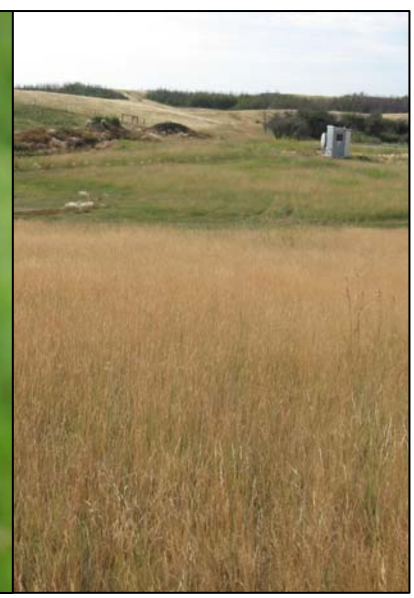
RECLAMATION STATUS OF PLAINS ROUGH FESCUE GRASSLANDS AT RUMSEY BLOCK AFTER WELL SITE AND PIPELINE DISTURBANCE

Mae E. Elsinger, M.Sc.

September 2009





EXECUTIVE SUMMARY

This document is a summary of a research thesis entitled Reclamation Status Of Plains Rough Fescue Grasslands At Rumsey Block In Central Alberta, Canada After Oil And Gas Well Site And Pipeline Disturbances written by Mae Elsinger as part of a Master of Science in Land Reclamation and Remediation program at the University of Alberta.

Rumsey Block is a remnant of plains rough fescue (*Festuca hallii* (Vasey) Piper) prairie in central Alberta, Canada. Reclamation success of 17 pipelines and 36 well sites was assessed by comparing them to undisturbed prairie and determining the influences of age, construction and revegetation methods and cattle grazing. With few exceptions, these disturbances had different soil and plant community characteristics than undisturbed prairie. Reclamation success was more closely related to methods of construction and revegetation and grazing pressure than to age. Greater similarity between undisturbed prairie and well sites or pipelines was related to construction methods that leave sod and topsoil intact. Revegetation by natural recovery resulted in a more diverse community than seeding either native or non native mixes but progress is slower on open soil disturbance than on minimal disturbance. In most cases increased grazing pressure was associated with lower reclamation success.

Key recommendations evolving from this research are minimizing area of soil disturbance, considering management of weeds and exotic species on disturbances, reducing prolonged livestock grazing on disturbances, and considering intervention of disturbances that appeared to be stalled in their successional status. Improvements in record keeping should also be made so that factors such as dates, seasons, environmental conditions, construction methods, stripping depth, duration of topsoil storage, revegetation methods and seed mixes can be correlated with the level of restoration success of oil and gas disturbances.

ACKNOWLEDGEMENTS

Research funding was provided by Alberta Sustainable Resource Development Public Lands Division, Husky Energy Incorporated, Trident Resources Corporation and Canadian Natural Resources Limited. Public Lands provided funding for this research summary. Public Lands provided all-terrain vehicles and a computer with software. Trident Exploration provided equipment for tracing underground pipelines and access to their Work Alone Hotline. Alberta Community Development granted permission to access Rumsey Block, use all-terrain vehicles off road and take plant and soil samples for research. The Stewart family provided me and my assistants with accommodations, furnishings, utilities, phone access and fuel for both field seasons. Background information on the project sites was provided by Barry Cole, Angela Burkinshaw and Ed Karpuk of Public Lands, David Foo of Paramount Resources and Laura Hickman of the University of Calgary. Peggy Desserud provided valuable assistance with logistics, funding and access to equipment, background information and statistical analyses. Sarah Wilkinson made equipment and lab space available and provided assistance with sampling methods and thesis writing.

Field and lab assistance was provided by Melanie Wood, Darin Sherritt, Stephanie Close, Mark Béasse, Alan Stewart, Tremayne Stanton-Kennedy, Anayansi Cohen-Fernandez and Hélène Marcoux. Melanie and Darin provided many of the photographs for this summary.

The Range and Biodiversity Division of Agriculture and Agri-Food Canada, Prairie Farm Rehabilitation Administration granted me paid leave to pursue this research. Thanks to Dr. M. Anne Naeth for faith, patience, confidence, optimism, determination, vision, encouragement and understanding as we worked through my study program, research project, thesis and several iterations of paperwork associated with my education leave from work. My other research committee members, Dr. Edward Bork and Dr. Walter Willms, and fellow graduate students contributed to experimental design and data analyses. Dr. Andreas Hamann enabled me to use multivariate analyses for this unique research project and provided software to run analyses.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 Background

1.1 Introduction

Attention to Rumsey Block has intensified in recent years due to increased proposals for energy development. Rumsey Block contains one of the few sizeable plains rough fescue (*Festuca hallii* (Vasey) Piper) plant communities in western Canada (Alberta Wilderness Association 2006a), mainly because topographical constraints have discouraged annual cultivation. Impacts of oil and gas activities on plains rough fescue prairie are understudied and few restoration successes have been documented. Investigating soil and plant community restoration status of these disturbances is necessary to inform future restoration efforts.

1.2 Site Description

Rumsey Block (a.k.a. Wildland or Parkland) is located east of Rumsey in Central Alberta, approximately 80 km southeast of Red Deer. It includes the 34 km^2 Rumsey Ecological Reserve in the north, and the 149 km^2 Rumsey Natural Area in the south. It lies on the border between the Northern Fescue and Central Parkland Natural Subregions (Natural Regions Committee 2006) and its hummocky topography has helped prevent it from being annually cultivated, like much of the grassland around it.

The continental climate brings cold winters and short hot summers, with a mean annual temperature of 3.1 ^{o}C and a mean annual precipitation of 407 mm (Strong and Leggat 1992, Environment Canada 2004). The May to September growing season has over 100 frost free days and a mean temperature of 13.8 ^{o}C (Environment Canada 2004, Natural Regions Committee 2006). Mean temperatures and precipitation for the 2006 and 2007 study years were higher than normal (Environment Canada 2007). Despite most precipitation occurring in summer months, moisture is limiting for plant growth due to high sun exposure and drying winds (Strong and Leggat 1992).

Table 1.1 Comparison of temperature and precipitation during sampling years and long-term average

Year	Period	Temperature (Comparison to Normal) (°C)[1]	Total Precipitation (Comparison to Normal) (mm)[1]
2006	Growing Season	15.2 (+1.5)	322.4 (+37.6)
	Full Year	4.6 (+1.5)	523.8 (+116.8)
2007	Growing Season	14.2 (+0.5)	362.8 (+78.0)
	Full Year	3.9 (+0.8)	498.1 (+91.1)

[1]Climate normals from 1971 - 2000

The landscape of Rumsey Block mostly originated from deposition of medium textured glacial till derived from freshwater sediments with marine sediments exerting some influence. Freshwater deposits developed into Orthic Dark Brown Chernozems dominating well drained uplands. The marine shales developed into Dark Brown Solodized Solonetzes comprising approximately 20 % of Rumsey Block soils (Bowser et al. 1951). The hummocky morainal topography results in a complex pattern of soil water dynamics because of variable exposures of sun on the soil surface, the variety of positions on slopes and differences in accumulation of rain and snow among hilltops, depressions, lee slopes and windward slopes. This results in differential soil development leading to establishment of a mosaic of vegetation communities.

Plains rough fescue dominates under mesic soil conditions (Natural Regions Committee 2006), forming dense stands with low diversity where undisturbed. Grazing and dry soil conditions favour western porcupine grass, Hooker's oatgrass (*Helictotrichon hookerii* (Scribn.) Henr.), bearded wheatgrass (*Elymus subsecundus* (Link) A.Love & D.Love), June grass (*Koeleria macrantha* (Ledeb.) J.A. Schultes), pasture sage (*Artemisia frigida* Willd.), fleabanes (*Erigeron* spp. L.) and other perennial forbs. Moister sites, like north facing slopes, contain western snowberry (*Symphoricarpos occidentalis* Hook.), silverberry (*Elaeagnus commutata* Bernh. ex Rydb.), Wood's rose (*Rosa woodsii* Lindl.) and saskatoon (*Amelanchier alnifolia* (Nutt.) Nutt. ex M. Roemer). On northerly slopes and adjacent to moist depressions, more trembling aspen is encountered.

1.3 Land Use History

Livestock grazing on Rumsey Block has occurred since before settlement just before the turn of the 20th century. Grazing leases were established after the Dominion Land Survey was completed in 1907. Grazing rates on the property had been conservative and Public Lands determined after assessment in 1968 that the minimum stocking rate needed to sustain forage production was 24 to 25 acres/head/year and only under superior grazing management. In 2000, there was a change from winter grazing, considered beneficial to sustaining plains rough fescue communities, to summer grazing (Alberta Wilderness Association 2006b).

Energy leaseholders have been exploring for oil and gas at Rumsey Block since the 1950s. At this time, sites were starting to be reclaimed, but construction was not designed to make reclamation easier and more successful (Sinton 2001). The idea of what a reclaimed site should look like was different from what it is today. Today, reclamation expectations and practices are regulated and successful examples have been reported for many landscapes.

For decades, topsoil was salvaged to protect the topsoil and seed bank during operations. Currently at Rumsey minimal disturbance is prescribed, as described in Informational Letter

EUB IL-2002-1 and Prairie oil and gas: a lighter footprint (Alberta Energy and Utilities Board 2002 and Sinton 2001).

Revegetation prior to the early 1980s involved seeding non native species. Three options for Rumsey Block have evolved since then to help reestablish native vegetation: natural recovery following topsoil replacement, spreading native mulch following topsoil replacement, or seeding a native mix. In recent years Public Lands has been more consultative in prescribing construction and reclamation measures, rather than providing blanket prescriptions such as the ones described above (Cole Personal Communication).

1.4 Need for Research

Research specific to Rumsey Block is limited to a few unpublished studies for by various consultants, as outlined in Desserud (2006a). Those studies concluded revegetated well sites were dissimilar to adjacent undisturbed prairie because of persistence of native wheatgrass cultivars and agronomic species and invasion of non native plants.

This research covers a larger number and age range of oil and gas disturbances at Rumsey Block and includes the more recent minimal disturbance techniques, which are expected to have more favourable restoration results. Soil restoration status was also assessed in addition to plant community status.

1.5 Research Objectives

Research surrounding the status of reclamation of well sites and pipelines at Rumsey Block was guided by the following objectives:

- to compare select plant community characteristics and soil properties on oil and gas well site and pipeline disturbances to undisturbed grassland,
- to determine if plant community characteristics and soil properties on these disturbances were affected by time since reclamation, construction methods, reclamation techniques and livestock access, and
- to make recommendations on appropriate construction, reclamation and grazing management practices for future disturbances in plains rough fescue grasslands.

2.0 Methods and Analysis

2.1 Field Sampling

Seventeen pipeline segments and thirty-six well sites on upland grasslands were selected for study; sampling locations were sometimes established on different legs of the same pipeline in different grazing units. Sites had various construction dates and seed mixes and were compared to adjacent undisturbed upland with similar topography. Information on construction date and method and revegetation strategy was obtained from Alberta Public Lands (Cole Personal Communication). Pipelines were constructed between 1976 and 2000, with reclamation likely occurring within months of construction. Well sites were constructed between 1967 and 2004, with reclamation not always occurring within months of construction.

Pipeline diameters were less than 115 cm, except the 1976 pipeline, which had a 273 mm diameter (Hickman Personal Communication). Construction method for the largest pipeline was likely full right of way topsoil and subsoil stripping, where subsoil is stored separate from topsoil and removed and replaced in one or two lifts by soil horizons. Most pipelines were constructed using bucket width (96 cm) topsoil stripping. The 1983 pipeline and one 1990 pipeline were constructed using a ditch witch (30 cm wide) without topsoil stripping where all soil horizons were removed and replaced together. The 1999 pipeline was constructed by plow-in where topsoil was not stripped and a small area was disturbed by a slice into the sod and soil prior to pipe insertion. Most pipelines were not seeded but revegetated via natural recovery. The 1976 pipeline was seeded to unknown non-native species and the 1987 pipeline was seeded to a native mix (Appendix A).

Most well sites were constructed between 1977 and 1991, three prior to that period and eight afterward. From 2000 to present, well sites were constructed with minimal disturbance techniques that kept sod intact. Construction methods for the two oldest well sites are unknown. The remaining well sites, except one from 1997, were constructed by stripping the entire right-of-way and replacing topsoil after drilling. The 1997 well site, on an existing right-of-way, was stripped near the new well head but topsoil was not replaced and the stripped area was too large to classify as minimal disturbance. Well sites constructed in 1995 and during or after 2000 were revegetated by natural recovery. Well sites constructed from 1983 to 1997 were prescribed to be seeded with native grasses (Appendix A), but many were seeded with or invaded by non-native species.

Sampling occurred at the centre of disturbance for pipelines and well sites. Undisturbed areas next to the rights-of-way had similar features to disturbed areas such as slope degree, aspect and position. GPS coordinates were recorded for the general location of each disturbance.

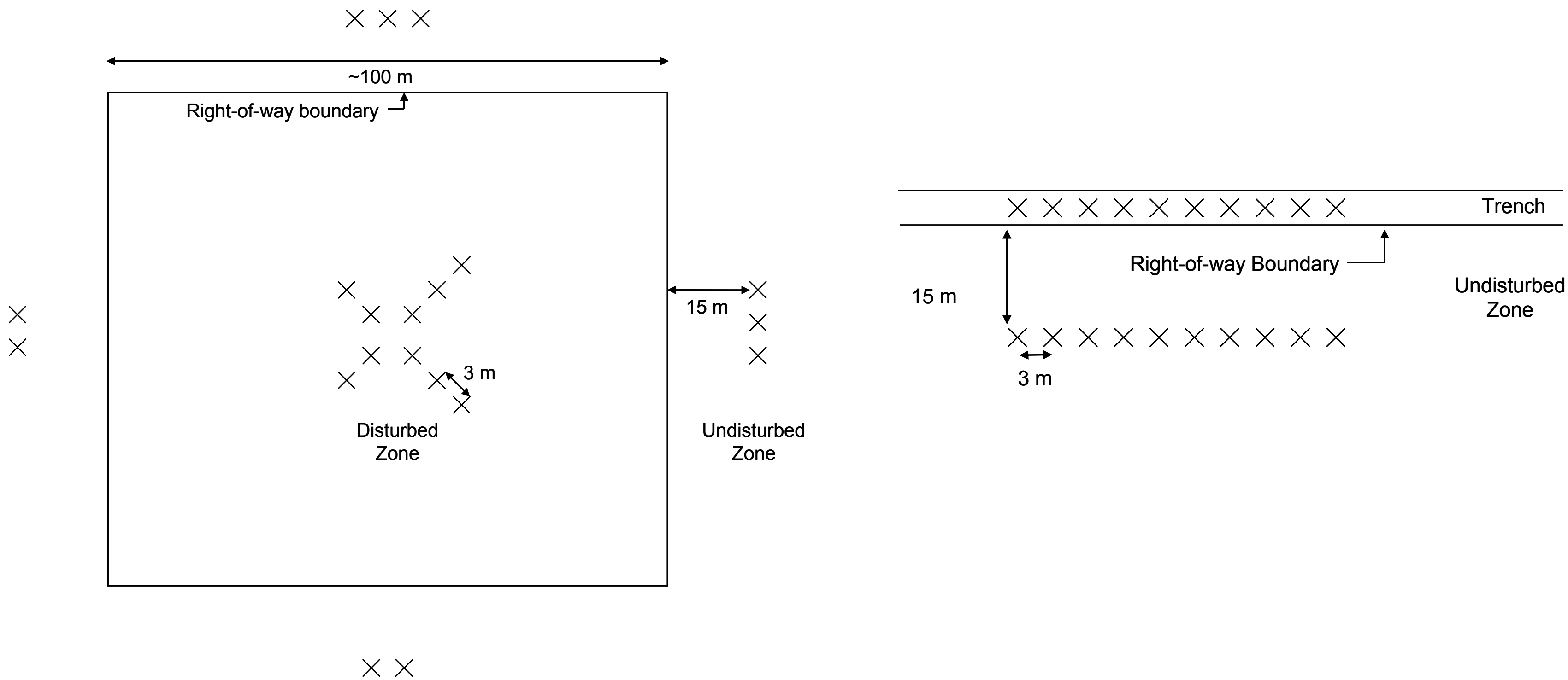
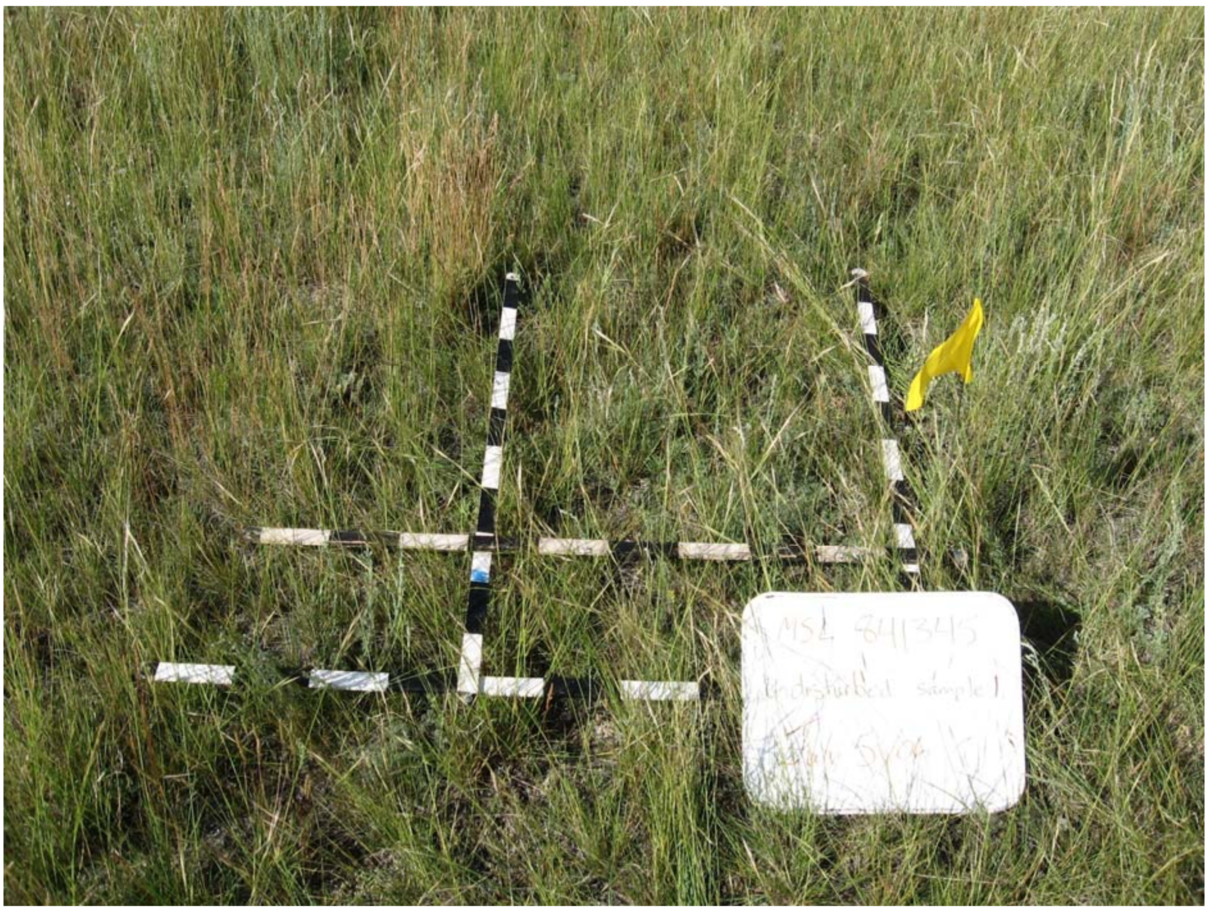


Figure 2.1 Sampling diagrams for well sites (left) and pipelines (right)

Vegetation sampling was conducted in July 2006. Canopy cover was used to determine area of ground cover types. Estimates included herbaceous cover (current year's green and yellow plant material), bare ground, plant litter (previous year's grey plant material), fecal material, stones, moss, lichens and microbiological crusts. Herbaceous species composition was estimated as proportions of biomass adding to 100 %. Species richness was determined as the number of different species found from sampling across each site. Data from rangeland reference areas established by Public Lands in the Northern Fescue Natural Subregion (Burkinshaw Personal Communication) were compared to data from the current study locations using five indicators of the Alberta Rangeland Health Assessment (Adams et al. 2003).



At the time of the plant community assessment, livestock utilization, trampling and trailing at each site were visually categorized as none, light, moderate and severe. Other observations regarding animal use were noted. Observations of aspect, slope and position for each location were also categorized.

Soil variables assessed were soil texture, bulk density, penetration resistance, sodium adsorption ratio, electrical conductivity, pH, concentrations of magnesium, potassium, calcium and sodium cations, and concentrations of total organic carbon and total nitrogen. Soil chemistry was analysed to 20 cm depth from multiple cores that were composited before analysis. Penetration resistance and bulk density values at five depths between 0 and 20 cm were averages of multiple measurements.

2.2 Data Analysis

Values for each plant community and soil parameter measured were averaged for each well site or pipeline disturbance and its undisturbed counterpart. Pivot Table and Chart Wizard functions in Microsoft Excel 2003 were used to generate bar graphs for comparing individual parameters between and among disturbed and undisturbed locations.

Sampling parameters were placed into groups for many of the data analyses. The soil group included cation concentrations, sodium adsorption ratio, pH, texture, electrical conductivity, total carbon and nitrogen concentrations and bulk density. The ground cover group included herbaceous, bare ground, moss/lichen, stone, feces and litter cover. Species composition data were grouped in three ways: species placed into plant functional groups (ie. native bunchgrasses, native rhizomatous grasses, non-native forbs, etc.), undesirable (non-natives) vs desirable plants (natives), and dominant native prairie plants as determined from the undisturbed samples.

In PC-Ord version 5.0 (McCune and Grace 2002), Bray-Curtis (Sørenson's quantitative) dissimilarity indices (Faith et al. 1987) were calculated to compare undisturbed and disturbed samples in data sets that grouped soil, ground cover and species composition parameters. Results were tabulated and bar graphs constructed, again, using Pivot Table and Chart Wizard functions in Microsoft Excel 2003.

The non-metric multidimensional scaling (NMS) method of ordination (Kruskal 1964 and Mather 1976) was used in PC-Ord 5.0 (McCune and Grace 2002) to assess multivariate trends in ground cover, species composition and soil data for well sites and undisturbed prairie. Spearman's rank correlation coefficient in SPSS software was used to determine relationship strength between ordination results and variables within data sets.

Treatment categories (disturbed vs. undisturbed, age, construction, revegetation and grazing exclusion) were compared using the multi-response permutation procedures (MRPP) test in PC-Ord 5.0 (Mielke et al. 1981, McCune and Grace 2002). Age categories were produced by assigning a category for every five years of the reclamation time period studied, resulting in eight age categories, 1967-1970, 1971-1975, and so on until 2004, plus one undisturbed category. Categories for method of construction included unknown construction, topsoil stripping, minimal disturbance, plow-in and ditch witch. Categories for method of revegetation included seeding an agronomic mix, seeding the native mix prescribed for Rumsey Block and natural recovery. Finally, a categorical variable for livestock exclusion of well sites indicated whether a right-of-way was fenced to prevent cattle use, was at one time fenced, or was never fenced.

Using Microsoft Excel, bar graphs were created from values of multiple variables for each well site that were relative to those of the adjacent undisturbed reference. Subsets of variables from three main data sets (soils, ground cover and species composition) were combined into a larger data set. These modified AMOEBA diagrams are adapted from the approach described by ten Brink et al. (1991) and Wefering et al. (2000). AMOEBA is an acronym for the Dutch description, “a general method of ecosystem description and assessment”. They help provide a visual of overall reclamation status of a disturbance.

3.0 Comparison of Disturbances to Undisturbed Prairie

3.1 Soils

With few exceptions, well site and pipeline disturbances were more likely to have lower organic carbon and nitrogen concentrations and higher calcium and magnesium concentrations, pH, electrical conductivity and bulk density than undisturbed prairie. Most differences were neither large in magnitude nor biologically significant.

3.2 Ground Cover

Most pipelines and well sites were more likely to have higher bare ground and stone cover and lower club moss and lichen cover than undisturbed prairie. Although mean values for herbaceous and litter cover for disturbances were similar to undisturbed prairie, they had broader ranges. For some locations values for the differences in ground cover types between disturbances and native prairie were often very large.

3.3 Plant Species Composition

With few exceptions, plant species composition on well site and pipeline disturbances was significantly different from that of undisturbed prairie. Disturbances were more likely to have higher abundance of early colonizers such as western or northern wheatgrass and pasture sage and lower abundance of later successional species such as plains rough fescue, western porcupine grass, June grass and upland sedges. Additionally, many well sites had higher abundances of exotics such as smooth brome, quack grass and/or Kentucky bluegrass. Disturbances that were most similar to undisturbed prairie had more late successional species; disturbances that were most different from undisturbed prairie were dominated by native colonizers or seeded species. Species richness was lower on most disturbances than on undisturbed prairie.

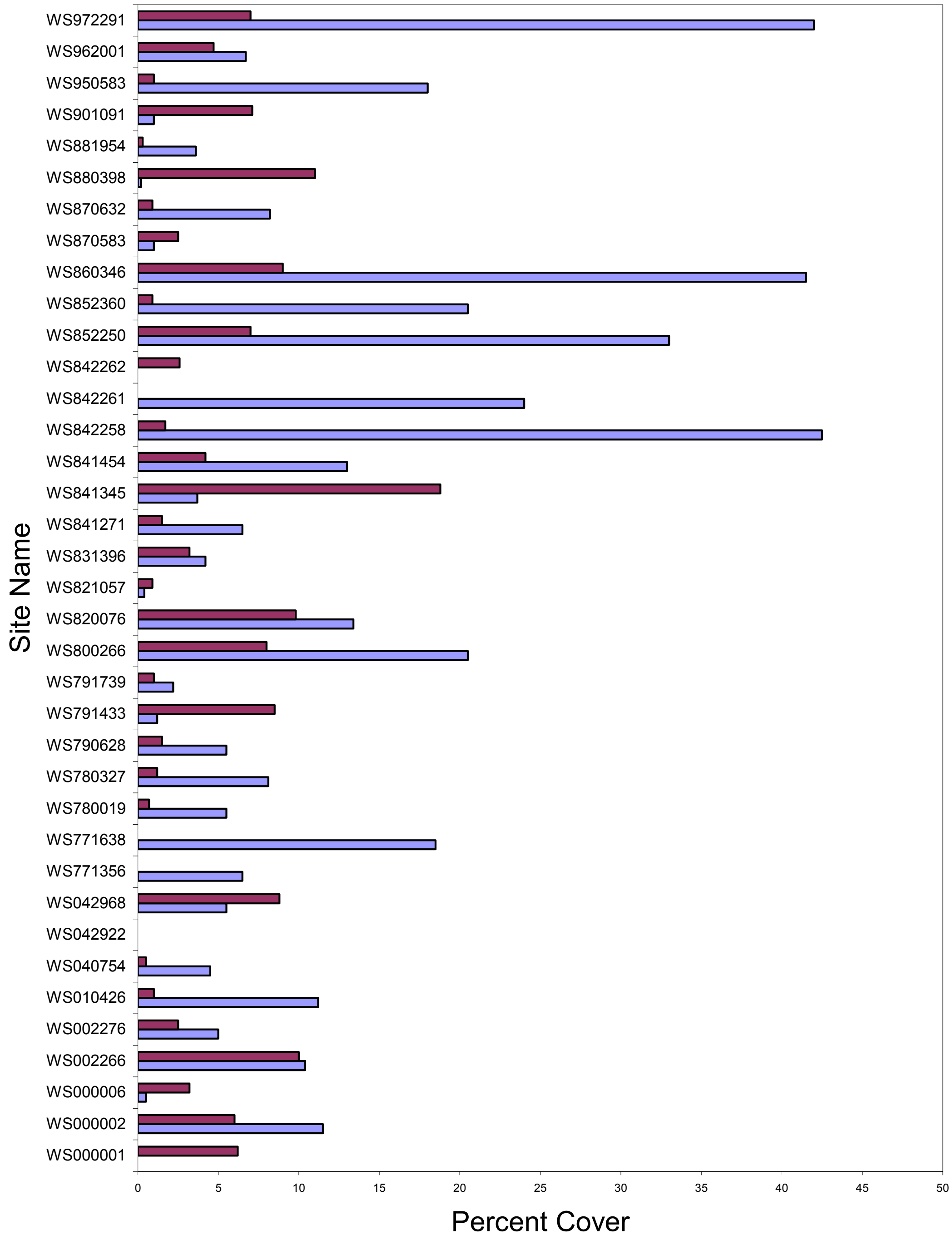


Figure 3.2 **Comparison of bare ground cover between well sites (light blue) and adjacent prairie (dark red). The overall pattern of lower bare ground on undisturbed areas is also reflected in the pipeline data.**

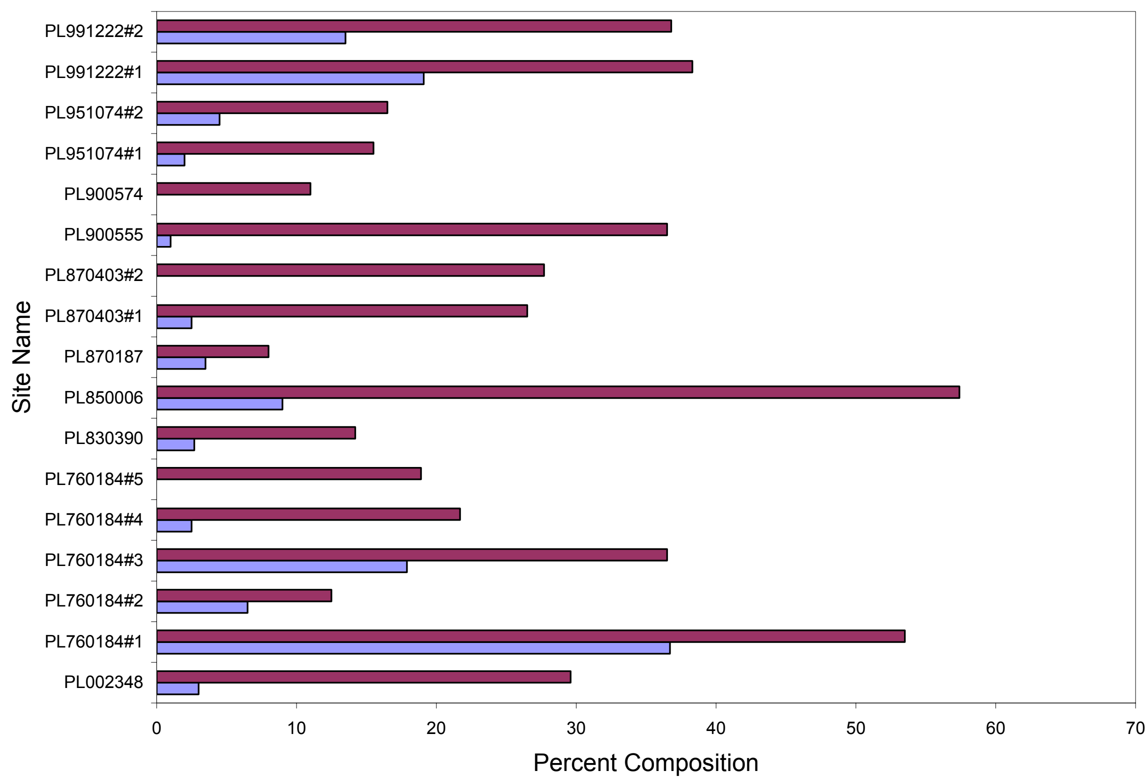


Figure 3.3 Comparison of plains rough fescue composition between pipelines (light blue) and adjacent prairie (dark red). The overall pattern of more fescue on undisturbed areas is also reflected in the well site data.

Table 3.1 Summary of general comparisons between well site and pipeline disturbances and undisturbed prairie

	Disturbed	Undisturbed
Soils	Higher cation concentration, pH, EC, surface bulk density and penetration resistance	Higher total organic carbon and nitrogen
Cover	More bare ground and broader range of litter and herbaceous cover	More clubmoss
Species Composition	More disturbance colonizers (wheat grasses, smooth brome, Kentucky bluegrass)	More rough fescue and porcupine grass

3.4 Overall Reclamation Status

Modified AMOEBA diagrams created from combined soils, ground cover and species composition data sets for all except four of the disturbances showed that all except six pipelines and six well sites had multiple characteristics dissimilar from adjacent undisturbed prairie and thus were still distant from reclamation success. Some pipelines had values for some characteristics that were higher than five times the reference. Some of the well sites that were in the worst condition had values for some characteristics greater than six times the reference. Two had characteristics higher than 12 times the reference. Modified AMOEBA diagrams for each well site and pipeline are in the appendix.

3.5 Discussion

Most soil variables that changed with disturbance did not exceed theoretical values that would affect plant growth and development. However, many vegetation variables were considerably different than expected for restoration success of plains rough fescue prairie.

Most shallow depth bulk densities did not exceed 1.5 Mg m^{-3}, the theoretical value at which root penetration can become limiting (Lutz 1952, Naeth et al. 1991b; Naeth et al. 1991c). Some disturbances constructed with ditch witch or topsoil stripping had surface bulk densities approaching or exceeding this value and noticeably sparse vegetation cover. At greater depths, some disturbances constructed with topsoil stripping or ditch witching exceeded 1.5 Mg m^{-3} but there was no consistent association with reduced plant cover. Although penetration resistance in disturbed and undisturbed locations may be considered high by some standards, it is not unexpected in mid summer when soils were driest. Mean values did not usually exceed the 4.0 MPa level proposed as a plant limiting value by Naeth et al. (1991c) although maximum values on most disturbances did. Most soil chemical properties did not exceed theoretical limits for plant response. Similar results were reported by Ostermann (2001) for 11-12 year old pipelines in mixed grass prairie and foothills grasslands. Naeth's results were similar for various aged pipelines in mixed grass prairie, except bulk density with depth decreased over the trench due to shattering of the Bnt horizon (Naeth 1985, Naeth et al. 1987). Hammermeister (Hammermeister 2001, Hammermeister et al. 2003) and Soulodre (2001) reported similar changes with well site disturbances in mixed grass prairie.

Many disturbances were discernible from undisturbed prairie by excessive bare ground, some exceeding the widespread reclamation standard of 15-20 %. Ostermann (2001) found bare ground over a 12 year old pipeline in mixed grass prairie exceeded 15 % but not 20%, and suggested drought could increase this beyond the threshold. Bare ground at the foothills grassland location was less than that of the mixed grass prairie location. Naeth (1985) and Naeth et al. (1987) found that bare ground on topsoil stripped pipelines from 2-25 years old exceeded these limits. In the disturbances studied at Rumsey, live vegetation and litter cover were highly variable on pipelines and well sites relative to undisturbed prairie. Other studies also had variable results (Naeth 1985, Hammermeister 2001, Ostermann 2001, Soulodre 2001).

Club moss and lichen cover was among the most defining features of undisturbed prairie. The soil exposure resulting from disturbance was expected to facilitate colonization of club moss, as it avoids grazing and tolerates xeric conditions (Clarke et al. 1942). However, even on old disturbances club moss had not colonized. Although not desirable for grazing clubmoss provides soil surface stability and thus reduces erosion. The elimination of club moss from disturbances is consistent with other studies involving physical alteration of grassland soil where little club moss did not return during recovery periods ranging from 1-75 years (Ryerson 1970, Naeth 1985, Ostermann 2001).

Many plant species defining the undisturbed prairie were absent from pipelines and well sites or were in low abundance. Plains rough fescue was reduced on pipelines and well sites compared with undisturbed prairie. It is a late successional species and may require specific soil and/or microenvironmental conditions to establish. Western porcupine grass is also a late successional species, often co-dominant with plains rough fescue but may establish more readily from the seed bank or invade from off the pipeline than plains rough fescue. In contrast to other more aggressive colonizers, the weakly rhizomatous rough fescue and tufted western porcupine grass produce fewer seeds with more specific germination and establishment requirements. Desserud (2006b) found foothills rough fescue and associated later seral grasses were absent on over half of the pipelines that she studied in foothills and montane regions of southern Alberta.

Other species of later seral grasslands include June grass and low sedge, which are often indicative of heavy grazing but slower to establish on soil disturbance than early colonizers. Although sedges thrive with moderate disturbance, including soil compaction, they cannot establish on disturbed soil and do not persist in the seed bank. The wheatgrasses are strongly rhizomatous and produce highly germinable seeds, making them aggressive colonizers of bare ground. Western wheatgrass was infrequent on pipelines and undisturbed prairie, but was more frequent on certain well sites. Pasture sage is tolerant of physical damage and soil compaction (Naeth 1985) and is an abundant seed producer (Peat and Bowes 2005), giving it a role in early secondary succession (Naeth 1985, Ostermann 2001).

Smooth brome and Kentucky bluegrass are colonizers of exotic origin that distinguished some disturbances from undisturbed prairie. They have creeping root growth and abundant seed production with broad germination requirements. Desserud (2006b) classified 25 of 56 disturbances as either Kentucky bluegrass or smooth brome communities. Although diversity was relatively high on rights-of-way classified as Kentucky bluegrass communities, late seral native species such as foothills rough fescue and Parry's oatgrass were found on only four. Smooth brome communities had the least diversity with minimal or absent foothills rough fescue. Ostermann (2001) found twice as many rhizomatous non-native grasses on 12 year old trenches than in undisturbed foothills grasslands, and almost none on trenches in mixed grass prairie and attributed that to inability of many non-native species to endure frequent moisture stress.

Differentiation of plant communities from undisturbed prairie after industrial disturbance has been found in other studies. The closest comparison to the present study was conducted by Desserud (2006b), who studied 56 pipelines constructed from 1987-1998, in three natural subregions and three hydrological types. Foothills rough fescue and later seral grasses (Parry's oatgrass, June grass and Idaho fescue) were absent on half the disturbances; 11 disturbances closely resembled adjacent grasslands (six were indistinguishable from undisturbed), 26 were heavily modified and 19 had intermediate modification.

4.0 Influence of Reclamation Date

4.1 Soils

Although there were significant differences in soil qualities among some age groups, the relationship of age to soil reclamation of well sites and pipelines was weak to absent. The only significantly different pipeline age groups were 1996-2000 and 1981-1985. Pipelines from the two oldest groups, 1976-1985, were the only ones significantly different from undisturbed prairie. Well site age groups were not significantly different from one another but 1976-1990 and 1996-2000 well sites were significantly different from undisturbed prairie. Overall, older disturbances had higher bulk density, pH, electrical conductivity and magnesium and calcium and lower carbon and nitrogen than newer disturbances or undisturbed prairie.

4.2 Ground Cover

Although there were significant differences in ground cover among some age groups, the relationship of age to ground cover of well sites and pipelines was weak to absent. Only 1981-1985 pipelines were significantly different from 1996-2000 pipelines and none were significantly different from undisturbed prairie. Pipelines constructed from 1981 to 1985 were likely to have higher herbaceous and feces cover and lower litter than 1996-2000 pipelines. Well sites constructed between 1967 and 1970 were significantly different from those constructed from 2001 to 2004, with higher herbaceous and lower litter cover. Well sites significantly different from undisturbed prairie were constructed from 1981 to 1990 and from 1996 to 2000, with lower cover of club moss and lichen.

4.3 Plant Species Composition

Although there were significant differences in species composition among some age groups, the relationship of age to species composition of well sites and pipelines was weak to absent. No pipeline age groups were significantly different from one another and only 1986-1990 pipelines differed significantly from undisturbed prairie, with overall higher abundance of native rhizomatous grasses (mostly western and northern wheatgrass), lower native tufted grasses (mostly plains rough fescue), higher pasture sage and lower prairie sage and Canada thistle. Dissimilarity indices showed the oldest pipeline (constructed in 1976) was most similar to undisturbed prairie in functional group abundance and 1981-1990 pipelines were most different in abundance of dominant prairie species.

Well sites constructed between 2001 and 2004 were significantly different from those constructed 1967-1970 and 1981-1995. All except the 2001-2004 sites were significantly different from undisturbed prairie. Older well sites were significantly different from newer ones and undisturbed prairie with higher abundances of non-native rhizomatous grasses (smooth brome and Kentucky bluegrass), non-native tufted grasses, non-native perennial forbs and native rhizomatous grasses (western wheatgrass), and lower native tufted grasses (plains rough fescue, western porcupine grass), sedges (low sedge) and pale comandra.

Dissimilarity indices showed differences in species composition between individual well sites and undisturbed prairie did not diminish with age. Most recently constructed well sites were more similar than others to undisturbed prairie in composition of prairie dominant species, undesirable species and abundance of species within functional groups.

4.4 Discussion

Age of disturbance was less related to reclamation success than period of reclamation. Construction year was usually coincidental with construction and reclamation techniques available and deemed most appropriate at that time. During or before 1995, pipelines and well sites were constructed with a ditch witch or topsoil stripping and thus had substantial soil disturbance. By the late 1990s the importance of careful topsoil salvage was well understood and practiced if plow-in construction and minimal disturbance were not applied instead. The most recent pipeline was constructed with topsoil stripping but likely with more careful soil handling. Disturbances by the plow-in were designed to reduce construction impacts. The most recent well sites were constructed with minimal disturbance. Well sites constructed prior to 1995 were also revegetated by seeding with a native or non-native mix and most of the recent ones were revegetated only by natural recovery. The lack of distinction in soil properties among older well sites revegetated with either seed mix may indicate construction method was more influential.

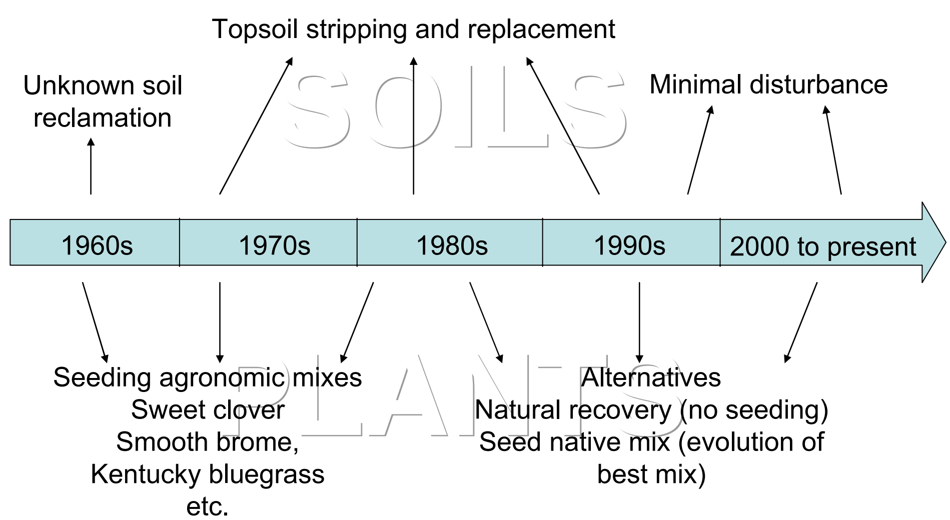


Figure 4.1 History of soil reclamation and revegetation at Rumsey Block

Soil properties impacted by construction were expected to be ameliorated over time through new above and below ground plant growth, organic matter accumulation, biological activity and freeze thaw cycles. However, in this study, many older disturbances were more compacted than recent ones constructed by plow-in or minimal disturbance, where intact sod buffered the impact of heavy machinery. From a study of pipelines of various ages in solonetzic mixed grass prairie Naeth (Naeth 1985, Naeth et al. 1987, Naeth et al. 1988) concluded surface bulk density was ameliorated by 12-20 % over 24 years, due to root penetration and swelling and shrinking of clays with wetting and drying. In reviewing other studies, she concluded rates of amelioration were likely governed by variable soil properties, type of disturbance and environmental conditions. On older pipelines, however, cation concentrations and electrical conductivity decreased and organic matter increased but were still different from undisturbed prairie. She projected at least 33 years were needed for values to return to predisturbance levels. Naeth also suggested plant rooting improves soil aeration and permeability and creates an environment favourable to soil microorganisms and fauna (Naeth et al. 1990a, Naeth et al. 1990b, Naeth et al. 1991a, Naeth et al. 1991b). Over time plant debris and roots degrade and contribute to soil organic matter. These changes could be a positive feedback to vegetation. Conversely, lack of established vegetation due to reduced nutrient availability and poor soil structure would contribute to persistence of negative soil physical and chemical changes.

In this study, there has been little return of club moss and lichen to disturbances even as old as 39 years where surface vegetation has been disturbed or removed during construction. Naeth (1985) reported complete elimination of little club moss from 1957-1981 pipelines with no return even on the oldest. Ostermann 2001 reported the same for a 12 year old pipeline. Club moss was not found on chernozemic and solonetzic mixed grass prairie well sites constructed with topsoil stripping (Hammermeister 2001, Soulodre 2001), despite its abundance on undisturbed prairie. Ryerson (1970) noted club moss had not returned to cultivated fields after 50-75 years.

Most 1981-1990 pipelines had high bare ground due to soil disturbance combined with revegetation via natural recovery (although one site seeded to the Rumsey native mix also had high bare ground). The two ditch witch pipelines constructed during this period had the highest soil exposure. Desserud (2006b) found little reduction of bare ground with pipeline age and Naeth (1985) proposed site treatment and age and timing of grazing were important in determining change of bare soil on a pipeline over time.

The relationships of age to live vegetation or litter cover were not consistent among disturbances of similar ages and were not as clear in this study as in others. Naeth (1985) found live vegetation cover on 15-25 year old pipelines was close to that of undisturbed prairie, but not as much recovery was seen on a 10 year old trench. Ostermann (2001) found no significant difference of live vegetation or litter cover on an 11 year old pipeline compared to undisturbed foothills grassland, but on a pipeline of similar age in mixed grass prairie, trenches had lower live vegetation cover and higher litter cover. Desserud (2006b) found litter was generally reduced on pipeline trenches, with little improvement with age.

Revegetation practices were closely associated with time periods. Older disturbances were revegetated with a variety of methods, but more recent ones were limited to natural recovery. Seed mixes were agronomic or native containing high amounts of aggressive native cultivars. The only pipeline seeded in the late 1970s was reportedly revegetated with an agronomic mix; the historical record may be incorrect as no agronomic species, except a small amount of Kentucky bluegrass, were found along the segments studied. Alternatively, 29 years of recovery for this pipeline may account for its being more similar to undisturbed prairie than the 1986-1995 pipelines still dominated by native colonizers (wheatgrasses, pasture sage), especially if the mix was dominated by short lived cultivars. On the 1987 pipeline seeded to native mix, establishment was successful but those species have persisted.

The reason for similarity in species composition between well sites constructed in the earliest years, those constructed in the 1990s, and undisturbed prairie is unclear. The oldest ones may have had sufficient time to evolve and the newest ones were constructed and reclaimed using advanced techniques that facilitated plant community succession. Naeth (1985) found species composition on older pipelines was moving towards predisturbance conditions, even reducing dominance of non-natives. She suggested the return was slowed by introduction of non-natives on some pipelines and grazing pressure. Soulodre (2001) expected natural recovery well sites in mixed grass prairie may take 20-50 years and would be held back by grazing.

Species richness was expected to increase with time on pipelines and well sites. There was no relationship. It appeared to be more dependent on construction and revegetation methods.

5.0 Influence of Construction Method

5.1 Soils

Although there appeared to be trends in NMS ordination of soil qualities among construction methods for well sites and pipelines at Rumsey, none of the methods were significantly different from one another. However, topsoil stripping and ditch witching did result in significantly different soil properties from undisturbed prairie. These types of disturbances were more likely to have lower organic carbon and nitrogen and higher soil bulk density, pH, electrical conductivity and magnesium and calcium concentration. Dissimilarity indices also showed the greatest differences in soil properties between undisturbed prairie and disturbances constructed with topsoil stripping or ditch witching.

5.2 Ground Cover

Ditch witching and topsoil stripping were the only construction types significantly different from one another and from undisturbed prairie for ground cover. Pipelines constructed with a ditch witch were more likely to have lower cover of moss and lichen and higher bare ground than topsoil stripping, and higher bare ground exposure than undisturbed prairie. Topsoil stripping pipelines were more likely to have lower cover of litter than undisturbed prairie. Plow-in pipelines were relatively similar to undisturbed prairie with greater likelihood of higher moss and lichen cover. Well sites constructed with topsoil stripping were more likely to have higher bare ground, higher herbaceous cover and lower club moss and lichen. Minimal disturbance well sites were more similar to topsoil stripping than undisturbed prairie. Dissimilarity indices showed that the greatest differences in ground cover were between individual well sites constructed with topsoil stripping and adjacent undisturbed prairie.

5.3 Plant Species Composition

Ditch witch and topsoil stripping pipelines had significantly different species composition from each other and from undisturbed prairie. Topsoil stripping was more likely than ditch witching to have lower abundance of northern wheatgrass and pasture sage and higher abundance of prairie sage and Canada thistle. Plow in pipelines and undisturbed prairie were further differentiated from ditch witch pipelines and were more likely to have lower abundances of pasture sage and native rhizomatous grass (northern wheatgrass) and higher abundance of native tufted grass (plains rough fescue) and prairie sage.

Well sites constructed with topsoil stripping had significantly different species composition from minimal disturbance well sites and undisturbed prairie, with greater likelihood of higher abundances of non-native perennial forbs, non-native rhizomatous grasses (smooth brome, Kentucky bluegrass), non-native tufted grasses, native rhizomatous grasses (western wheatgrass) and lower abundances of native tufted grasses (western porcupine grass, plains rough fescue and junegrass), sedges (low sedge) and pale comandra. Well sites most similar to undisturbed prairie were minimal disturbance and only one of the many well sites constructed with topsoil stripping. Individual minimal disturbance well sites were least different from their adjacent undisturbed prairie sites in composition of dominant prairie species and abundance of plants within different functional groups. Individual topsoil stripping well sites had greater range of dissimilarity with adjacent undisturbed prairie sites.

5.4 Discussion

Construction method had a significant impact on soil and vegetation on pipelines. Many of these effects were associated with how topsoil was handled during construction. Topsoil is not usually conserved in ditch witch construction and not always completely conserved in topsoil stripping; it is often difficult to separate from lower soil horizons during removal and can be mixed with subsoil containing higher cation concentrations, electrical conductivity and pH, and lower organic carbon, nitrogen and other nutrients. Although practical only for small diameter pipelines, plow-in minimizes soil disturbance by slicing into the topsoil where the pipe is placed. Plow in and minimal disturbance construction techniques are intended to leave topsoil and sod intact over most of the right of way, buffering against damage. Vegetation can re-establish from plant roots, crowns and seeds not damaged during construction, and have more suitable soil conditions than if topsoil was removed and replaced. If construction involves soil disturbance the seed bank may be diluted, or seeds may be buried too deep to germinate.

Soils were compacted with all construction types, with greater changes from topsoil stripping. At depths approaching 20 cm, bulk density and penetration resistance were reduced on some topsoil stripping sites, especially if on shallow soils; parent geological material frequently occurs within 20 cm of the soil surface and has no structure, few roots and high clay content, resulting in higher bulk densities and penetration resistance. Naeth (1985), studying pipelines constructed with topsoil salvage and replacement in solonetzic soils, also found bulk density increased in upper levels of the trench and decreased at lower depths, resulting from shattering of the Bnt horizon. On minimal disturbance sites surface compaction is partly buffered by sod (Naeth 1985) and is expected to persist over a shorter time because of retained organic matter, soil microorganisms and roots.

Soil moisture needs to be considered when implementing minimal disturbance construction techniques. One well site at Rumsey Block constructed in a depressional area with minimal disturbance may have failed due to excess moisture. Soil was impacted over a greater area and acquired more of the properties characteristic of topsoil stripping construction.

With all construction types soil aggregate destruction resulted from heavy machinery. Reduced organic matter can increase soil compaction and reduce productivity (Díaz-Zorita and Grosso 1998, Arvidsson 1998). Roots, organic matter, seed and soil microorganisms can be degraded or die during topsoil removal and storage. Organic matter loss on topsoil stripped disturbances has been quantified in other studies (Naeth 1985, Ostermann 2001, Petherbridge 2000). Diluting organic matter by admixing and degradation by soil handling and compaction may influence soil pH increases via microbial activity reduction. On topsoil stripping well sites in mixed grass prairie, Hammermeister (2001) recorded a decrease in total nitrogen and organic carbon. Ostermann (2001) proposed reduced carbon in the surface 5 cm had an impact on water holding capacity, which for mixed grass prairie, could limit plant growth in drier months. Data from Petherbridge's (2000) study showed that even minimal disturbance construction resulted in changes in carbon, electrical conductivity, pH, and surface bulk density with minimal disturbance, but pH and carbon changes were smaller than with topsoil stripping.

Topsoil stripping and ditch witching create soil disturbance partly responsible for excessive bare ground, but not all topsoil stripping sites had high bare ground. Revegetation method and low grazing pressure may have contributed to reduced bare ground. Scalping during topsoil replacement caused bare ground (Ostermann 2001). Petherbridge (2000) found higher bare ground and lower vegetation and litter cover the first year after construction when soil was not stripped. In year two, live vegetation was comparable to undisturbed prairie but bare ground stayed higher. Stripped work zones had lower live vegetation than unstripped ones in the first year but not the second year. Stripped pipelines had higher bare ground than unstripped ones both years.

Changes in soil quality from topsoil disturbance may be partly responsible for excessive bare ground. In turn, the smooth surface produced by soil particle redistribution during erosion probably offers few microsites where seeds and seedlings can take advantage of accumulated moisture and nutrients. Rapid germination and establishment on fresh disturbances are critical to curb this cycle. Soil compaction influences plant production by restricting roots and reducing size and continuity of pores important for water and nutrient availability (Naeth 1985, Naeth et al. 1988, Naeth et al. 1990a). Where soil compaction increased available water at the soil surface, germination may be facilitated (Naeth 1985), but with root penetration and hydraulic conductivity limitations, seedling survival would be poor. Exposed soil results in higher summer soil temperatures, beyond those optimal for plant water use efficiency, even though a longer period of warmer spring and fall temperatures could help plants to complete their life cycles (Naeth 1985).

Little club moss occurs in climax grasslands and increases with grazing pressure, so it was expected that minimal disturbance or plow in pipeline installment, with minor impacts to the soil, would impact the plant community similarly to heavy grazing. This was not the case. On the two plow-in pipeline locations club moss and lichen were unexpectedly absent or present in small amounts. One of them was as different from undisturbed prairie as pipelines constructed with the other techniques. It was constructed on a steep hill where dry growing conditions were exacerbated by drought, delaying vegetation recovery and accumulation of litter. It may have been too dry during plow-in construction, resulting in more tearing of the sod than cutting (Cole Personal Communication). On minimal disturbance well sites, moss and lichen were absent or present in small amounts, but never more than on undisturbed counterparts. Petherbridge (2000) reported a 75-80 % reduction in club moss over the work zone of a pipeline shortly after it was constructed without topsoil stripping. Ostermann (2001) found vehicle traffic on club moss in the work zone (which was unstripped during construction) reduced it by over 70 %; that which survived was more vulnerable to further reductions from livestock trampling.

With minor impacts on the plant community, minimal disturbance sites were expected to have more similar litter and herbaceous cover to undisturbed prairie than those constructed with other construction techniques, but most were just as different as the other construction techniques. Petherbridge (2000) found that after the second year, live vegetation cover on minimal disturbance pipelines was comparable to undisturbed mixed grass prairie although bare ground stayed higher. Stripped work zones had lower live vegetation than unstripped ones in the first year but not in the second year. Stripped pipelines had higher bare ground than unstripped ones in both years.

Topsoil stripping sites had higher amounts of native or introduced colonizers. Ostermann (2001) found the same results on 12 year old pipeline trenches in southern Alberta. Minimal disturbance techniques used at Rumsey Block left sod and topsoil intact over most of the right-of-way so vegetation could establish from plant roots, crowns and seeds. One exception was a well site constructed in a depression where sod was broken through because of high moisture during construction. As a result, the vegetation was composed of more disturbance colonizers than late seral species. Minimal disturbance in Desserud's (2006b) study of pipelines referred to trench stripping and construction after the growing season or in winter with dry or frozen soils. Although similar to topsoil stripping in the current study, she found better restoration. Compared to full right-of-way topsoil stripping, she found higher foothills rough fescue, likely due to increased exposure to seed rain and tillering of adjacent fescue plants. Petherbridge (2000), comparing trench and full right-of-way topsoil stripping, confirmed trench only construction conserved more of the predisturbance community.

Patchiness of construction techniques across a right-of-way can result in variable plant community establishment. The well site with the greatest species richness had over 2/3 more species than adjacent undisturbed prairie due to patchiness of vegetation across the right-of-way. This probably resulted from variability in disturbances. Soil removal and stockpiling close to the well head resulted in patches of native and non-native colonizers. Where topsoil was left intact, species that increase with disturbance or grazing established. The site was probably abandoned once production was stopped without final reclamation and revegetation that would have resulted in more uniform vegetation. Varying degrees of species diversity were found across the right-of-way in Ostermann's (2001) study. Trenches and undisturbed grassland had severe and minimal amounts of disturbance, respectively, and both had the least diversity. The spoil and work zones had moderate amounts of soil disturbance but had the most species diversity. At Rumsey, most minimal disturbance well sites and plow-in pipelines had comparable species richness to undisturbed prairie.

6.0 Influence of Revegetation Method

6.1 Soils

Pipelines seeded to an agronomic mix or revegetated through natural recovery had significantly different soil properties from undisturbed prairie and were more likely to have lower organic carbon and nitrogen and higher bulk density, pH, electrical conductivity and magnesium and calcium concentrations. Well sites seeded with either the agronomic or Rumsey mix had significantly different soil properties from undisturbed prairie, with greater likelihood of higher bulk density, calcium and potassium concentrations, clay and pH, and lower organic carbon and nitrogen. Some of the well sites whose soils were similar to those of undisturbed prairie were seeded to the Rumsey mix and some to an agronomic mix. Well sites revegetated by natural recovery and those seeded with Rumsey mix had significantly different soil properties from one another. Some natural recovery well sites had higher clay, calcium, magnesium and sodium concentrations and electrical conductivity and lower sand. Despite these patterns uncovered by NMS ordination and MRPP group testing, dissimilarity indices showed that differences in soil properties between undisturbed prairie and individual well sites or pipelines had no clear relationship to revegetation method.

6.2 Ground Cover

Ground cover was not significantly different among revegetation methods for well sites or pipelines. Only natural recovery pipelines were significantly different from undisturbed prairie and were more likely to have higher stones and bare ground and lower litter. Ground cover dissimilarity values between individual disturbances and undisturbed prairie were smallest on individual sites along the 1976 large diameter pipeline revegetated with an agronomic mix. Well sites revegetated with the Rumsey or agronomic mix had significantly different ground cover from undisturbed prairie. They were more likely to have lower club moss and lichen. Some of the seeded well sites were likely to have high bare ground and low herbaceous cover. Unlike with pipelines, well sites had no clear relationship between revegetation method and dissimilarity of ground cover between individual disturbances and undisturbed prairie.

6.3 Plant Species Composition

Species composition of pipelines seeded to the Rumsey mix or revegetated via natural recovery were significantly different from one another and from undisturbed prairie. Pipeline sites seeded with the Rumsey mix were more likely to have higher abundances of native rhizomatous grasses (mostly northern wheatgrass) and pasture sage and lower abundances of native tufted grasses (mostly plains rough fescue) than natural recovery and undisturbed prairie. Some sites revegetated with the agronomic mix were similar to undisturbed prairie and others were more similar to natural recovery.

Although the different well site revegetation types yielded significantly different species composition from one another, only seeded ones were different from undisturbed prairie. Sites most similar to undisturbed prairie were revegetated by natural recovery, and one seeded to the Rumsey mix. Many Rumsey mix well sites were different from agronomic mix sites with lower non-native plants and higher abundances of native rhizomatous grasses (western wheatgrass). Natural recovery well sites were more likely than seeded ones to have higher sedges and native tufted grasses (plains rough fescue) and lower non-native perennial forbs, non-native rhizomatous grasses (smooth brome) and non-native tufted grasses. Some exceptional natural recovery well sites were different from undisturbed prairie with higher non-native perennial forbs, non-native rhizomatous grasses (Kentucky bluegrass) and native rhizomatous grass (western wheatgrass) and lower native tufted grass (western porcupine grass, plains rough fescue), sedge (low sedge) and pale comandra. Individual natural recovery well sites were not as different from undisturbed prairie as individual well sites revegetated with either seed mix with respect to abundance of undesirable species, dominant prairie species and abundance within functional groups.

6.4 Discussion

The lack of differentiation in soil properties among older disturbances revegetated with various methods indicates construction method was more influential than revegetation method. Changes in soil physical and chemical properties may have reduced plant germination and establishment incrementally. Sites with the poorest soil reclamation in this study also had lowest live vegetation and litter cover, regardless of revegetation method. Environmental factors and grazing may have had a large influence on results for all revegetation methods. For example, pipelines with high bare ground were located on upper slope positions which can be a challenge for vegetation establishment.

In some cases, establishment and maintenance of a productive native or non-native stand from seed served to ameliorate some soil impacts. The greatest benefit seems to be to soil bulk density and total organic carbon and nitrogen. Six disturbances constructed with topsoil stripping had similar soil properties to undisturbed prairie, possibly related to vegetative productivity. All except one had been successfully seeded with either native or non-native species and were productive. Plant rooting starts a cycle of soil improvement (Naeth 1985) but poor establishment could allow changes in soil quality to persist. Caspall (1975), studying mine soils in Illinois, suggested that under controlled erosion and grass and legume cover, a topsoil layer with organic matter and desirable properties could develop in 20-30 years.

All except two pipelines with high bare ground were revegetated by natural recovery, but not all pipelines revegetated by natural recovery had high bare ground. Well sites experienced a different trend. All except one of the well site disturbances with high bare ground were seeded to an agronomic or Rumsey mix, but not all seeded sites had high bare ground cover. One of the key differences is that natural recovery was more frequently practiced on pipelines where topsoil was handled; well sites constructed with topsoil stripping were seeded to either the Rumsey native or agronomic mix. The ditch witch left very poor conditions for natural recovery with its mixing of topsoil and subsoil. The plow in method isn’t completely without soil disturbance and construction of this one was followed by several years of dry growing conditions.

In this study there was no distinction between ground cover properties of the agronomic mix and those of the Rumsey native mix. Ostermann (2001) found no difference in ground on pipelines with a tame pasture mix containing tame wheatgrasses, wild ryes and legumes and a native pasture mix containing native wheatgrasses, Canada bluegrass and Nuttall’s alkali grass. Bare ground remained above thresholds for the first four years, possibly due to the drought in the late 1980s but by year 12 was three times the amount of litter on the sites as on undisturbed prairie. Biomass yield for the pasture mix was slightly less than the native mix, but noticeably more than on undisturbed prairie. Other research comparing native and tame species over time also shows that although tame species have accelerated productivity after establishment, they quickly diminish to seeded native species productivity (Pelech 1997, Redente et al. 1984, Doerr et al 1983).

Early colonizing native species, such as wheatgrasses, and, despite no fertilizer application, non-native species have persisted in abundance on some well sites and pipelines at Rumsey Block. All well sites with low species richness were successfully revegetated with either seed mix. Seeding an agronomic or native mix can result in a community resistant to invasion of desirable native species, keeping it distinct from undisturbed prairie. Desserud (2006b) found that once sheep fescue became dominant, it prevented invasion by native grasses. The native northern wheatgrass, however, coexisted with both sheep fescue and native grasses but did not hinder or facilitate invasion of native grasses into the sheep fescue community. With the exception of weedy annuals and short lived perennials (Naeth 1985, Petherbridge 2000, Hammermeister 2001, Ostermann 2001), what vegetation initially developed after disturbance tended to prevail (Samuel and Hart 1994). Ostermann (2001) suggested rhizomatous non-native and native grasses dominating pipeline trenches in either foothills fescue grassland or mixedgrass prairie probably got an early start.

Most disturbances revegetated via natural recovery or seeded with the native Rumsey mix were dominated by native wheatgrasses and pasture sage because those are disturbance colonizers. That portion of the Rumsey mix containing disturbance colonizers is likely the most successful to establish, which is supported by Ostermann's (2001) findings of successful initial establishment of slender wheatgrass but not June grass or foothills rough fescue. From studies of pipelines seeded on mixed grass prairie, she proposed western and northern wheatgrasses in a native mix were supplemented by seed bank supply and invasion of these colonizers from undisturbed grassland.

Only one well site constructed with both topsoil stripping and seeded to the Rumsey native mix had similar species composition to undisturbed prairie. Study of soil chemical and physical properties of this well site showed topsoil was handled carefully, creating a suitable growth medium for plant establishment. Despite this it may be possible that poor success was found in seeding the right-of-way with the Rumsey native mixture and that early successional species, followed by later successional ones, could more easily invade. The remoteness of this well site may have resulted in lower grazing pressure during vegetation establishment.

Where smooth brome and Kentucky bluegrass were seeded, they occurred in large amounts; where small amounts occurred, they may have originated from seed on unclean equipment or as a contaminant in seed sources. Unlike the bunch-forming introduced grasses in the mix allowing invasion of desirable native wheatgrasses in Ostermann's (2001) study, smooth brome and Kentucky bluegrass are mat forming perennials which can minimize invasion of native plant species. They are aggressive invaders of undisturbed prairie where grazing puts too much pressure on native plant communities and/or soil moisture is abundant. Because of these qualities they are among the non-native species of most concern at Rumsey Block. Even though very small amounts of these species were found on or adjacent to the pipelines or well sites studied, reconnaissance observations revealed moister locations had abundant Kentucky bluegrass or smooth brome. Desserud (2006b) also found more Kentucky bluegrass in moister sites in the foothills and montane regions. Neither smooth brome nor Kentucky bluegrass was included in any seed mixes on the pipelines that she studied. They were likely present in the seed bank and activated after soil disturbance. Smooth brome seed may have originated in hay brought on site to feed livestock. The 1976 pipeline at Rumsey Block is the only one studied that was reportedly seeded to an agronomic mix although few non-native species were found. This may be a failed establishment or species planted were short lived, allowing invasion of native species.

Sites constructed with minimal disturbance, including plow-in pipelines, were revegetated by natural recovery. They had species composition and richness similar to that of undisturbed prairie, because sod containing plant roots, crowns and seeds was left intact. One well site did have slightly different species composition from the other natural recovery sites because sod and topsoil were damaged during constructed in moist conditions and some of the soil physical and chemical conditions of the soil were altered. Thus, it was dominated by western wheatgrass and other native colonizers. On the remainder of the minimal disturbance well sites, changes in species composition were expected to reflect disturbances that put pressure mostly on the plant community. Like with grazing, rough fescue was expected to decrease, with subsequent increases in increaser species such as western porcupine grass, northern and western wheatgrasses, June grass, sedges and pasture sage. Except for one minimal disturbance well site, there were increases in plains rough fescue and decreases in western porcupine grass.

As mentioned above, natural recovery pipelines that were distinct in ground cover characteristics from undisturbed prairie were constructed with soil removal and replacement over the trench. The same distinctness occurred in species composition. Natural recovery had better results with ditchline topsoil stripping in Desserud's (2006b) study. These narrow disturbances constructed between August and April were most similar to, if not indistinct from, undisturbed grassland because they were directly exposed to invasion through seed rain and tillering of foothills rough fescue plants on the intact right-of-way. Possible explanations for the contrary results may be moister growing conditions of the foothills and montane regions or more careful topsoil handling.

Very many pipelines and well sites with low species richness were successfully revegetated with either the agronomic or the Rumsey native seed mixes. Natural recovery resulted in high species richness on some pipelines but on only one well site. Soulodre (2001) suggested natural recovery is better to achieve a diverse plant community than seeding with mixes containing even small amounts of native wheatgrass cultivars, but drawbacks included risk of invasion by non-native perennials and soil erosion due to greater amount of bare soil and slower vegetation recovery time. Petherbridge (2001) found the opposite. Seeding disturbances, whether constructed by minimal disturbance or topsoil stripping, resulted in higher species richness than non seeded trenches, but species richness was still lower than on undisturbed prairie. This likely resulted from presence of native and introduced annual weeds and species. With natural recovery, he did not find as many perennial native species on recent topsoil stripping or minimal disturbance pipelines (as with seeding). He suggested that although seeding minimized competition from annuals, this competitive advantage may result in exclusion of perennial natives over the longer term.

Smaller scale disturbances, like those over small diameter pipelines or at the well head of minimal disturbance sites, could be colonized rapidly by native wheatgrasses, but such invasion would be delayed on open soil disturbance over an entire well site right-of-way. Natural recovery potential can be limited by environmental conditions, grazing pressure, and growing conditions imposed by soil changes after construction. Moister growing conditions are an additional risk; non-native rhizomatous grasses, if present on adjacent undisturbed grassland, may invade natural recovery sites, making this a less favourable means to restore larger areas. For example, the only well site in the present study constructed with topsoil stripping and revegetated by natural recovery was contaminated with Kentucky bluegrass which will probably continue to increase because it is a more aggressive colonizer of disturbances than native colonizers.

Although ditch witching of two pipelines resulted in the most severe soil disturbance, leaving poorer soil physical and chemical conditions for natural recovery they still had near average species richness values. The only natural recovery pipeline with low species richness was also the youngest. Dry conditions of the upper slope, higher relative grazing pressure and sequential drought years have likely delayed its recovery.

On two well sites, lack of revegetation success combined with grazing resulted in greater species richness. One had over 2/3 more species than undisturbed prairie due to vegetation patchiness across the right-of-way; there were communities of non-native species, native colonizers, native species that increased with grazing and shrubs. This is suspected to have resulted from variability in disturbances across the right-of-way and site abandonment without a final revegetation effort that would have resulted in a more uniform vegetation community.

7.0 Influence of Grazing

7.1 General Rangeland Health of Well Sites and Pipelines and Undisturbed Prairie

Most pipelines and well sites have poorer rangeland health scores than adjacent undisturbed prairie, with differences ranging from small to large. Most pipelines are very different from adjacent undisturbed prairie on scores of ecological integrity and soil stability. Litter cover was inadequate on almost half of the sites, whether they were pipelines or undisturbed prairie. Scores for plant community structure and noxious weed distribution and

Table 7.1 Summary of Range Health Scores for Well Sites and Pipelines and Undisturbed Prairie

Health Class (Score)	Pipelines		Well Sites	
	Disturbed	Undisturbed	Disturbed	Undisturbed
Healthy (45 - 60)	4	8	2	21
Healthy with Problems (30 - 44)	7	8	13	8
Unhealthy (0 - 29)	6	1	21	7

abundance were high for most pipelines and undisturbed prairie. Most well sites were very different from undisturbed prairie in ecological integrity, plant community structure and presence and abundance of noxious weeds. Litter cover was inadequate for approximately half the sites, regardless of whether they were disturbed or not. It was more plentiful on twelve of 36 well sites than on undisturbed prairie. Scores for soil exposure and stability indicators were lower on half the well sites than undisturbed prairie and a quarter of the well sites had higher scores.

7.2 Soils

Well site exclusion fencing categories had no significantly different soil properties from one another, but those never fenced and those currently fenced were significantly different from undisturbed prairie. They are more likely to have greater pH and 0-20 cm bulk density and lower organic carbon and nitrogen. The greatest dissimilarities in overall soil properties between individual well sites and adjacent undisturbed prairie occurred where there was never exclusion from livestock use.

7.3 Ground Cover

As a group, currently fenced well sites had significantly different ground cover characteristics from those never fenced; both were significantly different from undisturbed prairie. In general, club moss and lichen cover was higher on undisturbed prairie than on sites never fenced and even higher than on sites that were fenced at the time of sampling. Most historically fenced well sites had similar ground cover to undisturbed prairie. Dissimilarity indices showed differences in ground cover between individual well sites and adjacent undisturbed prairie were highly variable but there was no clear relationship to livestock exclusion.

7.4 Plant Species Composition

None of the well site fencing groups had significantly different species composition from one another but they were all different from undisturbed prairie. They were more likely to have higher abundance of native rhizomatous grass, western wheatgrass, non-native rhizomatous grass, smooth brome and/or Kentucky bluegrass and lower abundance of native tufted grass, plains rough fescue, western porcupine grass, June grass and/or low sedge than undisturbed prairie. Dissimilarity in species composition between individual well sites and adjacent undisturbed prairie showed no clear relationship to livestock exclusion.

7.5 Discussion

Care must be taken in using rangeland health assessment to explain soil and plant community status after pipeline or well site disturbance. Many factors other than grazing impacted each of the indicators. This discussion is based on the relative grazing pressure on pipelines and well sites at Rumsey and considers livestock trailing, forage utilization, presence of cattle or feces and hoof imprints.

Lack of soil property differences among fencing strategies was expected since construction and revegetation were expected to play stronger roles. Fencing was not coincidental with age, construction method or revegetation technique, so cannot be tied to relationships discussed previously. Fencing did not provide permanent exclusion from grazing as gates were occasionally opened to allow grazing.

Much ground cover variability among pipelines and well sites may have been due to topography and changes in relative grazing pressure across the landscape. A good example of this is in the five samples along the same pipeline. Since the pipeline was sampled on upper to mid slopes, grazing differences were suspected to play a large role in cover. All except two disturbances with high bare ground were associated with relatively high grazing pressure, loafing or trailing. One exception was a plow-in pipeline on a steep hill that was slow to revegetate due to dry conditions. This hill is probably too steep for cattle to access frequently.

Disturbances with high bare ground appeared to be heavily impacted by cattle grazing or loafing. Naeth (1985) warned against using palatable and productive species to reclaim disturbances because that would lead to over use. All except one well site at Rumsey Block with high bare ground from grazing were dominated by palatable non-native plants that led to over utilization. However, not all sites seeded to palatable non-natives had excessive bare ground. Ostermann (2001) also found grazing significantly increased bare ground on pipelines in mixed prairie and foothills grassland.

The differences in live vegetation cover between disturbances and undisturbed prairie were not consistent among pipelines or well sites regardless of age or construction or revegetation method. Other studies also had inconsistent results. Live vegetation cover on disturbances can increase with grazing in some cases (Ostermann 2001), decrease in others (Soulodre 2001) or be unaffected (Ostermann 2001). Soulodre (2001) found that although June and July grazing transitioned live vegetation into litter cover through trampling, bare ground still increased, even in highly productive wheatgrass swards.

Some pipelines had substantial shrub cover which may have facilitated revegetation through protection from livestock and snow trapping. Soil bulk density reduction at greater depths from deep shrub roots may have created favorable conditions for water conductivity, but bulk density was not consistently lower on these pipelines. This was not always the case; one pipeline with high herbaceous cover had little shrub cover but was close to the road and thus had frequent cattle access. It successfully revegetated with grazing tolerant species (sedges, pasture sage, wheatgrasses, June grass) so substantial herbaceous cover still exists.

The differences in litter cover between disturbances and undisturbed prairie were also not consistent among pipelines or well sites regardless of age or construction or revegetation method. Grazing decreases accumulated litter in some cases (Ostermann 2001) but increases it in others (Naeth 1985, Soulodre 2001). Naeth (1985) suggested timing of grazing was critical. Later in the growing season, plants on disturbances are mature and less palatable so they are likely to be trampled or avoided, especially if they are annual weeds.

Litter of seeded disturbances can accumulate until it exceeds that of undisturbed prairie and can even become stifling in moister regions like the foothills grassland (Ostermann 2001). Several well sites at Rumsey Block were characterized by excessive litter accumulation. One was fenced and successful establishment of an agronomic mix in the absence of grazing led to litter accumulation. Another seeded to the native Rumsey mix was fenced but occasionally opened to allow grazing. At the time of sampling, much of the vegetation was trampled rather than eaten, which contributed to the high litter. Access to this site may have occurred after forage growth and maturation, making it less palatable.

Remoteness from roads, gates or watering sites often means certain locations are accessed less frequently or later in the grazing season than locations closer to these amenities. This could affect the season of use and palatability of forages, resulting in higher potential to revegetate after disturbance and possibly accumulate litter. One productive well site seeded to a mix of non-native species was not excluded from cattle but located far from main roads, fences and water sources so cattle use was low. Remoteness of one topsoil stripping well site seeded to the Rumsey mix may have led to lower grazing pressure, which may have, in turn, resulted in species composition very similar to undisturbed prairie.

Judging from commonalities among pipelines and well sites whose species composition was most distinct from undisturbed prairie, grazing at Rumsey could be improving species diversity but limiting establishment of later seral species. Those with the highest species richness had signs of heavier long term grazing. Limiting growth potential of established plants by grazing probably gave native invaders a better chance of establishing on a disturbance, thereby improving diversity. Ostermann (2001) also found diversity (including evenness) was improved by grazing. Research on seed bank diversity has shown that the commonly held idea that higher diversity accompanies intermediate levels of disturbance can be reflected in diversity of the seed bank (Levassor et al. 1990). Soulodre (2001) found grazing on disturbances revegetated through natural recovery increased weed seed density in the seed bank but suggested this may delay seed bank succession when weed abundance impacts grass seed production.

Soulodre (2001) determined that disturbances successfully established with native wheatgrass cultivars will remain in that state unless the state is broken by grazing impacts. Grazing is expected to have played a part in creating or perpetuating the patchiness of vegetation on one abandoned well site that has the greatest species richness.

Grazing may have combined with the effects of soil impacts and sequential years of drought to limit succession on some disturbances constructed with topsoil stripping or ditch witching. Heavier grazing in moist areas of the landscape may be responsible for presence of Kentucky bluegrass and smooth brome that put pipelines and well sites at risk of invasion by these non-native grasses which may lead to restoration failure. Ostermann (2001) found grazing increased tufted plants in foothills grasslands, partly by reducing stifling litter cover; grazing in mixed grass prairie decreased tufted grass cover, partly by removing insulating litter cover. She also found late season grazing aided in reducing cover of Kentucky bluegrass in foothills grasslands by increasing cover of tufted grasses. This allowed tufted grasses, whose spread is dependent on seed, to complete their life cycles before being utilized (Naeth 1985). Rhizomatous native and non-native grasses able to spread vegetatively, are more tolerant of disruption during their annual cycles. Early to late summer grazing is practiced at Rumsey, which is detrimental to the longevity of plains rough fescue (Willms et al. 1988) and western porcupine grass (Naeth 1985, Ostermann 2001). Although Desserud's (2006b) pipeline survey did not focus on grazing impacts, she suggested higher grazing pressures may partly determine species composition, especially the presence of non-native species. She suggested spring grazing by cattle and/or elk may have contributed to absence or low cover of foothills rough fescue on pipelines; sheep fescue may have increased because of its tolerance of grazing.

8.0 Research Conclusions

Almost all well sites and pipelines studied at Rumsey block have not yet reached reclamation goals for vegetation or soils. Most disturbances were easy to spot on the landscape because of different ground cover characteristics and species composition.

Pipelines and well sites had consistently different soil and plant characteristics from undisturbed prairie. Contrary to the assumption that soil and plant community conditions improve with time, differences between older pipelines and well sites and undisturbed prairie were greater than for newer ones, since construction and reclamation methods have improved over time.

Disturbances where topsoil was removed and replaced appear to be furthest from reclamation success. Some of the well sites and pipelines constructed recently with minimal disturbance techniques are in better condition than many constructed a few decades ago with topsoil stripping. Regardless of revegetation method and age, pipelines and well sites constructed with methods involving topsoil handling were generally dominated by early colonizing plant species. Ditch witch construction of pipelines was more disruptive to soil properties than topsoil stripping construction. Soil handling should be avoided or minimized to the smallest possible area.

This study focused on the degree of impact of sampling points within each disturbance. It does not take into account the area of land disturbed. For example, ditch witch pipeline installment has a narrower area of soil disturbance compared to bucket-width topsoil salvage over the trench but it has greater impacts on soil quality. Topsoil salvage and replacement occur over a larger area, but may have better chance than ditch witching for revegetation success because soil chemical and physical properties have undergone less alteration.

Most soil properties on the disturbances lie within biological limits, although what the cumulative impacts are of these changes is uncertain. For example if disturbance elevates bulk density and increases pH and dilutes organic matter through admixing, is it less likely to be successfully reclaimed than if there is simply an increase in bulk density?

Natural recovery was more effective on pipelines constructed without soil and sod disturbance than on disturbances where sod was removed and soil handled. Disturbances did not establish cover as quickly with natural recovery as with revegetation by seeding. Natural recovery is the most appropriate revegetation strategy for small scale soil disturbances.

Seeding with native or agronomic mixes can ameliorate soil conditions, assuming successful establishment and well managed grazing, but the seeded community is expected to persist indefinitely.

For some reclamation efforts at Rumsey Block there appears to be a disconnect between prescribed revegetation methods and those that actually occurred. This may be caused by misinterpretations or modifications of prescriptions without the understanding of the ecological implications of those actions. Despite the inclusion of plains rough fescue in the prescribed Rumsey seed mix, it is unlikely that this species has been seeded on any of the disturbances studied.

Heavy and repetitive grazing was associated with poor restoration of soil and plant community characteristics even though many of these sites had higher species richness. This study cannot scientifically conclude that heavier grazing pressure will result in invasion of non native plant species onto undisturbed prairie from disturbances established with those species, but given the aggressive nature of some of those species it is reasonable to expect this, especially on moist to mesic sites which are favourable to smooth brome and Kentucky bluegrass.

Neither complete livestock exclusion nor non-exclusion is suitable for improving reclamation success. Some balance of livestock access and exclusion is needed to allow the recovery of soil and plant community characteristics after disturbance.

None of the influential factors works alone in determining reclamation success. One good example is the performance of natural recovery on minimal disturbance versus topsoil stripping or ditch witch disturbances. Another example is the variability in outcomes among seeded disturbances exposed to a variety of relative grazing pressures. A combination of minimal disturbance with natural recovery appears to have the highest probability of reclamation success.

A multi-stage approach may be most appropriate for revegetating large scale disturbances. This would involve seeding a native early seral mix to ameliorate soil conditions, then modifying the cover so that later seral plant species can invade or be seeded onto the disturbance.

The lack of importance placed historically on record keeping and verification of construction and reclamation methods frustrates those acquiring and managing these disturbances or those managing land that contains them. The good species composition conditions found on one well site constructed in the 1980s and on the large diameter pipeline constructed in 1976, both with topsoil stripping, are of particular interest but due to lack of reclamation records, it is difficult to determine what caused these conditions.

9.0 Recommendations

Better records of construction and reclamation methods and grazing management should be kept so that the relationship of these factors to reclamation success can be evaluated.

Because knowledge of how to successfully restore plains rough fescue prairie is unavailable, construction techniques should be restricted to those that will reduce disturbance to sod and soil. Area of disturbance should be minimized. Moisture conditions and plant growth stages influence a technique’s impact and thus, equipment size and type and timing of construction should be managed to address these factors. Revegetation by natural recovery should continue on these areas of minimal disturbance. Where larger topsoil disturbances are necessary, however, seeding with the most up to date native mix may be more appropriate.

Topsoil salvage and replacement should continue where necessary only over trenches. If possible, sod should be conserved, and should be cut deep enough to prevent damage to deep rooted native grasses such as plains rough fescue, western porcupine grass, bearded wheatgrass, June grass and sedges. It should be kept from drying out and be replaced as soon as possible.

Even though the influence of weeds was not investigated in this research, it is worthwhile to note that disturbances need to be monitored for these species and suitable control measures applied as soon as possible. Measures may need to be taken to prevent non-native grasses from outcompeting desired native species, on or off the right of way, whether by grazing management or mowing, or selective application of herbicide.

Grazing management improvements may enhance reclamation success. Livestock access should be allowed, but not for prolonged periods. Making an effort to monitor livestock impact on all disturbances will help land managers to make changes to short-and long-term grazing management.

Some pipelines and well sites may need intervention to improve reclamation, especially for species composition. Although some seeding strategies have resulted in ameliorated soil, the seeded plant community appears resistant to invasion of later seral native species. One alternative is multiple stage reclamation: first ameliorating soil with short lived and deep rooted productive grasses, then altering the vegetation cover with herbicide application or grazing to allow establishment of later seral native species from broadcast seed or invasion from adjacent prairie.

The modified AMOEBA diagrams, bar graphs summarizing measured variables in this study for each pipeline (Appendix B), can be compared to determine which disturbances are priorities for intervention. By assessing many variables from different data sets (soils, ground cover, species composition) managers can interpret the larger picture of reclamation status of a disturbance and formulate appropriate measures for improvement.

10.0 References

Adams, B.W., G. Ehlert, C. Stone, M. Alexander, D. Lawrence, M. Willoughby, D. Moisey, C. Hincz and A. Burkinshaw. 2003. Rangeland health assessment for grassland, forest, and tame pasture. Public Lands and Forests Division, Alberta Sustainable Resource Development. Pub. No. T/044. Edmonton, Alberta. 120 pp.

Alberta Energy and Utilities Board. 2002. Principles for minimizing surface disturbance in native prairie and parkland areas. Informational Letter EUB IL 2002-1. Edmonton, Alberta.

Alberta Wilderness Association. 2006b. Issues and Areas: Rumsey: Threats. http://issues.albertawilderness.ca/RM/threats.htm. Accessed November 19, 2006.

Alberta Wilderness Association. 2006a. Issues and areas: Rumsey. http://issues.albertawilderness.ca/RM/rumsey.htm. Accessed November 19, 2006.

Arvidsson, J. 1998. Influence of soil texture and organic matter content on bulk density, air content, compression index and crop yield in field and laboratory compression experiments. Soil Tillage and Research 49:159-170.

Bowser, W.E., T.W. Peters and J.D. Newton. 1951. Soil survey of the Red Deer sheet. Report no. 16 of the Alberta Soil Survey. Department of Extension. University of Alberta. Edmonton, Alberta.

Burkinshaw, A. 2006. Rangeland Agrologist, Alberta Public Lands. Personal Communication. August, 2006.

Caspall, F.C. 1975. Soil development on surface mine spoils in western Illinois. In: Proc. Third Research and Applied Technology Symposium on Surface Mining and Reclamation. Louisville, Kentucky, October, 1975. National Coal Association, Washington, D.C. 2:221-229.

Clarke, S.E., J.A. Campbell and J.B. Campbell. 1942. An ecological and grazing capacity study of the native grass pastures in southern Alberta, Saskatchewan and Manitoba. Dominion of Canada Department of Agriculture Technical Bulletin 46. Cited in: Naeth 1985.

Cole, B. Personal communication. Program Manager, Alberta Public Lands. August, 2008.

Desserud, P.A. 2006a. Rumsey ecological review and Rumsey Parkland South. Literature Review. University of Alberta. Edmonton, Alberta. 33 pp.

Desserud, P.A. 2006b. Restoration of rough fescue grasslands on pipelines in southwestern Alberta. MSc Thesis. University of Calgary. Calgary, Alberta. 190 pp.

Doerr, T.B., E.F. Redente and T.E. Sievers. 1983. Effects of cultural practices on intensely disturbed soils. Journal of Range Management 36:423-428.

Díaz-Zorita, M. and G.A. Grosso. 2000. Effect of soil texture, organic carbon and water retention on the compactability of soils from the Argentinean pampas. Soil Tillage and Research 54:121-126.

Environment Canada. 2004. Canadian climate normals 1971-2000: Scollard, AB, and Craigmyle, AB Stations.http://www.climate.weatheroffice.ec.gc.ca/climateData/canada_e.html. Accessed November 15, 2006.

Environment Canada. 2007. Canadian Climate Data Online. http://www.climate.

Faith, D.P, Minchin, P.R. and L. Belbin. 1987. Compositional dissimilarity as a robust measure of ecological distance. Vegetatio 69:57-68.

Hammermeister, A.M. 2001. An ecological analysis of prairie rehabilitation on petroleum wellsites in southeastern Alberta. Ph.D. Dissertation. University of Alberta. Edmonton, Alberta.

Hammermeister, A.M., M.A. Naeth, J.J. Schoenau and V.O. Biederbeck. 2003. Soil and plant response to wellsite rehabilitation on native prairie in southeastern Alberta, Canada. Canadian Journal of Soil Science 83:507-519.

Hickman, L. MSc Candidate. University of Calgary. Calgary, Alberta. Personal Communication. September 17, 2008.

Kruskal, J.B. 1964. Nonmetric multidimensional scaling: a numerical method. Psychometrika 29:115-129.

Levassor, C., M. Ortega and B. Peco. 1990. Seed bank dynamics of Mediterranean pastures subjected to mechanical disturbances. Journal of Vegetation Science 1:339-344.

Lutz, J.F. 1952. Mechanical impedance and plant growth. In B.T. Shaw (ed.). Soil physical conditions and plant growth. Agronomy 2:43-47. Cited in: Naeth 1985.

Mather, P.M. 1976. Computational methods of multivariate analysis in physical geography. J. Wiley and Sons. London, England. 532 pp.

McCune, B. and J.B. Grace. 2002. Analysis of ecological communities. MjM Software Design. Glenedon Beach, Oregon. 300 pp.

Mielke, P.W., Berry, J.K. and G.W. Brier. 1981. Application of multi-response permutation procedures for examining seasonal changes in monthly mean sea-level pressure patterns. Monthly Weather Review 109:120-126.

Naeth, M.A. 1985. Ecosystem reconstruction and stabilization following construction through

Solonetzic native rangeland in southern Alberta. M.Sc. Thesis. University of Alberta. Edmonton, Alberta. 213 pp.

Naeth, M.A., A.W. Bailey, D.J. Pluth, D.S. Chanasyk and R.T. Hardin. 1991b. Grazing impacts on litter and soil organic matter in mixed prairie and fescue grassland ecosystems of Alberta. Journal of Range Management 44:7-12.

Naeth, M.A., D.J. Pluth, D.S. Chanasyk, A.W. Bailey and A.W. Fedkenheuer. 1990b. Soil compacting impacts of grazing in mixed prairie and fescue grassland of Alberta. Canadian Journal of Soil Science 70:157-167.

Naeth, M.A., D.J. White, D.S. Chanasyk, T.M. Macyk, C.B. Powter and D.J. Thacker. 1991c. Soil physical properties in reclamation. Alberta Land Conservation and Reclamation Council Report Number RRTAC 91-4. Edmonton Alberta. 213 pp.

Naeth, M.A., D.S. Chanasyk, R.L. Rothwell and A.W. Bailey. 1990a. Grazing impacts on infiltration in mixed prairie and fescue grassland ecosystems of Alberta. Canadian Journal of Soil Science 70:593-605.

Naeth, M.A., D.S. Chanasyk, R.L. Rothwell and A.W. Bailey. 1991a. Grazing impacts on soil water in mixed prairie and fescue grassland ecosystems. Canadian Journal of Soil Science 71:313-325.

Naeth, M.A., D.S. Chanasyk, W.B. McGill, A.W. Bailey and R.T. Hardin. 1988. Changes in soil water regime after pipeline construction in solonetzic native rangeland. Canadian Journal of Soil Science 68:603-610.

Naeth, M.A., W.B. McGill and A.W. Bailey. 1987. Persistence of changes in selected soil chemical and physical properties after pipeline installation in solonetzic native rangeland. Canadian Journal of Soil Science 67:747-763.

Natural Regions Committee. 2006. Natural regions and subregions of Alberta. Compiled by D.J. Downing and W.W. Pettapiece. Government of Alberta Pub. No. T/852. Edmonton, Alberta. 264 pp.

Ostermann, D.K. 2001. Revegetation assessment of a twelve-year old pipeline on native rangeland in southern Alberta. MSc Thesis, University of Alberta. Edmonton, Alberta. 121 pp.

Peat, H. and G. Bowes. 2005. Management of pasture sage. Agriculture and Agri-Food Canada, Research Branch. http://www.agriculture.gov.sk.ca/Management_of Pasture_Sage. Accessed November 25, 2008.

Pelech, W.E. 1997. Performance of selected native and introduced plant species under mowing and herbicide management during the establishment period. M.Sc. Thesis.

University of Alberta. Edmonton, Alberta. 104 pp.

Petherbridge, W.L. 2000. Sod salvage and minimal disturbance pipeline restoration techniques: implications for native prairie restoration. MSc Thesis. University of Alberta. Edmonton, Alberta. 204 pp.

Redente, E.F., T.B. Doerr, C.E. Grygiel, and M.E. Biondini. 1984. Vegetation establishment and succession on disturbed soils in northwestern Colorado. Reclamation and Revegetation Research 3:153-165.

Ryerson, D.E. 1970. Club moss on Montana rangelands: distribution, control, range. Montana Experimental Station. Bozeman, Montana. Bulletin 645.

Samuel, M.J. and R.H. Hart. 1994. Sixty one years of secondary succession on rangelands of the Wyoming High Plains. Journal of Range Management 47:184-191.

Sinton, H.M. 2001. Prairie oil and gas: a lighter footprint. Alberta Environment. 67 pp.

Soulodre, E.M.J. 2001. Restoration ecology of cattle grazing on mixed prairie wellsites: a hierarchical approach. MSc Thesis. University of Alberta. Edmonton, Alberta. 151 pp.

Strong, W.L. and K.R. Leggat. 1992. Ecoregions of Alberta. Alberta Forestry, Lands and Wildlife. Pub. No. T/245. Map at 1:1,000,000 scale. Edmonton, Alberta.

ten Brink, B.J.E., Hosper, S.H. and F. Colijn. 1991. A quantitative method for description and assessment of ecosystems: the AMOEBA-approach. Marine Pollution Bulletin 23:265-270

Wefering, F.M., Danielson, F.E. and N.M. White. 2000. Using the AMOEBA approach to measure progress towards ecosystem sustainability within a shellfish restoration project in North Carolina. Ecological Modelling 130:157-166.

Willms, W.D., J.F. Dormaar and G.B. Schaalje. 1988. Stability of grazed patches on rough fescue grasslands. Journal of Range Management 41:503-508.

APPENDIX A SEED MIXES PRESCRIBED FOR REVEGETATION AT RUMSEY BLOCK

Mix Name (Year)	Species (Cultivar)	Latin Name and Authority	% Composition (By Weight)	Total Seeding Rate (Lb/ac)	Accompanying Practices
Agronomic (pre-1983)	Unknown	Unknown	Unknown	Unknown	Unknown
Rumsey "A" (1983)[1]	Plains rough fescue	*Festuca hallii*	70	30	Any of mixes A, B or C may be broadcast or drilled shallow; fertilize no more than 35 lb/ac N only on sites excluded from grazing; exclude from grazing for at least 2 years
	Slender wheatgrass	*Elymus trachycaulus* ssp. *trachycaulus*	20		
	Streambank wheatgrass	*Elymus lanceolatus* ssp. *lanceolatus*	10 (combined)		
	Northern wheatgrass (Elbee)	*Elymus lanceolatus* ssp. *lanceolatus*			
	Western wheatgrass	*Pascopyrum smithii*			
	Bearded wheatgrass	*Elymus trachycaulus* ssp. *subsecundus*			
Rumsey "B" (1983)[1]	Plains rough fescue	*Festuca hallii*	55	22	
	Slender wheatgrass	*Elymus trachycaulus* ssp. *trachycaulus*	30		
	Streambank wheatgrass	*Elymus lanceolatus* ssp. *lanceolatus*	15 (combined)		
	Northern wheatgrass (Elbee)	*Elymus lanceolatus* ssp. *lanceolatus*			
	Western wheatgrass	*Pascopyrum smithii*			
	Bearded wheatgrass	*Elymus trachycaulus* ssp. *subsecundus*			
Rumsey "C" (1983)	Slender wheatgrass	*Elymus trachycaulus* ssp. *trachycaulus*	45	12-15	
	Streambank wheatgrass	*Elymus lanceolatus* ssp. *lanceolatus*	45 (combined)		
	Northern wheatgrass (Elbee)	*Elymus lanceolatus* ssp. *lanceolatus*			
	Western wheatgrass	*Pascopyrum smithii*			
	Bearded wheatgrass	*Elymus trachycaulus* ssp. *subsecundus*			
	Kentucky bluegrass	*Poa pratensis*	10		

[1]Preferred mix

Mix Name (Year)	Species (Cultivar)	Latin Name and Authority	% Composition (By Weight)	Total Seeding Rate (Lb/ac)	Accompanying Practices
Rumsey "A" (1990)[1]	Perennial or annual ryegrass (Common)	*Lolium perenne or L. perenne* ssp. Multiflorum	10	20	Any of mixes A, B or C may be broadcast or drilled shallow; fertilize no more than 35 lb/ac N only on sites excluded from grazing; exclude from grazing for at least 2 years
	Aurora Hard Fescue (Durar)	*Festuca brevipila*	25		
	Western wheatgrass (Walsh)	*Pascopyrum smithii*	30		
	Northern wheatgrass (Elbee)	*Elymus lanceolatus* ssp. *lanceolatus*	15		
	Canada bluegrass (Reubens)	*Poa compressa*	10		
	Slender wheatgrass (Revenue)	*Elymus trachycaulus* ssp. *trachycaulus*	10		
Rumsey "B" (1990)	Perennial or annual ryegrass (Common)	*Lolium perenne or L. perenne* ssp. Multiflorum	10	20	
	Sheep fescue (Nakiska)	*Festuca ovina*	35		
	Streambank wheatgrass (Sodar)	*Elymus lanceolatus* ssp. *lanceolatus*	25		
	Slender wheatgrass (Revenue)	*Elymus trachycaulus* ssp. *trachycaulus*	15		
	Canada bluegrass (Reubens)	*Poa compressa*	15		
Rumsey (1991)	Green needle grass	*Nasella viridula*	25 by vol.	rate not specified	Slender wheatgrass to be seeded alone at 20% or at 10% with one other wheatgrass; preferred seeding method is by packer drill; fertilization dependent on soil test
	June grass	*Koeleria macrantha*	35 by vol.		
	Sheep fescue	*Festuca ovina*	20 by vol.		
	Slender wheatgrass	*Elymus trachycaulus* ssp. *trachycaulus*	10 x 2 or 20 x 1 by vol.		
	Western wheatgrass	*Pascopyrum smithii*			
	Northern wheatgrass	*Elymus lanceolatus* ssp. *lanceolatus*			

[1]Preferred mix

Mix Name (Year)	Species (Cultivar)	Latin Name and Authority	% Composition (By Weight)	Total Seeding Rate (Lb/ac)	Accompanying Practices
Rumsey "A" (1992)[1]	Plains rough fescue	*Festuca hallii*	12.5	20	Seeding and fertilizing with press drill preferred; broadcast is acceptable if harrowed and packed; fertilize at 100 lb/ac N and 40 lb/ac P
	Indian ricegrass	*Oryzopsis hymenoides*	20		
	Green needle grass	*Nasella viridula*	25		
	June grass	*Koeleria macrantha*	10		
	Western wheatgrass	*Pascopyrum smithii*	17.5		
	Streambank wheatgrass	*Elymus lanceolatus* ssp. *lanceolatus*	15		
Rumsey "B" (1992)	Blue grama grass	*Bouteloua gracilis*	30	20	
	Needle and thread	*Hesperostipa comata*	30		
	Streambank wheatgrass	*Elymus lanceolatus* ssp. *lanceolatus*	15		
	June grass	*Koeleria macrantha*	10		
	Indian ricegrass	*Oryzopsis hymenoides*	15		

[1]Preferred mix

APPENDIX B

SITE DESCRIPTIONS AND MODIFIED AMOEBA DIAGRAMS FOR 17 PIPELINES AND 36 WELL SITES AT RUMSEY BLOCK

AMOEBA is the Dutch acronym for “a general method of ecosystem description and assessment”. It can be used to illustrate the overall reclamation status of each disturbance and to make decisions on how to improve individual site status and prioritize improvement efforts among many sites.

The methods for constructing the following bar charts were modified from the AMOEBA approach described by ten Brink et al. (1991) and Wefering et al. (2000) and are further described in the methods sections of this report. Each diagram contains a subset of variables selected from multiple data sets.

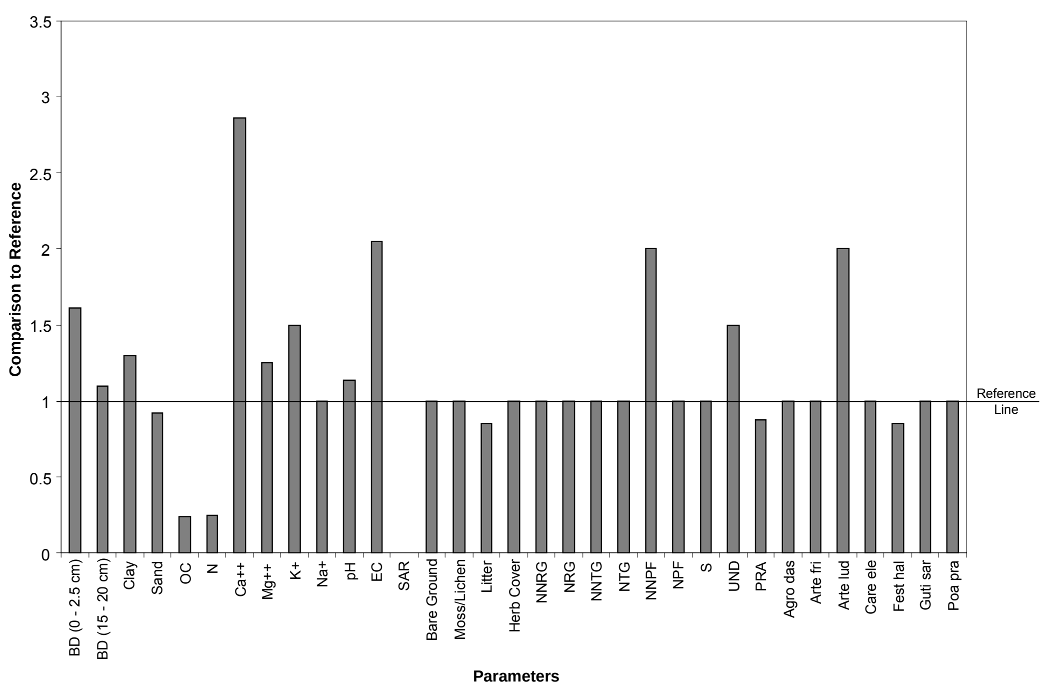
The reference line in each diagram represents the value of each variable on undisturbed prairie adjacent to the disturbance, standardized to 1. The bars represent values for each variable relative to the reference. For example, if organic carbon concentration on the disturbance is half of that on adjacent undisturbed prairie, the bar will have a magnitude of 0.5 on the y axis. The closer a bar is to the reference line, the more similar the disturbance is to the undisturbed prairie for that variable. If many bars are far from the reference line, then many variables are different for the disturbance relative to undisturbed prairie.

The abbreviations on the following page apply to the x axis of each bar chart.

BD	Soil bulk density (Mg m^{-3})
OC	Total organic carbon (%)
N	Total nitrogen (%)
Ca++	Calcium ion concentration (mg $L-^{1}$)
Mg++	Magnesium ion concentration (mg L^{-1})
K+	Potassium ion concentration (mg L^{-1})
Na+	Sodium ion concentration (mg L^{-1})
pH	pH
EC	Electrical conductivity (dS m^{-1})
SAR	Sodium adsorption ratio
NNRG	Non-native rhizomatous grass abundance (%)
NRG	Native rhizomatous grass abundance (%)
NNTG	Non-native tufted grass abundance (%)
NTG	Native tufted grass abundance (%)
NNPF	Non-native perennial forb abundance (%)
NPF	Native perennial forb abundance (%)
S	Sedge abundance (%)
UND	Undesirable species abundance (%)
PRA	Prairie dominant species abundance (%)
Agro smi	Western wheatgrass abundance (%)
Agro das	Northern wheatgrass abundance (%)
Agro rep	Quack grass abundance (%)
Arte fri	Pasture sage abundance (%)
Arte lud	Prairie sage abundance (%)
Brom ine	Smooth brome abundance (%)
Care ele	Low sedge abundance (%)
Fest hal	Plains rough fescue abundance (%)
Guti sar	Broom weed abundance (%)
Stip cur	Western porcupine grass abundance (%)
Koel mac	June grass abundance (%)
Poa pra	Kentucky bluegrass abundance (%)

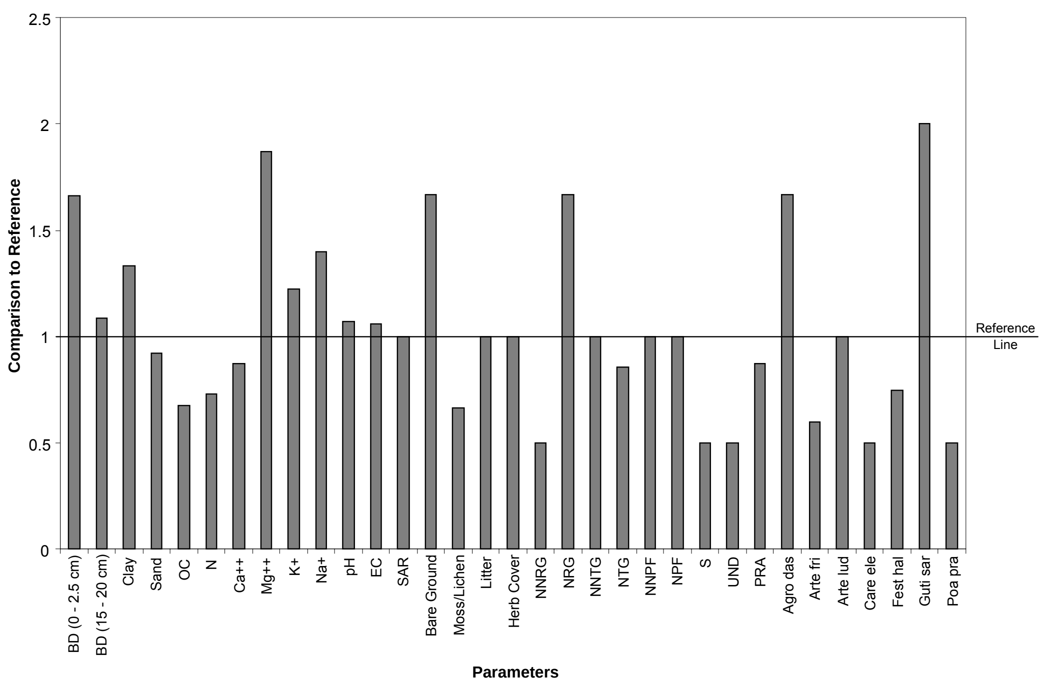
PL760184#1 (2-4-34-19 W4)

This pipeline was a large diameter ethane mainline constructed in summer 1976. It was assumed that topsoil stripping and replacement were part of the construction method. It was documented that revegetation was via seeding of agronomic species, mix unknown, but during sampling there was no evidence of drill rows and successful establishment of any agronomic species, including Kentucky bluegrass. Over most of this pipeline, it was easy to spot the trench as a 2 m wide line of taller vegetation and shrubs. Sampling was on the upper to lower position of a steep northwesterly slope. The reference was a healthy community dominated by plains rough fescue with high herbaceous and litter cover. The trench had minor soil erosion. There was evidence of either subsidence or down-cutting along the trench. The slope was too steep for cattle to prefer grazing, and the only evidence of cattle use appeared to be minor trailing along the trench. Willows in the reference area were heavily browsed, probably by deer. Kentucky bluegrass was present along the pipeline and reference transects, increasing towards the depression at the base of the slope.



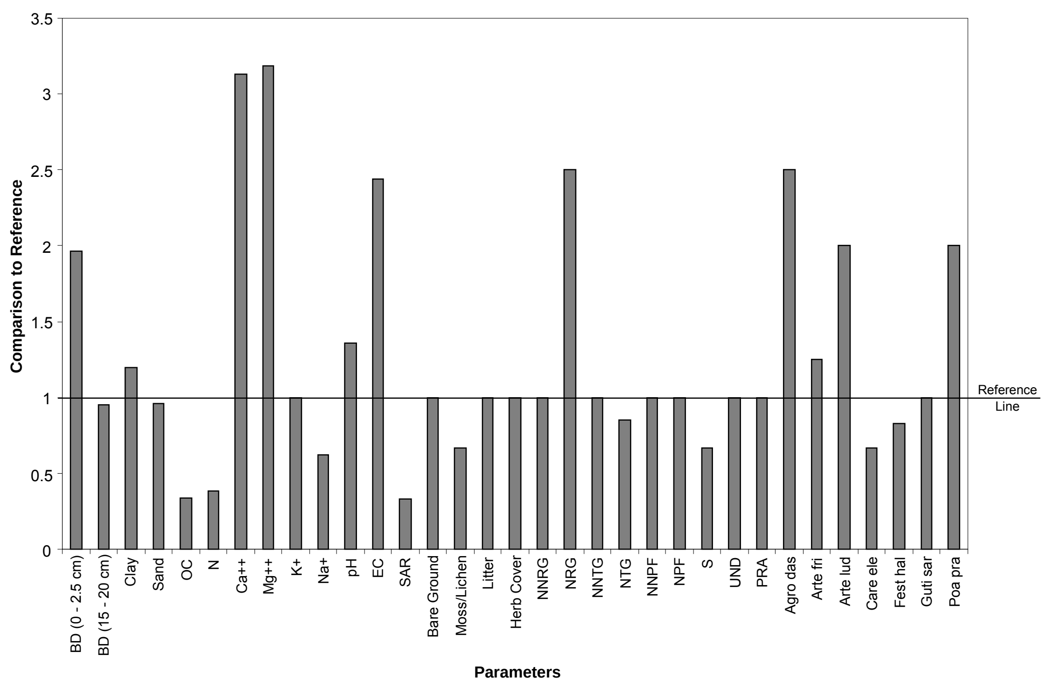
PL760184#2 (12-34-33-19 W4)

This is the second sample along a large diameter ethane mainline constructed in summer 1976. It was assumed that topsoil stripping and replacement were part of the construction method. It was documented that revegetation used seeding of agronomic species, mix unknown, but during sampling there was no evidence of drill rows and successful establishment of any agronomic species, including Kentucky bluegrass. It was easy to spot the trench as a 2 m wide line of taller vegetation and shrubs. Sampling sites were located on the northeastern edge of a large plateau that was dry and exposed to wind. Cattle trailed along the trench and occasionally loitered on the reference site.



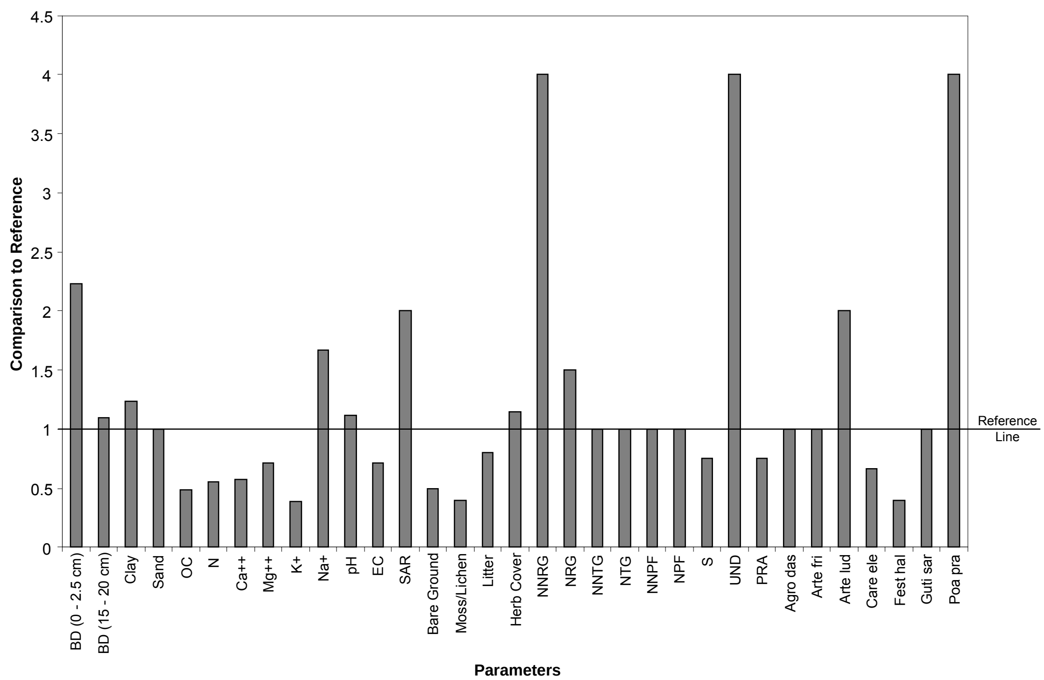
PL760184#3 (3-35-33-19 W4)

This is the third sample along a large diameter ethane mainline constructed in summer 1976. It was assumed that topsoil stripping and replacement were part of the construction method. It was documented that revegetation used seeding of agronomic species, mix unknown, but during sampling there was no evidence of drill rows and successful establishment of any agronomic species, including Kentucky bluegrass. Over most of this pipeline, it was easy to spot the trench as a 2 m wide line of taller vegetation and shrubs. Sampling was parallel to pipeline PL900555 and shared the same reference site. The pipeline and reference transects were in the mid position of a northerly slope with a degree range of 10-20 %.



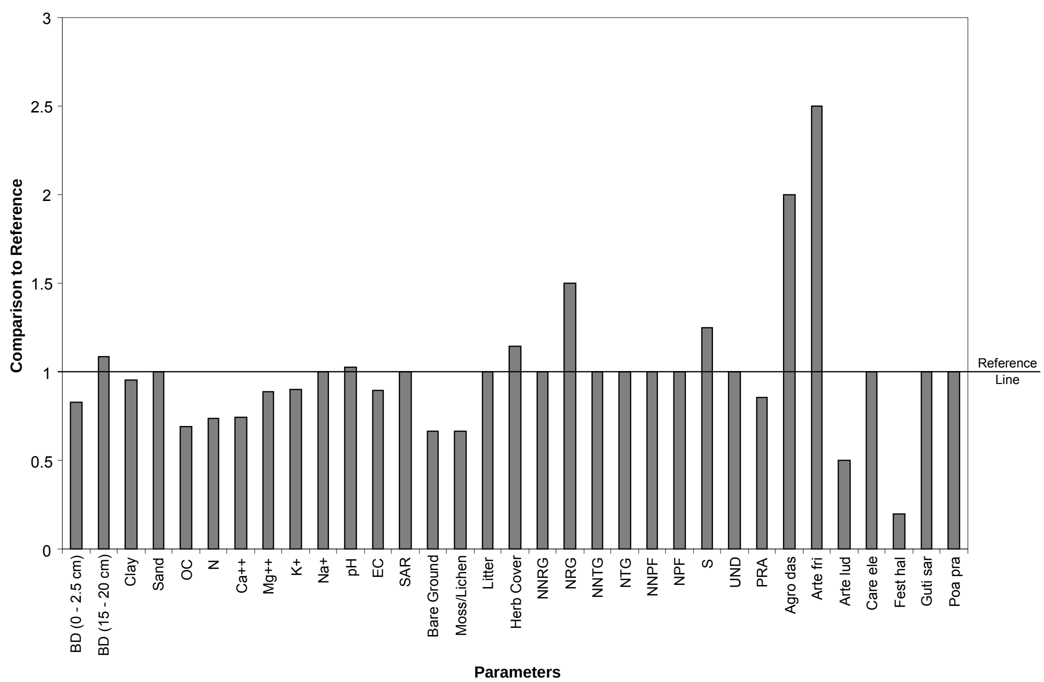
PL760184#4 (15-19-32-18 W4)

This is the fourth sample along a large diameter ethane mainline constructed in summer 1976. It was assumed that topsoil stripping and replacement were part of the construction method. It was documented that revegetation was via seeding of agronomic species, mix unknown, but during sampling there was no evidence of drill rows and successful establishment of any agronomic species, including Kentucky bluegrass. Over most of this pipeline, it was easy to spot the trench as a 2 m wide line of taller vegetation and shrubs. Sampling occurred on the mid position of a steep southwesterly slope. The soil surface appeared to be catching soil moisture and supporting shrubs and deeper rooted grasses. No grazing or trampling was noticed. Kentucky bluegrass was abundant in low lying areas near the pipeline but absent on the drier reference area sampled.



PL760184#5 (13-5-34-19 W4)

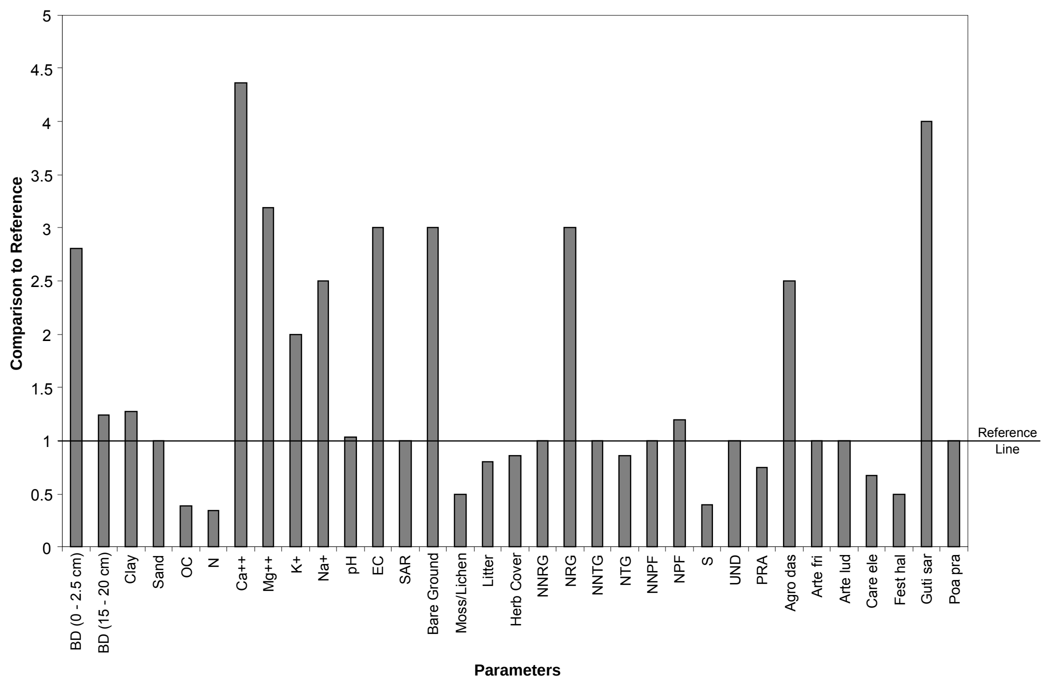
This is the fifth sample along a large diameter ethane mainline constructed in summer 1976. It was assumed that topsoil stripping and replacement were part of the construction method. It was documented that revegetation used seeding of agronomic species, mix unknown, but during sampling there was no evidence of drill rows and successful establishment of any agronomic species, including Kentucky bluegrass. Over most of this pipeline, it was easy to spot the trench as a 2 m wide line of higher vegetation cover and shrubs. Sampling and reference sites were located on the mid position of a steep southwesterly slope. Some



reference samples were on an easterly exposure and may be on the pipeline work area.

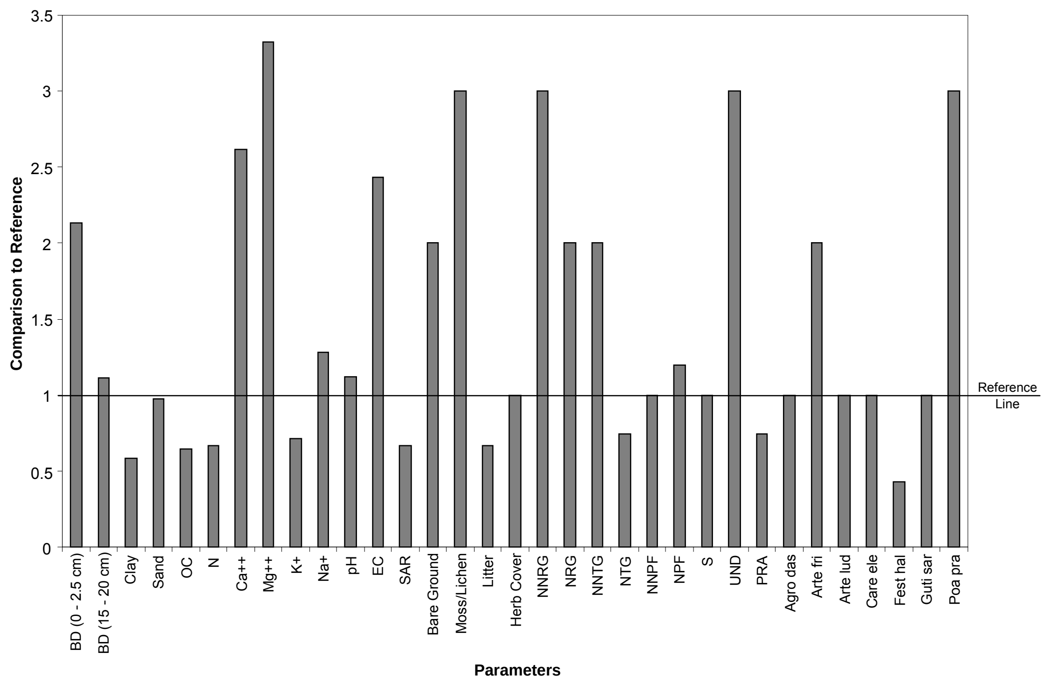
PL830390 (14-22-34-19 W4)

This pipeline was constructed in fall 1983 with a ditch witch without topsoil salvage. Sampling occurred on the western arm of this pipeline along a ridge with southerly exposure. The adjacent reference also occurred on the upper slope but faced west. The undisturbed community was healthy. The disturbance had soil exposure and erosion and low litter cover. Animal traffic was evident along the trench and had likely contributed to the poor revegetation and surface soil compaction. Poor revegetation was probably exacerbated by the low soil moisture inherent in the south facing ridge top position of the disturbance and the surface channeling of water along the trench.



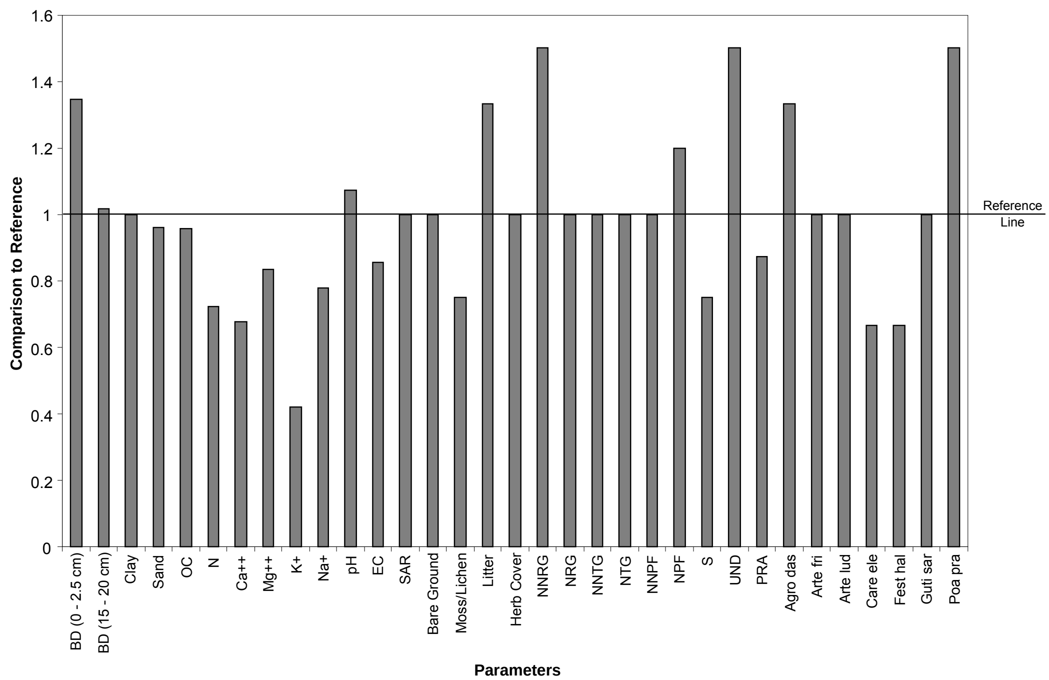
PL850006 (12-5-33-19 W4)

This pipeline was constructed in February 1985 with ditchline topsoil stripping. Sampling locations were on the mid to lower position of a westerly slope. The reference site was a healthy plains rough fescue. The disturbance had noticeable soil exposure, low litter cover, reduced plains rough fescue and increased Kentucky bluegrass and western wheatgrass. Revegetation was via natural recovery. Judging from the litter accumulation, grazing pressure on the reference was low.



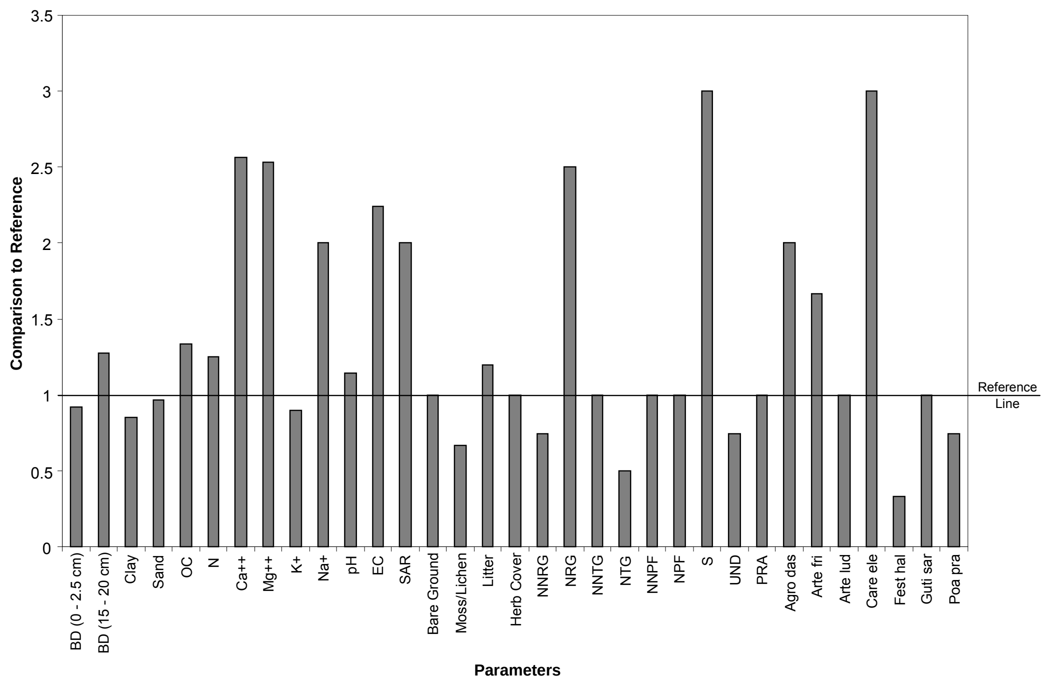
PL870187 (11-31-33-19 W4)

This pipeline was constructed in winter 1987 using topsoil stripping with revegetation by natural recovery. Records indicate topsoil salvage was deeper than requested. Some points along this pipeline were difficult to distinguish from the surrounding prairie, but other locations were recognizable by a raised area of soil and/or a band of wheatgrass cover. The sampling location was on the upper to lower positions of a steep northeasterly slope. The reference community had some soil erosion. Close by there was a patch of crested wheatgrass; smooth brome was in a nearby aspen grove. The disturbance had Kentucky bluegrass.



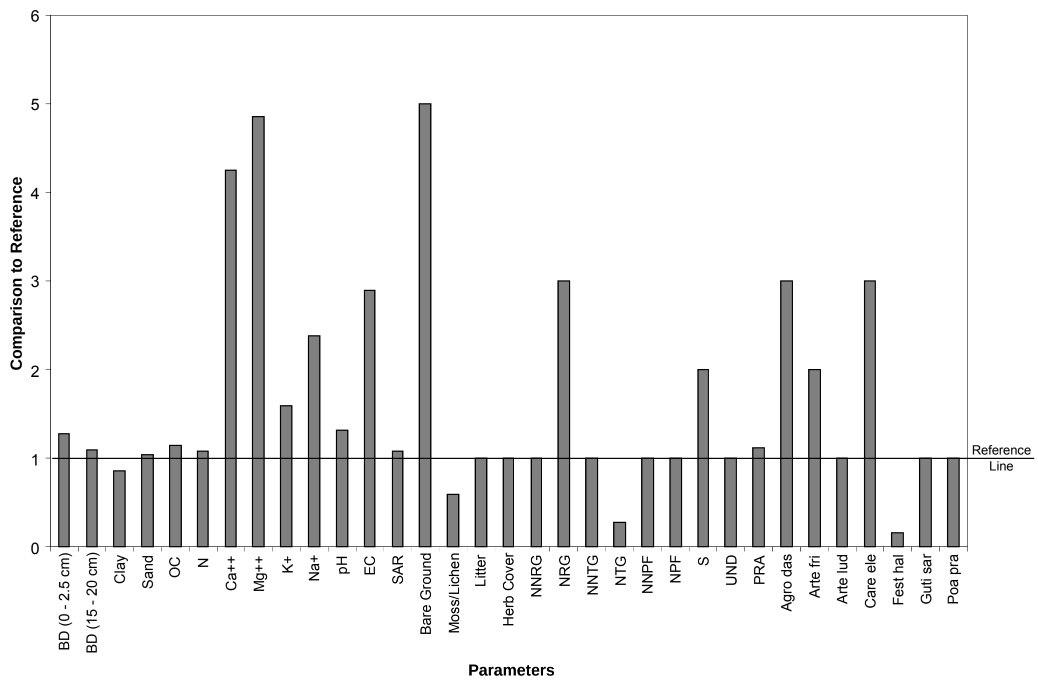
PL870403#1 (4-12-34-19 W4)

This is the first sample on a pipeline constructed using topsoil stripping and replacement in June 1987 and revegetated with the native Rumsey mix. The trench was difficult to locate except by the raised area and greenish blue band of pasture sage. The sampling site was located on the upper position of an easterly slope. Degree of slope was 10-20 %. The reference community had an overabundance of Kentucky bluegrass and western snowberry and plains rough fescue cover was high. Grazing influence appeared light. Further down the pipeline in moister areas, Kentucky bluegrass was noticeably high and moving aggressively into the undisturbed grassland.



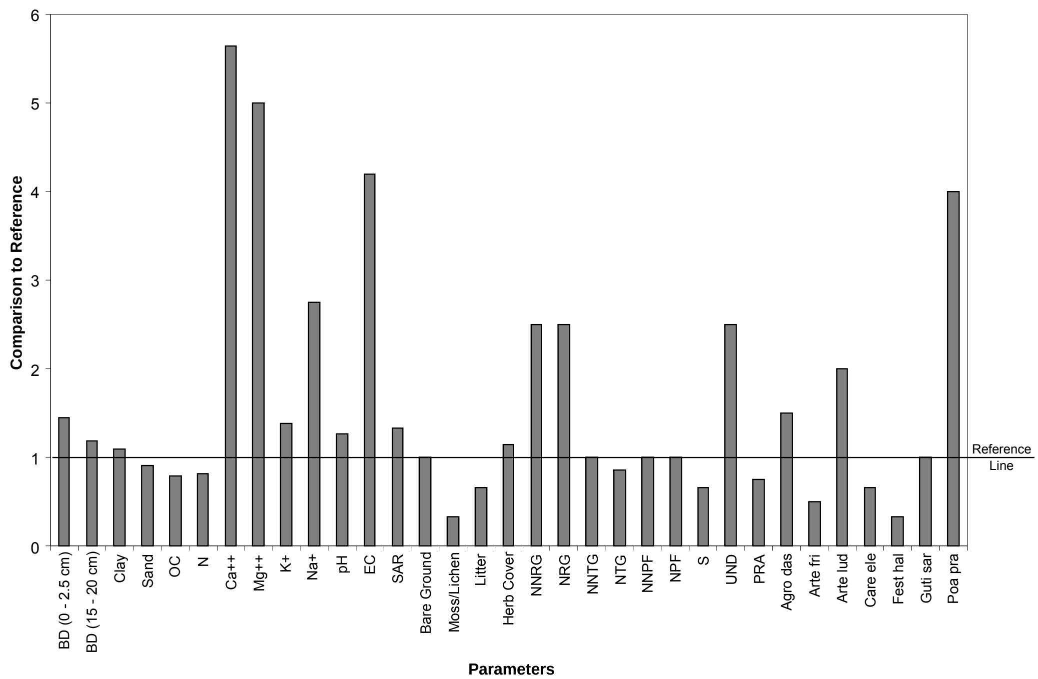
PL870403#2 (11-2-34-19 W4)

This is the second sample along a pipeline constructed using topsoil stripping and replacement in June 1987 and revegetated with the native Rumsey mix. The sampling area was located on the upper to mid position of a steep southwesterly slope. The reference stand of plains rough fescue and western porcupine grass had minor soil erosion, weeds and reduced litter accumulation from livestock use and its dry topographic position. The trench was noticeable by its increased soil exposure and bluish green colour of pasture sage and wheatgrass. Further down the pipeline in a moist depression, Kentucky bluegrass dominated the right-of-way.



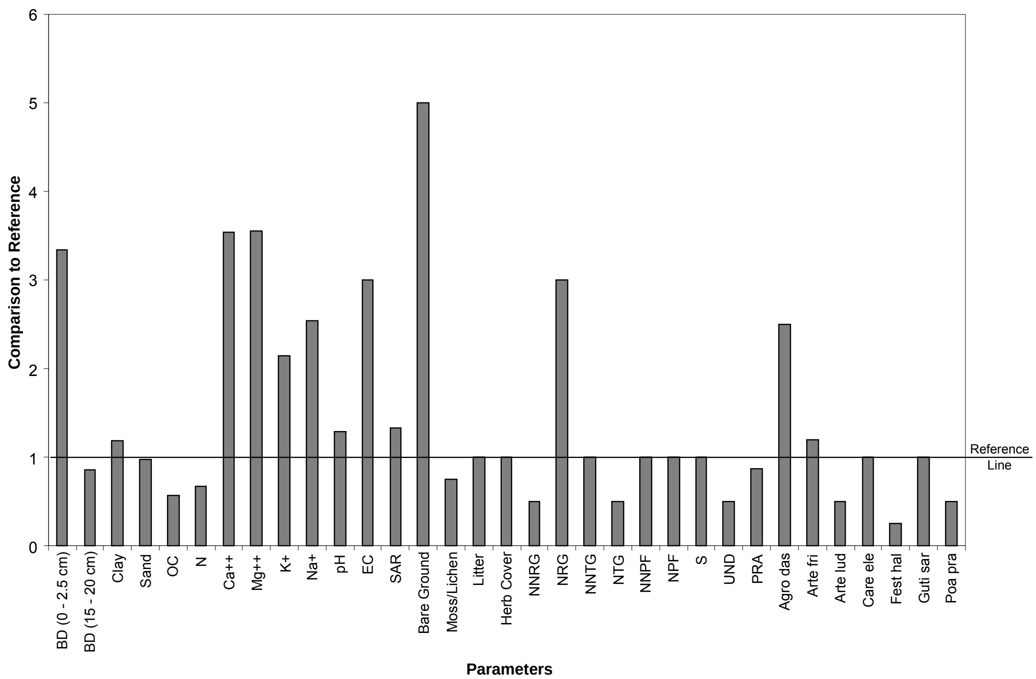
PL900555 (3-35-33-19 W4)

The date of this pipeline construction is unclear, but it was probably constructed in early 1990 with topsoil stripping and replacement. The disturbance and reference sampling locations were on the mid position of a northerly slope. The undisturbed reference was a healthy plains rough fescue community. The disturbance had Kentucky bluegrass. Revegetation was through natural recovery.



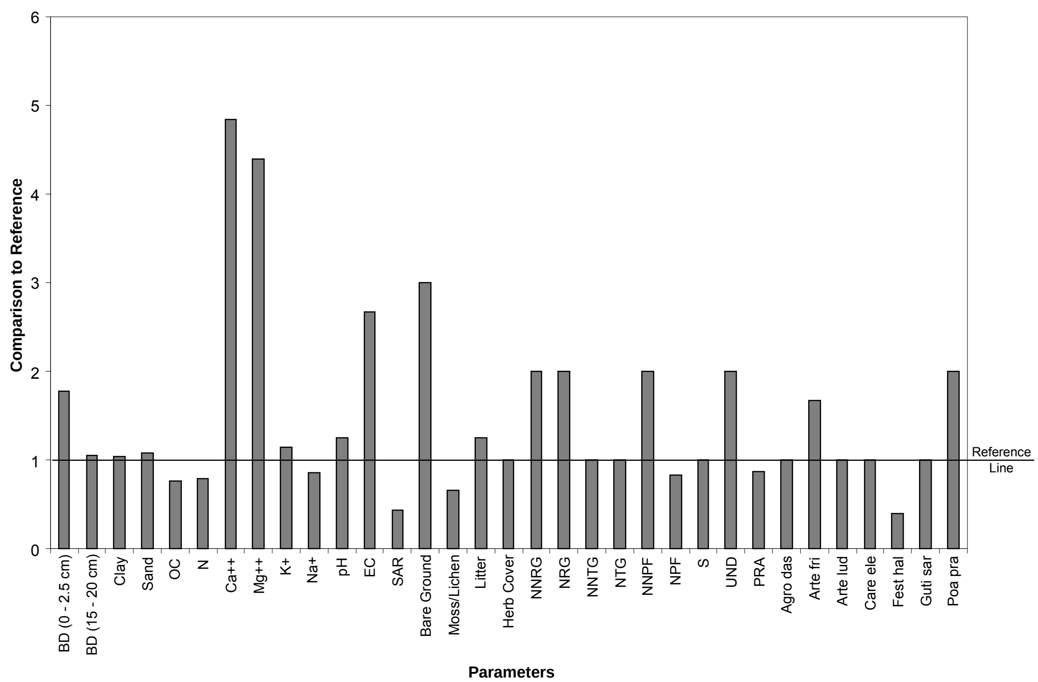
PL900574 (16-19-33-18 W4)

This pipeline was constructed in winter of an unknown year in the early to mid 1990s using a ditch witch to dig an 11-12 inch trench. No topsoil was salvaged and the pipeline was revegetated through natural recovery. The pipeline was easy to spot as a bluish line of western wheatgrass, northern wheatgrass and pasture sage. The vegetation sampling site was located on the upper position of a southwesterly slope.



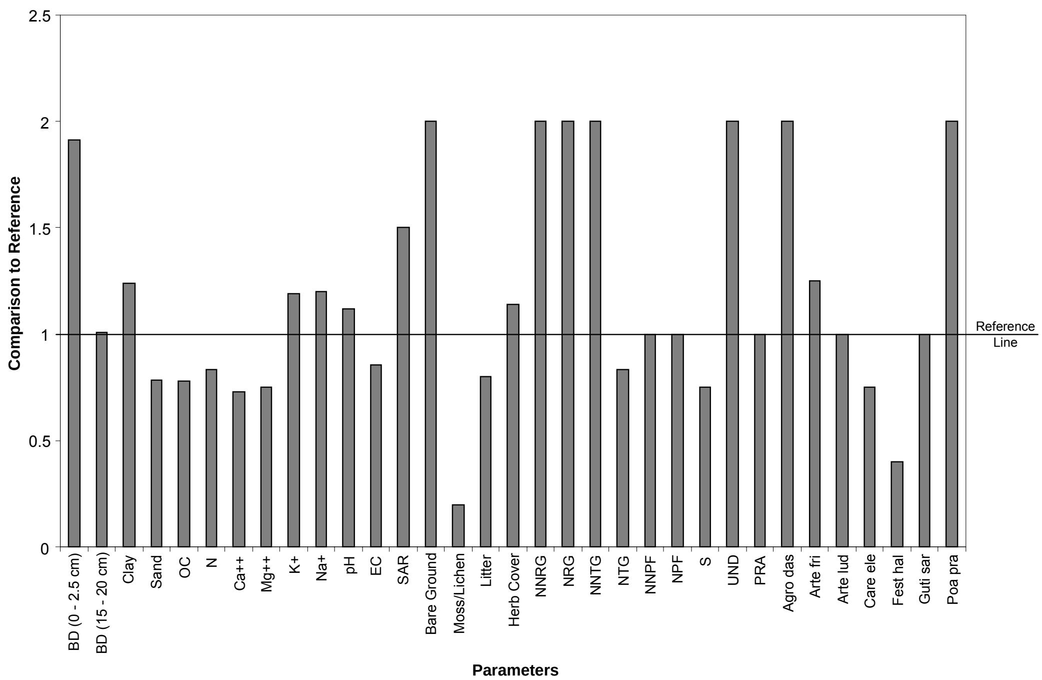
PL951074#1 (14-4-33-19 W4)

This is the first sample along a pipeline constructed in fall 1995 using topsoil stripping over the trench only, followed by natural recovery. Records indicate minor admixing was visible after soil replacement. The pipeline is easily spotted on the landscape by the 2 m wide swath of wheatgrass. It was located on a plateau with almost level slope. Long term heavy grazing had occurred although at the time of sampling there was none.



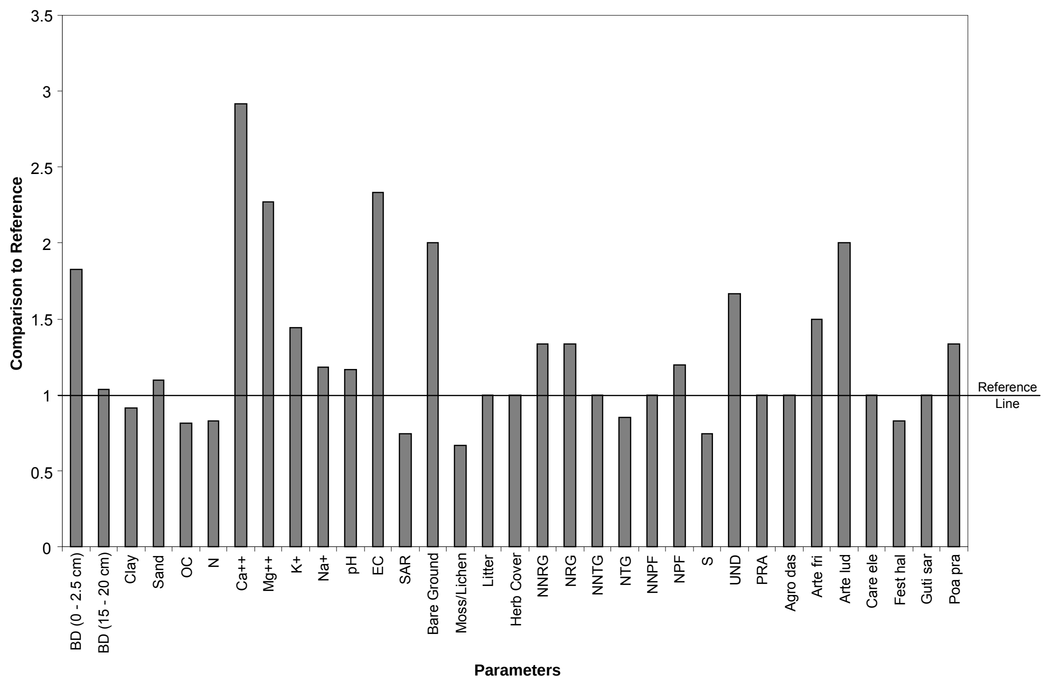
PL951074#2 (10-9-33-19 W4)

This is the second sample along a pipeline constructed in fall 1995 using topsoil stripping over the trench only, followed by natural recovery. Records indicate minor admixing was visible after soil replacement. The pipeline was easily spotted on the landscape by the swath of wheatgrass in some areas but difficult to locate in others. The disturbance and its reference were located on the upper position of an easterly slope of 10-20 %. Cattle use was high.



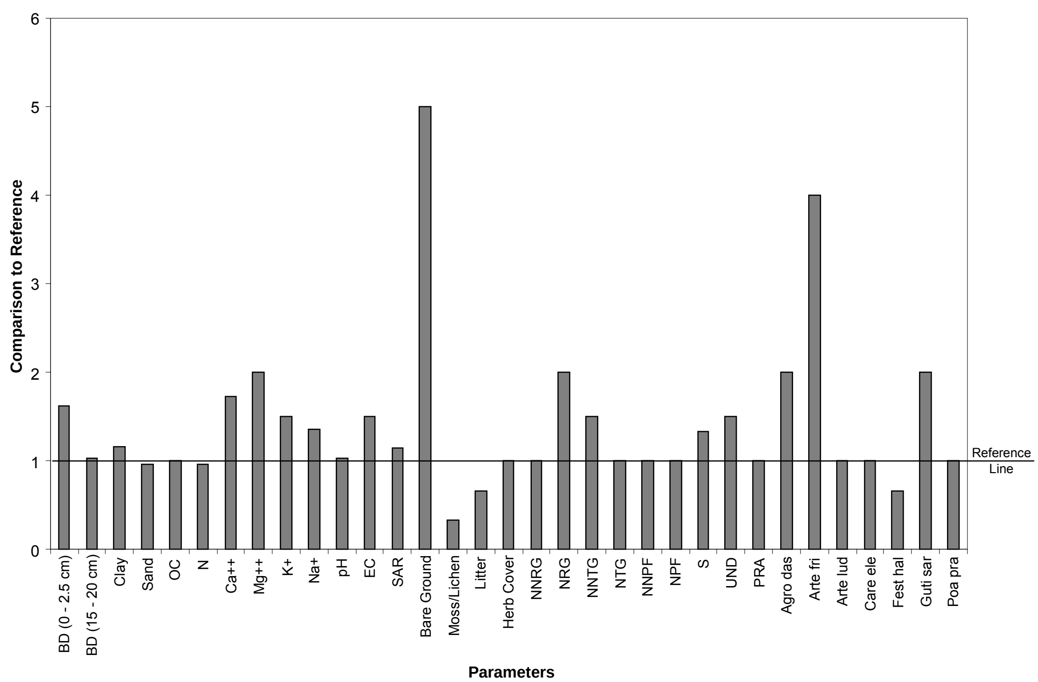
PL991222#1 (6-16-33-19 W4)

This is the first sample along a pipeline constructed in fall 1999 by plow-in and revegetated through natural recovery. The site was difficult to locate because it was in a productive valley and blended in well. It was found as a raised area adjacent to some cattle trailing. This was a likely place for cattle to graze, but minimal use was found at the time of sampling. Both disturbed and reference sampling areas were located at the toe position of a southwesterly slope with a degree of no more than 10 %. Both the reference and disturbance had Kentucky bluegrass. Kentucky bluegrass was common all along this valley due to increased soil moisture.



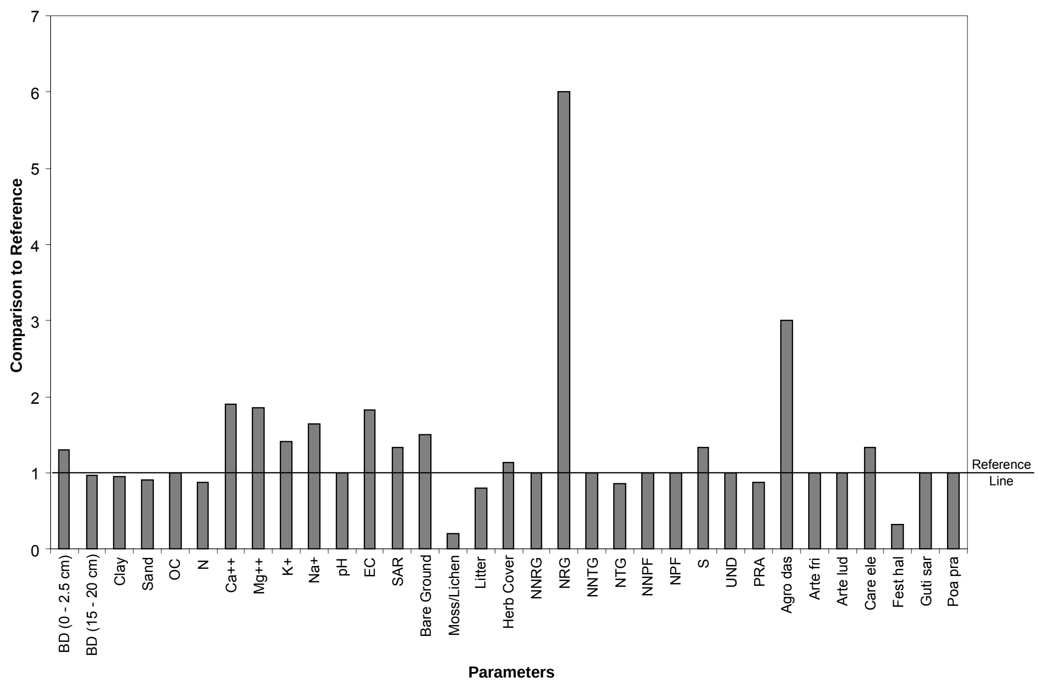
PL991222#2 (2-21-33-19 W4)

This is the second sample along a pipeline constructed in fall 1999 by plow-in. It left a raised area over the trench at the second site and despite this technique there was still a noticeable amount of soil disturbance. The sampling area was located on the upper to mid slope position of a steep (>20%) north easterly slope. The disturbance had soil exposure and erosion and low litter cover. The reference was healthy but had low litter cover. Grazing and livestock traffic were unlikely to be a major influence because of the steep slope. There was light to moderate browsing on the few willows on the reference area towards the bottom of the slope, but trampling and utilization of the herbaceous cover was unnoticeable on either the pipeline or the reference.



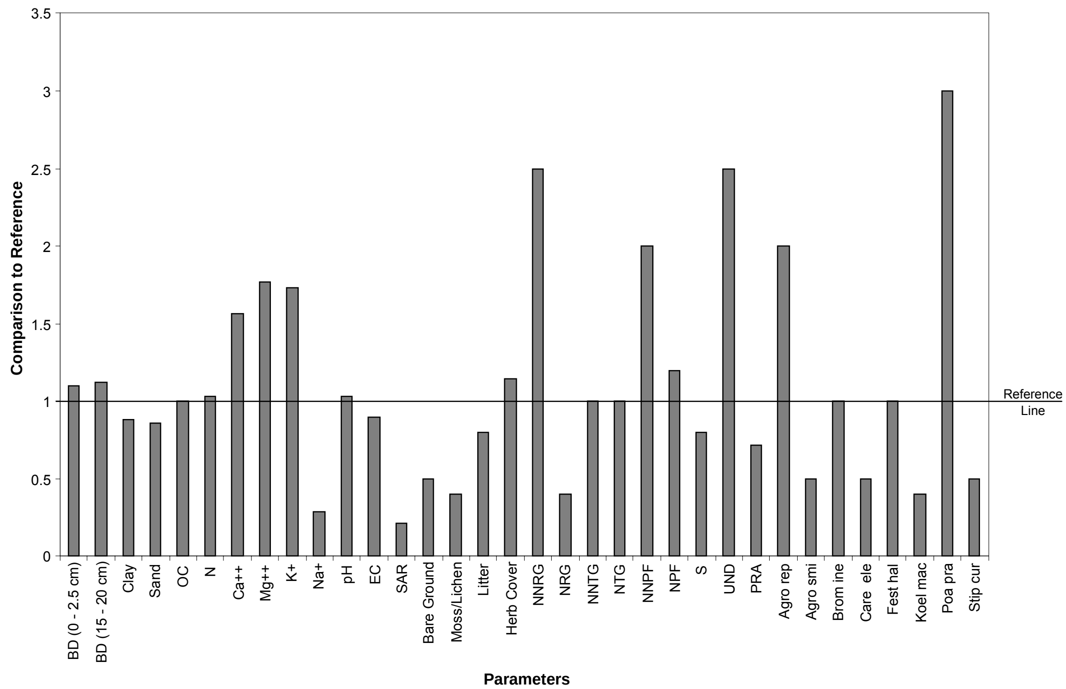
PL002348 (5-7-33-19 W4)

This pipeline was constructed in fall 2000 using topsoil salvage and replacement and revegetation was through natural recovery. The pipeline was noticeable by the very narrow band of pasture sage and foxtail barley and subsidence along the trench. The sampling site was on the upper position of a steep southwesterly slope. The reference was healthy. Trailing from livestock traffic was evident on the reference and disturbance. The disturbance had soil exposure and erosion and low litter cover.



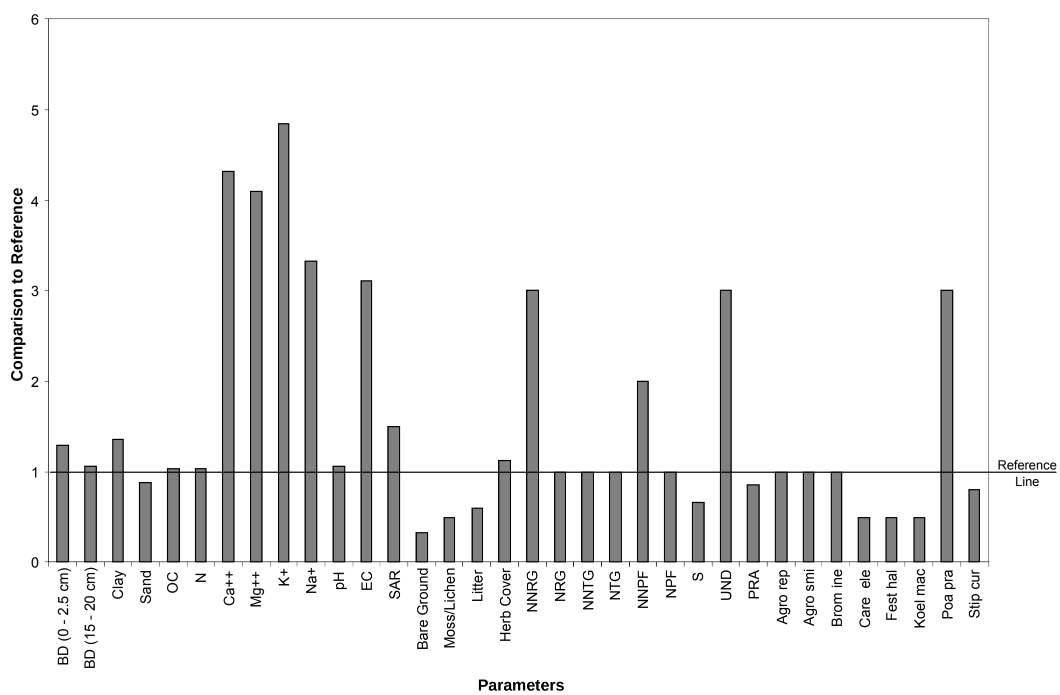
WS000006 (6-7-33-19 W4)

There are conflicting dates for the construction of this well site but it was during the mid 1960s. Methods of construction and revegetation are unknown. The site was located by the presence of several patches of heavy western snowberry and Wood's rose cover in an almost level depression at the base of a westerly hill. The reference was located on the relatively level toe of the westerly slope. Herbaceous cover was very productive compared to the undisturbed reference.



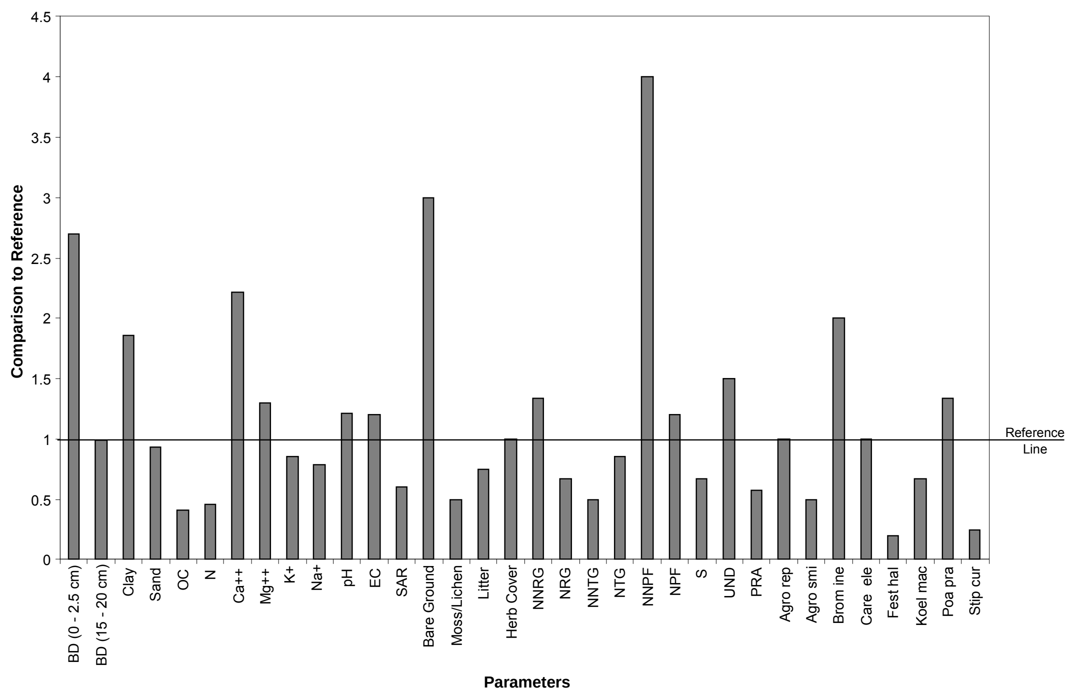
WS000001 (5-20-33-18 W4)

This well site was drilled in December 1970 but was dry and subsequently reclaimed. It was supposed to be a full build site seeded to agronomic species. The only agronomic present in significant amounts was Kentucky bluegrass. Some sweet clover was found in the northeast corner and had encroached onto the undisturbed area along with smooth brome. The well site was in a depression, probably leveled during construction, favoured by cattle and appearing to be relatively dry. Productivity was low on much of the site except on about 15-20 % of the right-of-way where thick patches of western snowberry and Wood's rose dominated. This shrub cover was judged to be related to disturbance, as similar situations have occurred on other well sites and pipelines. The reference had noxious weeds, soil exposure and minor erosion.



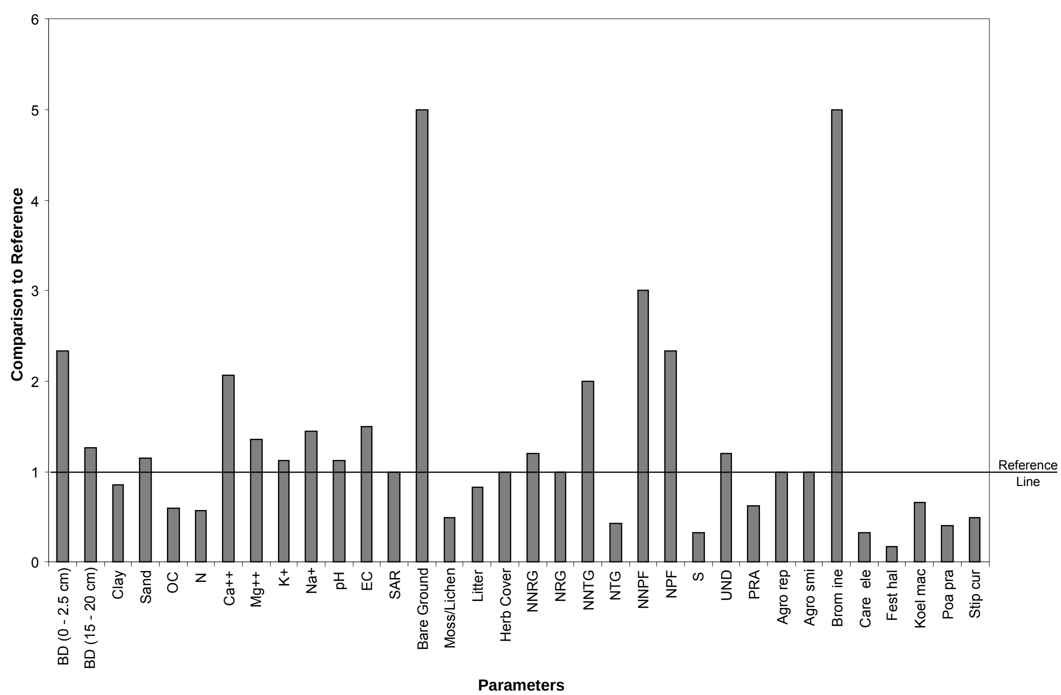
WS771356 (10-31-33-19 W4)

This well site was constructed in October 1977 using full build topsoil stripping and replacement over the entire right-of-way and revegetation was with agronomic species. The well head was excluded with a 7 x 7 m fence and a pad immediately around it where sampling was avoided. The site was in a low area with almost level northerly slope. Trailing shows the area was favourable for cattle use. The reference community surrounding the well site had more noticeable westerly slope and had Kentucky bluegrass. Public Lands requested seeding with intermediate and pubescent wheatgrass, but the only agronomics found on site were Kentucky bluegrass and Sherman big bluegrass. The disturbance had an abundance of noxious weeds.



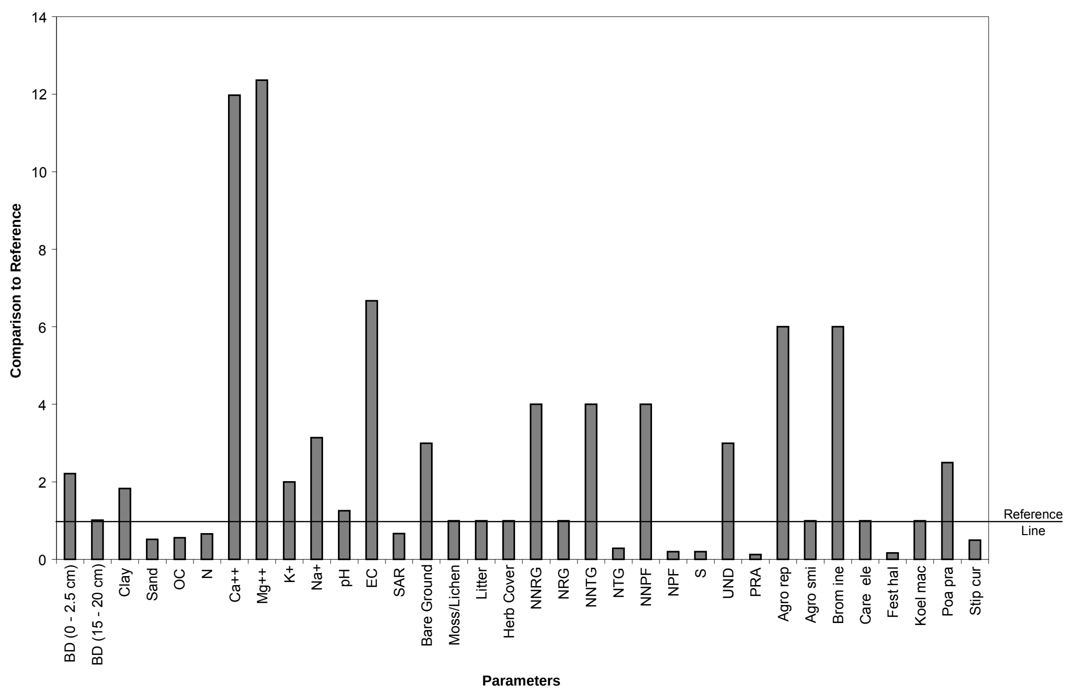
WS771638 (11-23-34-19 W4)

This well site was constructed in December 1977 using full build topsoil stripping over the entire right-of-way. It was unclear whether it was seeded to an agronomic mix or revegetated through natural recovery. Productivity of smooth brome and sweet clover was markedly improved towards the edges of the right-of-way, to the point that they are invading undisturbed prairie. Kentucky bluegrass was frequent in the moist areas around the right-of-way. In 1996 some hydrocarbon contaminated soil was removed from around the pipeline riser to the north of the well head. The well head was still operational and excluded with cattle panels but the right-of-way is not excluded. It lay on a level hilltop. The site had Canada thistle, soil exposure and erosion. The reference samples had an abundance of Kentucky bluegrass.



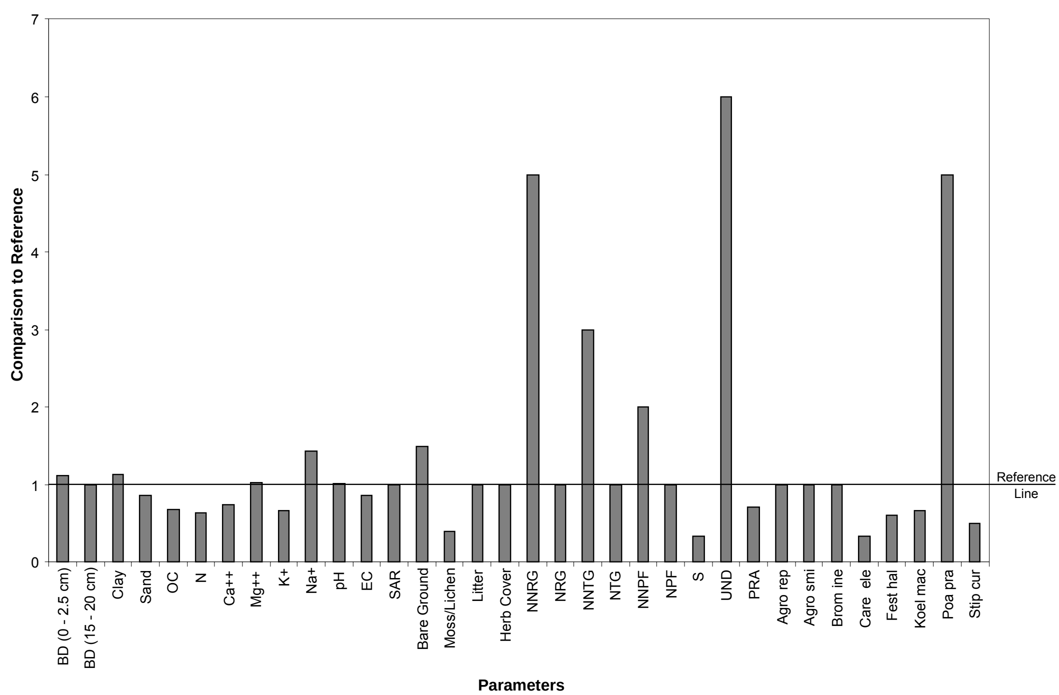
WS780019 (11-31-34-19 W4)

This well site was constructed in June 1978 using full build topsoil stripping and replacement followed by seeding with the current Rumsey mix. Evidence strongly indicated that the mix actually seeded included Kentucky bluegrass, smooth brome, quackgrass and sweet clover as these species comprised the majority of the stand. The site was on top of a hill with slight slope in a northerly direction. The reference was located on an adjacent hill to the south along an open corridor leading to more open grasslands. Cattle trailing was severe along the corridor but the area sampled for the reference appeared to have low to moderate grazing pressure. Aspen cover was heavy in this field and the well site right-of-way was almost completely surrounded by aspen.



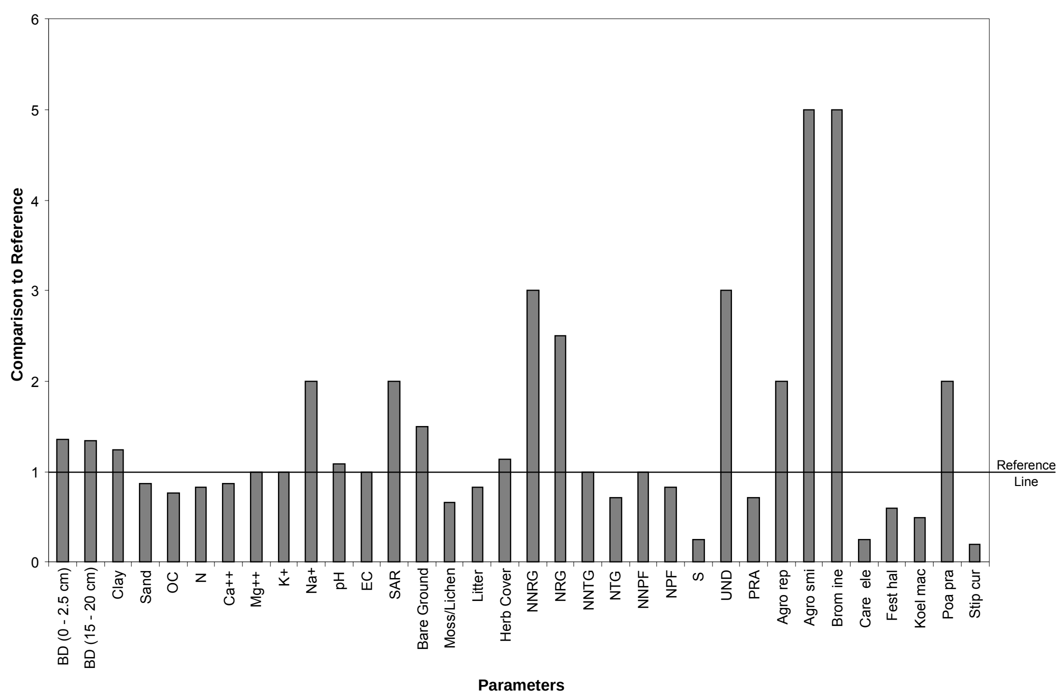
WS780327 (11-11-33-19 W4)

This well site was constructed in February 1978 using full build topsoil stripping over the entire right-of-way and seeding to an agronomic mix. The establishment must have been poor because the only agronomic species are Kentucky bluegrass and riparian wheatgrass in relatively small amounts. The corners were missed during seeding and naturally revegetated with strawberry and plains rough fescue. The site was located on the upper position of a southeasterly exposure with 2-10 % slope. It was difficult to locate except by the patchy shrub cover which was unusual for a hilltop. The site had Canada thistle, soil exposure and erosion. Soil exposure was noticeably higher on the well site than on the reference. Cattle use was heavy because the site was transected by a major access road. The reference was located on upper to mid positions of a northeasterly slope of 2-20 %.



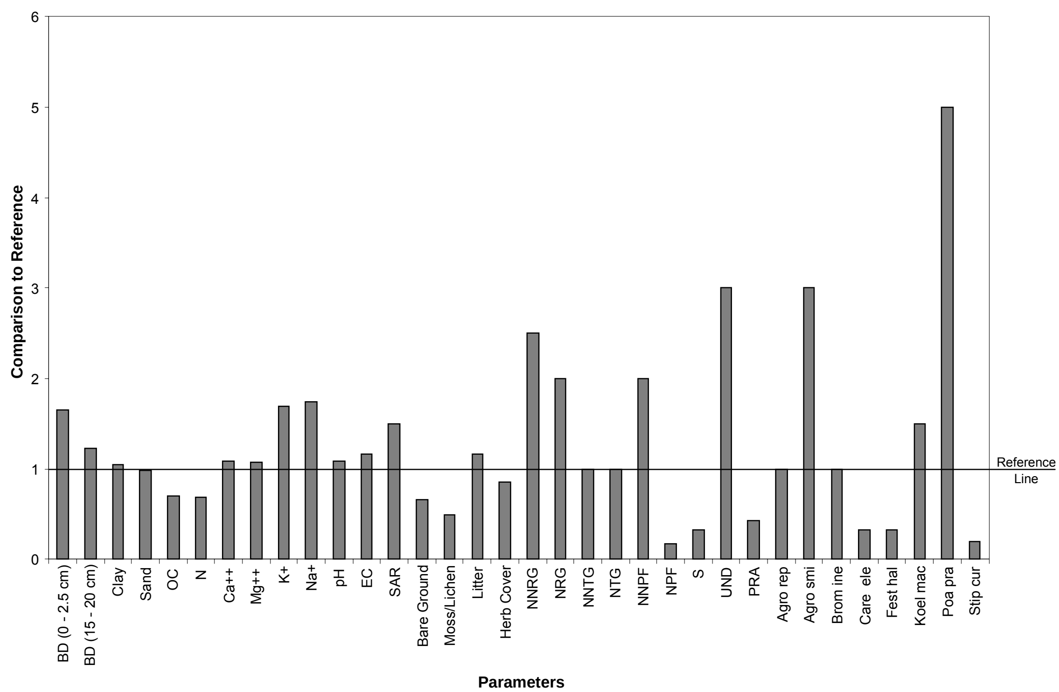
WS790628 (14-22-34-19 W4)

This site was constructed in September 1979 using full build topsoil stripping. It was supposed to be seeded to a native mix. Kentucky bluegrass is most abundant. Some brome was moving off right-of-way onto the undisturbed prairie. The site was almost level and some leveling and clearing of the original terrain may have occurred. The corners of the right-of-way were missed during seeding and were vegetated with strawberry, bearded wheatgrass and plains rough fescue. The well site was one of few open areas and almost completely surrounded by mature brush except for the access road and the ridge to the north. Thus some of the reference samples had to be located about 50 m down the road on the other side of the aspen grove. The reference areas were located on the mid positions of southerly slopes of 2-20 %.



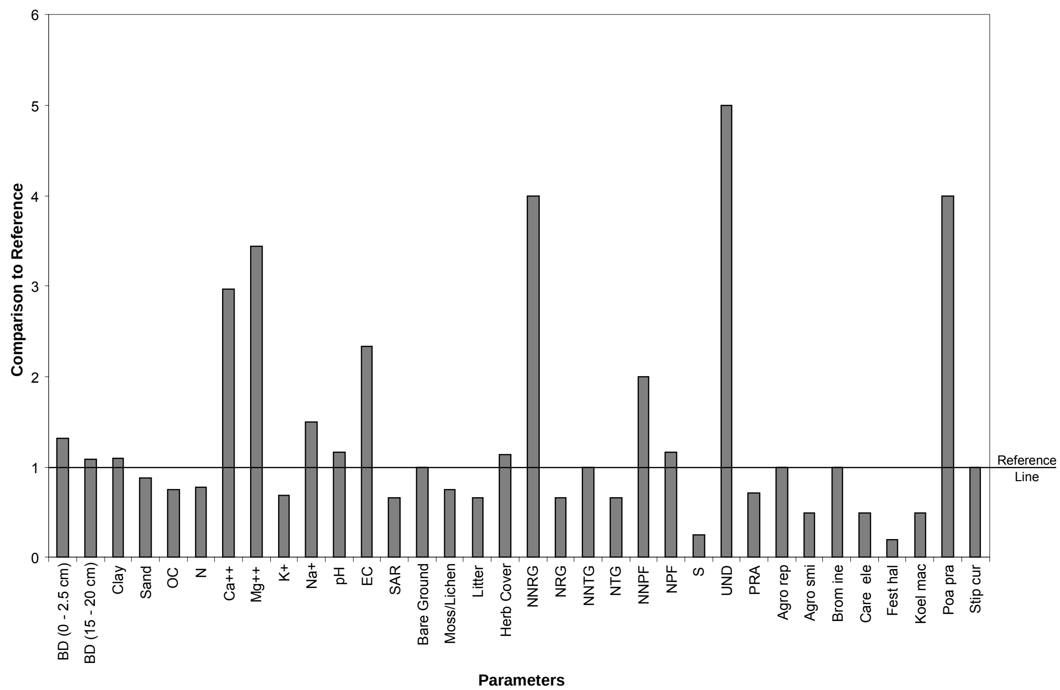
WS791433 (7-23-33-19 W4)

This well site was constructed in October 1979 using topsoil stripping and replacement but the most recent reclamation effort was in the late 1990s. The site must have been leveled because recontouring was required upon abandonment in the late 1990s. The prescribed revegetation mix for 1980 was the Rumsey mix but inspection in 1997 indicated that there was very poor vegetation cover and unsatisfactory reclamation. The site was reworked and revegetated using a later version of the Rumsey mix. The site was in the upper position of a southerly exposure with slopes of no more than 10 %. The reference samples were midslope but steeper with half of the subsamples facing south and half facing northwest. Cattle use was light on the undisturbed reference because of the slopes but trailing was heavy around the exclosure fence surrounding the well site. Despite the exclosure, cattle accessed the well site for a period when the gate was opened.



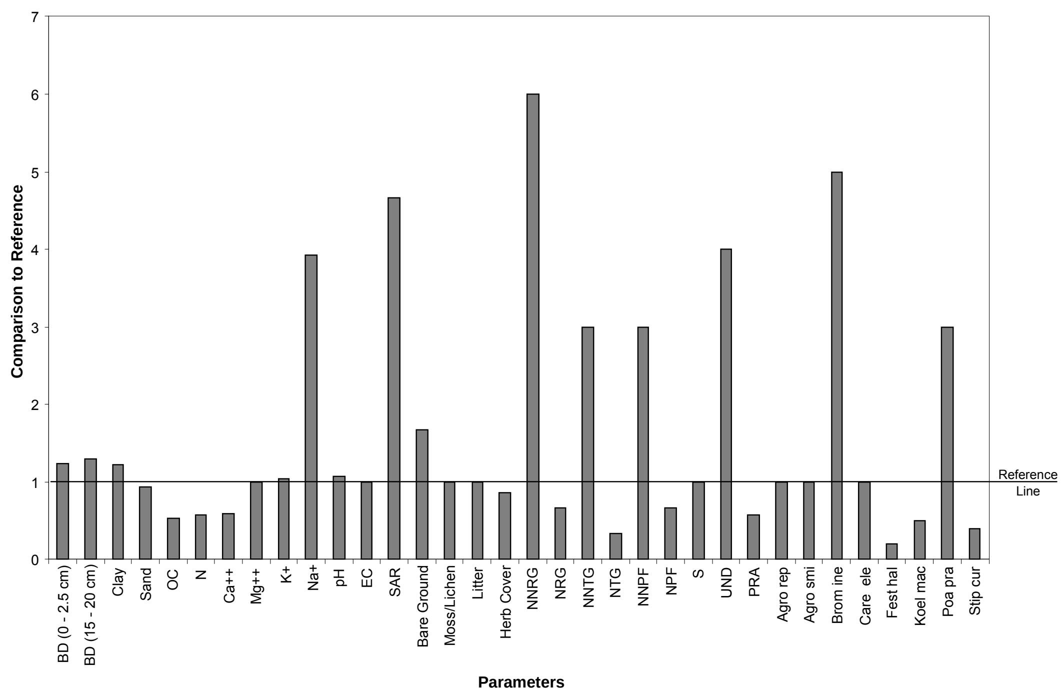
WS791739 (6-8-33-19 W4)

This well site was constructed in January 1980 using full build with topsoil stripping and replacement throughout the right-of-way. It was drill seeded to an agronomic mix and excluded for an unknown period from cattle grazing. Some fence posts remained on site. The location of both disturbance and reference samples was on the mid to upper position of a steep westerly to northwesterly slope. There was a minor discontinuity in the slope on the upper side of the well site which probably resulted from the topsoil stripping. Soil was still exposed and cattle traffic continued to shear at the opening. The well site had patches of thistle. After its failure to establish the agronomic plant mix, it became a natural recovery effort. Small aspen trees were developing near the centre of the right-of-way.



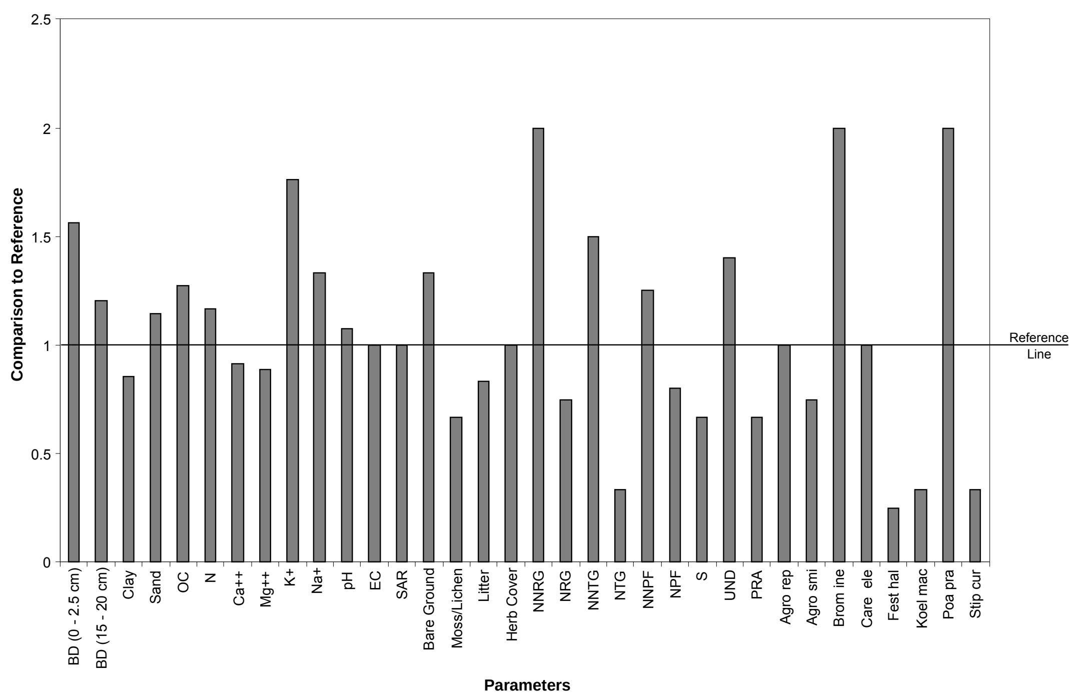
WS800266 (10-24-33-19 W4)

This well site was initially constructed in February 1980. Site inspections since 1980 had mixed results. In 1986 the site was deemed to have adequate vegetation cover but something happened between then and 1993 to cause the inspector to deem it a reclamation failure with poor plant species composition, soil contouring and compaction. During redrilling in July 2000 topsoil was salvaged and a fence of unknown dimensions was installed. At the time of sampling the only fence was the small one immediately adjacent to the well head and the gate was open. This well site was on a hilltop along a major road in Rumsey, a favored location for cattle use. The reference site was on the steep upper slope around a nearby hilltop next to a reclaimed compressor site.



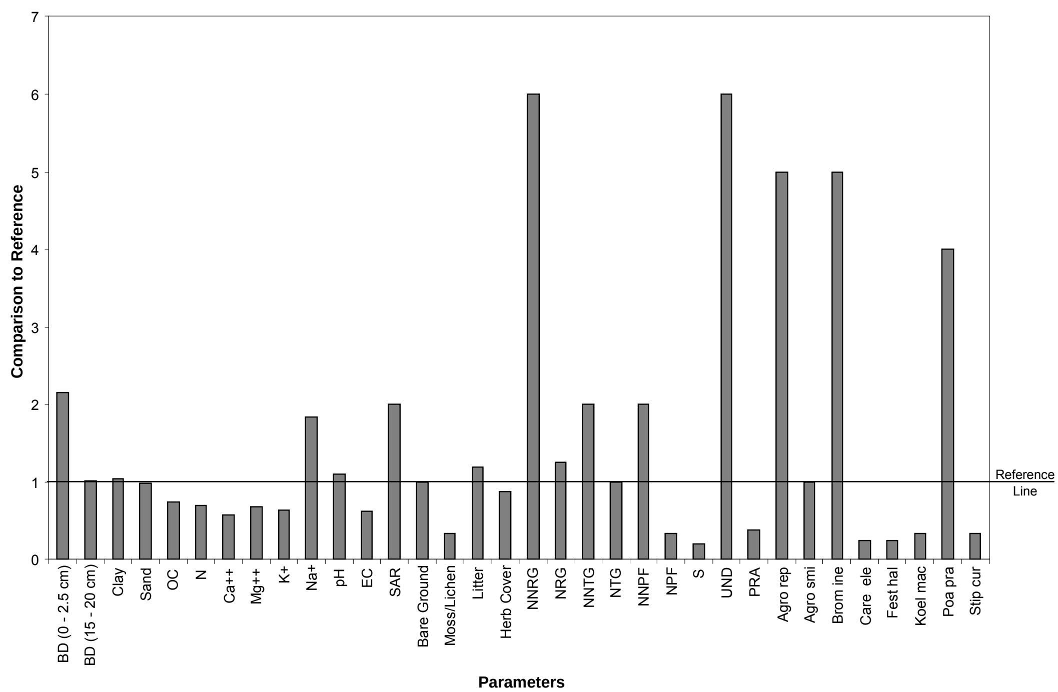
WS820076 (10-24-33-19 W4)

This site was constructed in February 1982 using full build topsoil stripping. It was seeded with an agronomic mix, probably containing sweet clover, smooth brome and alfalfa, as these were abundant on the site. Kentucky bluegrass and crested wheatgrass were also present. These species were frequently found on the undisturbed prairie adjacent to the right-of-way. The edge of the right-of-way was easily distinguishable from the undisturbed prairie. The well head was on the top of a hill and fenced with a small exclosure and surrounded by a gravel pad. The reference areas were on mid slope positions of steep northerly and easterly slopes. The soil exposure on both the disturbance and reference were favourable for rodent habitation. None of the other sites sampled have rodent activity as severe.



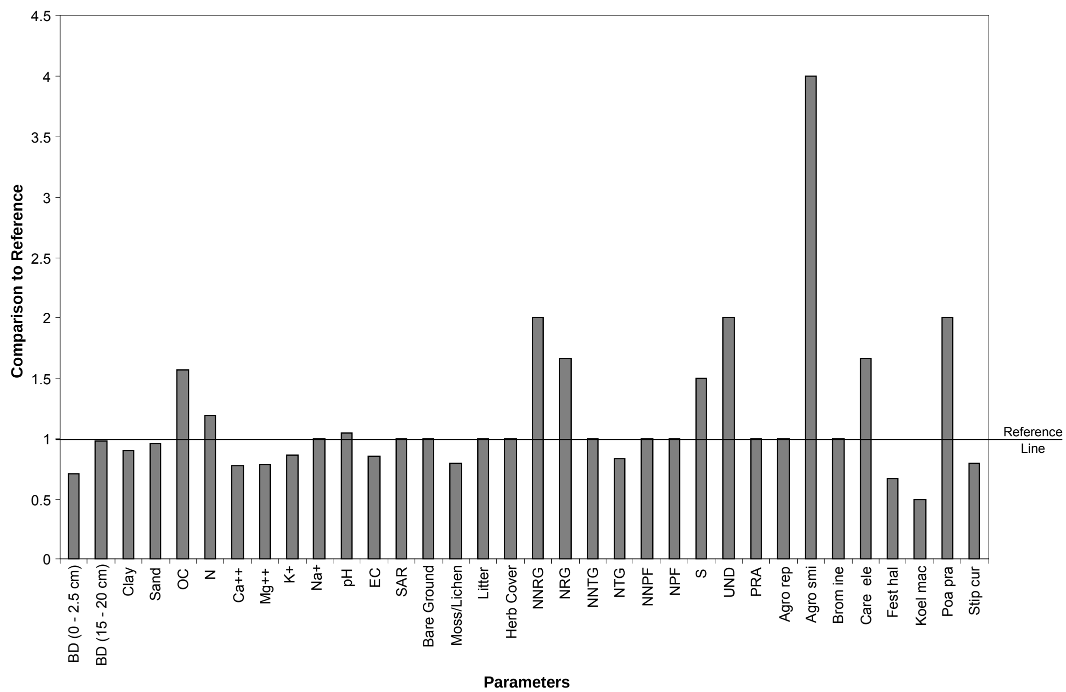
WS821057 (15-34-33-19 W4)

This well site was constructed in November 1982 using full build topsoil stripping and was to be seeded to the Rumsey mix. Although native wheatgrasses were present and green needle grass was abundant, there were large percentages of quackgrass, smooth brome and Kentucky bluegrass. Although there was no fence around the right-of-way, livestock use appeared minimal. The well site was located on the mid position of a northeasterly slope of no more than 10 %. The closest suitable reference areas were on mid to upper positions of easterly slopes of varying steepness. Cattle trailing was evident. Smooth brome, Kentucky bluegrass and Russian wild rye were encroaching onto the undisturbed areas from the right-of-way.



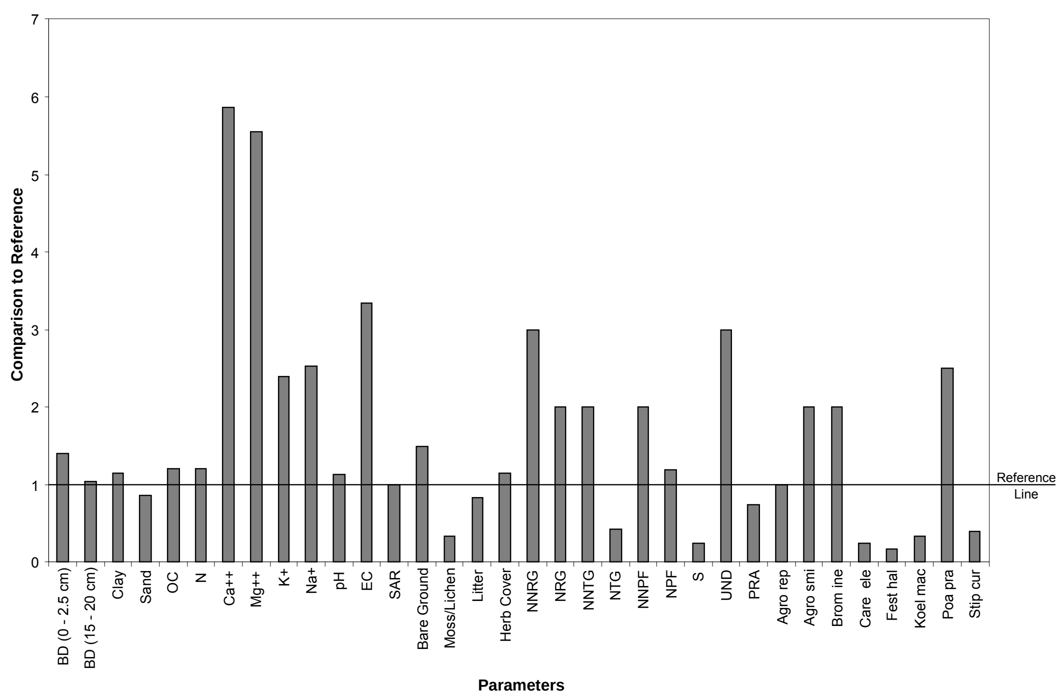
WS831396 (5-15-33-19 W4)

This well site was constructed in January 1984 using full build topsoil stripping over the entire right-of-way. It was then seeded using the current Rumsey mix. The site was on the upper position of a westerly slope of 2-10 %. Some leveling of the site was done and there was still a cut into the side of the adjacent hill. The site had Canada thistle and soil erosion. Patches of smooth brome were present on the right-of-way and there was some encroachment onto native prairie. The reference was located on the upper positions of westerly slopes no greater than 10 %.



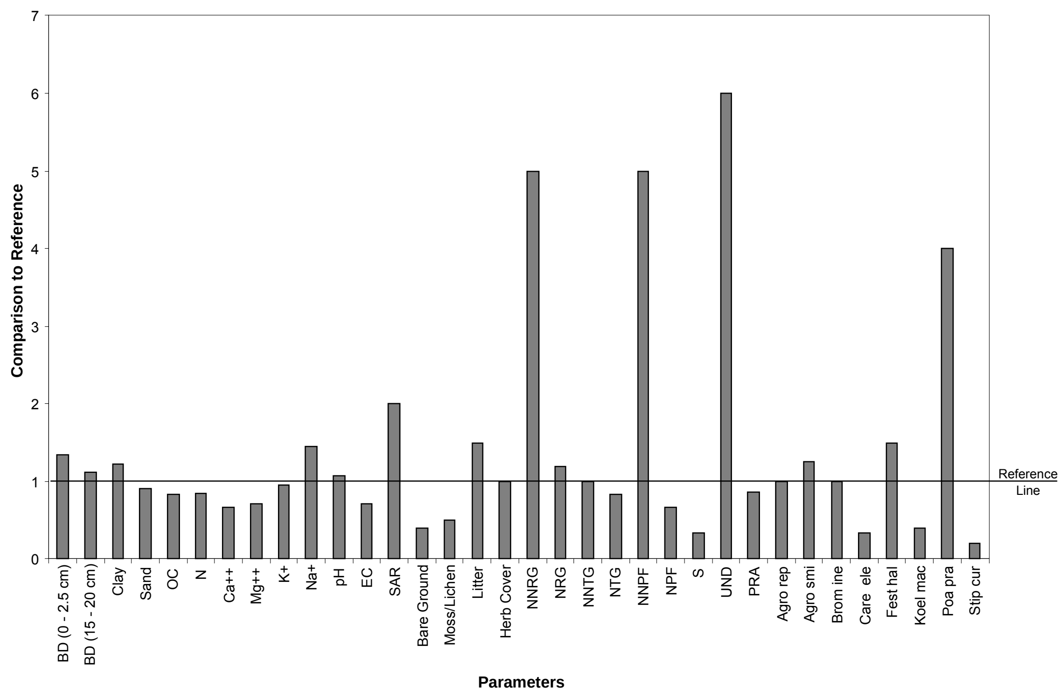
WS841271 (12-34-33-19 W4)

This well site was constructed in September 1984 using full build topsoil stripping and salvage and revegetated with the current Rumsey mix. The disturbance sampling location was on a dry ridge top with some samples in each of the NW, SW, SE and NE directions. Slopes were steep. The reference samples were taken on steep westerly slopes in upper and lower positions. The disturbance had some soil exposure and erosion, noxious weeds and Kentucky bluegrass. Wooden exclosures remained on the site, a small one around the well head and a larger one around an impoundment. Salt blocks were placed near the impoundment and soil disruption in that location was severe. Because of the hilltop location, the structure and the salt lick, this location was probably favoured by cattle.



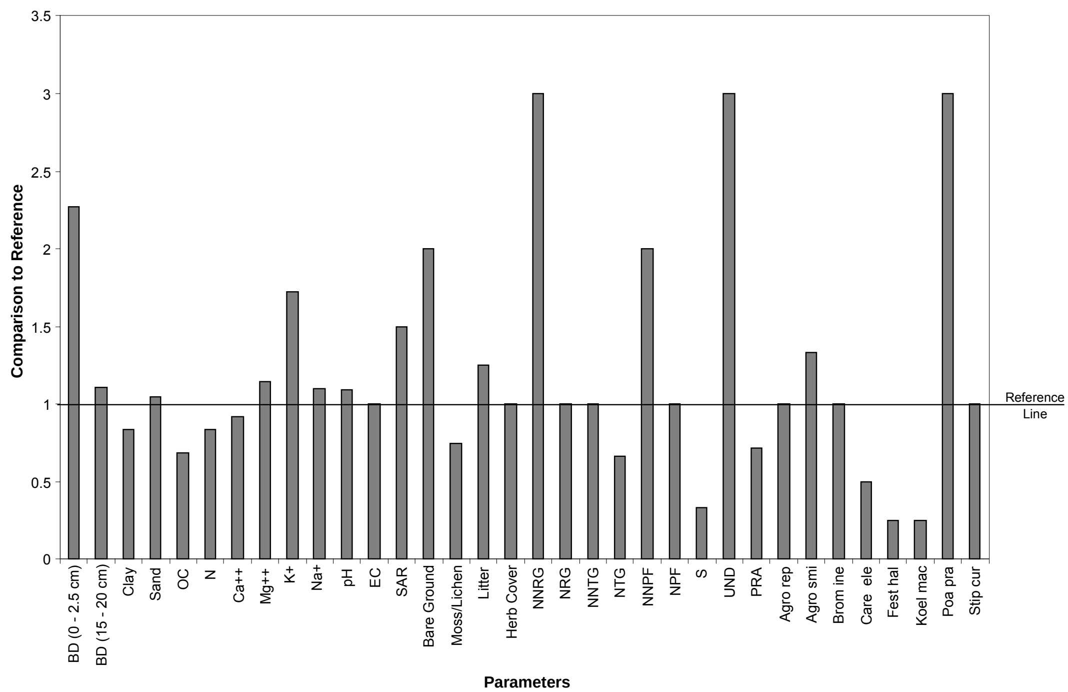
WS841345 (8-19-33-18 W4)

This well site was constructed in August 1984 using full build topsoil stripping. The current Rumsey mix was prescribed for revegetation but a 50-50 mix of crested wheatgrass and smooth brome was seeded. In the early 1990s the site was treated with glyphosate, reworked and seeded to the current Rumsey mix. Creeping red fescue was found on site so it was reworked again in 1996 and seeded to the current Rumsey mix. A reclamation certificate was refused again in 2001 due to topsoil and subsoil compaction and cover of Canada thistle. The site was located on the mid position of a northerly slope of 2-10 %. The site was fenced for a period of time after the first reclamation. There were some spots on the perimeter where smooth brome was encroaching onto the prairie. Smooth brome and crested wheatgrass were also found along the abandoned access road. The site had an abundance of Canada thistle, Kentucky bluegrass and American vetch. Some plains rough fescue was found established on the site. The only places where nearby reference areas could be found were on the upper positions of steep southerly and easterly hills around the right-of-way. Cattle appeared to favour hilltops and upper slopes.



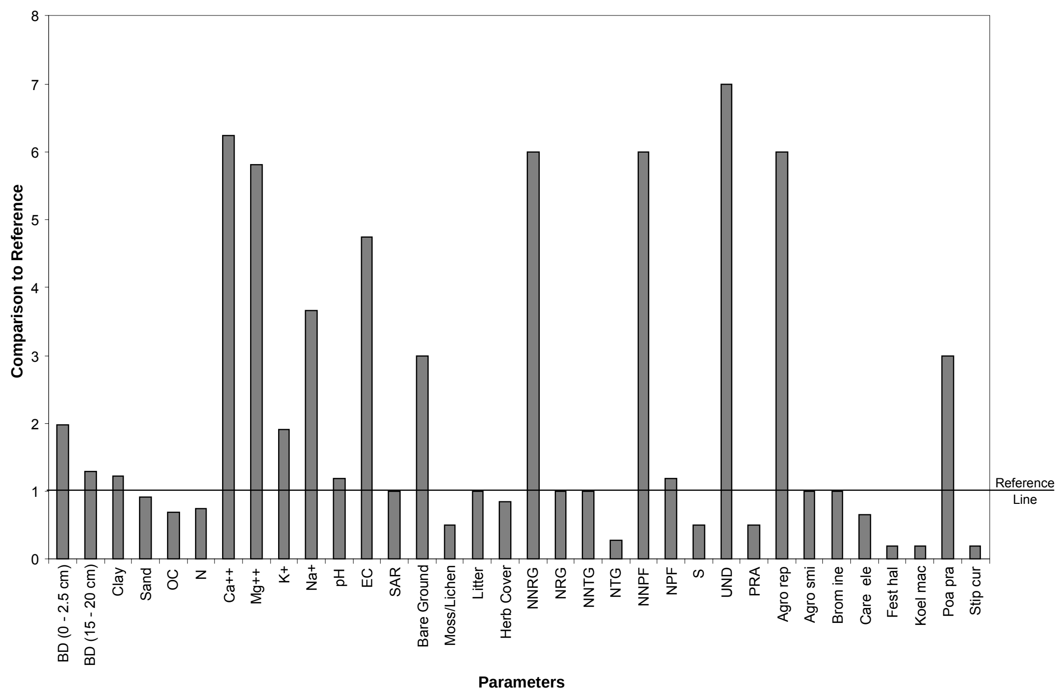
WS841454 (6-3-33-19 W4)

This well site was constructed in October 1984 using full build topsoil stripping. It was supposed to be seeded to the current Rumsey mix but establishment was poor. The site was dominated by Kentucky bluegrass, western and northern wheatgrass and various native forbs. The site was located on the mid slope position of a northwesterly slope of 10-20 %. It had Canada thistle, soil exposure and erosion. The site was fenced at one point, as shown by posts still remaining. The only suitable adjacent reference areas were on southeasterly and northwesterly upper slopes of 2-20 %.



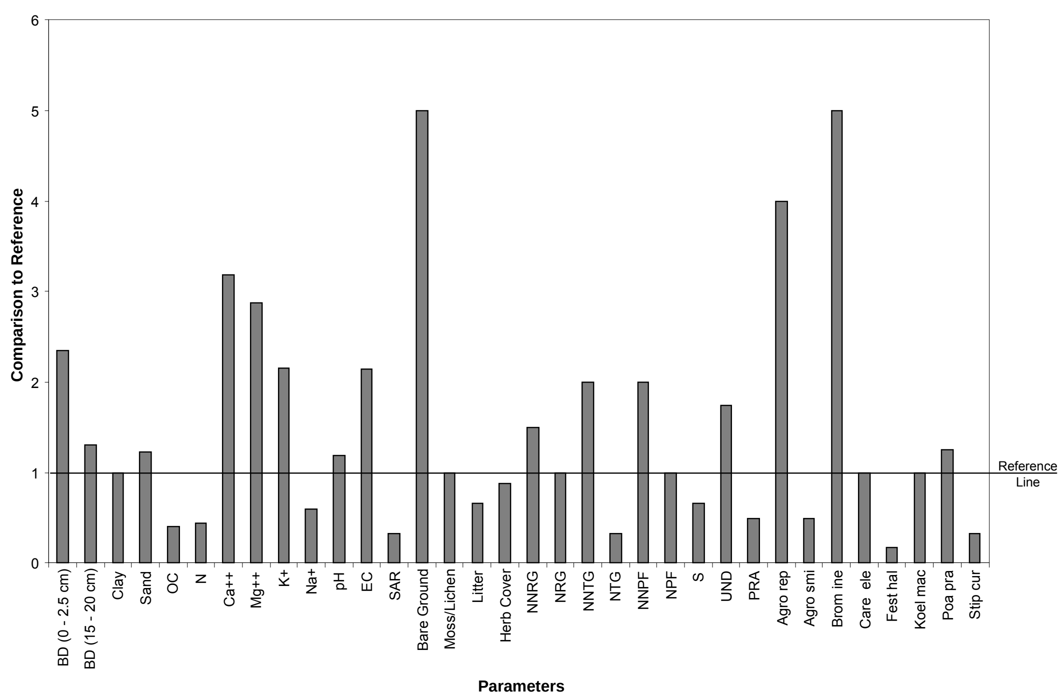
WS842258 (6-11-34-19 W4)

This site was constructed in January 1985 using full build construction with topsoil salvage over the entire well site and seeded with the current Rumsey mix. Although the third inspection in 1986 showed no further work was needed, the right-of-way was in poor condition. Although the well head was at one time excluded from cattle access it was unknown whether or not the entire right-of-way was ever excluded. Cattle grazed and rested on the right-of-way because it was in a dry southeasterly upper slope position, was very open and had palatable grasses.



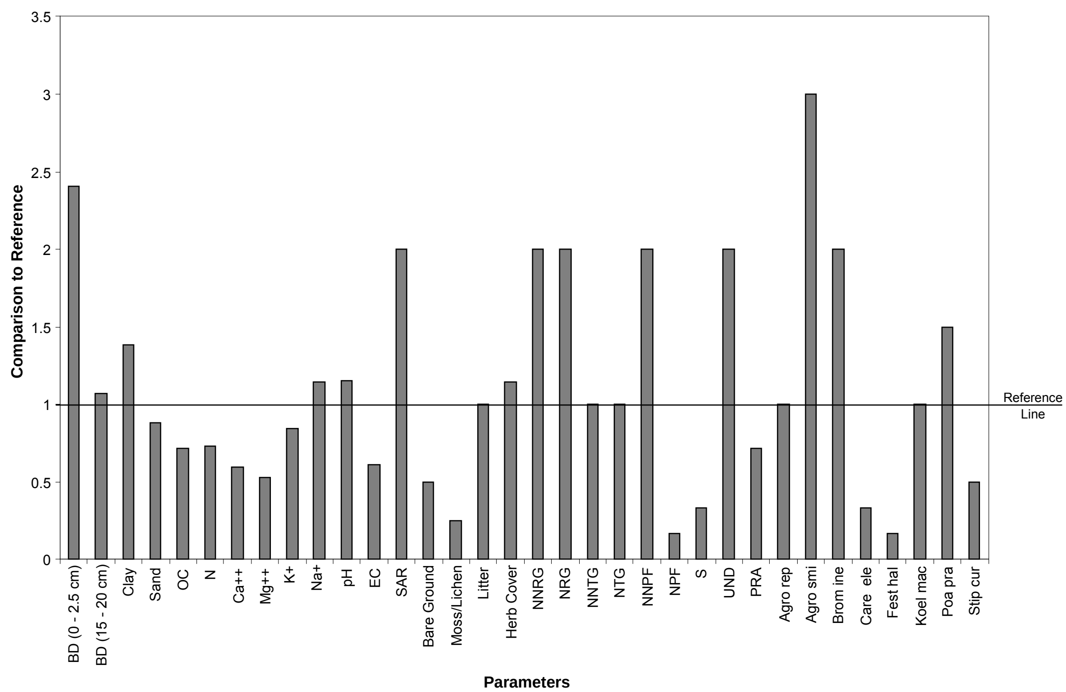
WS842261 (6-4-34-19 W4)

This well site was constructed in January 1985 using full build topsoil stripping and revegetated with the current Rumsey mix. The well site and reference area were on the lower toe position of a long, steep easterly slope. The reference had Kentucky bluegrass. Livestock trailing and grazing pressure were heavy on the well site and reference due to the proximity to the main road and watering site and the confinement of the large steep hill to the west. There was an exclosure around what appeared to be the well head and cattle liked to rub on it. The disturbance had an abundance of noxious weeds, soil exposure and erosion.



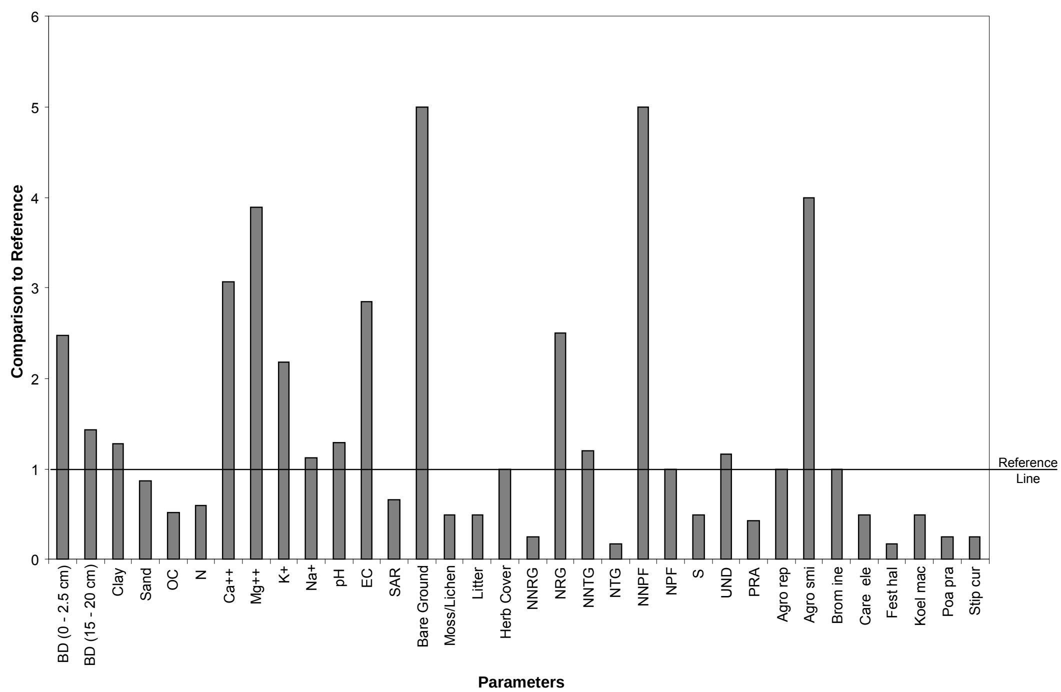
WS842262 (10-1-34-19 W4)

This well site was constructed in February 1985 using full build topsoil and subsoil stripping. The site was seeded to the current Rumsey mix. The entire right-of-way was excluded from grazing but the gate was open at the time of sampling in 2006 and there were light indications of use by cattle. The well centre was located on the upper position of an easterly slope of 10-20 %. The site had Canada thistle and Kentucky bluegrass. The reference locations with similar topography were difficult to locate because the field was hummocky and had a high cover of brush. As a result the reference was made up of a variety of positions from lower to upper positions of level to steep slopes facing in easterly, southeasterly and westerly directions.



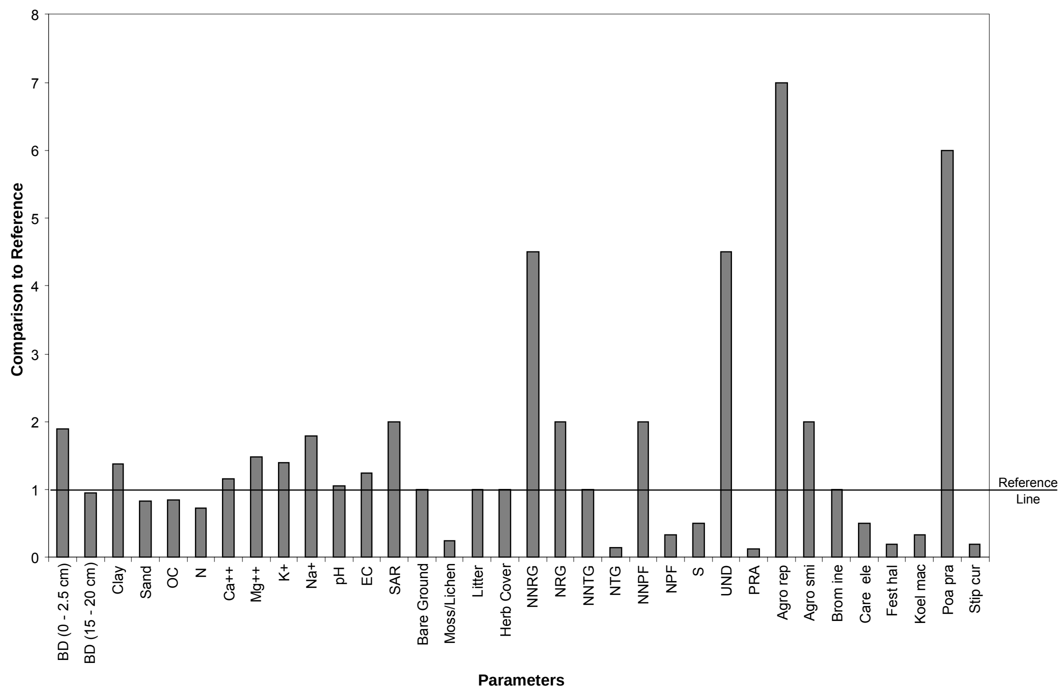
WS852360 (6-12-34-19 W4)

This well site was constructed in February 1985 using full build topsoil stripping over the entire right-of-way. It was supposed to be seeded to the current Rumsey mix, but the site was dominated by sheep fescue and native wheatgrasses. The disturbance was located on the mid position of a steep southeasterly slope. It had an abundance of Canada thistle, soil exposure and erosion. Sheep fescue was invading onto the native prairie from the right-of-way, especially where pipelines accessed the site. The reference areas were located on mid positions of steep easterly slopes and had some sheep fescue and Kentucky bluegrass. The well site and reference were located close to a livestock watering site so use was expected to be high even though at the time of sampling there was only moderate use.



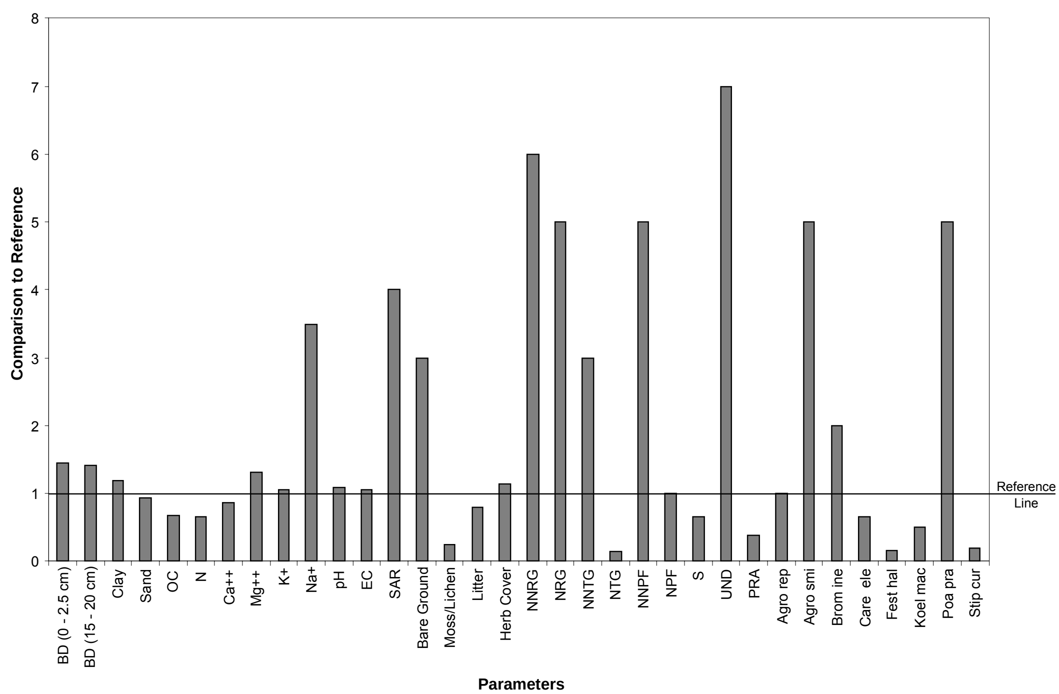
WS870583 (6-36-33-19 W4)

This well site was constructed in June 1987 using full build topsoil stripping of the entire right-of-way. It was supposed to be revegetated with the current Rumsey mix but the community was a very productive stand of Kentucky bluegrass and quackgrass. Kentucky bluegrass was invading past the right-of-way onto the undisturbed prairie. The sampling site was located on the mid position of an easterly slope of no more than 10 %. The reference area was located on mid to upper positions of westerly slopes from 2-20 %. Grazing appeared light. The right-of-way was excluded from grazing.



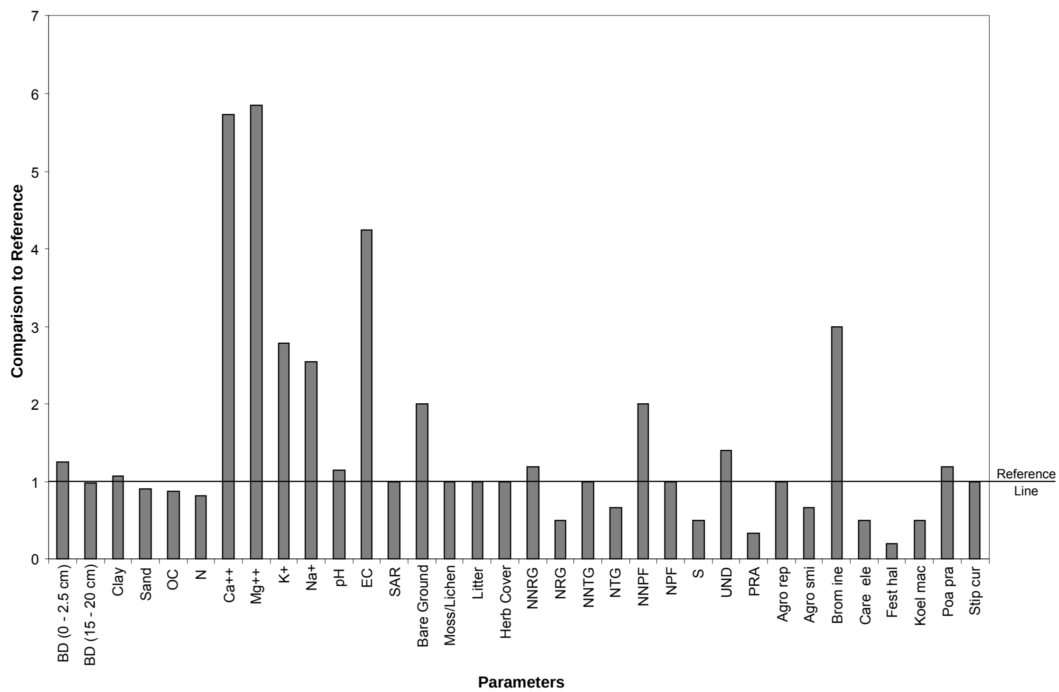
WS870632 (8-1-34-19 W4)

This well site was constructed in June 1987 using full build construction with topsoil stripping over the entire right-of-way. It was supposed to be seeded to the current Rumsey mix, but there was patchy establishment of various plant communities. The well head was fenced at one point. At the time of sampling in 2006 and 2007 there was a lot of soil exposure from cattle traffic and pooling of water around the well head due to lack of contouring. The sampling site was in the mid position of an easterly slope of 10-20 %.



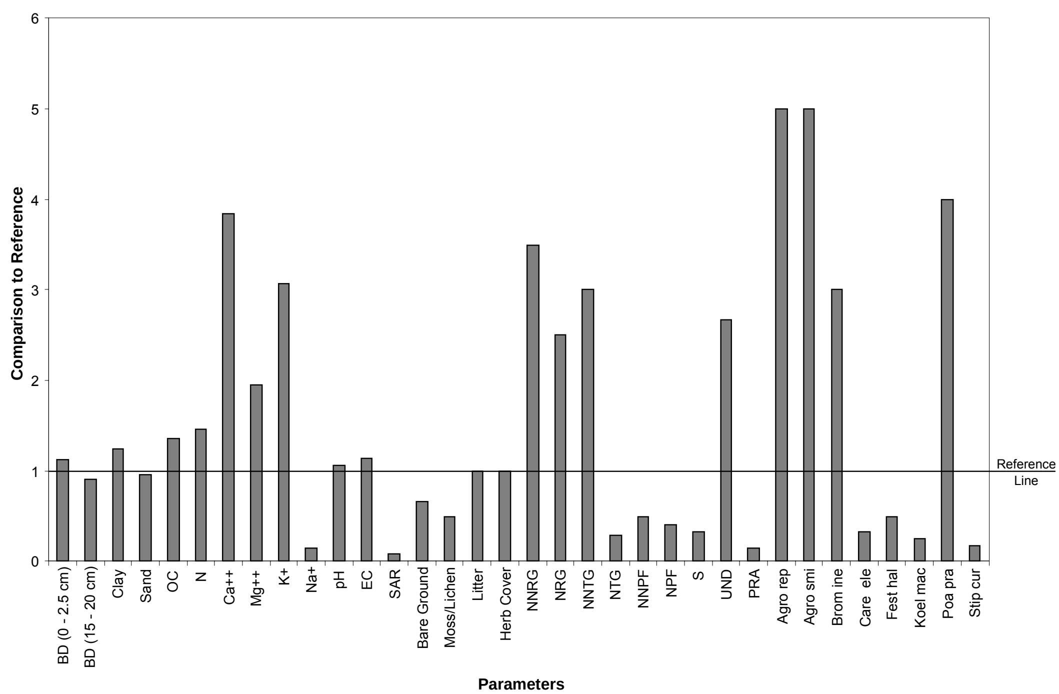
WS881954 (10-4-34-19 W4)

This well site was constructed in February 1989 using full build topsoil stripping over the entire right-of-way and revegetated with the current Rumsey mix. The site was almost level and lying on the edge of a large plateau. The right-of-way had an exclosure fence, but cattle accessed the site before vegetation sampling in 2006. The plateau held a lot of moisture, favourable for Kentucky bluegrass expansion. This, in combination with heavy use by cattle, made it difficult to find a reference not invaded by Kentucky bluegrass. The best location was 200 m to the south in a shallow swale on the plateau.



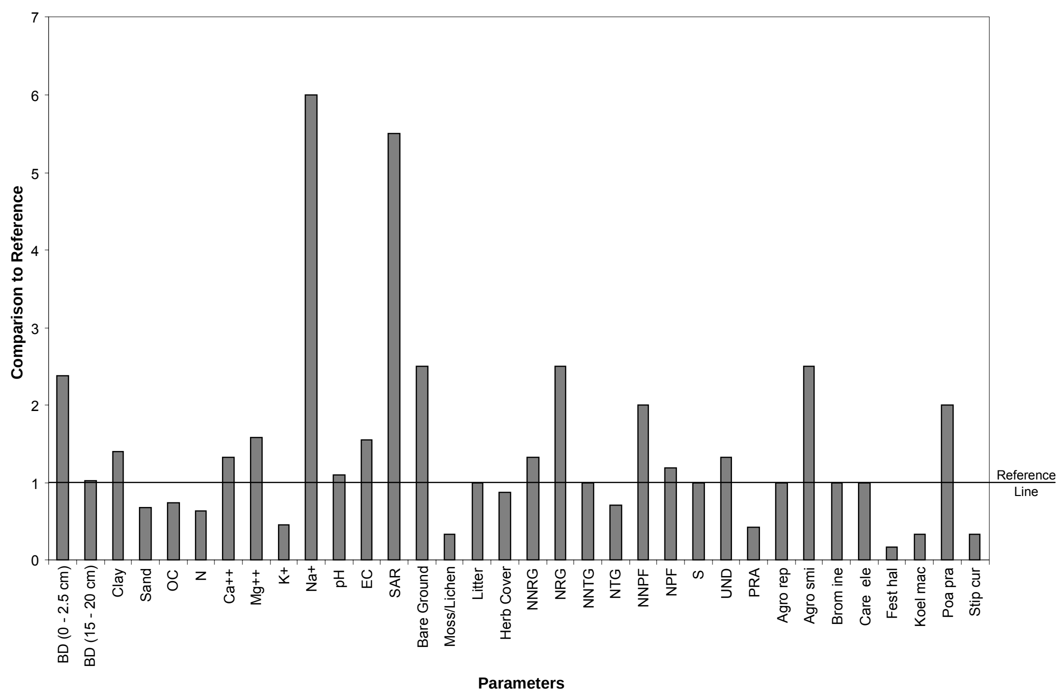
WS901091 (1-33-33-18)

This well site was constructed in February 1991 using full build construction with topsoil stripping and replacement followed by seeding with the current Rumsey mix. The site was located at the toe of a southwesterly slope. The degree of the slope was no more than 10 %. The reference was similar except that the position was mid slope and noticeably drier. The disturbance had noxious weeds. Grazing probably reduced productivity of the reference but the disturbance was very productive.



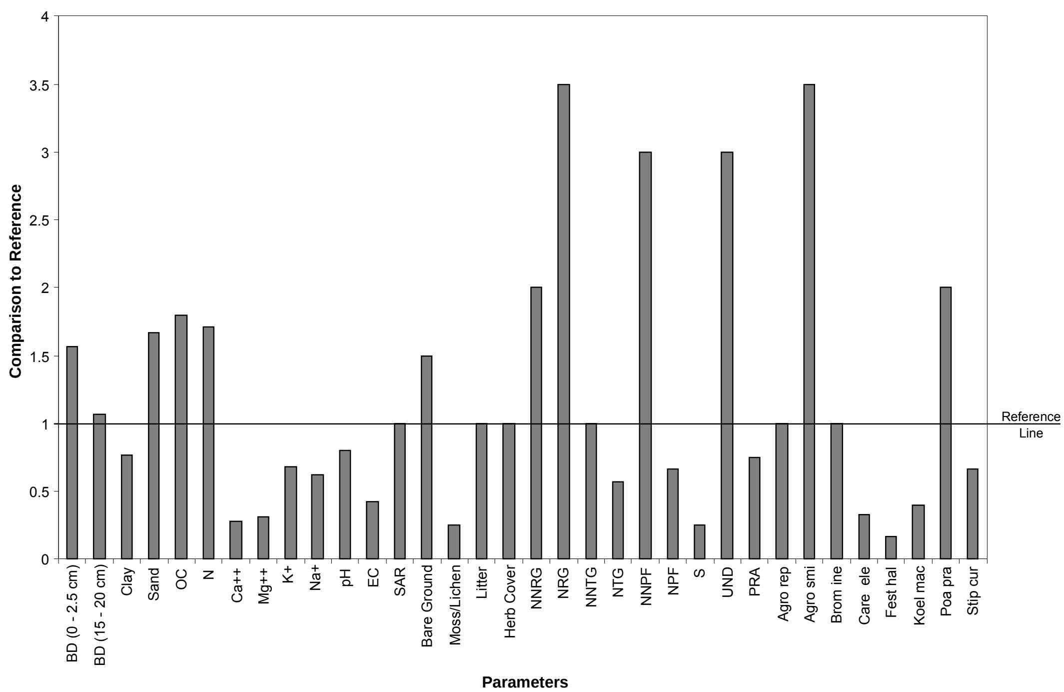
WS950583 (3-16-33-19 W4)

This well site was constructed in February 1995 using full build A horizon stripping but B horizon stockpiling only where the sump and rig were located. Conditions were wet when the rig left the site and there was pooling on the north end. The site was still producing in 2006 but the right-of-way was revegetated via natural recovery after topsoil was replaced. A graveled access road pad around the enclosed well head were kept vegetation free. Vegetation management was poor as evidenced by the patchy death of the weeds some time after spraying in 2006. The right-of-way was on the toe of a northeasterly slope. The well head was located on a level area, but on the south half of the right-of-way the slope becomes greater than 10 %. The right-of-way was excluded for some period after recontouring but the fence was removed and replaced in 2006. The reference areas were a combination of westerly, level toe slopes and steeper, easterly upper slopes. The site had Kentucky bluegrass. Cattle use was evidenced by the heavy trailing but long term grazing appears to be low except in flat depressions.



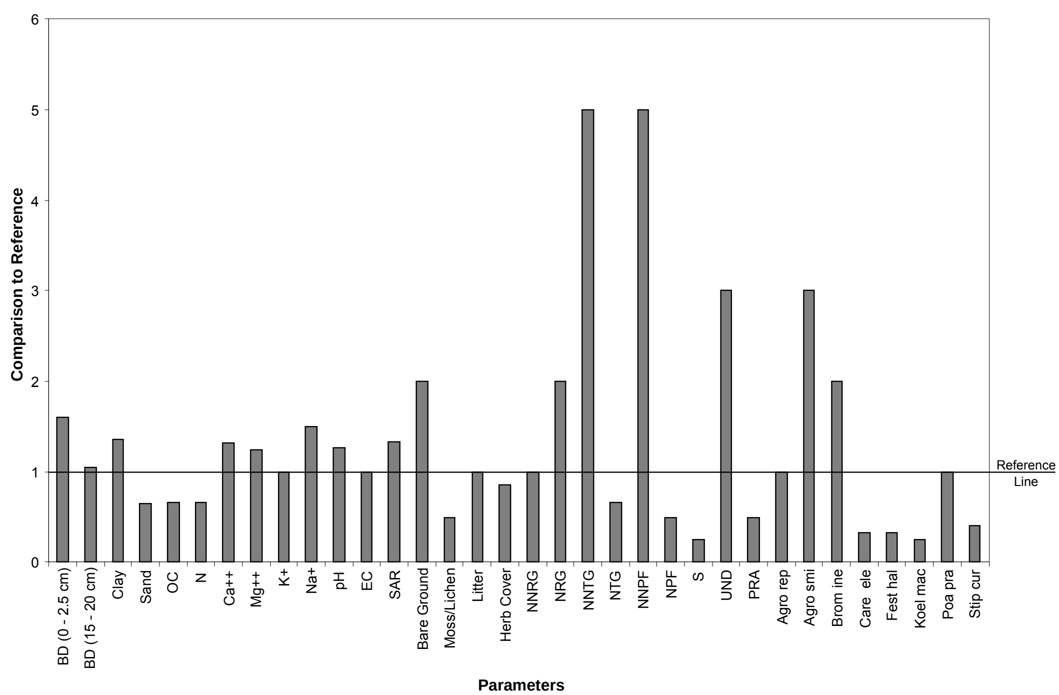
WS962001 (5-29-33-18 W4)

This well site was constructed on a flat hilltop in summer 1996 using full build topsoil stripping and replacement and revegetation with the current Rumsey mix. Revegetation was a failure because the community was composed of over 50 % quackgrass and small amounts of other non native and native plants. The site had an abundance of Canada thistle and quackgrass. No exclusion from cattle grazing was evident and this site was heavily used by cattle because of its flatness, proximity to the home corrals and abundance of quackgrass. The reference areas were located on southerly and northwesterly upper slopes of no more than 10 %.



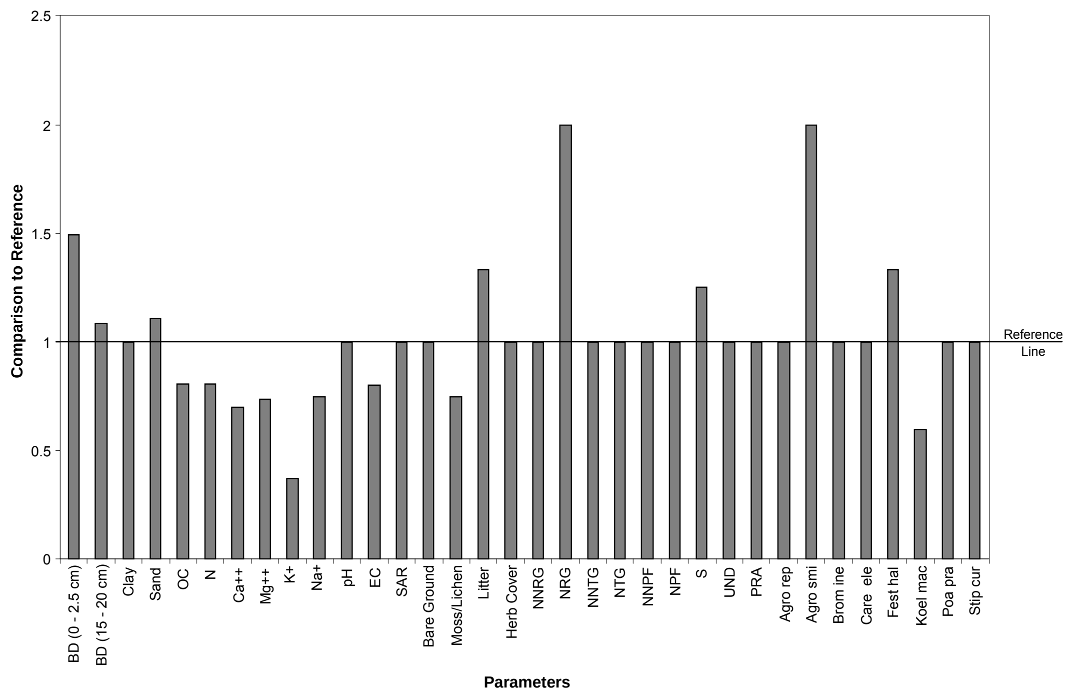
WS972291 (3-30-33-18 W4)

This well site was still producing and was drilled in August 1997 on an existing right-of-way dating back to the mid 1980s that had been reclaimed and revegetated at least twice. Revegetation with an inappropriate seed mix the first time necessitated treatment with glyphosate and reseeding. The new drilling construction was supposed to be minimal disturbance, but topsoil was stripped over a considerable area and not replaced. The topsoil remained in a pile which became overgrown with annual weeds and annual grasses. The right-of-way was excluded from grazing and a packed access road lead up to and away from the well head, surrounded by a small gravel pad. A zone of exposed subsoil lay to the east of the well head. Both the sampling site and the reference were on almost level terrain with an easterly aspect. Cattle trailing and long term grazing were evident, but immediate cattle impacts were absent.



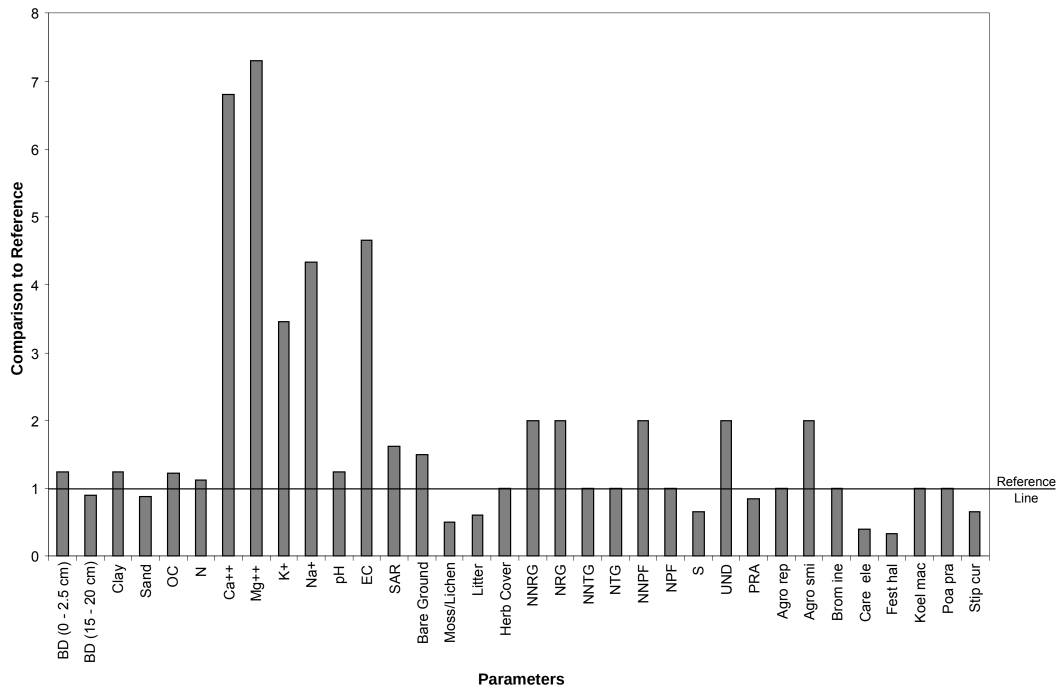
WS002266 (12-3-33-19 W4)

This minimal disturbance well site was drilled in October 2000 and any disturbance was revegetated through natural recovery. Some topsoil and/or subsoil was not replaced and remained as a small hill to the southeast of the well head. The well head was fenced and sat on top of a dry steep sided hill. Cattle liked to graze and rest on this hill and where the reference samples were located there was visibly reduced the vegetation. Samples follow the slopes of the hill in all four directions. The reference areas were on the upper positions of northwesterly, southerly, easterly and westerly slopes of 2-10 %.



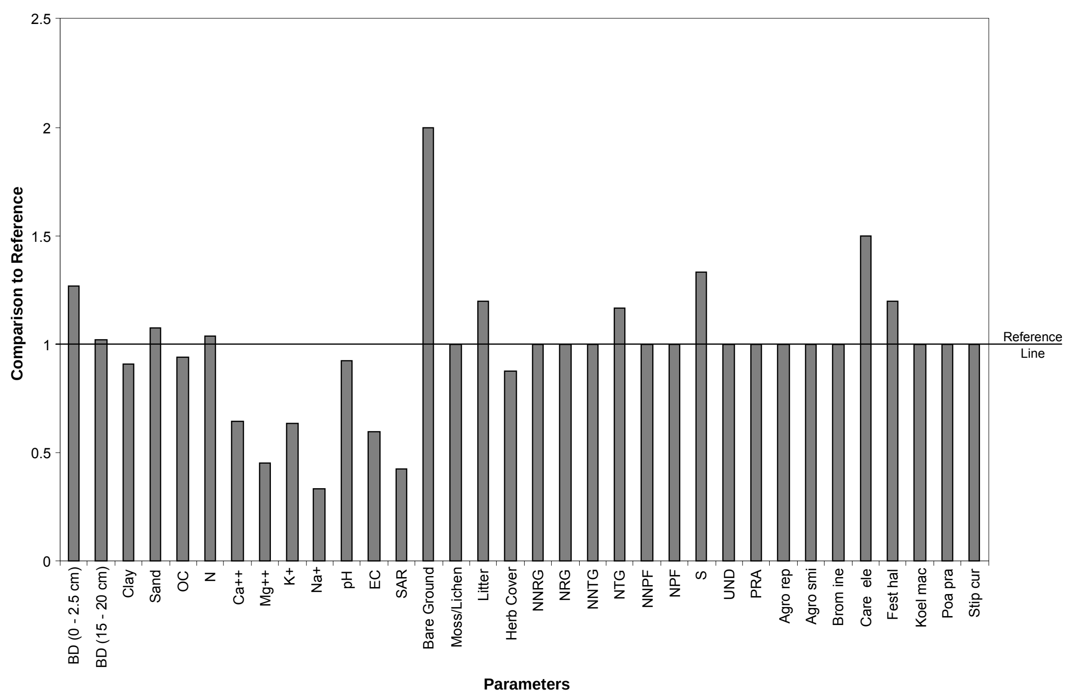
WS002276 (4-7-33-19 W4)

This site was constructed in October 2000 in a flat depressional area using minimal disturbance and revegetated by natural recovery. Damage to soil happened in the area around the well head due to moisture during construction. Here the ground was uneven from compaction due to anthropogenic disturbance and cattle traffic. The only exclosure was immediately around the well head. There was some slumping over the pipeline coming into the well head.



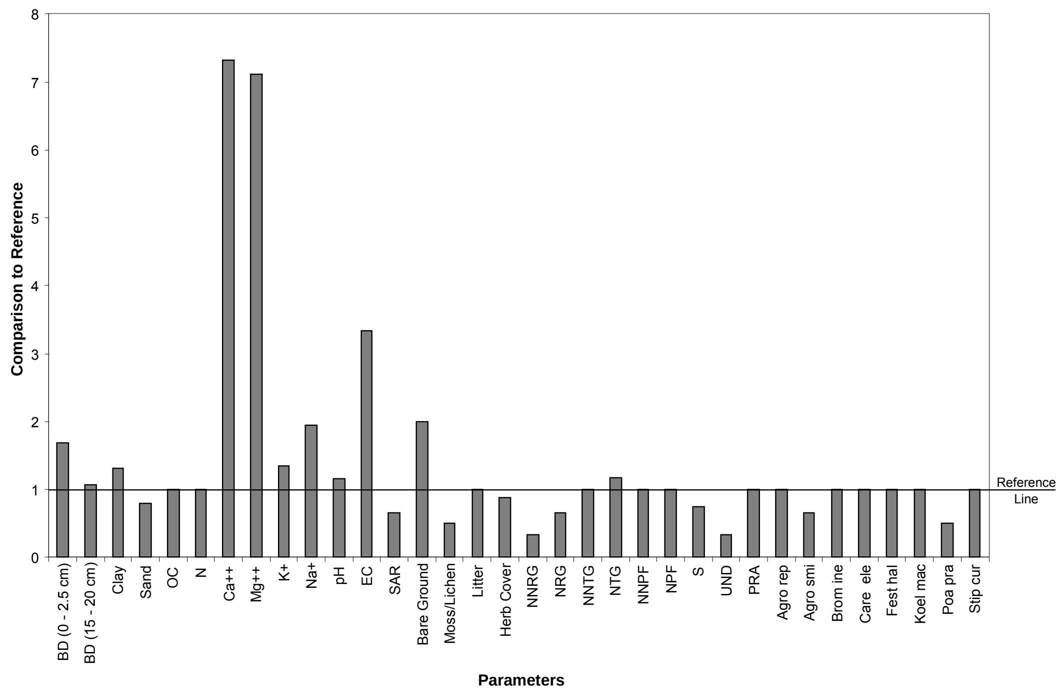
WS010426 (9-18-34-19 W4)

This well site was constructed in August 2002 using minimal disturbance. No topsoil was stockpiled even though construction occurred in summer. The well site was located on top of a low flat hill and excluded from livestock grazing. The reference grasslands around the site were on northerly to westerly slopes of no greater than 10%. The well site had some soil exposure and minor erosion. The only on going disturbance on this producing well site was from vehicular traffic.



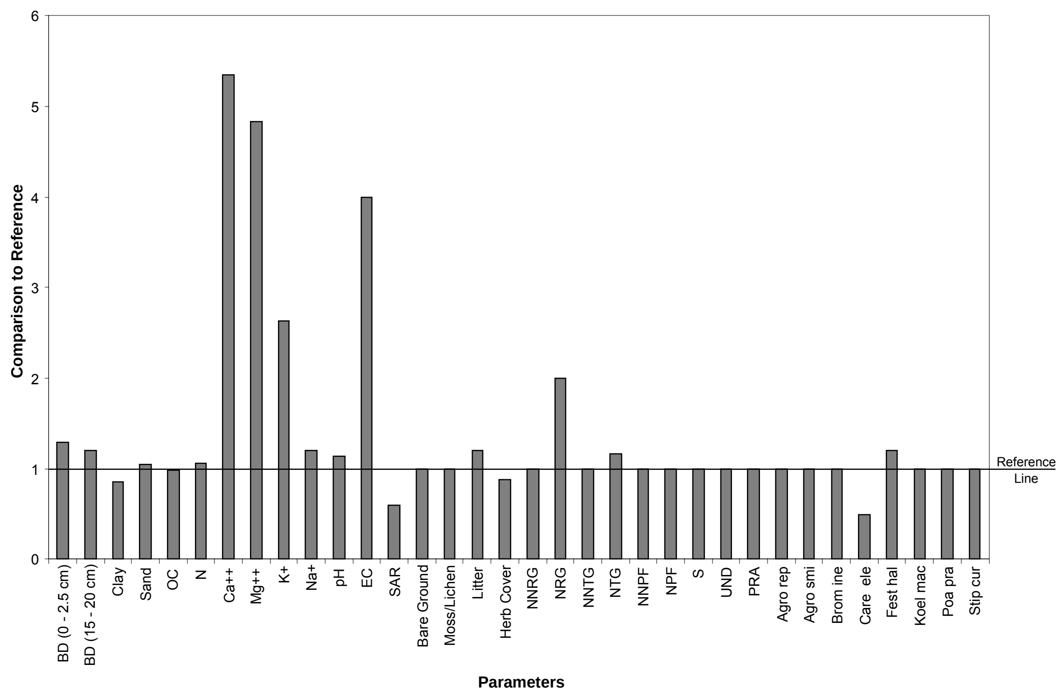
WS040754 (4-5-34-19 W4)

This well site was drilled in June 2004 and directionally drilled from in 2005. The sod and topsoil were left intact while equipment accessed this site and tanks and instrument shacks were placed on skids. The site and its reference were located on a flat plateau. Even though it was close to a corral and stock watering site, the reference was in good condition. The right-of-way was excluded from cattle grazing with a fence and Texas gate.



WS042922 (15-18-34-19 W4)

This minimal disturbance well site was drilled in summer 2004. It was quickly abandoned and the small disturbance was revegetated through natural recovery. It was difficult to locate except for a couple of strangely placed patches of western snowberry, Wood's rose and heavy grass cover. Most of the right-of-way appeared undisturbed except for a patch of smooth brome close to the well head. The site was located on rough ground at the northerly base of a very short hill with 10-20 % slope. The reference was on the mid position of a northerly slope of 2-10 %. Trailing was light to moderate.



The following four well sites were only sampled for plant community characteristics in 2006. During soil sampling in 2007, the first site could not be penetrated with sampling tools. The other three well sites were altered in 2007 which was expected to impact results of soil analyses. Due to the incomplete analyses, no AMOEBA diagrams are provided for these four sites.

WS000002 (3-30-33-19 W4)

This site was constructed in 1968, season unknown, methods of construction unknown and method of revegetation unknown. The site appeared to have been leveled as it was cut out of the side of a large hill to the west. Some slumping may have occurred at the well head as there was a severe dip in the terrain. It was difficult to tell if topsoil was salvaged or removed. Only vegetative sampling could be completed as the site was too compacted for soil sampling at any depth with manual equipment. In 2007 the entire field was heavily grazed and the well site appeared to be like pavement. The edge of the right-of-way was difficult to locate as the soil conditions improved towards the edge and sweet clover was invading undisturbed prairie. The reference areas were located in mid positions of short but steep southerly and easterly slopes.

WS852250 (8-21-33-19 W4)

This well site was constructed in December 1985 using full build topsoil stripping over the entire right-of-way. It was supposed to be seeded to the current Rumsey mix but was dominated by Kentucky bluegrass, smooth brome and western wheatgrass. The site was in an almost level upper slope position with northeasterly aspect. Only vegetation sampling was completed on this well site as it was sprayed with glyphosate before soil sampling. At the time of sampling the well appeared to be producing and was immediately surrounded with cattle panels to exclude access. Although there was no exclusion fence the right-of-way was clearly distinct from the undisturbed prairie from the different colour of the vegetation. Cattle use was heavy due to level terrain, openness and palatability of grasses on the well site. Trailing was light except to the east where hoof action exposed a large area of soil. Kentucky bluegrass appeared to be invading the undisturbed prairie from the well site.

WS860346 (6-25-33-19 W4)

This well site was constructed in February 1986 using full build construction with topsoil stripping over the entire right-of-way. The site was to be reseeded to the current Rumsey mix but smooth brome, sweet clover and Kentucky bluegrass dominated. The well site was located on the mid to upper position of a northwesterly slope of 10-20 %. Only vegetation sampling was completed on this well site because it was sprayed with glyphosate before soil sampling. The site had an abundance of Canada thistle, soil exposure and erosion. The right-of-way was fenced but at the time of sampling cattle had been allowed access. The reference areas were in mid positions of steep easterly to northeasterly slopes and were overgrazed by cattle because of proximity to the road and a watering site. It was difficult to find a location that was not overgrazed so half of the reference subsamples were located 150 m to the south on an adjacent hillside. Trailing around the exclosure was severe.

WS880398 (16-13-33-19 W4)

This well site was constructed in April 1988 using full build topsoil stripping over the entire right-of-way. It was supposed to be seeded to the current Rumsey mix, but instead was seeded to a mix containing smooth brome, sheep fescue and Kentucky bluegrass. Although there were some native grasses on site that may have been seeded, these three species dominated. Sampling was completed on the mid position of a steep northwesterly slope. Only vegetation sampling was completed on this well site because the site was sprayed with glyphosate before soil sampling was initiated.