 was similar for the 1981, 1957, 1963, and 1972 trenches for depths of 35 to 55 cm, generally increasing with depth (Figure 28). The pattern in the 1968 trench was different, with soil water relatively constant with depth (near 12%). The 35 cm depth is significant with different soil water patterns above and below. This is often the interface between B and C horizons, possibly reflecting the change in soil structure and density within the mixed trench.

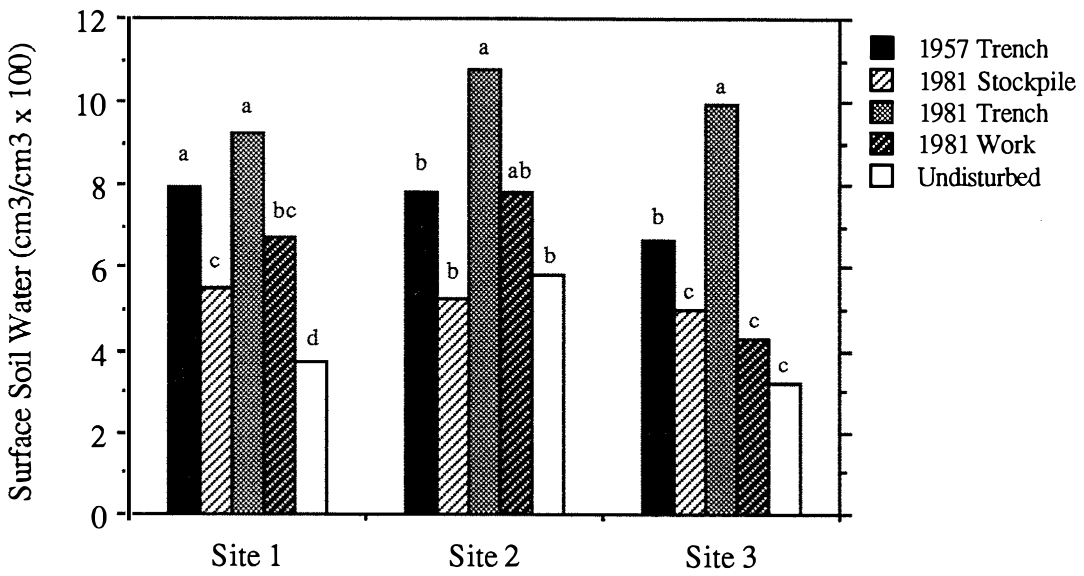

Figure 23. Surface soil water in Sites 1, 2, and 3 for August 1991.

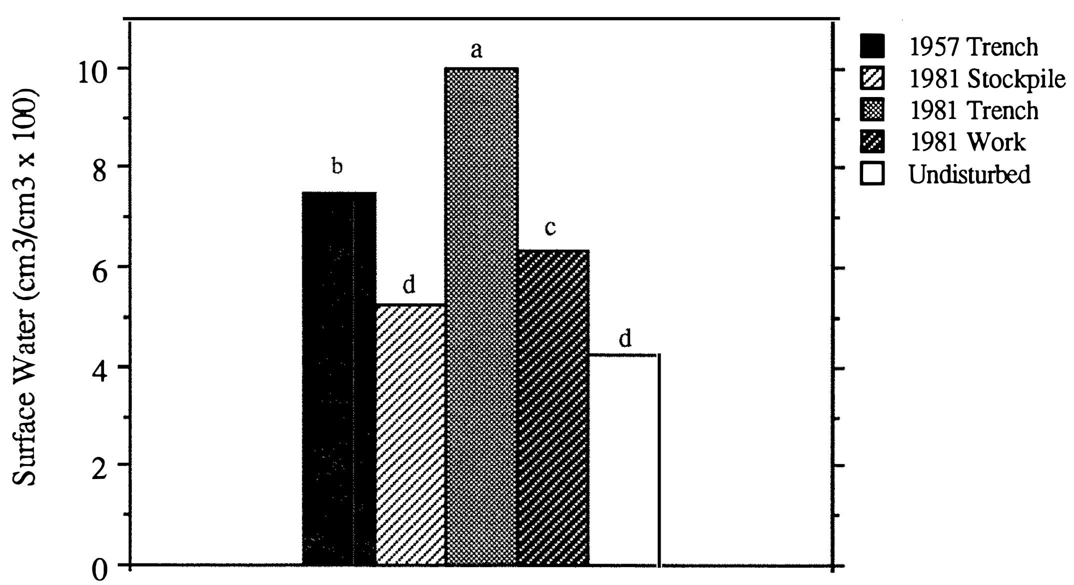

Figure 24. Site-averaged surface soil water for August 1991.

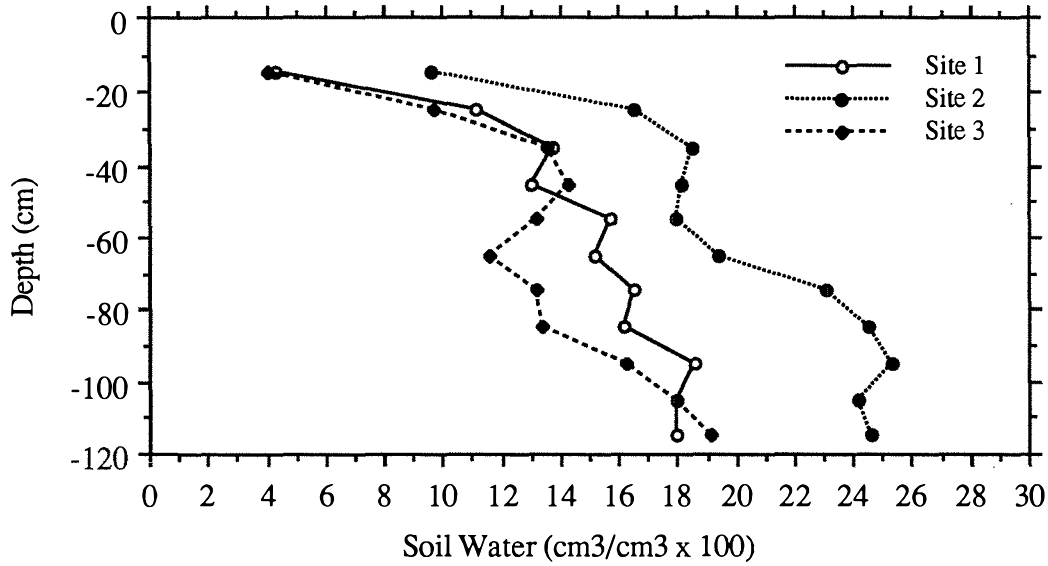

Figure 25. Soil water in the undisturbed prairie at Sites 1, 2, and 3, for August 1991.

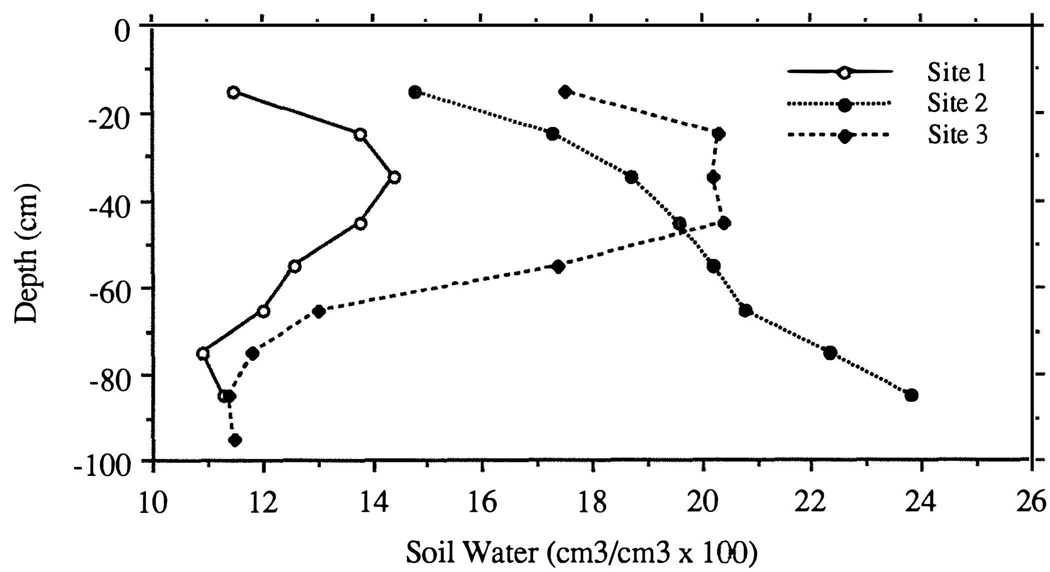

Figure 26. 1981 trench soil water at Sites 1, 2, and 3 for August 1991.

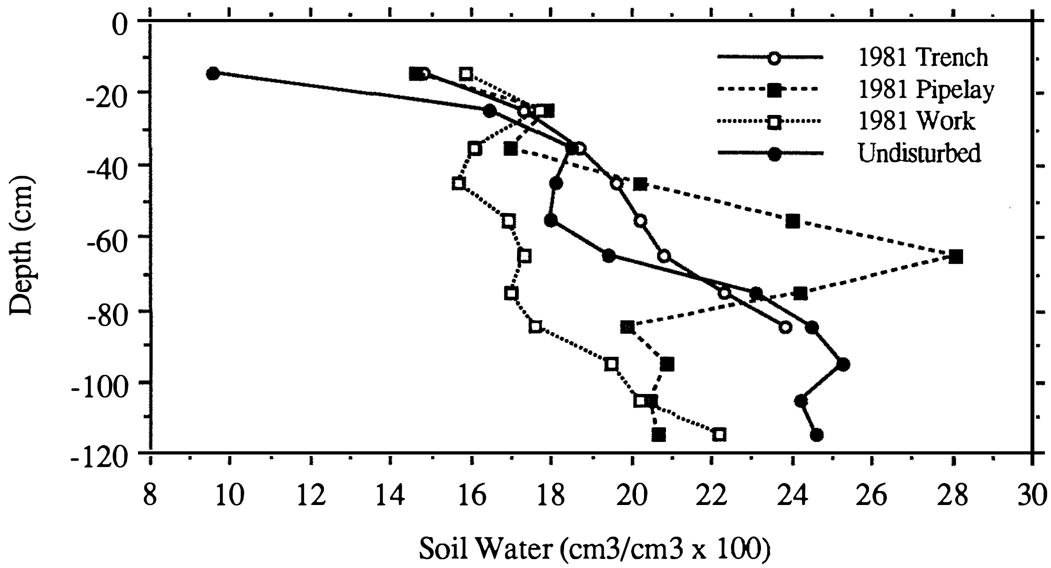

Figure 27. Site-averaged soil water on the 1981 RoW and in the undisturbed prairie for August 1991.

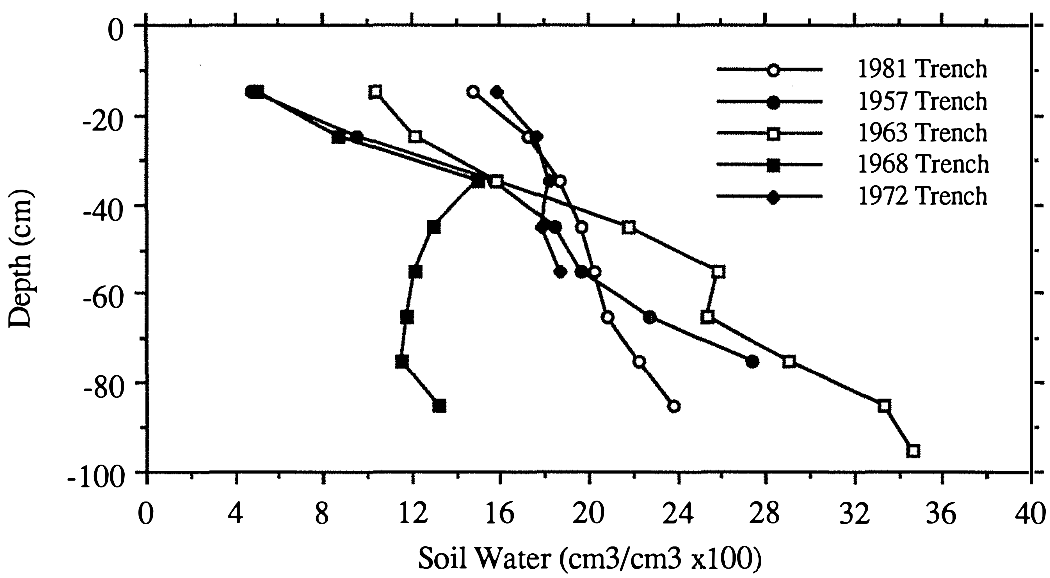

Figure 28. In-trench soil water at Site 2 for August 1991.

C. VEGETATION PROPERTIES

1. Ground Cover

In all sites and treatments, live vegetation dominated ground cover (Figure 29). Site-averaged bare ground ranged from 5 to 51%. Statistically highest values of bare ground were on the 1981 trench with lowest values in undisturbed prairie. Bare ground on all other disturbed treatments were similar; the significantly lower values on the 1957 trench (31%) compared to the 1981 trench (51%) indicate a trend towards predisturbed conditions. Litter cover did not differ significantly among any of the treatments. Live vegetation followed the opposite trend to that from bare ground, as expected. Again, a trend towards predisturbed conditions was evident. The major difference in live vegetation is for the very high cover of *Selaginella densa* on the undisturbed prairie; this species was not present on the disturbed treatments.

2. Species Composition

Undisturbed prairie vegetation was dominated by *Selaginella densa* and grass species, with significant components of forbs and sedges (Table 2). *Selaginella densa* had not invaded any disturbed treatments (Tables 3 to 6, inclusive). Grasses dominated all other treatments; forbs were lowest on the 1981 trench and similar on other disturbed treatments.

Species diversity was highest in undisturbed prairie (Tables 7 to 11, inclusive). Introduced species were highest on the 1981 trench, similar on work and stockpile treatments, and lowest on the 1957 trench; there were no introduced species in undisturbed prairie. The 1981 trench was dominated by *Agropyron smithii* and *Agropyron pectiniforme* (Table 7). On the stockpile, these two *Agropyron* species were dominant, but *Bouteloua gracilis* had significant cover, as did *Stipa comata*, and *Polygonum arenastrum* (Table 8). On the 1957 trench, *Agropyron smithii* and *Bouteloua gracilis* co-dominated, with significant cover of *Stipa* species and *Poa sandbergii* (Table 9). The 1981 work area was dominated by *Agropyron* species, with significant occurrences of *Carex* species, *Chenopodium* species, and *Polygonum arenastrum* (Table 10). *Selaginella densa* dominated undisturbed prairie with significant occurrences of *Agropyron smithii*, *Bouteloua gracilis*, *Carex* species, and *Stipa comata* (Table 11). Species composition was often more favourable than that in the undisturbed prairie, being more palatable and more productive. The large amount of *Selaginella densa* in the undisturbed prairie may reduce erosion potential by covering bare ground, but from a grazing perspective it is undesirable, being unpalatable and reducing the productivity of the rangeland.

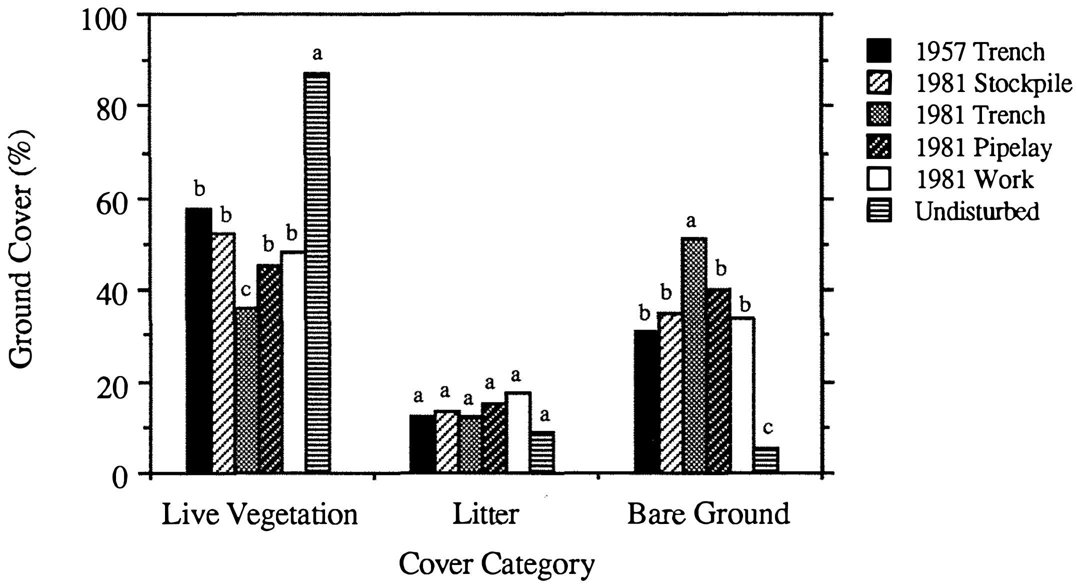

Figure 29. Site-averaged ground cover for August 1991. Means within a given vegetation type with the same letters are not significantly different at the 5% level of significance.

Table 2. Percentage composition of vegetation types on undisturbed prairie for August 1991.

	Late Season Grazed Sites			Early Season Grazed Sites			All Sites
Vegetation Type	1	4	Mean	2	3	Mean	Mean
Grasses	42	19	31	27	13	20	25
Forbs	14	6	10	8	9	9	9
Club Moss	31	68	50	55	69	62	56
Sedges	13	6	10	8	11	10	10

Table 3. Percentage composition of vegetation types on the 1981 work area for August 1991.

	Late Season Grazed Sites			Early Season Grazed Sites			All Sites
Vegetation Type	1	4	Mean	2	3	Mean	Mean
Grasses	94	73	84	77	79	78	81
Forbs	5	25	15	21	13	17	16
Club Moss	0	0	0	0	0	0	0
Sedges	1	2	2	2	8	5	3

Table 4. Percentage composition of vegetation types on the 1981 trench for August 1991.

Vegetation Type	Late Season Grazed Sites 1	Late Season Grazed Sites 4	Late Season Grazed Sites Mean	Early Season Grazed Sites 2	Early Season Grazed Sites 3	Early Season Grazed Sites Mean	All Sites Mean
Grasses	98	95	97	97	92	95	96
Forbs	2	5	4	3	8	6	5
Club Moss	0	0	0	0	0	0	0
Sedges	0	0	0	0	0	0	0

Table 5. Percentage composition of vegetation types on the 1981 stockpile for August 1991.

Vegetation Type	Late Season Grazed Sites 1	Late Season Grazed Sites 4	Late Season Grazed Sites Mean	Early Season Grazed Sites 2	Early Season Grazed Sites 3	Early Season Grazed Sites Mean	All Sites Mean
Grasses	85	73	79	84	96	90	85
Forbs	14	26	20	15	2	9	15
Club Moss	0	0	0	0	0	0	0
Sedges	1	1	1	1	2	2	2

Table 6. Percentage composition of vegetation types on the 1957 trench for August 1991.

Vegetation Type	Late Season Grazed Sites 1	Late Season Grazed Sites 4	Late Season Grazed Sites Mean	Early Season Grazed Sites 2	Early Season Grazed Sites 3	Early Season Grazed Sites Mean	All Sites Mean
Grasses	79	77	78	80	77	79	79
Forbs	20	20	20	14	21	18	19
Club Moss	0	0	0	0	0	0	0
Sedges	1	3	2	6	2	4	3

Table 7. Percentage species composition on the 1981 trench for August 1991.

	Late Season Grazed Sites			Early Season Grazed Sites			All Sites
Species	1	4	Mean	2	3	Mean	Mean
Agoseris glauca	0	<1	<1	1	0	<1	<1
Agropyron elongatum	0	0	0	1	<1	<1	<1
Agropyron pectiniforme	10	13	12	26	1	14	13
Agropyron smithii	88	72	80	62	58	60	70
Agropyron trichophorum	0	0	0	1	0	<1	<1
Antennaria parvifolia	0	0	0	1	4	3	2
Artemisia cana	0	<1	<1	<1	<1	<1	<1
Artemisia frigida	0	1	1	1	0	1	1
Aster ericoides	0	0	0	<1	0	<1	<1
Astragalus cicer	0	0	0	1	1	1	<1
Crepis tectorum	0	0	0	<1	0	<1	<1
Descurainia sophia	0	<1	<1	0	0	0	<1
Elymus angustus	<1	10	6	7	33	20	13
Grindelia squarrosa	1	0	1	1	0	1	1
Gutierrezia sarothrae	0	<1	<1	<1	1	1	<1
Hordeum jubatum	0	<1	<1	0	0	0	<1
Medicago sativa	0	<1	<1	<1	5	3	2
Mellilotus officinalis	0	0	0	<1	0	<1	<1
Opuntia polyacantha	0	0	0	0	1	1	1
Poa sandbergii	0	<1	<1	0	0	0	<1
Polygonum arenastrum	1	0	<1	0	1	<1	<1
Ratibida columnifera	0	<1	<1	0	0	0	<1
Rosa acicularis	0	0	0	0	<1	<1	<1
Sphaeralcea coccinea	0	3	2	0	0	0	1
Stipa viridula	0	0	0	<1	0	<1	<1
Thermopsis rhombifolia	<1	0	<1	0	0	0	<1
Vicia americana	0	1	1	1	0	1	1

Table 8. Percentage species composition on the 1981 stockpile for August 1991.

	Late Season Grazed Sites			Early Season Grazed Sites			All Sites
Species	1	4	Mean	2	3	Mean	Mean
Achillea millefolium	0	0	0	<1	0	<1	<1
Agoseris glauca	0	<1	<1	2	<1	1	1
Agropyron pectiniforme	32	34	33	11	18	15	24
Agropyron smithii	40	42	41	37	44	41	41
Artemisia cana	0	4	2	1	9	5	4
Artemisia frigida	1	<1	<1	1	<1	1	1
Aster ericoides	0	0	0	<1	0	<1	<1
Astragalus cicer	0	0	0	0	1	<1	<1
Bouteloua gracilis	13	9	11	9	8	9	10
Carex species	0	1	<1	0	2	1	1
Chenopodium species	0	1	<1	0	0	0	1
Campanula rotundifolia	<1	0	<1	0	0	0	<1
Descurainia sophia	3	1	2	0	0	0	1
Elymus angustus	0	2	1	<1	9	5	3
Grindelia squarrosa	0	<1	<1	1	<1	1	1
Gutierrezia sarothrae	1	<1	1	1	<1	1	1
Heterotheca species	0	<1	<1	0	0	0	<1
Koeleria macrantha	0	1	1	2	0	1	1
Lappula redowskii	0	0	0	0	1	<1	<1
Lichen species	0	0	0	<1	0	<1	<1
Medicago sativa	0	<1	<1	0	0	0	<1
Opuntia polyacantha	<1	0	<1	0	<1	<1	<1
Plantago patagonica	0	<1	<1	0	0	0	<1
Poa sandbergii	0	0	0	7	0	4	2
Phlox hoodii	0	0	0	2	0	1	<1
Polygonum arenastrum	9	24	17	1	1	1	9
Ratibida columnifera	0	0	0	<1	0	<1	<1
Sphaeralcea coccinea	0	0	0	1	<1	1	1
Stipa comata	0	0	0	15	2	9	5
Stipa viridula	0	0	0	3	0	2	1
Taraxacum officinale	<1	<1	<1	<1	<1	<1	<1
Tragopogon dubius	0	<1	<1	0	0	0	<1
Vicia americana	0	<1	<1	<1	0	<1	<1

Table 9. Percentage species composition on the 1957 trench for August 1991.

	Late Season Grazed Sites			Early Season Grazed Sites			All Sites
Species	1	4	Mean	2	3	Mean	Mean
Achillea millefolium	0	1	1	2	1	2	2
Agoseris glauca	<1	<1	<1	3	1	2	1
Agropyron pectiniforme	0	0	0	7	0	4	2
Agropyron smithii	38	14	26	18	28	23	25
Androsace septentrionalis	0	0	0	<1	0	<1	<1
Antennaria parvifolia	0	0	0	1	4	3	2
Artemisia cana	0	4	2	1	9	5	4
Artemisia frigida	0	<1	<1	1	0	1	1
Aster ericoides	10	3	7	0	<1	<1	4
Astragalus cicer	3	3	3	2	0	1	2
Bouteloua gracilis	15	30	23	5	34	20	22
Carex species	1	3	2	6	2	4	3
Chenopodium species	1	0	1	<1	<1	<1	1
Coryapantha species	<1	0	<1	<1	0	<1	<1
Descurainia sophia	0	<1	<1	0	0	0	<1
Grindelia squarrosa	0	<1	<1	2	<1	1	1
Gutierrezia sarothrae	1	<1	1	2	<1	1	1
Koeleria macrantha	2	1	2	4	0	2	2
Lappula redowskii	0	0	0	<1	<1	<1	<1
Lichen species	0	0	0	0	1	1	1
Linum lewisii	2	0	1	<1	1	1	1
Lonicera species	0	0	0	<1	<1	<1	<1
Opuntia polyacantha	0	0	0	0	1	1	1
Phlox hoodii	0	<1	<1	0	0	0	<1
Plantago patagonica	<1	<1	<1	0	<1	<1	<1
Poa sandbergii	0	1	1	18	15	17	9
Polygonum arenastrum	0	6	3	0	0	0	2
Ratibida columnifera	<1	<1	<1	<1	<1	<1	<1
Rosa acicularis	0	0	0	0	<1	<1	<1
Sphaeralcea coccinea	1	2	2	2	0	1	2
Stipa comata	1	1	1	26	1	14	8
Stipa viridula	23	31	27	2	2	2	15
Taraxacum officinale	<1	1	1	3	<1	2	2
Tragopogon dubius	0	<1	<1	0	0	0	<1
Vicia americana	0	2	1	1	0	1	1

Table 10. Percentage species composition on the 1981 work area for August 1991.

	Late Season Grazed Sites			Early Season Grazed Sites			All Sites
Species	1	4	Mean	2	3	Mean	Mean
Achillea millifolium	0	0	0	0	<1	<1	<1
Agoseris glauca	1	8	5	<1	1	1	3
Agropyron pectiniforme	63	58	61	50	49	50	56
Agropyron smithii	28	13	21	18	29	24	23
Artemisia cana	<1	<1	<1	0	<1	<1	<1
Artemisia frigida	1	2	2	<1	1	1	2
Aster ericoides	<1	<1	<1	<1	1	1	<1
Astragalus cicer	<1	0	<1	3	<1	2	1
Bouteloua gracilis	1	2	2	0	0	0	1
Carex species	1	2	2	2	9	6	4
Chenopodium species	1	19	10	<1	2	2	6
Elymus angustus	0	0	0	<1	0	<1	<1
Gaura coccinea	0	<1	<1	0	0	0	<1
Grindelia squarrosa	0	1	1	1	<1	<1	1
Gutierrezia sarothrae	0	0	0	0	<1	<1	<1
Hordeum jubatum	<1	0	<1	0	<1	<1	<1
Koeleria macrantha	0	0	0	3	0	2	1
Lappula redowskii	0	0	0	<1	1	1	<1
Lepidium densiflorum	0	0	0	<1	0	<1	<1
Lichen species	<1	1	<1	0	0	0	<1
Medicago sativa	<1	0	<1	0	<1	<1	<1
Opuntia polyacantha	0	0	0	0	<1	<1	<1
Plantago patagonica	0	<1	<1	0	0	0	<1
Poa sandbergii	0	1	1	0	0	0	<1
Polygonum arenastrum	1	2	2	17	7	12	7
Solidago species	0	0	0	0	<1	<1	<1
Sphaeralcea coccinea	1	<1	1	1	0	<1	1
Stipa comata	1	0	<1	6	0	3	2
Vicia americana	0	1	1	0	0	0	<1

Table 11. Percentage species composition for the undisturbed prairie for August 1991.

	Late Season Grazed Sites			Early Season Grazed Sites			All Sites
Species	1	4	Mean	2	3	Mean	Mean
Achillea millifolium	0	<1	<1	1	0	<1	<1
Agoseris glauca	<1	0	<1	<1	0	<1	<1
Agropyron smithii	3	4	4	11	3	7	6
Allium textile	<1	0	<1	0	0	0	<1
Androsace septentrionalis	0	<1	<1	<1	<1	<1	<1
Antennaria parvifolia	<1	0	<1	1	<1	1	1
Arnica fulgens	<1	0	<1	0	<1	<1	<1
Artemisia cana	<	<1	<1	1	0	<1	<1
Artemisia frigida	5	1	3	1	2	2	3
Aster ericoides	<1	<1	<1	<1	<1	<1	<1
Astragalus bisulcatus	0	0	0	0	<1	<1	<1
Astragalus cicer	<1	0	<1	0	1	<1	<1
Astragalus drummondii	0	0	0	<1	0	<1	<1
Bouteloua gracilis	28	8	18	8	6	7	13
Campanula rotundifolia	<1	0	<1	<1	<1	<1	<1
Carex species	13	6	10	8	11	10	10
Cerastium arvense	<1	0	<1	0	0	0	<1
Chenopodium species	4	0	2	<1	1	1	2
Erysimum inconspicuum	0	<1	<1	0	0	0	<1
Gaura coccinea	<1	0	<1	<1	0	<1	<1
Geum triflorum	<1	<1	<1	<1	0	<1	<1
Grindelia squarrosa	<1	<1	<1	<1	0	<1	<1
Gutierrezia sarothrae	0	<1	<1	2	1	2	2
Helianthus villosa	<1	<1	<1	<1	0	<1	<1
Hordeum jubatum	<1	0	<1	<1	0	<1	<1
Koeleria macrantha	0	2	1	2	0	1	1
Lappula redowskii	<1	<1	<1	<1	<1	<1	<1
Lepidium densiflorum	<1	<1	<1	<1	0	<1	<1
Lichen species	0	0	0	1	2	2	1
Linum lewisii	0	0	0	<1	0	<1	<1
Lithospermum ruderale	0	0	0	0	<1	<1	<1
Opuntia polyacantha	<1	<1	<1	2	<1	1	1
Phlox hoodii	1	3	2	3	2	3	3
Plantago patagonica	1	<1	<1	<1	<1	<1	<1
Poa sandbergii	0	<1	<1	0	0	0	<1
Polygonum arenastrum	<1	0	<1	<1	0	<1	<1
Potentilla bipinnatifida	0	0	0	<1	<1	<1	<1
Ratibida columnifera	0	<1	<1	0	0	0	<1
Selaginella densa	31	68	50	55	69	62	56
Sphaeralcea coccinea	3	2	3	<1	<1	<1	2
Stipa comata	11	5	8	6	3	5	7
Stipa viridula	0	0	0	<1	0	<1	<1
Taraxacum officinalis	<1	0	<1	<1	0	<1	<1
Thermopsis rhombifolia	<1	0	<1	0	0	0	<1
Tragopogon dubius	<1	0	<1	0	0	0	<1
Vicia americana	1	0	<1	1	0	1	1

From a visual assessment of the 1963, 1968, and 1972 trenches, and between trench areas, it was noted that the 1963 trench species composition and cover were similar to that of the 1957 trench. *Agropyron pectiniforme, Agropyron smithii, Stipa viridula,* and *Bouteloua gracilis* were the dominant species comprising 75% of the cover. *Artemisia cana* and *Gutierezzia sarothrae* were abundant. Species diversity was lower on the 1968 trench than on the 1963 trench, but species composition was similar.

3. Grazing Treatment Effects

Grazing treatment differences were most evident on the 1981 RoW, particularly the 1981 trench (Figures 30 and 31). Live cover was generally higher under early season than under late season grazing; 6% (absolute) higher on the stockpile, 14% higher on the 1981 trench, 8% higher on the pipelay, and 7% higher on the work treatment. Bare ground was higher under late season grazing than under early season grazing; 17% (absolute) higher on the 1981 trench, 5% higher on the pipelay and work treatments. Of particular interest is the larger amount of bare ground under late season grazing than under early season grazing on the 1981 trench. This is likely due to species composition differences; with grass covering ground less effectively than the higher basal area forbs. Litter cover was similar under both grazing regimes, with few treatment differences.

Vegetation type composition was also affected by grazing regime. Under late season grazing versus early season grazing, there were more grasses and there was less *Selaginella densa* under grazed treatments than in the undisturbed prairie (Table 2). There were few grazing treatment differences on the 1981 (Table 4) or 1957 trenches (Table 6). On stockpile treatments, grass cover was greater under early season grazing (Table 5); on the 1981 work area there was greater grass cover under late season grazing (Table 3). There were twice as many forbs under late season grazing as under early season grazing on the 1981 stockpile.

Species composition differences between early season grazed and late season grazed treatments were few but generally consistent. Under early season grazing, *Elymus angustus* was significantly higher on the 1981 trench and stockpile; *Poa sandbergii* and *Stipa comata* on the stockpile and 1957 trench; and *Selaginella densa* on undisturbed prairie. Under late season grazing, *Agropyron pectiniforme* was significantly higher on the stockpile and work treatments; *Stipa viridula* on the 1957 trench; and *Bouteloua gracilis* in the undisturbed prairie. Although *Polygonum arenastrum* was higher under early season grazing on the work treatment, it was higher under late season grazing on the stockpile treatment. Similarly, *Agropyron smithii* was higher under early season grazing in the undisturbed prairie but higher under late season grazing on the 1981 trench.

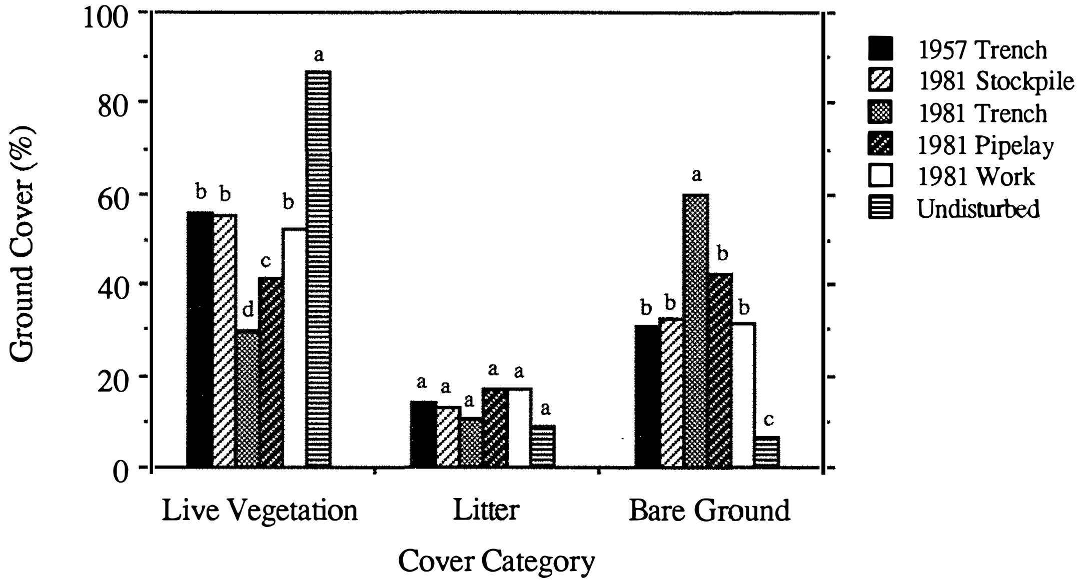

Figure 30. Ground cover under late season grazing for August 1991. Means within a given ground cover category with the same letters are not significantly different at the 5% level of significance.

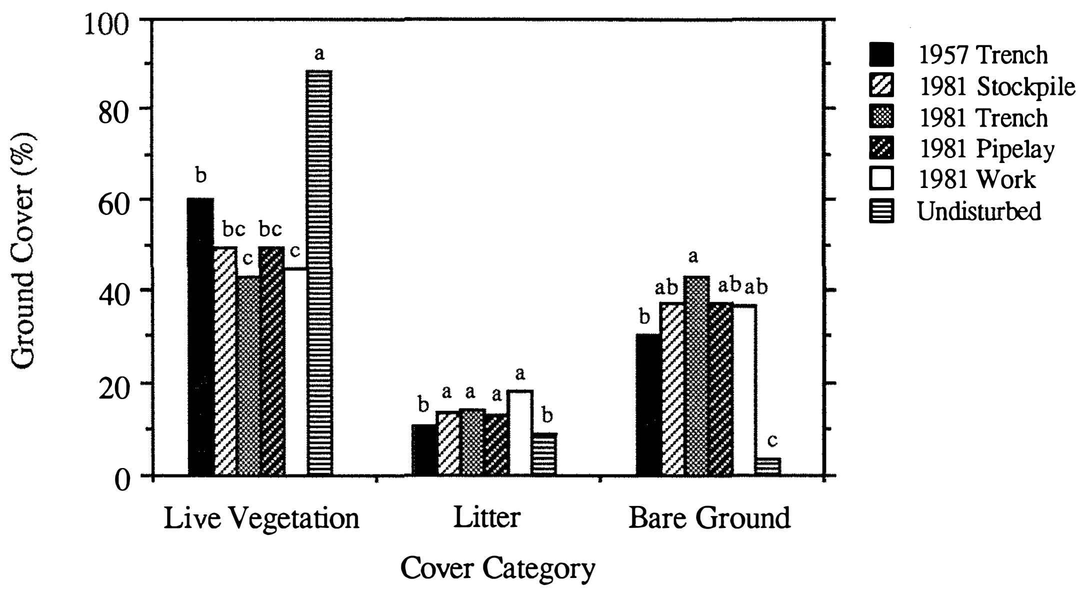

Figure 31. Ground cover under early season grazing for August 1991. Means within a given ground cover category with the same letters are not significantly different at the 5% level of significance.

D. CHANGES FROM AUGUST 1983 TO AUGUST 1991

1. Soil Chemical Properties

Changes over the eight year period from August 1983 to August 1991 indicated some salt movement in various treatment profiles. However, the magnitude of the changes were often small, following no recognizable pattern, except in the 1981 trench and stockpile treatments. Changes in the undisturbed prairie were often small and of little practical significance. If these changes represent normal annual variability and limitations of sampling and analyses, then they can be used as a guideline to the significance of changes in the disturbed treatments. The undisturbed blowouts were much more dynamic than the non-blowout native prairie. Evidence of salt movement was highest and most consistent in the 1981 trench and stockpile treatments. This is expected, since these treatments were more highly disturbed than any other area on the 1981 RoW; the former through trenching and the latter through placement of soil material during pipeline construction.. It would be expected that after some time, salt equilibrium would be re-established with the surrounding soil. This is evidenced in the 1957 trench.

Soil pH changes over time varied with depth of soil measured and with treatment (Table 12). Changes were generally small in magnitude and not statistically significant. Fluctuations in the pipeline treatments were of the same magnitude as those in the undisturbed prairie.

Changes with time in electrical conductivity were also small in magnitude and varied with soil depth and treatment (Table 13). The most notable changes were in the top 15 cm in the 1981 trench and the 1981 stockpile treatments, where EC dropped significantly from 1983 to 1991. The only other statistically significant change occurred at 60+ cm in the 1981 work treatment and in the undisturbed blowouts at all depth increments, except the upper 5 cm.

Calcium concentration tended to increase with time, particularly below 5 cm depths (Table 14). These changes were statistically significant in the 1981 trench and the 1981 stockpile treatments where calcium decreased in the upper 5 cm and increased at depths below this in the 1981 trench. In the 1981 stockpile, calcium decreased in the upper 15 cm then increased thereafter. These trends indicate calcium salts are moving down into the soil profile with time. Calcium increased significantly with time in the 1957 trench below 15 cm. Magnesium changes with time were similar in pattern to those of calcium (Table 15). Magnesium decreased significantly in the 1981 trench and stockpile treatments in the upper 15 cm., then increased thereafter. These changes were also evident in the 1981 work treatment, but to a lesser degree. These trends indicate that magnesium salts are also moving down into the profile with time after pipeline construction.

Table 12. Changes in pH from August 1983 to August 1991.

	Depth (cm)					
Treatment	0-5	5-15	15-30	30-45	45-60	60+
Undisturbed Prairie in 1983	6.0 (0.4)	5.9 (0.3)	6.8 (0.6)	8.2 (0.3)	8.3 (0.7)	8.5 (0.2)
Undisturbed Prairie in 1991	6.3 (0.4)	6.3 (0.4)	7.1 (0.6)	7.9 (0.3)	8.2 (0.2)	7.2 (2.6)
Blowout in 1983	7.2 (0.8)	8.1 (0.4)	8.2 (0.3)	8.3 (0.3)	8.4 (0.3)	8.4 (0.0)
Blowout in 1991	6.8 (0.6)	8.1 (0.3)	8.1 (0.3)	8.2 (0.1)	8.3 (0.2)	8.3 (0.3)
1957 Trench in 1983	7.6 (0.4)	7.7 (0.1)	7.5 (0.2)	7.6 (0.4)	7.9 (0.5)	8.3 (0.5)
1957 Trench in 1991	7.6 (0.2)	7.7 (0.2)	7.8 (0.2)	7.7 (0.2)	7.9 (0.2)	8.0 (0.2)
1981 Trench in 1983	7.3 (0.3)	7.8 (0.1)	7.8 (0.2)	7.7 (0.2)	8.0 (0.2)	8.0 (0.2)
1981 Trench in 1991	7.8 (0.1)	7.8 (0.1)	7.9 (0.1)	7.9 (0.1)	7.9 (0.2)	7.8 (0.1)
1981 Work in 1983	7.3 (0.4)	6.8 (0.9)	7.8 (0.7)	8.2 (0.5)	8.3 (0.4)	8.3 (0.5)
1981 Work in 1983	6.6 (0.4)	7.2 (0.8)	7.4 (0.8)	7.9 (0.3)	8.0 (0.2)	8.1 (0.3)
1981 Stockpile in 1983	7.4 (0.6)	6.7 (0.9)	6.9 (0.6)	8.1 (0.6)	8.4 (0.4)	7.6 (0.9)
1981 Stockpile in 1983	7.6 (0.2)	7.3 (0.4)	7.0 (0.8)	7.7 (0.5)	8.2 (0.2)	8.3 (0.2)

Numbers in brackets are standard deviations.

Table 13. Changes in electrical conductivity (dS m^{-1}) from August 1983 to August 1991.

Treatment	Depth (cm) 0-5	5-15	15-30	30-45	45-60	60+
Undisturbed Prairie in 1983	0.1 (0.1)	0.2 (0.0)	0.4 (0.3)	1.5 (1.4)	2.5 (3.7)	2.3 (3.3)
Undisturbed Prairie in 1991	0.4 (0.2)	0.2 (0.1)	0.8 (1.0)	2.1 (2.7)	3.2 (3.1)	3.3 (2.5)
Blowout in 1983	0.9 (0.6)	2.4 (1.6)	4.9 (2.7)	5.0 (2.3)	4.6 (2.3)	3.5 (0.5)
Blowout in 1991	0.9 (0.6)	4.4 (0.1)	7.1 (1.8)	7.1 (2.9)	5.3 (2.6)	4.6 (2.9)
1957 Trench in 1983	1.1 (1.1)	1.1 (0.7)	1.5 (1.0)	2.4 (2.1)	4.0 (3.3)	5.4 (3.8)
1957 Trench in 1991	0.7 (0.1)	1.3 (0.8)	1.9 (0.9)	3.5 (1.7)	5.5 (2.8)	6.7 (2.4)
1981 Trench in 1983	3.3 (1.5)	5.1 (1.6)	5.9 (2.1)	6.3 (1.9)	7.7 (1.1)	7.1 (1.6)
1981 Trench in 1991	1.9 (0.8)	4.5 (0.1)	6.7 (1.9)	8.7 (1.4)	7.5 (1.2)	7.1 (1.3)
1981 Work in 1983	0.5 (0.2)	0.6 (0.4)	2.1 (2.9)	3.1 (2.0)	4.1 (3.7)	5.9 (3.8)
1981 Work in 1983	0.4 (0.1)	1.2 (0.9)	1.9 (2.4)	3.6 (3.0)	3.9 (3.1)	2.3 (2.0)
1981 Stockpile in 1983	2.9 (1.3)	3.2 (1.7)	2.7 (1.5)	2.7 (2.5)	4.7 (3.9)	5.3 (3.7)
1981 Stockpile in 1983	1.2 (0.6)	1.6 (0.8)	2.7 (1.6)	4.6 (1.8)	5.5 (3.6)	6.0 (4.1)

Numbers in brackets are standard deviations.

Table 14. Changes in calcium (meq L^{-1}) from August 1983 to August 1991.

	Depth (cm)					
Treatment	0-5	5-15	15-30	30-45	45-60	60+
Undisturbed Prairie in 1983	1.5 (0.4)	1.1 (0.4)	1.4 (1.2)	1.5 (0.7)	4.8 (9.1)	2.0 (0.8)
Undisturbed Prairie in 1991	1.9 (1.1)	0.9 (0.9)	1.9 (1.9)	4.8 (8.7)	5.1 (8.0)	9.1 (11.5)
Blowout in 1983	0.8 (0.6)	1.8 (2.5)	10.8 (9.7)	11.6 (9.4)	7.0 (8.0)	3.2 (0.0)
Blowout in 1991	0.6 (0.6)	5.9 (6.1)	10.6 (7.7)	16.2 (11.4)	8.5 (9.0)	8.3 (12.3)
1957 Trench in 1983	5.8 (2.0)	11.3 (8.6)	14.0 (11.8)	10.9 (9.1)	9.5 (8.3)	9.7 (6.8)
1957 Trench in 1991	6.5 (0.8)	13.3 (10.3)	21.9 (12.4)	23.1 (11.2)	24.3 (9.5)	23.2 (8.2)
1981 Trench in 1983	22.8 (7.1)	24.1 (2.1)	20.6 (5.9)	23.5 (2.8)	23.4 (1.4)	18.2 (9.6)
1981 Trench in 1991	16.1 (9.4)	39.2 (3.3)	26.8 (1.7)	25.9 (8.1)	23.9 (6.0)	26.8 (2.0)
1981 Work in 1983	1.5 (0.7)	1.5 (0.6)	3.6 (7.2)	6.8 (9.0)	9.8 (9.8)	14.0 (13.9)
1981 Work in 1983	1.9 (1.6)	1.6 (0.8)	4.7 (7.4)	4.6 (11.3)	13.3 (13.3)	6.5 (10.2)
1981 Stockpile in 1983	17.2 (10.9)	17.2 (10.1)	8.8 (6.1)	3.9 (6.0)	4.5 (7.3)	9.5 (7.8)
1981 Stockpile in 1983	11.9 (7.1)	14.3 (11.9)	16.1 (12.6)	10.8 (9.2)	9.0 (9.5)	10.1 (10.2)

Numbers in brackets are standard deviations.

Table 15. Changes in magnesium (meq L^{-1}) from August 1983 to August 1991.

Treatment	Depth (cm) 0-5	5-15	15-30	30-45	45-60	60+
Undisturbed Prairie in 1983	1.0 (0.3)	0.7 (0.4)	3.5 (10.1)	1.6 (1.2)	5.9 (10.7)	4.4 (5.8)
Undisturbed Prairie in 1991	1.1 (0.6)	0.4 (0.4)	1.0 (1.0)	4.3 (8.9)	5.8 (8.4)	7.9 (8.5)
Blowout in 1983	0.7 (0.4)	3.2 (4.2)	9.9 (8.3)	9.2 (7.8)	6.8 (6.2)	4.4 (0.0)
Blowout in 1991	0.4 (0.3)	9.6 (9.3)	14.8 (9.9)	22.4 (15.7)	11.7 (11.6)	10.9 (14.8)
1957 Trench in 1983	2.3 (1.5)	2.3 (1.1)	3.1 (2.3)	7.9 (8.1)	10.6 (8.1)	11.0 (6.7)
1957 Trench in 1991	2.2 (0.7)	3.2 (2.5)	5.1 (2.8)	14.5 (9.2)	23.3 (11.8)	23.7 (6.0)
1981 Trench in 1983	12.6 (3.1)	17.4 (4.8)	15.2 (6.3)	18.2 (6.7)	21.0 (3.6)	18.9 (3.2)
1981 Trench in 1991	5.1 (2.5)	16.8 (3.8)	23.8 (4.0)	28.0 (6.2)	24.3 (6.4)	24.6 (5.3)
1981 Work in 1983	1.3 (0.4)	0.9 (0.5)	3.6 (10.4)	5.5 (5.8)	12.8 (9.9)	18.0 (9.6)
1981 Work in 1983	1.1 (0.9)	1.5 (1.0)	5.9 (11.8)	12.9 (14.4)	13.6 (15.2)	4.3 (5.0)
1981 Stockpile in 1983	9.3 (4.8)	11.2 (6.5)	6.2 (4.9)	4.4 (7.0)	10.6 (12.0)	10.8 (8.7)
1981 Stockpile in 1983	3.7 (2.0)	6.4 (5.9)	10.4 (8.4)	13.1 (10.3)	12.1 (9.3)	14.8 (15.6)

Numbers in brackets are standard deviations.

Changes in sodium were similar to those of calcium and magnesium (Table 16). There were no statistically significant changes with time for potassium concentrations (Table 17). Sulphate movement was significant in the 1981 trench and the 1981 stockpile, decreasing to 15 cm then increasing thereafter (Table 18). Below 30 cm, increases in all treatments were statistically significant. Changes in bicarbonate were small in magnitude in all treatments (Table 19). Bicarbonate generally changed slightly in the upper 5 cm, and mostly decreased with depth. SAR was significantly altered in the 1981 trench and in the 1981 stockpile treatments (Table 20), decreasing in the upper 15 cm and increasing thereafter.

In the 1981 trench, there was a pattern of downward salt movement, although often of a small magnitude, and not always statistically significant. Similar trends occurred in the 1981 stockpile. Salts tended to move downward from the upper 15 cm. In the 1957 trench, there was evidence of salt movement but the pattern was more random than that in the 1981 trench indicating equilibrium has likely been re-established with the surrounding soil. Changes in the work treatment were of a smaller magnitude and less consistent than in the trench and stockpile treatments.

Soil organic carbon changes from 1983 to 1991 were not statistically significant, except in the upper 5 cm (Table 21). Here the organic carbon increased by 1.2% in the undisturbed prairie and 0.7% in the work treatment, possibly reflecting an increase in root growth after good growing years. The slight decreases of 0.5% in the 1981 trench and stockpile treatments are not significant.

2. Soil Physical Properties

Changes in bulk density were often small but there was a trend towards reduced bulk density with time since pipeline construction (Table 22). In 1991, surface bulk density in the undisturbed prairie was higher than in 1983. This may be partly due to the very dry conditions at sampling in 1991. However, bulk density declined slightly in the 1981 trench work treatments. Since these changes were in the opposite direction to those in the undisturbed prairie, it can be taken as an indicator of changes with time since disturbance. These decreases in bulk density were likely due to the ameliorating effects of plant growth, wet/dry, and freeze/thaw cycles.

Changes in bulk density with depth were similar for both years in many treatments (Table 22). In undisturbed prairie and blowouts, bulk density was lower in 1991 than in 1983 at all depths. In the 1957 and 1981 trenches and the 1981 work treatment, bulk density decreased at all depths, except for the 1981 trench at 15 cm. From previous work (Naeth 1985), it is evident that late summer (August) is the time of highest bulk densities, thus values presented were likely maximal for 1991. Changes in bulk density were statistically significant only for the 1981 work treatment.

Table 16. Changes in sodium (meq L^{-1}) from August 1983 to August 1991.

	Depth (cm)					
Treatment	0-5	5-15	15-30	30-45	45-60	60+
Undisturbed Prairie in 1983	0.3 (0.1)	0.9 (0.5)	2.9 (3.5)	14.4 (14.5)	21.8 (20.8)	24.0 (29.2)
Undisturbed Prairie in 1991	0.3 (0.2)	1.1 (0.8)	6.5 (11.2)	19.3 (11.2)	29.7 (28.9)	27.9 (25.5)
Blowout in 1983	8.0 (6.0)	19.6 (12.1)	42.6 (12.3)	45.4 (16.8)	39.8 (24.7)	29.5 (1.0)
Blowout in 1991	8.6 (5.4)	41.2 (17.8)	62.1 (21.6)	63.6 (29.6)	49.6 (9.2)	43.0 (25.7)
1957 Trench in 1983	0.5 (0.1)	0.5 (0.2)	1.8 (0.4)	12.3 (14.4)	27.0 (28.3)	34.9 (30.5)
1957 Trench in 1991	0.5 (0.6)	1.1 (1.3)	2.4 (1.7)	14.3 (17.2)	34.4 (32.2)	48.5 (7.2)
1981 Trench in 1983	13.3 (12.2)	31.7 (9.3)	34.8 (12.9)	45.9 (20.0)	53.7 (11.4)	44.3 (24.9)
1981 Trench in 1991	4.4 (6.2)	23.2 (22.6)	50.8 (25.8)	75.2 (14.6)	59.6 (15.3)	53.8 (32.9)
1981 Work in 1983	2.1 (1.3)	5.2 (4.9)	20.9 (23.5)	25.9 (17.9)	28.3 (21.4)	42.3 (24.4)
1981 Work in 1983	1.2 (0.4)	11.4 (10.8)	16.2 (19.8)	28.5 (24.9)	30.6 (22.2)	19.8 (15.8)
1981 Stockpile in 1983	11.8 (10.1)	17.9 (9.6)	16.0 (10.8)	25.0 (23.0)	34.9 (28.3)	42.5 (30.8)
1981 Stockpile in 1983	0.7 (0.4)	4.3 (3.4)	13.4 (8.7)	36.2 (17.5)	52.1 (39.2)	57.7 (43.2)

Numbers in brackets are standard deviations.

Table 17. Changes in potassium (meq L^{-1}) from August 1983 to August 1991.

Treatment	Depth (cm)					
	0-5	5-15	15-30	30-45	45-60	60+
Undisturbed Prairie in 1983	0.9 (0.3)	0.2 (0.2)	0.2 (0.2)	0.3 (0.2)	0.5 (0.4)	0.5 (0.3)
Undisturbed Prairie in 1991	0.9 (0.6)	0.2 (0.1)	0.2 (0.1)	0.3 (0.1)	0.5 (0.4)	0.5 (0.3)
Blowout in 1983	0.2 (0.2)	0.3 (0.2)	0.7 (0.3)	0.7 (0.5)	0.8 (0.5)	0.7 (0.0)
Blowout in 1991	0.2 (0.1)	0.5 (0.3)	0.8 (0.2)	0.7 (0.4)	0.7 (0.5)	0.6 (0.3)
1957 Trench in 1983	2.3 (3.9)	0.7 (0.2)	0.4 (0.2)	0.4 (0.2)	0.6 (0.3)	0.6 (0.3)
1957 Trench in 1991	0.8 (0.3)	0.5 (0.3)	0.5 (0.3)	0.6 (0.4)	0.7 (0.5)	0.7 (0.4)
1981 Trench in 1983	0.9 (0.2)	0.8 (0.6)	0.8 (0.1)	0.8 (0.1)	0.8 (0.2)	0.7 (0.1)
1981 Trench in 1991	0.7 (0.2)	0.7 (0.1)	0.8 (0.4)	0.8 (0.2)	0.8 (0.2)	0.9 (0.3)
1981 Work in 1983	0.6 (0.3)	0.3 (0.2)	0.3 (0.2)	0.4 (0.2)	0.5 (0.4)	0.6 (0.3)
1981 Work in 1983	0.6 (0.4)	0.2 (0.2)	0.3 (0.3)	0.5 (0.4)	0.5 (0.5)	0.4 (0.4)
1981 Stockpile in 1983	0.8 (0.2)	0.8 (0.3)	0.5 (0.2)	0.4 (0.2)	0.7 (0.3)	0.8 (0.5)
1981 Stockpile in 1983	0.7 (0.3)	0.3 (0.2)	0.3 (0.2)	0.5 (0.4)	0.7 (8.2)	0.8 (0.3)

Numbers in brackets are standard deviations.

Table 18. Changes in sulphate (meq L^{-1}) from August 1983 to August 1991.

Treatment	Depth (cm)					
	0-5	5-15	15-30	30-45	45-60	60+
Undisturbed Prairie in 1983	0.6 (0.1)	0.4 (0.1)	1.1 (0.9)	8.2 (11.3)	22.8 (40.1)	22.7 (38.9)
Undisturbed Prairie in 1991	1.0 (1.4)	0.8 (0.6)	3.1 (6.3)	19.3 (9.8)	28.3 (39.5)	32.3 (34.8)
Blowout in 1983	5.0 (7.3)	25.8 (20.4)	47.0 (35.1)	52.2 (36.7)	47.0 (34.3)	27.5 (1.0)
Blowout in 1991	4.2 (3.3)	41.9 (30.1)	82.1 (41.3)	91.4 (49.1)	59.1 (39.6)	50.7 (47.9)
1957 Trench in 1983	2.9 (2.3)	16.4 (16.4)	15.7 (16.5)	26.6 (27.8)	41.1 (37.9)	48.6 (38.5)
1957 Trench in 1991	1.3 (1.3)	12.0 (13.5)	24.1 (14.7)	45.8 (24.5)	75.1 (38.2)	88.8 (32.7)
1981 Trench in 1983	42.1 (20.7)	85.9 (17.1)	73.1 (27.4)	83.4 (23.4)	79.2 (34.7)	78.3 (21.2)
1981 Trench in 1991	20.9 (12.9)	64.8 (23.2)	97.3 (27.9)	122.1 (21.2)	97.5 (17.2)	95.5 (16.1)
1981 Work in 1983	1.3 (0.8)	1.4 (0.8)	21.8 (43.9)	27.9 (25.8)	40.7 (30.0)	52.4 (33.5)
1981 Work in 1983	1.1 (1.0)	4.8 (5.3)	18.1 (37.2)	41.8 (46.8)	46.7 (48.6)	20.9 (28.9)
1981 Stockpile in 1983	30.0 (15.9)	33.9 (18.5)	15.0 (16.7)	20.3 (31.5)	42.4 (23.2)	51.3 (36.1)
1981 Stockpile in 1983	8.7 (9.2)	18.7 (18.5)	33.0 (25.5)	50.4 (26.1)	63.6 (56.2)	73.2 (67.5)

Numbers in brackets are standard deviations.

Table 19. Changes in bicarbonate (meq L^{-1}) from August 1983 to August 1991.

	Depth (cm)					
Treatment	0-5	5-15	15-30	30-45	45-60	60+
Undisturbed Prairie in 1983	2.5 (1.0)	1.4 (0.4)	2.0 (0.8)	5.6 (1.9)	4.5 (1.9)	4.8 (1.2)
Undisturbed Prairie in 1991	2.2 (1.4)	1.3 (0.6)	4.8 (4.5)	6.4 (1.9)	6.1 (2.2)	6.1 (3.2)
Blowout in 1983	2.0 (1.8)	4.7 (0.8)	5.2 (1.7)	4.3 (1.1)	3.9 (1.0)	4.4 (1.7)
Blowout in 1991	3.4 (3.3)	8.8 (3.6)	6.4 (1.9)	4.6 (0.7)	4.6 (1.2)	5.1 (1.9)
1957 Trench in 1983	9.1 (1.6)	2.9 (1.0)	3.6 (1.3)	3.5 (1.7)	3.1 (1.2)	2.8 (0.8)
1957 Trench in 1991	7.3 (1.3)	4.7 (1.8)	3.7 (0.5)	3.5 (0.9)	3.3 (0.8)	3.1 (0.8)
1981 Trench in 1983	2.4 (0.9)	2.4 (0.4)	2.4 (0.5)	2.3 (0.3)	2.7 (0.3)	2.5 (0.3)
1981 Trench in 1991	4.3 (9.2)	2.8 (0.3)	2.7 (0.4)	3.1 (0.6)	3.5 (0.7)	3.1 (0.8)
1981 Work in 1983	2.3 (1.5)	3.6 (2.9)	6.1 (2.1)	5.2 (1.2)	4.8 (1.1)	3.6 (0.1)
1981 Work in 1983	1.1 (1.0)	8.1 (6.5)	5.7 (3.8)	6.1 (1.5)	5.8 (2.5)	6.5 (2.7)
1981 Stockpile in 1983	6.3 (0.9)	4.5 (2.4)	2.9 (2.4)	5.0 (2.7)	4.5 (2.0)	5.0 (1.2)
1981 Stockpile in 1983	8.7 (9.9)	4.3 (1.6)	4.2 (3.1)	5.8 (3.0)	5.3 (0.9)	5.3 (0.8)

Numbers in brackets are standard deviations.

Table 20. Changes in sodium adsorption ratio from August 1983 to August 1991.

	Depth (cm)					
Treatment	0-5	5-15	15-30	30-45	45-60	60+
Undisturbed Prairie in 1983	0.3 (0.1)	1.0 (0.7)	3.6 (4.4)	11.0 (8.5)	9.9 (6.2)	11.2 (7.6)
Undisturbed Prairie in 1991	0.3 (0.2)	1.7 (2.2)	6.6 (7.4)	11.6 (9.6)	13.2 (9.5)	12.1 (8.6)
Blowout in 1983	9.5 (6.0)	12.6 (12.1)	14.1 (3.4)	16.6 (3.4)	16.5 (2.6)	15.0 (2.8)
Blowout in 1991	12.6 (6.5)	17.3 (6.5)	13.8 (5.6)	15.7 (3.5)	19.2 (3.9)	22.4 (8.2)
1957 Trench in 1983	0.1 (0.2)	0.2 (0.2)	0.8 (1.1)	5.3 (5.9)	9.4 (8.2)	11.1 (7.9)
1957 Trench in 1991	0.2 (0.3)	0.4 (0.6)	0.7 (0.5)	3.5 (4.2)	7.2 (5.9)	10.4 (7.1)
1981 Trench in 1983	4.0 (4.1)	6.6 (3.5)	8.1 (5.2)	10.0 (4.2)	11.4 (2.4)	10.4 (6.4)
1981 Trench in 1991	1.5 (2.1)	4.9 (4.8)	10.0 (5.0)	14.6 (3.9)	12.5 (4.2)	10.6 (2.7)
1981 Work in 1983	2.1 (1.5)	5.1 (4.8)	12.0 (7.4)	12.1 (5.3)	11.3 (4.8)	12.7 (3.3)
1981 Work in 1983	2.0 (3.3)	8.5 (7.3)	7.2 (4.9)	8.1 (4.8)	9.7 (5.3)	10.6 (6.8)
1981 Stockpile in 1983	4.6 (10.0)	5.5 (7.3)	7.5 (4.4)	14.3 (9.5)	13.5 (8.4)	14.6 (7.5)
1981 Stockpile in 1983	0.3 (0.2)	1.4 (0.7)	5.2 (4.7)	14.7 (9.9)	16.6 (9.1)	17.5 (7.1)

Numbers in brackets are standard deviations.

Table 21. Organic carbon (%) changes from August 1983 to August 1991.

Year	Undisturbed Prairie	Blowouts	1957 Trench	1981 Trench	1981 Work	1981 Stockpile
1983	2.7 (0.5)	1.0 (0.2)	1.4 (0.3)	0.9 (0.1)	1.8 (0.8)	1.5 (0.9)
1991	3.9 (1.0)	0.9 (0.5)	1.1 (0.2)	0.5 (0.1)	2.5 (1.2)	1.0 (0.5)

Although the magnitude of changes in soil water can not be realistically compared from year to year, trends in soil water with treatment can be an indication of changes with time after pipeline construction. Treatment trends were similar in 1983 and 1991 with few deviations. In 1983, all sites were similar for soil water amounts and trends with depth; but in 1991, Site 2 differed considerably from the other two. There were no indicators of why this may have happened. In 1983, soil water was lowest in the undisturbed prairie, but in 1991, it was lowest in the work treatment. Lowest soil water usually occurs in treatments with the highest water use by plants. The vegetation parameters of the 1981 work treatment were not such to indicate higher water use and thus can not serve as a reason for the differences.

3. Vegetation Properties

The undisturbed prairie species composition did not change significantly over the evaluated period, indicating that changes in grazing regime and weather conditions did not have a major impact on vegetation. Most of the changes in both ground cover and species composition occurred over the 1981 RoW, indicating the change resulted from time since pipeline construction.

In all disturbed treatments, bare ground declined significantly, especially over the 1981 trench where values changed from between 95% and 100% in 1983 to between 30% and 50% in 1991. There was a trend towards predisturbed conditions in all disturbed transects. This was reflected in the reduction in bare ground, the increase in native species and the reduction of weedy species in all disturbed transects.

One of the most significant changes in species composition that occurred was the virtual elimination over time of *Descurainia sophia*, which had comprised a major component of the vegetation over the 1981 RoW, particularly in the late season grazed sites. This species is a weedy pioneer, stored in the seed bank, which emerges when bare ground is exposed after disturbance. It is much more dominant in late season grazed sites because if mature before grazing it becomes

Table 22. Changes in soil bulk density (Mg m^{-3}) from August 1983 to August 1991.

	Depth (cm)						
Treatment	Surface	15	25	35	45	55	65
Undisturbed Prairie in 1983	1.05 (0.11)	1.44 (0.08)	1.46 (0.10)	1.51 (0.11)	1.47 (0.28)	1.56 (0.15)	1.61 (0.12)
Undisturbed Prairie in 1991	1.11 (0.09)	1.26 (0.09)	1.30 (0.05)	1.41 (0.08)	1.44 (0.10)	1.48 (0.10)	1.51 (0.13)
Blowout in 1983	1.47 (0.06)	1.45 (0.08)	1.53 (0.03)	1.74 (0.14)	1.65 (0.10)		
Blowout in 1991	1.39 (0.13)	1.41 (0.13)	1.32 (0.03)	1.45 (0.14)	1.58 (0.08)		
1957 Trench in 1983	1.36 (0.06)	1.29 (0.16)	1.36 (0.16)	1.35 (0.01)	1.30 (0.10)	1.49 (0.01)	1.53 (0.19)
1957 Trench in 1991	1.38 (0.06)	1.26 (0.07)	1.02 (0.07)	1.04 (0.11)	1.22 (0.07)	1.26 (0.13)	1.35 (0.06)
1981 Trench in 1983	1.49 (0.09)	1.39 (0.15)	1.30 (0.16)	1.27 (0.14)	1.34 (0.12)	1.22 (0.19)	1.17 (0.19)
1981 Trench in 1991	1.46 (0.06)	1.42 (0.07)	1.21 (0.09)	1.16 (0.04)	1.25 (0.06)	1.11 (0.07)	1.05 (0.04)
1981 Work in 1983	1.50 (0.37)	1.60 (0.11)	1.61 (0.17)	1.69 (0.19)	1.71 (0.23)	1.69 (0.16)	1.71 (0.15)
1981 Work in 1983	1.25 (0.06)	1.19 (0.12)	1.43 (0.11)	1.49 (0.19)	1.56 (0.25)	1.58 (0.31)	1.57 (0.28)

Numbers in brackets are standard deviations.

unpalatable and is not easily removed by grazing pressures. It is, however, short-lived in the succession sequence of mixed prairie and tends to be eliminated after two to three years. Although these weedy species are often considered highly undesirable because they are poor forage and tend to compete with grass seedlings for nutrients and water, they do serve the purpose of reducing bare ground and trapping snow after disturbance, thus reducing the erosion hazard, modifying the microclimate and possibly increasing soil water on the RoW.

The dominance of introduced grasses on the 1981 RoW had been reduced somewhat with the introduction of some native species, particularly forbs. Species diversity had increased in all treatments. The older RoW seeded to *Agropyron pectiniforme* mixtures were still heavily dominated by this grass, as in 1983. This species, like *Descurainia sophia*, is very affected by grazing regime, tending to dominate late season grazed sites which are grazed once it has set seed and becomes virtually unpalatable. There had been less emphasis on early and late season grazing since 1987, in the study area, due to recommendations emerging from the first study (Naeth 1985). This change in grazing regime seems to have had an impact on the dominance of *Agropyron pectiniforme* on the 1981 RoW, with the species being equally represented in both grazing treatments. There was no evidence of *Selaginella densa* on the RoW.

V. CONCLUSIONS

The following conclusions are based on the August 1991 study data collected from RoW that were constructed with 1957 and 1981 single-lift techniques.

A. GENERAL CONCLUSIONS

1. Single-lift pipeline construction in Solonetzic mixed prairie had significant effects on soil chemical, soil physical, hydrologic, and vegetative parameters of the ecosystem.

2. These effects and their changes over time were in turn affected by both grazing regime imposed on the system and different construction activities at the time of pipeline construction.

3. There is a distinct trend towards predisturbed conditions evident in vegetation and soil chemical and physical parameters.

B. SPECIFIC CONCLUSIONS

1. With time (1983 to 1991) after single-lift pipeline construction, a distinct trend towards predisturbed conditions was characterized by:
   a. Decreasing bare ground.
   b. Increasing species diversity and native species, decreasing native pioneer species.
   c. Downward salt movement in the 1981 trench and 1981 stockpile; as evidenced by decreases in electrical conductivity, sodium, sulphate, and sodium adsorption ratio to 15 cm and increases in these parameters below 15 cm.
   d. Slight increases in organic carbon in the upper 5 cm.
   e. Decreasing surface bulk density and bulk density with depth.

2. Grazing regime continued to impact the revegetated pipeline rights-of-way by:
   a. Increasing *Elymus angustus* under early season grazing.
   b. Increasing *Agropyron pectiniforme* under late season grazing.

3. Single-lift pipeline construction in Solonetzic mixed prairie affected soil chemical parameters by:
   a. Increasing soil pH to depths of 15 cm.
   b. Increasing electrical conductivity to depths of 45 cm.
   c. Decreasing amounts of calcium, magnesium, sodium, sulphate, and chloride to 45 cm.
   d. Decreasing amounts of potassium below 5 cm and increasing it between 0 and 5 cm.

e. Increasing sodium adsorption ratio to 15 cm.

f. Decreasing soil organic carbon to depths of 15 cm.

4. Single-lift pipeline construction in Solonetzic mixed prairie affected soil physical parameters by:
   a. Increasing surface bulk density.
   b. Decreasing soil bulk density with depth in the trench treatments and increasing it on the work and stockpile treatments.
   c. Decreasing penetration resistance and depth to maximum in the trench.
   d. Increasing surface soil water.
   e. Increasing soil water with depth in the trench.

5. Single-lift pipeline construction in Solonetzic mixed prairie affected vegetation parameters by:
   a. Increasing the amount of bare ground.
   b. Reducing species diversity.
   c. Increasing introduced and pioneer (weedy) species and reducing native species.
   d. Significantly reducing (almost eliminating) *Selaginella densa* on the rights-of-way.

6. Single-lift pipeline construction activity specifically affected soil and vegetation parameters with trenching having the most significant effect. Soil parameters were less affected than vegetation parameters by work and stockpile treatment activities.

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VII. APPENDIX

A. PLANT SPECIES LIST FOR THE STUDY SITES

Latin Name	Common Name
Achillea millifolium	woolly yarrow
Agoseris glauca	false dandelion
Agropyron pectiniforme	crested wheatgrass
Agropyron elongatum	tall wheatgrass
Agropyron intermedium	intermediate wheatgrass
Agropyron repens	quackgrass
Agropyron dasystachyum	northern wheatgrass
Agropyron smithii	western wheatgrass
Agropyron trachycaulum	slender wheatgrass
Agropyron trichophorum	pubescent wheatgrass
Allium textile	prairie onion
Amaranthus graecizans	prostrate amaranth
Androsace septentrionalis	fairy candelabra
Antennaria parvifolia	pussytoes
Arnica fulgens	arnica
Artemisia cana	sagebrush
Artemisia frigida	pasture sage
Aster ericoides	tufted white prairie aster
Astragalus dasyglottis	milk vetch
Astragalus bisulcatus	two-grooved milk vetch
Astragalus cicer	cicer milk vetch
Astragalus drummondii	Drummond's milk vetch
Atriplex nuttallii	Nuttall's atriplex
Bouteloua gracilis	blue grama
Campanula rotundifolia	harebell
Carex elocharis	sedge
Carex filifolia	thread-leaved sedge
Cerastium arvense	field chickweed
Chenopodium album	lamb's quarters
Chenopodium salinum	saline goosefoot
Chenopodium leptophyllum	narrow-leaved goosefoot
Circium arvense	Canada thistle
Coryapantha vivipara	cushion cactus
Cruciferae species	mustard
Descurainia sophia	flixweed
Elymus angustus	Altai wild rye
Elymus junceus	Russian wild rye
Erigeron glabellus	rough fleabane
Erigeron canadensis	horseweed
Erysimum inconspicuum	small-flowered prairie rocket
Gaillardia aristata	gaillardia
Gaura coccinea	scarlet gaura
Geum triflorum	three-flowered aven
Grindelia squarrosa	gumweed

Latin Name	Common Name
Gutierrezia sarothrae	broomweed
Helianthus villosa	hairy golden aster
Hordeum jubatum	wild foxtail barley
Koeleria macrantha	Junegrass
Lactuca species	wild lettuce
Lappula squarrosa	blueburr
Lappula occidentalis	burr
Lepidium densiflorum	common peppergrass
Linum lewisii	wild blue flax
Linum rigidum	large-flowered yellow flax
Lithospermum ruderale	yellow poccoon
Lolium perenne	perennial rye grass
Medicago falcata	alfalfa
Medicago sativa	alfalfa
Mellilotus officinalis	yellow sweet clover
Monolepis nuttalliana	spear-leaved goosefoot
Onobrychis vicaefolia	sainfoin
Onograceae species	evening primrose
Opuntia polyacantha	prickly-pear cactus
Oxytropis sericea	early yellow locoweed
Parmelia chlorochroa	lichen
Phlox hoodii	moss phlox
Plantago elongata	linear-leaved plantain
Plantago lanceolata	ribgrass
Plantago patagonica	Pursch's plantain
Poa pratensis	Kentucky bluegrass
Poa sandbergii	Sandberg bluegrass
Polygonum arenastrum	common knotweed
Portulaca oleracea	purslane
Potentilla anserina	silverweed
Potentilla bipinnatifida	plains cinquefoil
Potentilla fruticosa	shrubby cinquefoil
Ratibida columnifera	long-headed coneflower
Rosa acicularis	prickly rose
Salsola kali	Russian thistle
Selaginella densa	little club moss
Setaria viridis	green foxtail
Sisyrinchium montanum	blue-eyed grass
Solanum triflorum	wild tomato
Sonchus arvensis	perennial sow thistle
Sphaeralcea coccinea	apricot mallow
Stipa comata	spear grass
Stipa curtiseta	western porcupine grass
Stipa viridula	green needle grass
Taraxacum officinale	dandelion
Thermopsis rhombifolia	golden bean
Thlaspi arvense	stinkweed
Tragopogon dubius	goat's beard
Vicia americana	American vetch