University of Alberta

IMPACTS OF DISTANCE TO PIPELINE DISTURBANCE ON MIXED GRASS PRAIRIE AND *HALIMOLOBOS VIRGATA* (NUTT.) O.E. SCHULZ (SLENDER MOUSE EAR CRESS)

By

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DEDICATION

This MSc thesis is dedicated to my Opa and Oma,

Henry and Ella Nannt, for their unconditional

love and support

ABSTRACT

Halimolobos virgata (slender mouse ear cress) is an at risk plant species in the Dry Mixed Grass Subregion of Southern Alberta. Little is known about effects of disturbances such as pipelines on *Halimolobos virgata* and its habitat. Environment Canada recommends a non species specific set back of 300 m from species at risk for pipeline disturbances. This research addressed whether this set back was meaningful for *Halimolobos virgata* by studying effects of distance to pipelines on it. *Halimolobos virgata* tended to occupy micro habitats with soil properties different from surrounding habitat and comprised of several features impacting soil water content. Pipeline impacts to soil and vegetation were generally confined within right of way boundaries when steep terrain and extensive grading were not factors, therefore no set back is recommended. Right of ways may negatively impact *Halimolobos virgata* habitat; thus careful planning of route and construction timing is recommended.

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CHAPTER I. INTRODUCTION

1. BACKGROUND

With the world human population reaching 7 billion in 2011 (UN News Centre 2012) and continually growing, there is an increasing demand for natural resources. This demand coupled with the recent economy has caused Canada to shift from exporting manufactured products to exporting natural resources (Statistics Canada 2005).These natural resources include forestry, mineral, oil and gas products. For natural resources to be harvested or extracted, disturbances such as mines, roads and pipelines are constructed.

Infrastructure associated with natural resource exploration and development has affected flora and fauna habitat, air and water quality and aesthetics of Canada's natural landscape (Statistics Canada 2005). Extent and size of each disturbance varies but all have an impact on surrounding ecosystems. Mine disturbances can be less than 5 ha to over 1000 ha in size. Although pipelines are narrow they extend for hundreds of kilometers, crossing several different ecosystems. The pipeline network in Canada for crude oil and natural gas alone extends 700,000 km; the majority of this network is found in Alberta, the south half of Saskatchewan and northern British Columbia (Natural Resources Canada 2009).

Anthropogenic disturbances associated with extracting or harvesting natural resources can change surrounding ecosystem structure and function beyond their natural range. Ecosystems can be directly or indirectly affected through damage or removal of vegetation, soil, hydrologic regime and landform. For example, in the forestry industry tree and shrub canopy can be decreased by humans directly which indirectly affects biodiversity of understory plant species. Effects are often complicated with acute and cumulative impacts occurring on different temporal and spatial scales. Changes to ecosystems can result in varying effects for individual plant and animal species; these include threatened and at risk species.

The International Union for Conservation of Nature increased the number of threatened species in the world to 21,286 of the 71,576 assessed (IUNC 2013). Currently 99 % of threatened species result from human activities; primarily habitat loss, exotic species introduction and climate change (Centre for Biological Diversity 2012). In Canada over 600 species are listed at risk, including 187 vascular plants (Committee on the Status of Endangered Wildlife in Canada (COSEWIC) 2012). To prevent species extinction or extirpation in Canada, the Species at Risk Act (SARA) was introduced December 2002 (Parks Canada 2012). This act protects species listed at risk by the Governor in Council in Canada by encouraging management to facilitate recovery and prevent further loss. With SARA it is illegal to kill, harm, harass, capture, possess, collect, buy, sell or trade an individual or any part of an individual or damage or destroy the residence or critical habitat of individuals.

Grasslands cover approximately 40 % of the world's surface; Canada is one of five countries with the largest area of grassland (World Resources Institute 2011). Canadian prairie is home to 464 flora and fauna species of concern, of which 327 are endemic to native prairie (Alberta Environmental Protection 1997). With the large number of organisms endemic to native prairie, its conservation and protection is of concern. Approximately 25 % of native grassland remains and continually faces threats of anthropogenic disturbances (Bradley and Wallis 1996). The native grasslands are home to 81 of Canada's rare vascular plants.

Alberta grasslands comprise 14.5 % of the province, with the Dry Mixed Grass Subregion covering 7.1 % (Alberta Environmental Protection 1997). Alberta grasslands support 24 of Alberta's 31 species at risk. Many anthropogenic activities threaten these species by altering the ecosystem, fragmenting it with roads and pipelines. Many of the more than 392,000 km of energy related pipelines in Alberta cross the Dry Mixed Grass Subregion (Energry Resources Conservation Board 2011). Pipeline construction directly and indirectly affects the ecosystem and vegetation through soil stripping, trenching, soil compaction, introduction of undesirable species and changes to the hydrologic regime.

Plants are sessile and cannot move when faced with disturbances and habitat loss, making them vulnerable to anthropogenic activities. Protection of rare plant communities is important to biodiversity (Bevill and Louda 1999) and genetic variability (Goff et al. 1982). It requires humans to note rare or at risk plant communities and to protect plants from destructive activities. However, the knowledge base for understanding and managing rare plant populations is weak, requiring research to understand how developments will affect them.

Little research has been conducted on impacts of human activities on rare plants in Alberta. Such research would enhance federal and provincial rare plant policy and assist development of ecologically sound and cost effective mitigation measures for industry. The exponentially growing oil and gas industry in Alberta is challenged to meet current set back guidelines. This research focuses on effects of three year old pipeline disturbance on two prairie plant species at risk, *Halimolobos virgata* (Nutt.) O.E. Schulz (slender mouse ear cress) and *Cryptantha minima* Rydb. (tiny cryptanthe) and their associated habitat on the pipeline right of way (ROW) and varying distances from it. The research aims to determine the distance needed between rare plant species and pipelines to protect individuals and their habitat. Results can be used by resource managers to determine appropriate pipeline routes and mitigation strategies. Valuable information on the biology and response of these species to a disturbance in their habitat will contribute to recovery strategies. The research can be applied to other disturbances and habitats to aid in balancing human disturbance and environmental integrity.

2. RARE PLANTS

In Canada all species at risk of extirpation or extinction and their critical habitat are protected by SARA (Canada Department of Justice 2002). Critical habitat is anything deemed necessary for survival or recovery; including biological, chemical and physical features. Six plant species at risk occur in Alberta (Environment Canada 2009); *Halimolobos virgata*, *Yucca glauca* Nutt. (soap weed), *Cryptantha minima*, *Iris missouriensis* Nutt. (western blue flag), *Tripterocalyx micranthus* (Torrey) Hooker (small flowered sand verbena) and *Tradescantia occidentalis* (Britton Smyth) (western spiderwort). All except *Tradescantia occidentalis* occur in the Dry Mixed Grass Subregion of the Grassland Natural Region (Alberta Environmental Protection 1997).

Reduction or modification of habitat and introduction of exotics are major causes of endangerment and extinction (Thomas 1994, Foin et al. 1998, Wu and Smeins 2000). These causes can result from anthropogenic or natural disturbances;

discrete events in time that disrupt the ecosystem, community or population structure and change resources, substrate availability or the physical environment (Pickett and White 1985, Larson 2002). For rare and declining species, extinction is usually the deterministic consequence of local habitat becoming unsuitable through environmental stochastic events or anthropogenic landscape changes (Thomas 1994). Understanding effects of disturbance on variability in habitat, environment, demographics and genetics is needed to assess long term survival and conserve threatened and endangered species (Root 1998). With limited information on the biology and ecology of rare plants (Wu and Smeins 2000), research is essential for protection of unique species.

Disturbance regime is important in many ecosystems and variations can affect community structure and function (Hobbs and Huenneke 1992). Natural and anthropogenic disturbances are sources of mortality for some species and of establishment for others (Denslow 1980, Larson 2002). In New England rare plants are often found in anthropogenically disturbed sites or undisturbed areas along animal paths where root and shoot competition is reduced (McIntyre 1995). Researchers concluded disturbances are required to create suitable rare plant habitat in sand plain forests and shrub lands (Thomas 1994, Clarke and Patterson 2007), although water and soil disturbance can reduce rare species richness (McIntyre and Lavorel 1994).

2.1 *Halimolobos Virgata* (Slender Mouse Ear Cress)

COSEWIC designated *Halimolobos virgata* as endangered in 1992 and reassessed it as threatened in 2000 (Environment Canada 2010). Reassessment was due to an updated status report with new information on locations (Alberta Sustainable Resource Development and Alberta Conservation Association 2009, Environment Canada 2010). In 2003 it was listed as threatened under SARA and ranked as S1 (≤ 5 occurrences in the province with low populations size) by Alberta Conservation Information Management System (Gould 2006).

Halimolobos virgata is native to Canada and the United States (Figure 1.1); Canadian populations are only found in Alberta and Saskatchewan (Environment Canada 2010). Alberta numbers differ slightly with one extirpated, one historical, three failures to find and nine extant (Alberta Sustainable Resource Development and Alberta Conservation Association 2009). These populations can be found within a 9,998 km^2 extent in Southeastern Alberta, with each occupying roughly 18 km^2. In Saskatchewan there are 17 recorded populations; two do not have accurate information to relocate and five are historic and have not been relocated (Environment Canada 2010).

Halimolobos virgata is mainly found in the Mixed Grassland Ecoregion, characterized by extreme summer and winter temperatures and growing season water deficits (Alberta Sustainable Resource Development and Alberta Conservation Association 2009, Environment Canada 2010). It occurs in flat to gently rolling prairies, with some in valleys of the South Saskatchewan and Red Deer Rivers. Habitats include subxeric (moderately dry) to occasionally xeric (very dry) sites on flat to very gently undulating sand plains, dry to vernally moist (in spring) low depressions with level to > 5 % slopes, or submesic (moderately moist) sites with a 3 to 8 % slope in a southerly aspect (Alberta Sustainable Resource Development 2005). Soils are typically Orthic Brown Chernozem, Dark Brown Chernozem or Regosolic with glacial fluvial, lacustrine and eolian parent materials and sandy to loamy texture (Environment Canada 2010).

Halimolobos virgata appears to require disturbance. Most known locations in Alberta were lightly grazed (Alberta Sustainable Resource Development 2005). A modest disturbance that exposes sand and creates depressions may assist seedling establishment. While plants are associated with grassland dominated communities, they are found in close proximity to *Artemisia cana* Pursh. (silver sage bush) shrubs or stout succulents such as *Opuntia polyacantha* Haw. (prickly pear cactus) (Smith 1992, Alberta Sustainable Resource Development 2005). This may be due to protective cover and winter snow deposits in the lee of mounds providing soil water early in the growing season and late autumn (Alberta Sustainable Resource Development 2005).

Koeleria macranthra (Ledeb.) Schult (june grass), *Stipa comata* Trin. & Rupr. (needle and thread grass), *Stipa curtiseta* Hitchc. (western porcupine grass), *Agropyron trachycaulum* (Link) Gould ex Shinners (western wheat grass), *Agropyron smithii* (Rydb.) A. Löve (slender wheat grass), *Carex stenophylla* Wahlenb. (low sedge), *Chenopodium pratericola* Rydb. (goosefoot), *Arabis holboellii* var. r*etrofacta* Hornem (reflexed rock cress) and *Draba reptans* (Lam.)

Fernald (whitlow grass) are associated native species (Alberta Sustainable Resource Development and Alberta Conservation Association 2009). *Halimolobos virgata* also occurs in low thickets dominated by *Artemisia cana* and *Opuntia polyacantha*.

Halimolobos virgata is a member of the *Brassicaceae* (mustard) family and the only *Halimolobos* species in Alberta (Alberta Sustainable Resource Development 2005). It is biennial, but can complete its life cycle as an annual or exhibit traits of a short lived perennial (Alberta Sustainable Resource Development and Alberta Conservation Association 2009). Plants vary in appearance. Stems are 10 to 40 cm tall, with single stemmed or branched branches; plants can be robust or thin, and pubescent with long, straight, simple or forked hairs and short, branched hairs. Basal rosette leaves are toothed with stalks (petioles); leaves are clasping at the base, and get smaller near the top (Looman and Best 1979, Moss 1994). It flowers mid May to early June with siliques forming late June to mid July (Alberta Sustainable Resource Development and Alberta Conservation Association 2009, Environment Canada 2010). Flowers have four small whitish petals 4 to 8 mm across and four hairy sepals. Siliques are circular with a slightly compressed cross section, typically hairless and up to 4 cm long and 1 mm wide. Siliques grow erect from 7 to 11 mm long stalks and extend at a 45 degree angle from the stem; with ripening they turn reddish brown and split open, each releasing 16 to 26 seeds by mid July. Seeds are held to the silique by a thin stalk and readily pull away from the septum. Seed germination and seedling survival are unknown.

The wind shakes the stalks to release seeds, but seeds have only narrow wings, limiting the distance they can be dispersed. Like most biennial and annual species, *Halimolobos virgata* may not disperse to new sites quickly but seeds can remain viable for years until conditions become suitable for germination (Alberta Sustainable Resource Development 2005). Biennials of this nature often produce large numbers of seeds after a local disturbance or unusual climate event (Harper 1977, Alberta Sustainable Resource Development 2005).

Halimolobos virgata is threatened by habitat loss and degradation from anthropogenic and natural processes, including drought, alteration or lack of grazing and fire, oil and gas activities, cultivation, competition from alien species, urban development, military and industrial activities (Environment Canada 2010).

In Wyoming it withstood disturbances such as grazing and fires; hoofs created small depressions and exposed soil, creating suitable micro habitat and fire removed competition and released valuable nutrients (Alberta Sustainable Resource Development and Alberta Conservation Association 2009).

Research on this pipeline disturbance, concluded *Halimolobos virgata* occupied a unique rim niche that supports early colonizers with high resistance to stress and low competitive ability (Nemirsky 2011). The rim niche was characterized as habitat surrounding digressional areas that seasonally flood or are subject to deposition and had slightly compacted loam to sandy loam textured soil on gently undulating sites. Soil at occupied sites had higher total and organic carbon, base saturation and sodium than unoccupied sites. Occupied sites had more bare ground, less litter, shorter vegetation and were commonly associated with *Agropyron smithii, Koeleria macrantha* and *Artemisia frigida*. *Halimolobos virgata* occupied sites on ROW, deemed less than ideal for perennial native plants due to higher penetration resistance, electrical conductivity, pH and exchangeable calcium, magnesium and sodium.

2.2 *Cryptantha Minima* (Tiny Cryptanthe)

In April 2008, COSEWIC listed *Cryptantha minima* as endangered (Environment Canada 2006). The Alberta Conservation Information Management System and the province of Saskatchewan rank it as S1 (Gould 2006, Saskatchewan Conservation Data Center 2012).

Cryptantha minima is native to North America (Figure 1.2); with the Canadian populations in southeastern Alberta and southwestern Saskatchewan (Alberta Sustainable Resource Development 2004). There are 28 known populations in Alberta and 4 in Saskatchewan. The majority of populations are along the South Saskatchewan River near the Alberta and Saskatchewan border (Environment Canada 2006). It has been found in the vicinity of lower Bow and upper Oldman Rivers in Alberta and the vicinity of the Red Deer River in Saskatchewan.

Cryptantha minima is mainly found in the Dry Mixed Grass Subregion of the Mixed Grassland Ecoregion (Alberta Sustainable Resource Development 2004, Environment Canada 2006). It occurs in sandy, level to rolling uplands, sand dunes near valley breaks, valley slopes up to 50 % and level or gently sloping terraces in valley bottoms, particularly meander lobes. Habitats are xeric to subxeric on south to east aspects > 20 degrees. It occupies areas with little litter, 10 to 40 % bare soil and typically Orthic Regosols or Rego Chernozems. Soil is sandy loam to loamy sand textured, of glacial fluvial or eolian parent materials.

Cryptantha minima habit usually includes periodic disturbance from water (terraces in meander lobes), wind (sandy, upland plains, dunes), gravity (valley and upland slopes) and soil disturbing animals that create bare soil patches. Plants do not inhabit areas with active erosion or with continuous or repeated disturbance such as active sand bars, cultivation and actively eroding slopes (Alberta Sustainable Resource Development 2004, Environment Canada 2006).

Associated plant communities are dominated by *Stipa comata* and *Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths (blue grama grass) (Alberta Sustainable Resource Development 2004, Bradley and Ernst 2004, Environment Canada 2006). Other associated species are *Opuntia polyacantha*, *Plantago patagonica* Jacq. (pursh's plantain), *Chenopodium pratericola*, *Artemisia frigida* Willd (pasture sage), *Carex filifolia* Nutt. (thread leaved sedge), *Carex stenophylla* Wahlenb. (needleleaf sedge), *Lepidium densiflorum* Schrad (pepper grass), *Oryzopsis hymenoides* Roemer & J.A. Schultes (indian rice grass), *Poa juncifolia* Scribn. (alkali blue grass) and two non natives *Salsoa kali* L. (russian thistle) and *Lappula echinata* Gilib. (bluebur).

Cryptantha minima is a native annual in the *Boraginaceae* (borage) family (Alberta Sustainable Resource Development 2004, Environment Canada 2006). It grows up to 20 cm tall with stems branched near the base. Leaves are bristly haired and spatula shaped, up to 6 cm long, 0.5 cm wide and decrease in size up the stem (Moss 1994, Environment Canada 2006). It flowers late May to early July; seeds reach maturity in late July and August (Smith 1998, Kershaw et al. 2001, Alberta Sustainable Resource Development 2004, Environment Canada 2006). Flowers are tube shaped with white petals, yellow centre and bristly green sepals, up to 2 mm across and 3 mm long. Each flower has a small leaf or bract at the base. Sepals are enlarged, 5 cm long and have thick and hard whitish veins. Each flower contains four white nutlets; one larger nutlet with a smooth surface and three smaller nutlets covered in bumps.

Cryptantha minima spends most of its life cycle as dormant seed (Alberta Sustainable Resource Development 2004, Environment Canada 2006). Its existence is therefore reliant on seed bank populations. How long seeds remain viable, or what proportion produced reside in the seed bank is unknown. Annuals often depend on seed longevity to buffer environmental unpredictability (Harper 1977, Environment Canada 2006). Seed dispersal is likely passive with seeds falling close to the parent plant or carried on animal fur via calyx bristles. Most seeds move only a few metres, with movement beyond 100 m rare (Harper 1977, Primack and Miao 1992, Cain et al. 2000, Environment Canada 2006).

Numbers of plants vary greatly from year to year (0 to over 50,000 plants at one site) depending on amount of rainfall, timing of rainfall, seed production from past years and germination conditions. Different surveying techniques can result in varying counts within or between survey years (Alberta Sustainable Resource Development 2004, Environment Canada 2006).

Primary threats to *Cryptantha minima* are alteration and degradation of habitat (Environment Canada 2006). This includes land use changes such as cultivation, urban development, reduction or loss of grazing, fire control, invasive vegetation encroachment and oil and gas, sand and gravel and military activities.

3. PIPELINES AND SET BACK DISTANCES

3.1 Pipelines

Pipelines are used across Canada and around the world to efficiently transport large quantities of crude oil, natural gas, water, gases and refined petroleum products (Canadian Energy Pipeline Association 2012). In Canada approximately 15 billion cubic feet of natural gas and 3.2 million barrels of petroleum products are transported by pipelines daily. Without pipelines, for crude oil alone, more than 15,000 tanker trucks would be required each day to transport the amount.

Pipelines are used in upstream and downstream oil and gas industry to transport raw materials and products. This is done by a network of pipelines consisting of several different lines; gathering lines, feeder lines, transmission pipelines and distribution lines (Neville 2002). Gathering lines are used to collect products from wells and transport material short distances to oil batteries or gas processing plants. These lines are usually small in diameter, from 11.4 to 32.4 cm. From the batteries or processing plants feeder lines (21.9 to 50.8 cm) are used to transport material to transmission pipelines. Transmission pipelines, typically large in size (61 to > 120 cm), are used to transport products long distances to refineries. Transmission lines cross provincial and federal boundaries. As these lines are long they require additional infrastructure to keep products moving, including compressors and pumps. The last component of the pipeline network is distribution pipelines, used locally to distribute products to individual homes and businesses. Distribution lines are much smaller, from 2.1 to 16.8 cm.

When a pipeline is constructed, a ROW is developed to organize all components of pipeline construction. A right of way is comprised of a trench, work and storage areas (Figure 1.3). The trench is where soil is excavated and the pipeline is buried. The work areas is where equipment and traffic is located and traverses during construction. The storage area is where topsoil and subsoil that was stripped or excavated is stored during construction. The right of way can also contain areas that are considered permanent ROW or temporary ROW. Permanent ROW is the areas of the ROW that had vegetation and topsoil stripped for construction, whereas for the temporary ROW the vegetation and top soil were left in place.

Pipeline disturbance can be highly variable as construction methods are affected by operators, soil type, topography, timing, size and material. This variability, combined with changes in construction techniques and willingness of companies to experiment with methods, makes it difficult to generalize construction and associated effects. Disturbance is usually greater with large diameter pipelines as larger and heavier equipment is needed. More workspace is required and large pipelines typically form corridors for other pipelines to be looped into which increases temporal and spatial disturbance. The disturbance typically associated with pipeline construction on the prairie is fragmentation of undisturbed land, removal of native vegetation, invasion of non native plants, changes to soil and landscape structure, disturbances to wildlife and potential for spills during and after construction (Sinton 2001). As a result the native prairies in North America are considered one of the most endangered natural environments.

To protect and conserve native prairie a manual for best management practices for pipeline construction in native prairie was developed by stake holders (Neville 2002). Best management practices provide all of the operators with the same information so construction activities are implemented effectively, increasing long term conservation and reclamation goals to avoid sensitive areas, minimize disturbance, conserve prairie and vegetation, conserve prairie wildlife and fisheries habitat, conserve historical resources, conserve grazing capacity, set the stage for eventual restoration and prevent the spread of non native species.

Best management practices include those assisting with long term conservation and reclamation. Many are directly linked to rare plants and their associated habitat. For the planning stage, these may include pre construction surveys (soils, vegetation, rare plants, weeds, invasive species, wildlife), stakeholder involvement, route selection (using existing ROW and access roads, avoiding sensitive habitat features, identifying plant communities and rare plants, avoiding difficult to reclaim soils), consideration of cumulative impacts (developing cooperative management plans) and quality assurance (compiling an environmental issues list, a well documented conservation and reclamation plan, providing environmental education for contractors and operations personnel and providing environmental inspectors) (Neville 2002).

The construction stage includes best management practices for rare plants. These include constructing when native vegetation is dormant, constructing when soils are suitably dry or frozen, including voluntary shut down criteria in contracts, controlling wind erosion with tackifiers, reducing time between stripping and replacement, using special equipment to salvage topsoils, developing a site specific strip plan based on minimum stripping width, using woven geotextiles at crossings of seasonal drainages, minimizing grading using avoidance or spoil from the trench on geotextile fabric, minimizing traffic using special equipment for backfilling, compacting trench soil to prevent an elevated roach, using modified street sweepers to remove excess spoil from the storage area and matching the ROW to surrounding landforms and drainage (Neville 2002).

Post construction monitoring is a critical component aiding in mitigation success (Jacques Whitford AXYS Ltd. 2008). Monitoring is important for the continual improvement of native prairie construction, reclamation and revegetation techniques (Neville 2002). Monitoring reports can provide crucial information about successful procedures that can aid in future pipeline development planning and contribute to recovery plans of plant species at risk.

3.2 Right Of Way And Surrounding Habitat

The pipeline ROW is constructed by clearing vegetation, stripping topsoil and grading to create a level surface (Canadian Energy Pipeline Association 2012). It consists of a trench, working area and topsoil and subsoil storage areas. Installation typically results in initial disruption of soil properties and flora (Kerr et al. 1993). Many changes persist with time (Naeth 1985, Naeth et al. 1987), with changes to soil productivity temporary or permanent (de Jong and Button 1973).

In Saskatchewan pipeline construction did not affect Chernozemic soils, and improved Bnt permeability and aeration in Solonetzic soils (de Jong and Button 1973). In the upper 15 cm, copper sulphate ($CuSO_4$) extractable nitrate (NO_3), sodium bicarbonate ($NaHCO_3$), extractable phosphorus, ammonium acetate (NH_4OAc) and extractable potassium were similar in trench, storage and undisturbed areas. In soils of saline parent material the upper 15 cm of trench had increased pH and electrical conductivity. With mixed soil horizons, the upper 15 cm had decreased nitrate, phosphorus and potassium which increased below 30 cm. Trenching Solonetzic soil decreased Bnt bulk density and increased air filled pores, with increased bulk density on Chernozems and aeration unaffected.

In Southern Alberta pipeline installation affected physical and chemical properties of Solonetzic soils (Naeth 1985, Naeth et al. 1987, 1990, 1991, 1993). Bulk density decreased with depth in the trench and increased in undisturbed areas. Above 25 cm bulk density was higher than in undisturbed prairie, increasing by 51 to 82 %. In work areas compaction was evident to 55 cm. Pipeline installation increased surface clay and decreased surface silt. Calcium, magnesium, sodium and pH increased and organic matter decreased at the surface relative to undisturbed areas. An estimated 50 years is needed to restore half of the organic matter lost. Soil pH and electrical conductivity increased with depth.

Transportation corridors often impact surrounding habitat by altering plant communities, fragmenting habitat, altering environmental conditions, introducing non native species (Sousa 1984, Hansen and Clevenger 2005) and altering light, soil water and soil (de Jong and Button 1973, Parendes and Jones 2000, Hansen and Clevenger 2005). These conditions affect surrounding plant communities and create microhabitats where non native species can establish and spread. One study found grasslands had significantly more non native species than forest. In grasslands non native species were found up to 150 m from the transportation edge, in forests non native species were found up to 10 m.

3.3 Keystone Pipeline

The Keystone pipeline is 76.2 cm in diameter and 3,460 km in length, transporting crude oil from Hardisty, Alberta to United States markets at Wood River and Patoka, Illinois and Cushing, Oklahoma (TransCanada 2012). The pipe was buried with minimum cover of 1.2 m depending on land use. Construction and reclamation near research areas occurred February to May 2009.

Pre construction mitigation strategies included marking population sites within 30 m of the ROW, fencing known sites, establishing buffers if rare plants were within 30 m of ROW, installing signs warning of rare plants, not allowing temporary work spaces within 30 m of a known plant site, surveying known plant sites to confirm species presence and spatial boundaries, including SARA plant species location and mitigation as part of environmental inspector and contractor or visitor training and holding pre construction meetings with construction foremen to review construction plan and mitigation requirements (Jacques Whitford AXYS Ltd. 2008). Construction mitigation strategies included bringing equipment on site clean and free of vegetation, soil and other debris, scheduling construction following plant dormancy after flowering and set seed, topsoil stripping limited to ditch lines (2 m width), no grading within 30 m of a known SARA plant except where construction was within existing industrial easements, limiting construction traffic to equipment absolutely essential to safely install the pipe and one way traffic or pull outs for equipment passage (Jacques Whitford AXYS Ltd. 2008).

3.4 Set Back Distances

Set back distances, or distances from the pipeline ROW, reduce direct mortality of plant species and cumulative edge effects and can destroy plant habitat.

Studies addressing set backs for different activities are extremely limited. Therefore they are based on interpretation of related research and require more direct research to assess the effects of set backs.

To protect prairie plant species at risk, guidelines were developed in 2008 for Saskatchewan, Alberta and Manitoba to help avoid killing or harming plant species at risk and destroying their critical habitat (Environment Canada 2008). Guidelines for pipeline construction state no class 3 activity can be conducted within 300 m of endangered or threatened plant species on federal lands. The 300 m set back distance is the same for all sizes of pipelines and does not include seasonal lifting. Currently there are no provincial regulatory requirements outlining set backs on provincial, municipal or private lands from plant species at risk. On these lands threats to at risk species and critical habitat can be mitigated by best management practices and recommendations outlined in federal recovery plans (Environment Canada 2012).

Nemirsky (2011), who conducted research along the Keystone pipeline in southern Alberta in 2009 and 2010, found pipeline construction can impact the environment up to 25 m from the edge of the ROW within the first two growing seasons after pipeline construction disturbance. Impacts included decreased litter cover and increases in soil compaction, bare ground and non native plant species richness. *Halimolobos virgata* was able to recolonize the ROW. Nemirsky did not recommend a set back distance between *Halimolobos virgata* and the pipeline disturbance. However, *Cryptantha minima* was not found during Nemirsky's work period and therefore a 25 m set back distance was recommended as a safeguard.

This research was conducted to assess longer term effects of pipeline construction on two plant species at risk, *Halimolobos virgata* and *Cryptantha minima*, and their associated habitat on and off the pipeline ROW in the prairie region of southern Alberta. Research work was conducted in the growing seasons of 2012 and 2013.

The thesis is divided into two main sections. The first section addresses the impacts of the pipeline disturbance on soil and native prairie vegetation on and off ROW. The second section addresses how these pipeline impacts affected *Halimolobos virgata* plants and their habitat.

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Figure 1.1 Known *Halimolobos virgata* range in North America (Environment Canada 2010).

Figure 1.2. Known *Cryptantha minima* range in North America (Environment Canada 2006).

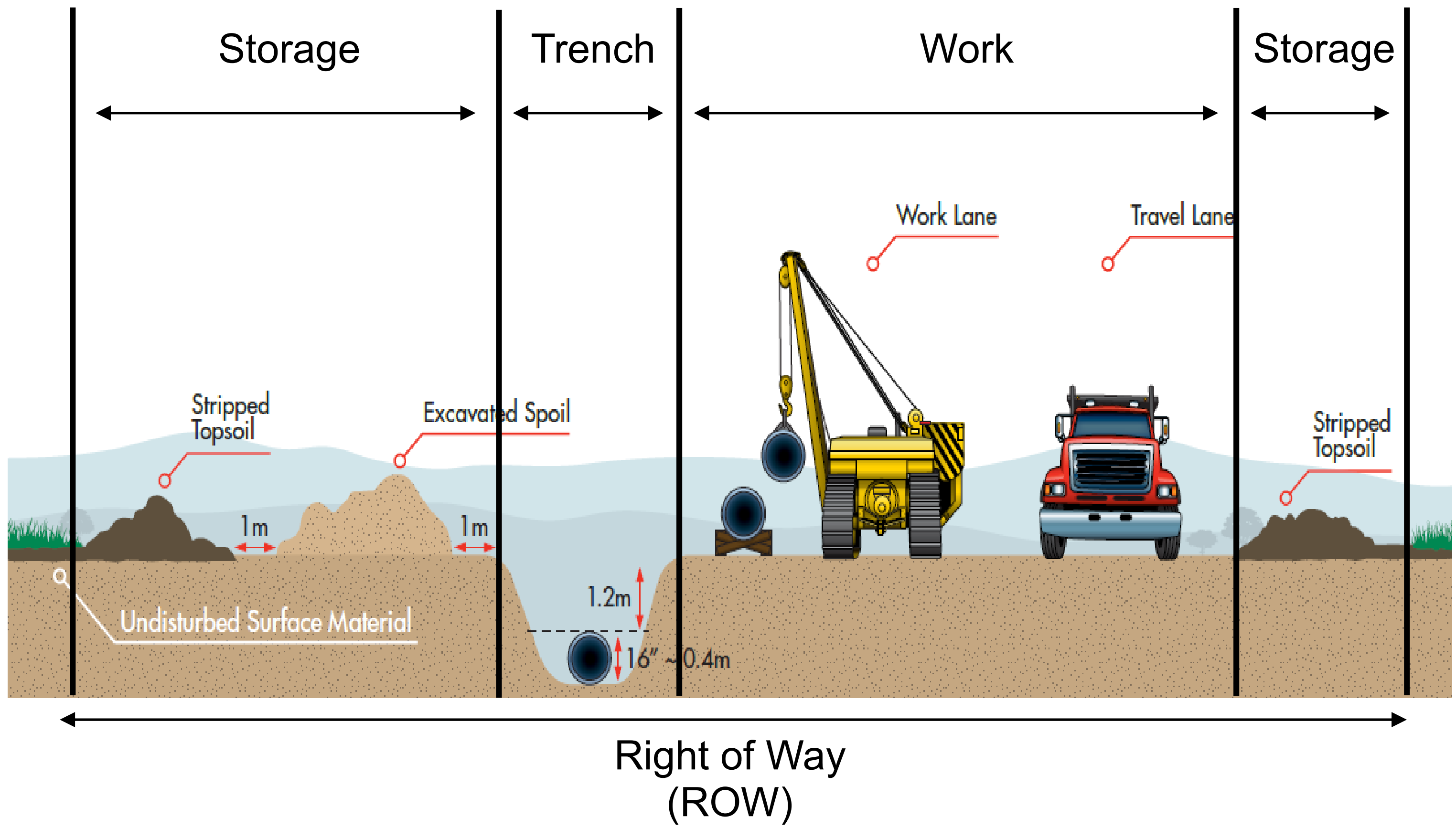

Figure 1.3. Diagram of pipeline right of way areas (Shell Canada 2014).

CHAPTER II. EFFECTS OF PIPELINE CONSTRUCTION ON NATIVE MIXED GRASS PRAIRIE IN SOUTHERN ALBERTA

1. INTRODUCTION

Native prairie is an important natural resources, providing ecological, economical, cultural and aesthetic value (Sinton 2001). Important ecological services provided by grasslands include watershed function, carbon storage, nitrogen fixation, filtration of contaminants and sediments, erosion control and critical habitat for flora and fauna (Neville 2002, Bailey et al. 2010). The Dry Mixed Grass Subregion makes up half of the grasslands in Alberta covering 7.1% of the province (Alberta Environmental Protection 1997). Of the original 2 million hectares of mixed grass prairie in Alberta approximately 31 % remains today (Adams et al. 2005). As a result of anthropogenic activities native prairie is considered one of the most endangered natural environments in North America (Sinton 2001). Anthropogenic activities such as roadways, urbanization, cultivation and natural resource development have caused cumulative effects that drastically changed the prairie over the last 75 to 100 years (Alberta Environmental Protection 1997). Alberta alone has more than 392,000 km of energy related pipelines that cross the Dry Mixed Grass Subregion (Energry Resources Conservation Board 2011).

Pipelines are used to efficiently transport large quantities of crude oil, natural gas, water, gases and refined petroleum products (Canadian Energy Pipeline Association 2012). Without pipelines crude oil transport would require more than 15,000 tanker trucks each day. Pipeline networks consist of several different lines; gathering lines, feeder lines, transmission pipelines and distribution lines (Neville 2002). The size of the lines depend on their use, and can range from 2.1 cm (distribution pipelines) to over 120 cm (transmission pipelines) in diameter. The larger the pipeline diameter, the greater the disturbance, as larger and heavier equipment are required for installation. Pipeline construction involves vegetation clearing, topsoil stripping and grading to create a level surface (Canadian Energy Pipeline Association 2012). The pipeline right of way (ROW) consists of a trench, working area and topsoil and subsoil storage areas.

Construction results in habitat fragmentation, removal of native vegetation, invasion of non native plant species, disruption of soil properties, soil compaction, changes in landscape structure, disturbances to wildlife and potential for spills during and after construction (Kerr et al. 1993, Sinton 2001).

Pipeline construction can impact soil properties. Mixing topsoil and subsoil can alter pH, electrical conductivity, organic matter, soluble salts and texture on a pipeline right of way (ROW) (de Jong and Button 1973, Naeth 1985, Naeth et al. 1987, Culley and Dow 1988, Ivey and McBride 1999, Soon et al. 2000a, Soon et al. 2000b, Shi et al. 2013). Changes may persist with time (Naeth 1985, Naeth et al. 1987), affecting soil and plant productivity temporarily or permanently (de Jong and Button 1973). Plant communities may be affected by introduction of non native species (Sousa 1984, Hansen and Clevenger 2005) and altering light, temperature and soil water content (de Jong and Button 1973, Naeth et al. 1988, Naeth et al. 1993, Parendes and Jones 2000, Hansen and Clevenger 2005)

The longer term effects of pipeline construction on grassland soils have not been well studied. This research will provide specific insight into how distance from the pipeline ROW affects native mixed grass prairie. With so little native prairie remaining, this work is important to address prairie conservation efforts.

2. OBJECTIVES AND HYPOTHESES

2.1 Objectives

The objectives of this research were to determine the effects pipeline construction and management have on native dry mixed grass prairie. Specific objectives were to determine how the soil and vegetation on the ROW and with distances from pipeline centre had been impacted by pipeline disturbance.

2.2 Hypotheses

The following hypotheses were addressed in this research.

- Effects of disturbance will be greatest on the pipeline ROW and least detectable off ROW due to the nature and degree of disturbance.
- Disturbance over the trench will be the most intensive and longer lasting due

to removal and replacement of the soil horizons.

- Impacts to stripped areas on ROW will be more intensive and longer lasting than compaction disturbances at the edge of or off the ROW due to removal and replacement of the surface soil horizon.
- Differences in post construction management, such as grazing, will result in different recovery trends.

3. MATERIALS AND METHODS

3.1 Research Site Location

Research sites were located near Bindloss in southeastern Alberta, in the Dry Mixed Grass Subregion of the Grassland Natural Region (Figure 2.1). They were located between the South Saskatchewan and Red Deer Rivers, approximately 150 km north of Medicine Hat and 20 km west of the Alberta-Saskatchewan border in the Bindloss Plain Ecodistrict (Adams et al. 2013). Climate in the area is continental with low precipitation, short warm summers and long cold winters (Alberta Environmental Protection 1997, Adams et al. 2013). Mean summer and winter temperature are 16 and -10 °C, respectively. Mean annual precipitation is 306 mm, of which 80 % falls as rain (Environment Canada 2012).

The region is characterized by gently undulating topography with hummocky and dissected uplands (Pettapiece 1986, Natural Regions Committee 2006). The dominant surficial deposits on the Bindloss Plain are glaciofluvial and eolian (Pettapiece 1986, Adams et al. 2013). These sediments are typically composed of half cobbles and gravel and half coarse textured loamy sand or sand lenses and bands. Soils are primarily Orthic Brown Chernozems and Solonetzes; comprising 60 and 25 %, of the area respectively (Natural Regions Committee 2006, Shorthouse and Floate 2010). Major soil series of the area are Bingville, Cavendish, Purple Springs, Vendisant, Antelope and Chin. These are primarily Orthic Brown Chernozems, Rego Brown Chernozems or Orthic Regosols with sandy to loamy textures.

The Dry Mixed Grass Subregion is characterized by a mix of drought tolerant short and mid height grasses (Alberta Environmental Protection 1997, Natural

Regions Committee 2006); 85 to 95 % of the vegetation is comprised of grasses and sedges (Rowe and Coupland 1984, Coupland 1992). Plant species at risk include *Halimolobos virgata* (Nutt.) O.E. Schulz (slender mouse ear cress), *Yucca glauca* Nutt. (soap weed), *Cryptantha minima* Rydb. (tiny cryptanthe), *Iris missouriensis* Nutt. (western blue flag), *Tripterocalyx micranthus* (Torrey) Hooker (small flowered sand verbena) and *Tradescantia occidentalis* (Britton Smyth) (western spiderwort) (Environment Canada 2009).

3.2 Site Selection

Six research sites; Coulee, Coulee Upland, Highway, Remount Lowland, Hill and McNeil were selected for Nemirsky's MSc research program (Nemirsky 2011). The sites were located along the TransCanada Keystone pipeline (Figure 2.2). It is 76.2 cm in diameter and 3,460 km in length, transporting crude oil from Hardisty, Alberta to United States markets at Wood River and Patoka, Illinois and Cushing, Oklahoma (TransCanada 2012). The pipe was buried with minimum cover of 1.2 m depending on land use. Construction and reclamation near research areas occurred February to May 2009.

Hill, Highway and Coulee research sites were established in 2009 as locations with known occurrences of at risk plant species (Nemirsky 2011). Coulee Upland, Remount Lowland and McNeil were established in 2010 to represent prairie landscape that did not contain known occurrences of at risk plant species. All sites represented landscapes typical of surrounding prairie with differing elevations and aspects, and different management as land was not federally owned and therefore was managed by different individuals.

Highway, Remount Lowland and Hill were located in the Remount community pasture south of Secondary 555. Highway was about 500 m north west of Remount Lowland, which was 1000 m north west of Hill. The permanent TransCanada Keystone pipeline ROW fell within the Alberta Ethane Gathering System (AEGS) pipeline easement on these sites. The permanent ROW was a 4 m wide area stripped of soil and contained the 2 m wide trench. During construction the ROW had contained 7 m of temporary ROW to the east within the AEGS and 19 m to the west outside the AEGS (Figure 2.3). Where soil was stripped due to grading or trench construction standard two lift soil handling was used. Highway, Remount Lowland and Hill were under the same land management practices, including no fencing of the ROW. At Highway the pipeline passed through approximately 120 m of *Cryptantha minima* habitat (Nemirsky 2011), through undulating landscape. Remount Lowland was characterized by flat low lying topography, and had no known occurrences of plant species at risk. At Hill the pipeline crossed through 100 m of *Halimolobos virgata* habitat (Nemirsky 2011). The site contained a large hill with a saline seep and ephemeral draw at the toe of the slope.

Coulee, Coulee Upland and McNeil were located on private land; Coulee Upland was located 1200 m north west of Highway and Coulee was located 800 m north west of Coulee Upland. McNeil was located on the other side of the South Saskatchewan River, 21 km south east of Hill. Each site had a 20 m wide permanent ROW, with a 2 m wide trench and 10 m temporary ROW during construction. After construction the ROW was fenced and remained so for the duration of the project. Coulee and Coulee Upland were north of Secondary 555 on the same property.

At Coulee the pipeline passed through approximately 500 m of *Cryptantha minima* and *Halimolobos virgata* habitat (Nemirsky 2011). Coulee had steep slopes requiring extensive grading and resulted in the 20 m wide permanent ROW being stripped of soil. During construction the ROW contained 10 m of temporary work space on the south west side (Figure 2.3). Coulee upland had mainly flat terrain, slightly undulating to the west of the pipeline; no at risk plant species were known to occur. Coulee upland consisted of a 20 m permanent ROW that fell beside the AEGS. Up to 20 m of ROW was stripped depending on the grading required during construction. A 9 m wide temporary work space was located on the west side of the pipeline within the AEGS and a 1 m wide temporary workspace was on the east side of the ROW.

McNeil was located southeast of the Saskatchewan River near the Alberta Saskatchewan border, approximately 15 km north of Secondary 545, and does not fall within an existing pipeline corridor. McNeil had flat terrain and bordered a coulee with high relief. It consisted of a 20 m permanent ROW with a 10 m wide temporary work space to the north; up to 20 m of the ROW was stripped of soil depending on the amount of grading required.

3.3 Sampling Transects

At all six sites a stretch of pipeline that contained the fewest number of obstructions within 350 m was identified and divided into 10 m segments. Three 10 m segments were randomly selected for each site and were used as start points for perpendicular transects that ran both directions from the pipeline centre. Each transect was 350 m long and covered the ROW and surrounding habitat just over 300 m away from the edge of the ROW. A Brunton Type 15 compass was used to maintain straight and perpendicular transects. Depending on terrain and pipeline route, six full length transects were not always possible at each site. Due to the pipeline route at Highway only three transects were run off the north east side of the pipeline. Due to a saline seep at Hill three transects on the south west side were only 50, 100 and 150 m. At Coulee a steep hill resulted in one south transect ending at 50 m, and at McNeil a coulee with high relief resulted in three of the west transects ending at 300 m.

3.4 Soil Measurements, Sampling and Analyses

Soil was sampled May 7 to 10, 2013 at 0 (pipeline centre), 6, 16, 25, 35, 50, 65 and 350 m along three transects at each site (Figure 2.4). These distances were associated with pipeline trench, work space and storage areas and varying distances off ROW, while maintaining a reasonable analytical budget and relating to research conducted by Nemirsky (2011).

Soil was sampled with a 5 cm dutch auger at 0 to 5 cm and 5 to 15 cm, for a total of 144 soil samples. Samples were collected 50 cm off the left side of the transect when facing away from the pipeline to prevent interference with other measurements. Samples were placed in labeled plastic bags and stored in a cooler with ice packs until taken to a commercial laboratory for analyses.

Particle size analysis (sand, silt, clay) was determined by hydrometer (Carter 1993). Soil pH, electrical conductivity, sodium adsorption ratio, saturation and soluble salts (calcium, magnesium, sodium, potassium) were determined by saturated paste (Carter 1993). Cation exchange capacity was determined using ammonium extraction (McKeague 1978) and total carbon, total organic carbon and total nitrogen were determined by combustion (Nelson and Sommers 1996).

Penetration resistance was measured May 25 to 29, 2013 using a Rimik CP40II cone penetrometer with a 130 mm^2 cone. It was measured at 0, 3, 6, 11, 16, 21, 25, 30, 35, 40, 45, 50, 65 and 350 m along three transects per site on the side with the wider permanent or temporary ROW resulting in the 25 m measurement being just off ROW (Figure 2.5). Penetration resistance was measured at 3, 6 and 11 m along three transects at each site in the opposite direction, on the side with the narrower temporary workspace or permanent ROW resulting in the 11 m measurement being just off ROW (on the edge for Coulee Upland). Penetration resistance measurements were taken 1 m off the right side of the transect facing away from the pipeline, to avoid interference with other measurements.

The penetrometer was programmed to take measurements at 1 cm increments to a maximum depth of 20 cm; 5, 10, 15 and 20 cm measurements were maintained for statistical analyses. After each insertion data were inspected for errors; any measurement with an error was discarded and a new measurement recorded. Errors were a result of inserting too fast or too slow, rocks or interference from surrounding vegetation. Vegetation was trimmed to approximately 2 cm in height when interference became common. Five measurements were conducted at each sampling point; for a total of 1,530 measurements.

3.5 Vegetation assessments

Vegetation was assessed July 21 to 29, 2012 and July 10 to 12 and 15 to 20, 2013. Assessments were conducted along transects in both directions at 0, 1, 2, 3, 4, 5, 7, 9, 11, 13, 15, 20, 30, 40, 50, 100, 150, 200, 250, 300 and 350 m (Figure 2.6). A 0.1 m^2 (20 x 50 cm) quadrat was placed with the short side along the right side of the transect and the bottom corner on the sampling distance. Ocular estimates were made of percent ground cover (bare ground, litter, live vegetation, manure, scat, rocks, lichen, mushrooms, woody debris) and species canopy cover at each location. Each year 657 assessments were conducted.

3.6 Statistical Analyses

All statistical analyses were conducted using R version 3.0.1 (R Core Team 2013). An alpha value of 0.050 was used for all of the tests to balance Type I and Type II errors.

To determine the effect of ROW area on soil and plant properties, multiple samples within an area were considered subsamples and averaged per transect to total three samples per area of ROW per site. Shapiro-Wilks test for normality (Shapiro and Wilk 1965) and Levene's test for equality of variance (Levene 1965) were performed on the data; data met assumptions of normality and equal variance. Parametric two way analysis of variance was used to examine differences among ROW areas and individual sites for all soil properties, 5 and 10 cm penetration resistance, maximum penetration depth, ground cover (live, litter, bare ground) and native and non native cover for both years (Steel et al 1997). The Tukey test was used for pairwise comparisons (Tukey 1953).

To determine if differences with distance from pipeline centre exist, data were graphed to look for linear trends. For most parameters, chemical and physical soil properties, 5 and 10 cm penetration resistance, maximum penetration depth, ground cover (live, litter, bare ground), native and non native cover, and grass and forb species cover, there were multiple breaks in slope and thus piecewise linear regression was used. In piecewise regression a separate line segment is fit to intervals between break points (Toms and Lesperance 2003). Distance from pipeline centre was estimated from graphs for each break. Breaks were entered into R using the segmented module (Muggeo 2013). Following confirmation of a distance of effect, data were divided into pre and post distance of effect groups and a Welch's t-test performed to test for a significant difference between the two groups. In cases where piecewise linear regression did not produce a distance of effect or Welch's t-test was not significant, linear regression was run on the data (Welch 1938). Regression analyses were run for each site and with all sites combined. Ground cover, native cover and non native cover on ROW areas within sites were compared for 2012 and 2013 using Welch's t-test.

4. RESULTS

4.1 Soil

4.1.1 Soil chemical properties

At all sites 0 to 5 cm ammonium, cation exchange capacity, carbon to nitrogen ratio, total nitrogen, total inorganic carbon, electrical conductivity and sodium were similar among storage, trench and work areas of the ROW (Tables 2.1, A1). Organic matter, total organic carbon and percent saturation were significantly lower on the trench than on the work and storage areas. Significant area-site interactions occurred for pH, calcium, magnesium and potassium (Tables 2.2, A1), with values generally higher on trench than work and storage areas.

For all ROW areas at all sites 0 to 5 cm electrical conductivity was rated good (<2 ds/m) according to criteria to evaluate topsoil quality for reclamation in the plains region (Alberta Agriculture Food and Rural Development 1987) (Table 2.3). Sodicity and pH were rated good (sodicity <4, pH 6.5 to 7.5) or fair (sodicity 4 to 8, pH 7.6 to 8.4). Coulee, Hill and McNeil trenches and Coulee work area had some samples rated poor for organic carbon (<1 %); other sites and ROW areas were rated good (>2 %) or fair (1 to 2 %). Coulee Upland work area had some samples rated poor for saturation (80 to 120 %); other ROW areas and sites were rated good (30 to 60 %) or fair (60 to 80 %). Storage and work areas had some slight soil limitations and the trench had some severe soil limitations.

At all sites, 5 to 15 cm ammonium, cation exchange capacity, carbon to nitrogen ratio, total nitrogen, organic matter, total organic carbon, total inorganic carbon, sodium adsorption ratio, saturation, magnesium and sodium were similar among ROW areas (Tables 2.4, A2). Electrical conductivity was significantly higher on trench than storage areas. Significant area-site interactions occurred for pH, calcium and potassium (Tables 2.5, A2) with no detectable overall trend.

In all ROW areas at all sites electrical conductivity was rated good (<2 ds/m) (Alberta Agriculture Food and Rural Development 1987) (Table 2.6). Saturation and pH were rated good (saturation 30 to 60 %, pH 6.5 to 7.5) or fair (saturation 60 to 80 %, pH 7.6 to 8.4). Coulee and Hill sites and Highway work area, Remount Lowland storage area and Remount Lowland trench were rated poor for organic carbon (<1 %); other sites and areas were rated fair (1 to 2 %). Hill trench was rated poor for sodicity (8 to 12), other areas and sites were rated good (<4) or fair (4 to 8).

Distance of effect often varied with site and with depth (Tables 2.12 to 2.20, 2.27 to 2.34, A3, A17). At 0 to 5 cm depth they ranged from 7 to 35 and at 5 to 15 cm they ranged from 6 to 50. Thus for any of the soil properties, these distance of effects did not occur after 50 m.

No significant distance of effects were found for ammonium, cation exchange capacity, total nitrogen, calcium and potassium at 0 to 5 cm (Tables 2.7 to 2.11). Ammonium and cation exchange capacity showed a significant linear decrease with distance from pipeline at Coulee Upland and a significant linear increase at Hill (Tables A4, A5).

Significant distance of effects for other chemical properties at 0 to 5 cm were site specific (Tables 2.12 to 2.20, A3). With distance from pipeline at these specific sites, carbon to nitrogen ratio (Table 2.12), organic matter (Table 2.13), organic carbon (Table 2.15) percent saturation (Table 2.18) increased after the distance of effect and inorganic carbon (Table 2.14), pH (Table 2.16), electrical conductivity (Table 2.17), magnesium (Table 2.19) and sodium (Table 2.20) decreased after the distance of effect.

No significant distance of effects were generally found for ammonium, cation exchange capacity, total nitrogen, organic matter, total organic carbon and potassium at all sites for 5 to 15 cm (Tables 2.21 to 2.26). A few sites showed linear trends. At Hill ammonium, cation exchange capacity and potassium showed a significant linear increase with distance from pipeline centre (Tables A18, A19, A23), at Hill and McNeil organic matter significantly increased (Table A21) and at Coulee Upland where inorganic carbon and potassium showed a significant linear decrease (Tables A25, A23).

Significant distance of effects for other chemical properties at 5 to 15 cm were site specific (Tables 2.27 to 2.34, A17). At these specific sites carbon to nitrogen ratio (Table 2.27), inorganic carbon (Table 2.28), pH (Table 2.29), electrical conductivity (Table 2.30), saturation (Table 2.31), calcium (Table 2.32) and magnesium (Table 2.33) generally decreased after the distance of effect, while at some sites saturation, calcium and magnesium showed a significant linear increase with distance from pipeline (Table A28 to A 30).

Distance of effects for 0 to 5 cm with all sites combined were inconsistent with individual sites for ammonium, cation exchange capacity, organic matter, total inorganic carbon, total organic carbon, electrical conductivity and saturation (Tables 2.7, 2.8, 2.13, 2.14, 2.15, 2.17, 2.18). Overall distance of effects were consistent with most sites for total nitrogen, carbon to nitrogen ratio, pH, calcium, magnesium, sodium and potassium (Tables 2.9 to 2.12, 2.16, 2.19, 2.20).

Distance of effects for 5 to 15 cm with all sites combined were inconsistent with individual sites for pH, calcium and magnesium (Tables 2.29, 2.32, 2.33). Overall distance of effects were consistent with individual site results for ammonium, cation exchange capacity, total nitrogen, organic matter, total organic carbon, total inorganic carbon, carbon to nitrogen ratio, saturation, electrical conductivity, sodium and potassium (Table 2.21 to 2.28, 2.30, 2.31, 2.34).

4.1.2 Soil physical properties

At 0 to 5 cm sand was similar among ROW areas, silt was significantly lower on trench than storage areas and clay was significantly highest on the trench (Tables 2.35, A32). At 5 to 15 cm sand, silt and clay did not differ significantly with ROW area.

Distance of effects were site specific for sand, silt and clay at both depths, ranging from 6 to 56 m for 0 to 5 cm and 22 to 57 m for 5 to 15 cm (Tables 2.36 to 2.41, A33, A37). In these site specific distance of effects, sand increased and decreased after the distance of effect for 0 to 5 cm (Table 2.36), as did silt (Table 2.37) and clay (2.38). Similar trends were found for 5 to 15 cm depths (Tables 2.39 to 2.41). Texture varied between sites, but overall soil was predominately loam or sandy loam at 0 to 5 cm and 5 to 15 cm (Table 2.42).

Penetration resistance at 5 and 10 cm was similar among ROW areas at Coulee, Hill, Highway and Remount Lowland (Table 2.43, A41). Site specific significant differences at Coulee Upland and McNeil, showed highest values for the trench. Due to soil conditions there were insufficient measurements for 15 and 20 cm on the ROW to asses. In general penetration resistance increased from 5 to 10 cm, then decreased from 10 to 20 cm. Maximum penetration depth was similar among ROW areas at Coulee and Highway and higher at work and storage areas than the trench at Coulee Upland. At Hill and Remount Lowland work areas had significantly greater penetration depth than the trench and at McNeil values were significantly greater for storage than trench and work areas.

Significant distance of effects from the pipeline ranged from 6 to 35 m for 5 and 10 cm penetration resistance (Tables 2.44, 2.45, A42), penetration resistance decreased after distance of effect. In general 15 and 20 cm penetration resistance decreased with distance from pipeline (Tables 2.46, 2.47). Significant distance of effects for maximum depth penetration ranged from 5 to 35 m (Tables 2.48, A42), with maximum depth of penetration higher after the distance of effect.

4.2 Vegetation

4.2.1 Ground cover

Ground cover on the ROW in 2012 was site specific. Live vegetation cover was similar among areas at Coulee (Tables 2.49, A43), significantly less on the trench than work areas at Coulee Upland and significantly higher on the work area than the trench and storage areas at Hill. Areas at McNeil were significantly different, increasing from trench to work to storage. At Remount Lowland live vegetation cover was significantly lower on trench than storage and work areas. Litter was similar on ROW areas at Hill and McNeil but differed significantly at Coulee, increasing from trench to work to storage. At Coulee Upland litter was significantly higher on trench than work and storage areas. Remount Lowland trench had significantly less litter than storage areas. Bare ground was similar among all areas at Coulee Upland, Hill and McNeil. At Coulee all areas were significantly different, with the trench having highest bare ground and the storage area lowest. Bare ground was significantly higher on the trench at Remount Lowland than on storage and work areas.

Live vegetation cover in 2013 was significantly lower on the trench than on work and storage areas for all sites (Tables 2.50, A43). Bare ground was significantly higher and litter significantly lower on the trench area than the storage.

Live ground cover was similar at all sites and ROW areas from 2012 to 2013 (Table A44). Litter and bare ground were similar at all sites on trench and storage from 2012 to 2013. On the work area, litter increased from 2012 to 2013 at McNeil and bare ground decreased at Remount Lowland.

Significant distance of effect for live vegetation cover in 2012 were 4 to 30 m (Tables 2.51, A45). Mean live vegetation cover was higher after the distance of effect. Distance of effect of 3 to 10 m were significant for litter (Tables 2.52, A45); litter was lower after the distance of effect at Coulee Upland, but higher for the other sites. Significant distance of effect were 3 to 11 m for bare ground (Tables 2.53, A45), decreasing after the distance of effect.

Significant distance of effect for live vegetation cover in 2013 were 3 to 81 m (Tables 2.54, A46), increasing thereafter. Distance of effects for litter were 3 to 100 m (Tables 2.55, A46); litter decreased after distance of effect at Coulee Upland and McNeil and increased for the other sites. Distance of effect of 4 to 18 m were significant for bare ground (Tables 2.56, A46), decreasing after the distance of effect for all sites.

From 2012 to 2013 significant distance of effects for live vegetation cover at Remount Lowland and bare ground at McNeil disappeared. Distance of effect for litter at McNeil was significant in 2013 whereas in 2012 there was no distance of effect. Live vegetation cover at Coulee changed from two distance of effects in 2012 to one in 2013; the 2013 distance of effect decreased from the highest distance of effect in 2012. The significant distance of effect for live vegetation cover at Highway decreased from 2012 to 2013. The remaining distance of effects for live vegetation cover, litter and bare ground increased by 8 to 99 m from 2012 to 2013.

The overall distance of effect for live vegetation cover in 2012 appeared to be influenced by Coulee more than the other five sites (Table 2.51). Bare ground 2012 had a second significant distance of effect that was higher than that at each individual site (Table 2.53). Litter 2012 and 2013, live vegetation cover 2013 and bare ground 2013 had overall distance of effects similar to individual site distance of effects (Tables 2.52, 2.54 to 2.56).

4.2.2 Native species cover

Differences in native species cover for the pipeline ROW in 2012 were site specific. At Coulee Upland it was significantly higher on storage than trench areas (Tables 2.57, A48). All three areas at McNeil were significantly different, with the trench lowest and the storage area highest. At Remount Lowland native species cover was significantly higher on work than trench and storage areas. In 2013 native species cover was significantly lower on trench than storage and work areas for all sites (Tables 2.58, A48). From 2012 to 2013 cover increased on work areas at McNeil and was similar at other sites (Table A49).

Significant distance of effects for native species cover in 2012 were 4 to 35 m for Coulee, Coulee Upland, Highway, McNeil and Remount Lowland (Tables 2.59, A50), increasing after the distance of effect at all sites. In 2013 Coulee, Coulee Upland, Highway, McNeil and Remount Lowland had significant distance of effects for native species cover from 3 to 89 m (Tables 2.61, A50). At Hill in 2013 native cover showed a significant linear increase with distance from pipeline centre (Table A50). Distance of effect increased for native cover between 2012 and 2013 at Coulee, Coulee Upland and McNeil; only the distance of effect at McNeil increased by more than 8 m. Distance of effects at Highway decreased and were unchanged at Remount Lowland. Overall distance of effect was not consistent with the majority of the individual sites.

Several native forbs common off ROW and on storage and work areas were were not found on the trench in 2012 and 2013. These species were *Achillea millefolium* L. (common yarrow), *Lygodesmia juncea* (Pursh) D. Don (skeleton weed), *Opuntia polycantha* Haw. (prickly pear cactus), *Phlox hoodii* Richards (moss phlox), *Psoralea argophylla* Pursh (silver leaf sporalea), *Selaginella densa* Rydb. (little club moss) and *Sphaeralcea coccinea* (Pursh) Rydb. (scarlet mallow) (Tables A52 to A61). *Selaginella densa* and *Sphaeralcea coccinea* cover increased from 2012 to 2013. *Phlox hoodii* cover on storage and work areas was low relative to off ROW in 2012 and 2013. *Artemisia cana* Pursh (sage bush) was not found up to 4 m away from pipeline centre in 2012 and 2013, cover increased on ROW from 2012 to 2013. *Coryphantha vivipara* (Nutt.) Britt. & Rose (ball cactus) was not found on the ROW in 2012, but was only absent on the trench in 2013. *Carex* species were absent from the trench in 2012, with trace amounts in 2013. *Agropyron smithii* Rydb. (western wheat grass) cover decreased with distance from the pipeline, while *Stipa comata* Trin. and Rupr. var. comata (needle and thread grass) cover increased with distance in 2012 and 2013 (Tables A62, A65). *Bouteloua gracilis* (HBK) Lag. (blue grama grass) had lowest cover in the first 2 m from the pipeline in 2012 and 2013 (Table A63).

4.2.3 Non native species cover

Non native species cover in 2012 and 2013 were similar among ROW areas (Tables 2.58, A48). It was similar in 2012 to 2013 at all sites and ROW areas.

McNeil was the only site in 2012 with a significant distance of effect for non native species cover; 15 m with non native cover increasing after the distance of effect (Tables 2.60, A50). In 2013 only Coulee Upland had a significant distance of effect for non native species cover; 86 m with non native cover decreasing after the distance of effect (Tables 2.62, A50). Overall distance of effect was consistent with individual sites.

Non native forb cover generally increased from 2012 to 2013 (Tables A66 to A69); most forbs were low in abundance and cover, and sporadically located along transects. *Taraxacum officinale* Weber (dandelion) and *Tragopogon dubius* Scop. (goat beard) were most common non native forbs; found at nearly all distances in 2012 and 2013. In 2012 and 2013 *Chenopodium album* L. (lamb's quarters) and *Polygonum aviculare* L. (prostrate knotweed) were found within 3 m of the pipeline centre; increasing in cover and abundance in 2013. S*alsola kali* L. (russian thistle) was primarily within 5 m of pipeline centre, with the odd occurrence off ROW. *Descurainia sophia* (L.) Webb (flix weed) occurrence and cover was low in 2012; in 2013 it increased at McNeil where numerous large patches were found off ROW. Non native grasses included *Agropyron pectiniforme* R. & S. (crested wheat grass), *Bromus inermis* Leyss. (smooth brome) and *Hordeum jubatum* L. (common foxtail barley) (Table A70). In 2012 and 2013 *Agropyron pectiniforme* was consistently found 9 to 20 m from pipeline centre on the AEGS ROW. *Bromus inermis* was found on and off ROW in 2012, but only on ROW within 5 m of pipeline centre in 2013. *Hordeum jubatum* was only found in 2012 and was within 2 m of the pipeline centre.

4.2.4 Grass and forb cover

Significant distance of effects for grass cover in 2012 were 4 to 33 m at Coulee, Coulee Upland, Hill, Highway and Remount Lowland (Tables 2.63, A71), with grass cover higher after the distance of effect at all sites. In 2013 distance of effects for grass cover were 3 to 87 m at Coulee, Coulee Upland, Highway, McNeil and Remount Lowland (Tables 2.65, A71), increasing after the distance of effect. At Hill in 2013 grass cover showed a significant linear increase with distance from the pipeline (Table A72). Between 2012 and 2013 distance of effect distances at Remount Lowland and Highway were within a meter of each other, increasing by 11 and 7 m at Coulee and Coulee upland. In 2012 overall distance of effect for grass cover was similar to the majority of individual sites, but in 2013 it did not correspond with majority of sites.

Significant distance of effects for forb cover in 2012 were 11 to 26 m at Coulee Upland, McNeil and Remount Lowland (Tables 2.64, A71) and in 2013 were 46 to 88 m at McNeill and Remount lowland, respectively (Tables 2.66, A71). In 2012 and 2013 forb cover increased after the distance of effect. Overall distance of effect for forb cover in 2012 fell near the middle of the distance of effects at the individual sites, in 2013 the overall distance of effect was less than that of the individual site distance of effects.

4.3 Overall Effects Of Pipeline Disturbance On Soil And Vegetation

Overall pipeline disturbance, after 4 years, increased some properties and decreased others on ROW (Table 2.67). These differences were generally most pronounced in the 0 to 5 cm depth increment for soil and in 2013 for vegetation. For other properties and for 2012 vegetation, trends were highly site specific. In general the changes induced by pipeline disturbance were mostly on the ROW and/or within 100 m of pipeline centre (Table 2.68).

5. DISCUSSION

5.1 Soil

5.1.1 Soil chemical properties

The general effects of pipeline disturbance on soil chemical properties in this study were similar to those from other research (Naeth 1985, Culley and Dow 1988, Ivey and McBride 1999, Soon et al. 2000b, Shi et al. 2013). Decreased organic matter or organic carbon on the trench is common after pipeline construction. Organic matter decreased 0.5 to 1 % (Ivey and McBride 1999) and 12 to 28 % (Soon et al. 2000b) in the boreal forest after pipeline disturbance and in southern Alberta the trench had 6.5 times less than undisturbed prairie (Naeth 1985, Neath et al. 1987). Culley and Dow (1988) found that 10 years after pipeline disturbance top soil on the ROW had lower organic matter than adjacent fields. Lack of significant distance of effect for organic matter in this study supported results from Nemirsky (2011) and Shi et al. (2013). The significant distance of effect for organic matter at Hill was likely a direct result of pipeline construction as it occurred on ROW. At Remount Lowland the distance of effect was 7 m past the ROW edge and likely a combination of pipeline construction and natural vegetation differences (Hobbie 1992). Naeth (1985) estimated 50 years is needed to restore half of lost organic matter. Significant differences at 0 to 5 cm between ROW areas and with distance from the pipeline are expected as 5 to 15 cm naturally contain less organic matter than 0 to 5 cm therefore dilution of top soil or enhanced decomposition of stored soil did not have a significant impact on soil at 5 to 15 cm (de Jong and Button 1973, Soon et al. 2000b).

Changes in pH, electrical conductivity and soluble salts in top soil on trench and storage areas of the ROW are consistent with other studies with (de Jong and Button 1973, Naeth 1985, Naeth et al. 1987, Culley and Dow 1988, Ivey and McBride 1999, Soon et al. 2000a, Soon et al. 2000b, Shi et al. 2013), changes in pH coincided with changes in electrical conductivity (de Jong and Button 1973). Increases in pH of 0.2 to 2.0 were found with pipeline disturbance in other studies (de Jong and Button 1973, Ivey and McBride 1999, Shi et al. 2013). Increased pH can result from mixing top soil with sub soil from below 40 cm on the trench and improper cleanup on storage areas (Soon et al. 2000a), and can place slight limitations on the soil (Landsburg 1989).

When pipelines are constructed on saline parent material or salt enriched material, soluble salts and pH in the topsoil and storage area increase (de Jong and Button 1973, Landsburg 1989). Increased calcium, magnesium, sulfate, potassium and sodium on the trench and storage area were found in similar studies (de Jong and Button 1973, Landsburg 1989). Landsburg (1989) found significantly increased salts in the upper 6 cm of the trench, while de Jong (1973) found them below 15 cm in spoil material. In this study, increased salts and pH at 0 to 5 cm on storage and trench areas were primarily at Remount Lowland which could indicate greater admixing at this site, a difference in parent material or salt accumulation due to low lying areas (Greenlee et al. 1968). Differences between sites and depths for various chemical properties may indicate different recovery rates of soils. Naeth (1985) found greater amelioration of chemical than physical properties over time. Soon et al. (2000a) found electrical conductivity and sulfate returned to pre pipeline levels in 2 to 3 years, whereas pH and exchangeable cations, specifically calcium, took longer. This can be seen in this study at 5 to 15 cm where there were still significant differences in pH and calcium at half of the sites and significant differences in potassium at both depths.

Shi et al. (2013) found the trench disturbance was more intense than storage and work disturbances, with less intense disturbance than areas 20 and 50 m from pipeline. In this study site specific significant distance of effects for inorganic carbon, electrical conductivity, magnesium, sodium and calcium for both depths fell within ROW and corresponded with site specific significant differences seen between areas of the ROW; therefore distance of effect differences are likely a result of soil movement during construction. Several of these distance of effects were at Remount Lowland, indicating construction conditions led to greater spread of lower depth soil at this site or a difference in salts in parent material. At Coulee where extensive grading occurred, distance of effect for pH and saturation were 10 m from the ROW edge, which could be a result of increased disturbance during construction. Sites with less construction disturbance (Hill, Remount Lowland, McNeil) had significant distance of effect on ROW.

Some distance of effects that fell off the right of way do not have explanations. For example, carbon to nitrogen at Remount Lowland 0 to 5 cm, 3 m off edge of ROW; pH at Coulee Upland 0 to 5 cm, 10 m off edge or ROW (approximately where the ROW stops being fenced in); and carbon to nitrogen ratio at Coulee Upland 5 to 15 cm, 32 m off edge of ROW.

5.1.2 Soil physical properties

Increased clay and decreased silt in surface soil on the trench are consistent with the results of Naeth (1987), who concluded differences were a result of soil horizon mixing during construction, construction methods and weather during construction. Increased clay in topsoil on the trench may also cause lower percent saturation (Culley and Dow 1988).

Work in 2010 on the same study sites by Nemirsky (2011) showed no significant difference in sand, silt or clay among ROW areas. Hanson (1999) found no difference in texture between disturbed and undisturbed A horizons in southern Alberta, while Shi (2013) found less clay in top soils in work areas. Different soil texture in sub soils on ROW and with distance from the pipeline in top soil and sub soil was consistent with other studies (Hanson 1999, Nemirsky 2011, Shi et al. 2013).Texture for most sites did not change with distance. Significant distance of effects off ROW could result from changes in soil and topography as a result of different parent materials and erosion processes (Sobecki and Karathanasis 1992, Tomer and Anderson 1995, Pachepsky et al. 2001).

Higher penetration resistance on ROW is consistent with other studies that found increased bulk density and compaction on ROW (Culley et al. 1982, Naeth et al. 1987, Landsburg 1989, Soon et al. 2000a, Shi et al. 2013). Soil penetration resistance can approximate soil compaction as soil strength generally increases with compaction (Brady and Weil 2008). In Ontario compaction increased across ROW areas on fine and medium textured soils, and was 67 and 50 % greater on trench and work areas, respectively, than on undisturbed areas (Culley et al. 1982). De Jong and Button (1973) found only the trench on agricultural soils had higher penetration resistance, similar to other work in southern Alberta where increased bulk densities on the trench occurred to a depth of 55 cm with surface bulk density increasing 51 to 87 % (Naeth et al. 1987). In this study the lack of differences in ROW areas at Coulee may resulted from land clearing as there was a large amount of stripping due to the need for more intensive grading and topography. Soon (2000a) also attributed similar increases in soil strength and soil compaction across all ROW areas to land clearing.

Some studies found all ROW areas were not impacted. In southern Alberta soil compaction was not a factor on work areas with dry and favourable conditions (Landsburg 1989). At Hill, Highway and Remount Lowland a similar lack of differences among ROW areas was found, while at McNeil and Coulee Upland differences were found in ROW areas. As these sites are spread over a large area, with Hill, Highway and Remount Lowland closest together, changes in weather conditions and soil water during construction could be responsible for the differences among sites.

Decreased penetration resistance with distance from the pipeline supports results of Nemirsky (2011) and Shi et al (2013). Shi et al. (2013) found soil porosity and bulk density was similar 20 m from the pipeline to undisturbed soil 50 m away; the similarities was speculated to be a result of less activity or rapid recovery. At 5 and 10 cm soil penetration resistance was not significantly different from undisturbed prairie for any distance from edge of ROW (Nemirsky

2011). Similar results in this study were found at Coulee Upland, Hill and Remount Lowland where the significant distance of effect was on ROW. The differences in distance of effect could result from different activities during construction as exemplified with the greatest distance of effect at Coulee where disturbance during construction was high due to grading and steep topography.

Increased compaction can have negative effects on vegetation by reducing soil porosity, hydraulic conductivity, soil microbial activity, soil carbon and nitrogen cycling (Soon et al. 2000a, Shi et al. 2013). Compaction has an inverse relationship with the ability of roots to penetrate soil (Martino and Shaykewich 1994). Critical values for native plants are not known, however values based on agricultural crops range from 1.3 MPa to 2 MPa ((Taylor and Ratliff 1969, Martino and Shaykewich 1994), with an optimum value of 1 MPa (Dexter and Zoebisch 2005). Penetration resistance on and off ROW exceed critical limits for agriculture crops, therefore agricultural critical penetration values should not be used to assess native grassland. High penetration resistance on ROW may still be cause for concern due to the reduced ability of roots to penetrate compacted soil and constraints of reduced soil porosity in a dry environment.

5.2 Vegetation

5.2.1 Ground cover

Results from this study were similar to others which found greater impacts on litter, bare ground and live vegetation on the trench in comparison to other areas of the ROW (Naeth 1985, Kerr et al. 1993, Nemirsky 2011). In this study impacts of pipeline construction were site specific in 2012, indicating different construction methods could be a factor. The steep terrain at Coulee which required grading and more intensive construction methods impacted live vegetation equally across the ROW. As expected the trench had lowest litter and highest bare ground, but due to the terrain, litter and bare ground were impacted greater on the work than storage area. Nemirsky (2011) in 2009 and 2010 found size and storage technique of topsoil and subsoil piles impacted ground cover. Where soil was stored in large circular piles 2 to 4 m high ground cover was more similar between trench and storage, whereas at sites where soil was windrowed and 1 to 2 m high ground cover was more similar between work and trench. These impacts were not seen at all sites for all ground cover properties in 2012, indicating some recovery. Results from 2013 where impacts were no longer site specific may indicate that all sites have reached a similar stage of recovery despite initial differences in construction methods. Naeth (1985) found that it took 15 years for live vegetation on the trench to return to near pre disturbed conditions, 5 years longer than for non trench areas of the ROW. Results from 2013 indicate the trench may take longer to return to pre disturbed conditions than storage and work areas. However recovery of bare ground and litter may be different among the three areas. Work areas were similar to the trench in litter and bare ground, which may be a result of greater removal of litter by moving equipment than by cleanup of storage areas.

Changes in ground cover as a result of disturbance are of concern as a lack of live vegetation and increased soil exposure can result in splash erosion, puddling and wind erosion in native prairie (Naeth 1985, Kerr et al. 1993). Increased bare ground can reduce plant height (Willms et al. 1993). Litter plays a role in several ecological functions such as conserving soil water by reducing evaporation from soil by intercepting solar radiation and decreasing surface temperature (Naeth et al. 1988, Deutsch et al. 2010a). Lower or limited soil water in dry mixed grass prairie could reduce success of revegetation efforts and limit plant production (Facelli and Pickett 1991, Kerr et al. 1993, Deutsch et al. 2010a). Litter is important for conserving soil water in mid summer (Deutsch et al. 2010b). Biodiversity and plant community structure are affected by litter; as it increases biodiversity decreases (Facelli and Pickett 1991, Lamb 2008). Litter can impact seed germination (Willms et al. 1993) and can inhibit establishment of forb seedlings (Foster and Gross 1998).

In 2009 and 2010 Nemirsky (2011) found impacts to ground cover 14 and 35 m from the ROW edge. In 2012 distance of effects for ground cover, except live vegetation at Coulee, were within ROW boundaries at all sites. This may indicate that impacts to off ROW ground cover has recovered within 4 growing seasons after disturbance where challenging terrain was not a factor. The distance of effect for live vegetation at Coulee in both years was just off ROW, likely meaning the disturbance impacts off ROW were persisting although the decrease in distance of effect from 2012 to 2013 indicates Coulee is slowly recovering.

The increase in significant distance of effect from 2012 to 2013 likely results from high live vegetation cover outliers or terrain. High vegetation outliers were from high cover from *Bouteloua gracilis* and *Selaginella densa*, two mat forming species. Canopy cover was as high as 64 and 80 % for these two species, respectively. At Coulee from just off ROW to about 80 m, the terrain consists of small steep rolling sandy hills with higher bare ground. After 80 m the terrain was smooth with a gradual slope where litter buildup was likely more stable. At Highway 20 to 30 m from pipeline centre there is a small gully where vegetation is visibly lusher likely from increased soil water, resulting in greater vegetation and litter cover than drier upland where the pipeline ROW is located. Increased distance of effects from these natural outliers may indicate distance of effects on ROW are no longer strong enough to show results and are becoming similar to natural fluctuations in ground cover seen off ROW. At McNeil and Coulee Upland where the ROW was fenced, litter has built up resulting in higher values on ROW (or before distance of effect) than off ROW; this may affect successional pathways and native plant diversity (Gramineae Services Ltd. et al. 2008).

5.2.2 Native species cover

Lower native species cover on the trench is consistent with other studies (Kerr et al. 1993, Ostermann 2001, Nemirsky 2011). In 2012 trends in native cover at Coulee Upland and McNeil supported the trends in live vegetation cover as a result of different size and storage techniques of topsoil and subsoil piles. At sites where soil was stored in large circular piles 2 to 4 m high, ground cover was similar between trench and storage areas, while at sites where soil was windrowed and 1 to 2 m high, ground cover was more similar between work and trench areas. Outliers from *Bouteloua gracilis* and *Cirsium undulatum* (Nutt.) Spreg. (wavy leaf thistle) caused Coulee, Hill and Remount Lowland to have different trends. Results from 2013 where impacts were no longer site specific may indicate that all sites have reached a similar stage of recovery despite initial differences in pipeline construction methods.

Various biotic and abiotic forces can cause ecological communities to spatially and temporally vary (Collins 2000). The variable significant distance of effects for native cover among sites likely resulted from different construction techniques and natural plant community variability. Distance of effects at Hill, Highway and

Remount Lowland were within ROW boundaries and near the trench or non existent; this is likely a result of limited stripping during construction. Decreased distance of effect at Highway and absence of one at Hill indicate parts of the ROW recovered similar to off ROW. Coulee had a distance of effect surpassing ROW boundaries, associated with a greater disturbance during construction due to steep terrain. An increased distance of effect from 2012 to 2013 likely results from high annual variability in communities (Collins 2000). Distance of effects for native species cover extended past the ROW edge at Coulee Upland and McNeil in 2012 and 2013. Nemirsky (2011) in 2010 did not find a significant distance of effect for native cover off ROW. Both of these sites have been fenced from grazing since construction, which can affect native species diversity if the fence remains for a few grazing seasons (Gramineae Services Ltd. et al. 2008). At Coulee Upland and McNeil in 2012 the distance of effect falls at a distance between sampling points on either side of the fence (Coulee Upland fence ~29 m from pipeline centre and McNeil 15 to 20 m). In Colorado on semiarid grassland a lack of grazing in communities that evolved with heavy grazing resulted in communities more similar to disturbed communities (Milchunas et al. 1989). The fenced ROW at Coulee Upland and McNeil likely changed the recovery trajectory for native species to return to similar cover off ROW.

Selaginella densa as a climax species is heavily impacted by pipeline disturbance (Ostermann 2001); in one case it was not found on a 26 year old pipeline ROW when it occupied 50 % of undisturbed prairie (Naeth 1985). Nemirsky (2011) did not find *Selaginella densa* on ROW in 2009 and 2010; in 2012 and 2013 it was occasionally found with low cover on non trench areas of the ROW. Nemirsky (2011) did not find *Artemisia cana* or *Opuntia polycantha* on ROW, but both have started to recover with increasing occurrences from 2012 to 2013. Where *Opuntia polycantha* was one of the first plants to establish on ROW, it resulted from species being spread back on soil surfaces during topsoil replacement (Kerr et al. 1993). The above species are likely to have slow recovery, which is of concern as they are key prairie species which provide soil erosion control and water retention functions (Nemirsky 2011). *Achillea millefolium, Lygodesmia juncea*, *Phlox hoodii*, *Psoralea argophylla* and *Sphaeralcea coccinea* have had mixed results on early establishment on disturbed prairie (Kerr et al. 1993, Ostermann 2001, Nemirsky 2011). In this study they were not found on trench but prominently on other ROW areas, indicating they may tolerate moderate disturbance from construction equipment but not trenching.

Ostermann (2001) found trenching significantly increased rhizomatous grasses and reduced tufted grasses. In this study *Agropyron smithii* a rhizomatous grass decreased in cover with distance from the pipeline, while *Stipa comata* a bunch grass increased in cover with distance. Difference in *Agropyron smithii* and *Stipa comata* cover may result from changes in soil water and temperature from altered amounts of litter. *Agropyron smithii* is a successful competitor for meager amounts of soil water (Coupland 1958) and *Stipa comata* has narrower amplitudes of tolerance than most species for temperature and water (Ayyad and Dix 1964). Twelve years after pipeline construction in Southern Alberta *Carex* species (sedge) density was lower on ROW than off. In this study trace amounts established on the trench after five growing season. Native cover in general may recover on non trench areas as early as four growing seasons after construction with appropriate site conditions, however native cover of individual key prairie species indicates it could be a long time for communities on the ROW to become similar to off ROW. It can take 15 to 50 years to produce a climax community depending on disturbance and climate (Coupland 1952).

5.2.2 Non native species cover

Disturbances like pipelines increase community invasibility (Hobbs and Huenneke 1992), which can provide an opening for non native species that have established elsewhere in the area (Zink et al. 1995). Soil disturbance from pipeline construction increases openings for establishment of weedy and ruderal species (Hobbs and Huenneke 1992). Once invasive species are established, modification to soil biota can impede the restoration of native communities (Jordan et al. 2008). An increase in non native species has been found on other pipeline ROW relative to undisturbed soil (Kerr et al. 1993, Ostermann 2001, Nemirsky 2011). Grasslands had significantly more non native species than forest, with consistent frequency of non native species up to 150 m from the transportation edge (Hansen and Clevenger 2005). Invasion by non native species are a concern because they are a major threat to biodiversity and conservation of native ecosystems (Huntly et al. 2011).

In this study significant distance of effects for non native cover at McNeil and Coulee Upland were found in 2012 and 2013, respectively. Although cover of non native species was low and within the ranges of other sites, there was visibly more non native cover. These observations are important as transects can underestimate patchy distributions of invasive species and overestimate species with sparse but even distribution (Larson et al. 2001). At Coulee Upland there was visually more non native cover on non seeded parts of the ROW and off ROW up to the fence. This could be a direct result of no grazing, as grazing can reduce invasion of even unpalatable species where plant communities have a long history of grazing (Blumenthal et al. 2012). Although this was clear at Coulee Upland, the opposite occurred at McNeil where the fenced ROW had less non native cover. Heavy grazing in spring can lead to grazed plants being replaced by weedy species that are more resistant to grazing (Grasslands Conservation Council of British Columbia 2013). McNeil had various indications of heavy grazing relative to other sites which could explain why weedy non native species increased in cover after the significant distance of effect and fence line.

Other sites had relatively low non native cover among ROW areas and sampling points from pipeline centre to 350 m, supporting results from Nemirsky (2011). Since 2009 and 2010 cover and number of incidences of *Chenopodium album* and *Portulaca oleracea* L. (purslane) cover decreased substantially and that of *Tragopogon dubius* and *Taraxacum officinale* increased. Non native species at all distances are a concern for native prairie conservation and recovery of native communities on pipeline ROW, however low cover indicates management by TransCanada and land owners have prevented non natives from becoming a major component of invaded communities. Although some non native species were listed on seed certificates of lots seeded on ROW, the source of non native species cannot be verified. The sites are located on native prairie fragmented by well site roads and grazed each year by cattle; both of which can spread seed and propagules and could be a source of non native species.

5.2.3 Forb and grass cover

In general the more severe the disturbance the higher the initial cover of forbs (Ostermann 2001). In this study half of the sites did not have a significant distance of effect for forb cover, however forb cover was lower on the trench and even within a few meters at some sites. When higher forb cover was found on the trench it was from weedy species such as *Cirsium undulatum*, *Kochia scoparia* (L.) *Schrad.* (burning bush) and *Polygonum erectum* L. (striate knotweed). This may indicate forbs do not tolerate intensive disturbances such as trenching, as found by Naeth (1985).

In general significant distance of effects for grass cover were within a few meters of the distance of effects for native cover as native grasses make up the majority of the canopy cover. Forbs are generally more efficient than grasses in using environmental resources for germination and growth (Naeth 1985). This may be the reason why more distance of effects were seen for grass cover, as they were less efficient when faced with disturbed water and nutrient regimes.

6. CONCLUSIONS

After five growing seasons, most notable soil impacts from pipeline construction were compaction, organic matter, total organic carbon, saturation, pH, electrical conductivity and soluble salts, although this varied with site as a result of different construction techniques and parent materials. This is evidenced by impacts from pipeline construction on soil physical and chemical properties, specifically compaction, being contained to the ROW when steep topography and extensive grading were not factors.

After five growing seasons vegetation remains impacted by the pipeline. Impacts of different methods of soil storage are no longer seen on ground cover. Greater impacts to ground cover and species composition were seen when larger amounts of land were stripped. *Artemisia cana*, *Opuntia polycantha* and *Selaginella densa* are key prairie species with slow recovery. A lack of grazing on ROW caused a dissimilarity in ground cover and species composition from undisturbed land.

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Table 2.1. Soil chemical properties at 0 to 5 cm depth for pipeline ROW areas.

Property	Storage	Trench	Work
Ammonium Nitrogen (mg/kg)	2432 (456)	2336 (501)	2315 (557)
Cation Exchange Capacity (meq/100g)	17.34 (3.26)	16.67 (3.57)	16.53 (3.99)
Carbon to Nitrogen Ratio	9.62 (2.70)	7.87 (3.59)	10.18 (3.15)
Total Nitrogen (%)	0.21 (0.10)	0.20 (0.09)	0.20 (0.09)
Organic Matter (%)	3.66 (1.47) a	2.85 (1.17) b	3.95 (2.17) a
Total Inorganic Carbon (%)	0.18 (0.19)	0.27 (0.30)	0.23 (0.31)
Total Organic Carbon (%)	1.83 (0.74) a	1.43 (0.59) b	1.97 (1.08) a
Electrical Conductivity (dS/m)	0.48 (0.20)	0.52 (0.16)	0.43 (0.13)
Sodium Adsorption Ratio	0.16 (0.39)	0.59 (1.80)	0.13 (0.13)
Saturation (%)	60.61 (9.43) a	53.94 (7.32) b	59.11 (14.12) a
Soluble Sodium (mg/kg)	3.83 (9.05)	7.67 (18.25)	2.39 (2.28)

Numbers are means with standard deviations in brackets.

Different letters within rows denote significant differences between areas of ROW at $p<0.05$.

Table 2.2. Soil chemical properties for site by ROW area interactions for 0 to 5 cm.

Site	ROW Area	Reaction (pH)		Calcium* (mg/kg)		Magnesium* (mg/kg)		Potassium* (mg/kg)	
Coulee	Storage	7.77 (0.15)		33.97 (8.35)		8.83 (1.99)		12.67 (2.52)	
	Trench	7.70 (0.10)		29.30 (10.06)		7.93 (2.68)		9.67 (3.51)	
	Work	7.77 (0.06)		29.77 (9.19)		7.30 (3.50)		11.67 (4.04)	
Coulee Upland	Storage	6.57 (0.25)		27.80 (4.85)		8.03 (1.23)		22.00 (6.00)	
	Trench	7.07 (0.31)		31.77 (7.86)		8.13 (1.48)		37.33 (9.07)	
	Work	6.53 (0.32)		33.17 (14.24)		10.03 (4.10)		38.67 (11.93)	
Hill	Storage	7.67 (0.06)		32.97 (14.36)		9.50 (5.04)		8.33 (5.77)	
	Trench	7.90 (0.26)		24.67 (13.86)		6.23 (2.50)		8.00 (3.61)	
	Work	7.30 (0.46)		27.63 (2.85)		8.83 (2.12)		11.00 (5.00)	
Highway	Storage	7.77 (0.23)		41.37 (11.13)		10.07 (1.95)		7.33 (1.53)	
	Trench	7.77 (0.15)		52.67 (11.98)		15.43 (6.90)		9.67 (1.53)	
	Work	7.53 (0.64)		57.77 (5.71)		14.43 (3.73)		13.33 (5.77)	
McNeil	Storage	6.67 (0.21)		15.33 (3.39)		4.87 (1.25)		9.33 (1.15)	ab
	Trench	6.77 (0.15)		18.77 (5.16)		5.57 (1.36)		10.67 (0.58)	a
	Work	6.97 (0.25)		14.30 (4.11)		4.40 (1.13)		6.67 (1.53)	b
Remount Lowland	Storage	7.47 (0.06)	a	75.90 (31.90)	a	20.00 (4.22)	a	13.00 (4.36)	
	Trench	7.53 (0.12)	a	34.10 (2.60)	a	12.10 (0.89)	b	4.33 (1.53)	
	Work	6.63 (0.21)	b	18.33 (5.27)	b	7.67 (1.57)	b	9.33 (4.93)	

Numbers are means with standard deviations in brackets.

Different letters within columns for ROW areas for a given site denote significant differences at $p<0.05$.

*Soluble.

Table 2.3. Soil quality ratings for 0 to 5 cm for ROW areas on the study sites.

		Salinity (EC) (dS/m)			Organic Carbon			Reaction (pH)			Sodicity (SAR)			Saturation (%)		
Site	ROW Area	Min	Max	Rating	Min	Max	Rating	Min	Max	Rating	Min	Max	Rating	Min	Max	Rating
Coulee	Storage	0.48	0.61	Good	1.01	1.6	Fair	7.6	7.9	Fair	0.05	0.1	Good	42	51	Good
	Trench	0.41	0.56	Good	0.94	1.37	Poor	7.6	7.8	Fair	0.05	0.3	Good	41	53	Good
	Work	0.4	0.6	Good	0.71	1.41	Poor	7.7	7.8	Fair	0.05	0.2	Good	36	48	Good
Coulee Upland	Storage	0.3	0.41	Good	3.1	3.24	Good	6.3	6.8	Fair	0.05	0.05	Good	69	77	Fair
	Trench	0.4	0.59	Good	2.04	2.81	Good	6.8	7.4	Good	0.05	0.1	Good	61	67	Fair
	Work	0.27	0.51	Good	3.17	4.53	Good	6.3	6.9	Fair	0.05	0.1	Good	70	88	Poor
Hill	Storage	0.3	0.83	Good	1.15	1.43	Fair	7.6	7.7	Fair	0.1	1.7	Good	51	56	Good
	Trench	0.4	0.9	Good	0.9	0.97	Poor	7.7	8.2	Fair	0.2	7.8	Fair	47	53	Good
	Work	0.43	0.53	Good	1.06	2.07	Fair	6.8	7.7	Fair	0.1	0.6	Good	49	57	Good
Highway	Storage	0.31	0.55	Good	1.54	1.84	Fair	7.5	7.9	Fair	0.05	0.05	Good	62	73	Fair
	Trench	0.49	0.92	Good	1.05	1.45	Fair	7.6	7.9	Fair	0.05	0.4	Good	57	62	Good
	Work	0.49	0.62	Good	1.47	2.83	Fair	6.8	8	Fair	0.05	0.05	Good	58	79	Fair
McNeil	Storage	0.22	0.29	Good	1.16	1.99	Fair	6.5	6.9	Good	0.05	0.1	Good	58	62	Good
	Trench	0.3	0.38	Good	0.74	1.88	Poor	6.6	6.9	Good	0.05	0.2	Good	49	54	Good
	Work	0.19	0.29	Good	1.15	1.52	Fair	6.7	7.2	Good	0.1	0.2	Good	50	55	Good
Remount Lowland	Storage	0.7	0.86	Good	1.18	2.85	Fair	7.4	7.5	Good	0.05	0.1	Good	57	70	Fair
	Trench	0.48	0.53	Good	1.25	1.69	Fair	7.4	7.6	Fair	0.2	0.3	Good	50	60	Good
	Work	0.3	0.37	Good	1.44	3.38	Fair	6.4	6.8	Fair	0.05	0.1	Good	52	68	Good

Numbers are minimums and maximums.

Ratings are from soil quality criteria for reclamation (Alberta Agriculture, Food and Rural Development 1987).

Rating given are based on lowest criteria met by either minimum or maximum value.

EC = electrical conductivity, SAR = sodium adsorption ratio.

Table 2.4. Soil chemical properties for areas of the pipeline right of way areas for 5 to 15 cm.

	Storage		Trench		Work	
Ammonium (mg/kg)	2153 (429)		2188 (554)		2151 (443)	
Cation Exchange Capacity (meq/100g)	15.37 (3.07)		15.60 (3.96)		15.35 (3.16)	
Carbon:Nitrogen Ratio	8.59 (5.10)		9.52 (6.20)		9.58 (5.98)	
Total Nitrogen (%)	0.19 (0.10)		0.16 (0.09)		0.17 (0.11)	
Organic Matter (%)	2.60 (0.92)		2.55 (1.06)		2.46 (0.70)	
Total Inorganic Carbon (%)	0.35 (0.47)		0.39 (0.28)		0.34 (0.52)	
Total Organic Carbon (%)	1.30 (0.46)		1.27 (0.53)		1.23 (0.35)	
Electrical Conductivity (dS/m)	0.39 (0.14)	a	0.55 (0.13)	b	0.43 (0.28)	ab
Sodium Adsorption Ratio	0.36 (0.78)		0.88 (2.02)		0.23 (0.21)	
Percent Saturation (%)	51.39 (7.95)		51.78 (8.73)		51.61 (8.08)	
Soluble Magnesium (mg/kg)	7.20 (2.95)		10.41 (2.96)		8.71 (6.21)	
Soluble Sodium (mg/kg)	5.11 (10.33)		11.89 (20.31)		4.17 (5.61)	

Numbers are means with standard deviations in brackets.
Different letters within rows denote significant differences between areas of ROW at $p<0.05$.

Table 2.5. Soil chemical properties for site:area interactions for 5 to 15 cm.

Site	Area	pH		Soluble Calcium (mg/kg)		Soluble Potassium (mg/kg)	
Coulee	Storage	7.80 (0.30)		26.40 (13.40)		9.33 (5.03)	
	Trench	7.80 (0.17)		23.23 (4.13)		8.67 (2.08)	
	Work	7.80 (0.10)		40.90 (37.58)		9.33 (4.93)	
Coulee Upland	Storage	6.57 (0.21)	a	13.60 (0.46)	a	10.00 (3.00)	a
	Trench	7.23 (0.15)	b	46.33 (1.10)	b	23.67 (3.51)	b
	Work	6.40 (0.36)	a	14.77 (4.57)	a	14.33 (1.53)	a
Hill	Storage	7.80 (0.20)		21.47 (5.16)		3.00 (1.00)	
	Trench	8.03 (0.25)		19.73 (7.59)		4.00 (0.00)	
	Work	7.73 (0.15)		26.30 (3.73)		6.00 (3.46)	
Highway	Storage	7.90 (0.10)		39.67 (5.15)		4.67 (0.58)	
	Trench	7.87 (0.23)		39.33 (3.74)		7.00 (0.00)	
	Work	7.60 (0.69)		35.83 (12.80)		6.33 (2.31)	
McNeil	Storage	6.83 (0.06)	a	13.53 (2.32)	a	4.00 (1.00)	
	Trench	7.40 (0.10)	b	35.00 (1.75)	b	7.00 (0.00)	
	Work	7.27 (0.35)	ab	24.97 (10.99)	ab	4.33 (2.52)	
Remount Lowland	Storage	7.40 (0.20)	a	25.77 (5.51)	a	2.33 (0.58)	
	Trench	7.87 (0.06)	b	23.43 (1.17)	ab	2.67 (0.58)	
	Work	6.57 (0.21)	c	12.80 (4.85)	b	3.00 (2.65)	

Numbers are means with standard deviations in brackets.

Different letters within columns for ROW areas for a given site denote significant differences at $p<0.05$.

Table 2.6. Soil quality ratings for 5 to 15 cm for the plains region relative to disturbance and reclamation.

		Salinity (EC) (dS/m)			Organic Carbon			Reaction (pH)			Sodicity (SAR)			Saturation (%)		
Site	Area	Min	Max	Rating	Min	Max	Rating	Min	Max	Rating	Min	Max	Rating	Min	Min	Rating
Coulee	Storage	0.48	0.61	Good	1.01	1.6	Fair	7.6	7.9	Fair	0.05	0.1	Good	42	51	Good
	Trench	0.41	0.56	Good	0.94	1.37	Poor	7.6	7.8	Fair	0.05	0.3	Good	41	53	Good
	Work	0.4	0.6	Good	0.71	1.41	Poor	7.7	7.8	Fair	0.05	0.2	Good	36	48	Good
Coulee Upland	Storage	0.3	0.41	Good	3.1	3.24	Good	6.3	6.8	Fair	0.05	0.05	Good	69	77	Fair
	Trench	0.4	0.59	Good	2.04	2.81	Good	6.8	7.4	Good	0.05	0.1	Good	61	67	Fair
	Work	0.27	0.51	Good	3.17	4.53	Good	6.3	6.9	Fair	0.05	0.1	Good	70	88	Poor
Hill	Storage	0.3	0.83	Good	1.15	1.43	Fair	7.6	7.7	Fair	0.1	1.7	Good	51	56	Good
	Trench	0.4	0.9	Good	0.9	0.97	Poor	7.7	8.2	Fair	0.2	7.8	Fair	47	53	Good
	Work	0.43	0.53	Good	1.06	2.07	Fair	6.8	7.7	Fair	0.1	0.6	Good	49	57	Good
Highway	Storage	0.31	0.55	Good	1.54	1.84	Fair	7.5	7.9	Fair	0.05	0.05	Good	62	73	Fair
	Trench	0.49	0.92	Good	1.05	1.45	Fair	7.6	7.9	Fair	0.05	0.4	Good	57	62	Good
	Work	0.49	0.62	Good	1.47	2.83	Fair	6.8	8	Fair	0.05	0.05	Good	58	79	Fair
McNeil	Storage	0.22	0.29	Good	1.16	1.99	Fair	6.5	6.9	Good	0.05	0.1	Good	58	62	Good
	Trench	0.3	0.38	Good	0.74	1.88	Poor	6.6	6.9	Good	0.05	0.2	Good	49	54	Good
	Work	0.19	0.29	Good	1.15	1.52	Fair	6.7	7.2	Good	0.1	0.2	Good	50	55	Good
Remount Lowland	Storage	0.7	0.86	Good	1.18	2.85	Fair	7.4	7.5	Good	0.05	0.1	Good	57	70	Fair
	Trench	0.48	0.53	Good	1.25	1.69	Fair	7.4	7.6	Fair	0.2	0.3	Good	50	60	Good
	Work	0.3	0.37	Good	1.44	3.38	Fair	6.4	6.8	Fair	0.05	0.1	Good	52	68	Good

Numbers are minimums and maximums

Ratings are from soil quality criteria for reclamation (Alberta Agriculture, Food and Rural Development 1987).

Rating given are based on lowest criteria met by either minimum or maximum value.

Table 2.7. Ammonium (mg/kg) 0 to 5 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall	
0	1823 (271)	2943 (30)	1723 (221)	2523 (371)	2370 (46)	2630 (346)	2188 (554)	
6	1607 (348)	2870 (597)	1977 (285)	2603 (318)	2323 (114)	2863 (229)	2145 (459)	
16	1910 (295)	3170 (344)	1933 (57)	2353 (275)	2370 (166)	2503 (421)	2158 (411)	
25	1953 (280)	3153 (371)	2027 (342)	2620 (180)	2537 (131)	2853 (429)	2244 (370)	
35	2493 (450)	3023 (318)	2180 (322)	3090 (442)	2563 (200)	2957 (324)	2296 (363)	▪35
50	2190 (1081)	3033 (275)	1990 (30)	2520 (427)	2293 (201)	2810 (105)	2276 (499)	
65	1747 (423)	3160 (180)	2353 (597)	3273 (924)	2300 (243)	3047 (652)	2355 (587)	
350	2283 (321)	2580 (442)	4383 (344)	2423 (630)	2457 (298)	2800 (561)	2642 (819)	

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.8. Cation exchange capacity (meq/100g) 0 to 5 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall	
0	13.00 (1.91)	21.00 (0.20)	12.30 (1.61)	18.03 (2.65)	16.93 (0.31)	18.77 (2.46)	16.67 (3.57)	
6	11.47 (2.51)	20.47 (4.31)	14.10 (2.02)	18.57 (2.29)	16.57 (0.83)	20.43 (1.69)	16.93 (3.78)	
16	13.63 (2.11)	22.63 (2.43)	13.83 (0.40)	16.80 (2.00)	16.87 (1.17)	17.87 (3.06)	16.94 (3.55)	
25	13.97 (2.00)	22.50 (2.65)	14.50 (2.43)	18.70 (1.30)	18.13 (0.93)	20.40 (3.05)	18.03 (3.54)	
35	17.83 (3.22)	21.57 (2.29)	15.57 (2.31)	22.03 (3.15)	18.27 (1.45)	21.10 (2.34)	19.39 (3.56)	▪35
50	15.60 (7.71)	21.63 (2.00)	14.20 (0.20)	17.97 (3.01)	16.40 (1.44)	20.03 (0.75)	17.64 (4.01)	
65	12.47 (3.01)	22.57 (1.30)	16.80 (4.31)	23.33 (6.55)	16.43 (1.70)	21.73 (4.66)	18.89 (5.29)	
350	16.27 (2.26)	18.43 (3.15)	31.30 (2.43)	17.30 (4.50)	17.53 (2.15)	19.97 (4.01)	20.13 (5.83)	

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.9. Total nitrogen (%) 0 to 5 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	0.15 (0.03)	0.24 (0.03)	0.14 (0.07)	0.30 (0.12)	0.15 (0.03)	0.23 (0.08)	0.20 (0.09)
6	0.12 (0.04)	0.28 (0.06)	0.12 (0.04)	0.17 (0.04)	0.20 (0.07)	0.25 (0.18)	0.19 (0.10)
16	0.16 (0.03)	0.29 (0.07)	0.13 (0.07)	0.20 (0.08)	0.26 (0.12)	0.23 (0.11)	0.21 (0.09)
25	0.17 (0.05)	0.36 (0.12)	0.12 (0.01)	0.34 (0.32)	0.16 (0.01)	0.27 (0.07)	0.24 (0.15)
35	0.23 (0.05)	0.38 (0.04)	0.18 (0.05)	0.21 (0.12)	0.24 (0.16)	0.36 (0.07)	0.27 (0.13)
50	0.16 (0.17)	0.36 (0.08)	0.12 (0.03)	0.15 (0.06)	0.14 (0.06)	0.22 (0.05)	0.19 (0.11)
65	0.15 (0.02)	0.39 (0.32)	0.22 (0.06)	0.31 (0.09)	0.16 (0.06)	0.27 (0.04)	0.25 (0.10)
350	0.17 (0.04)	0.19 (0.12)	0.23 (0.07)	0.22 (0.10)	0.83 (1.12)	0.26 (0.09)	0.32 (0.45)

Numbers are means with standard deviations in brackets.

Table 2.10. Soluble calcium (mg/kg) 0 to 5 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	29.30 (10.06)	31.77 (14.67)	24.67 (13.86)	52.67 (11.98)	18.77 (5.16)	34.10 (2.60)	31.88 (13.43)
6	29.77 (9.19)	27.80 (23.58)	32.97 (14.36)	41.37 (11.13)	14.30 (4.11)	75.90 (31.90)	37.02 (23.70)
16	33.97 (8.35)	33.17 (12.10)	27.63 (2.85)	57.77 (5.71)	15.33 (3.39)	18.33 (5.27)	31.03 (15.62)
25	42.87 (32.56)	17.77 (11.98)	36.63 (29.05)	33.33 (12.81)	23.33 (6.86)	21.20 (16.26)	29.19 (19.37)
35	25.80 (16.21)	37.77 (11.13)	37.40 (22.10)	63.63 (16.98)	24.27 (4.58)	20.30 (13.14)	34.86 (21.51)
50	19.07 (2.73)	20.87 (5.71)	20.17 (14.67)	52.17 (6.19)	13.37 (1.96)	30.60 (15.04)	26.04 (15.54)
65	25.00 (3.17)	46.60 (12.81)	33.33 (23.58)	47.83 (5.13)	10.50 (1.39)	22.07 (5.59)	30.89 (24.84)
350	19.63 (14.07)	13.37 (16.98)	40.83 (12.10)	33.43 (17.15)	18.90 (18.24)	15.13 (5.46)	23.55 (15.06)

Numbers are means with standard deviations in brackets.

Table 2.11. Soluble potassium (mg/kg) 0 to 5 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	7.93 (2.68)	8.13 (3.15)	6.23 (2.50)	15.43 (6.90)	5.57 (1.36)	12.10 (0.89)	9.23 (4.52)
6	7.30 (3.50)	8.03 (8.46)	9.50 (5.04)	10.07 (1.95)	4.40 (1.13)	20.00 (4.22)	9.88 (5.70)
16	8.83 (1.99)	10.03 (5.40)	8.83 (2.12)	14.43 (3.73)	4.87 (1.25)	7.67 (1.57)	9.11 (3.72)
25	11.10 (8.71)	5.53 (6.90)	11.23 (9.24)	9.20 (3.05)	6.53 (1.14)	7.83 (5.53)	8.57 (5.47)
35	7.63 (4.02)	10.63 (1.95)	13.57 (7.78)	16.57 (6.42)	7.10 (1.35)	8.37 (5.09)	10.64 (6.02)
50	7.00 (3.59)	6.13 (3.73)	6.37 (3.15)	13.27 (6.60)	4.03 (0.67)	10.53 (4.00)	7.89 (4.52)
65	7.33 (2.42)	16.57 (3.05)	11.23 (8.46)	14.07 (3.29)	3.03 (0.21)	8.63 (1.29)	10.14 (9.08)
350	6.60 (3.35)	4.70 (6.42)	17.23 (5.40)	11.97 (6.18)	5.23 (4.45)	5.80 (1.71)	8.59 (5.84)

Numbers are means with standard deviations in brackets.

Table 2.12. Carbon to nitrogen ratio 0 to 5 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	7.53 (1.87)	11.57 (2.82)	7.93 (3.35)	4.73 (2.40)	9.10 (4.52)	6.37 (1.12)	7.87 (3.59)
6	9.20 (0.44)	11.13 (1.28)	11.40 (4.05)	10.20 (1.22)	7.53 (3.25)	8.87 (2.89)	9.72 (2.51)
16	8.53 (0.85)	13.40 (2.72)	11.87 (4.20)	10.07 (2.35)	7.57 (4.12)	9.00 (0.35)	▪24 10.07 (3.32)
25	9.33 (2.05)	10.87 (2.40)	11.67 (1.12)	8.13 (4.15)	10.90 (3.54)	11.30 (1.99)	10.37 (2.51)
35	8.83 (1.23)	10.07 (1.22)	9.10 (3.54)	15.80 (5.75)	12.80 (7.94)	9.43 (1.68)	11.01 (4.51)
50	22.47 (22.31)	10.30 (2.35)	10.70 (2.82)	10.83 (1.46)	11.83 (5.69)	12.13 (3.95)	13.04 (9.21)
65	9.67 (1.16)	9.60 (4.15)	8.50 (1.28)	8.70 (4.25)	10.00 (1.25)	11.07 (1.56)	9.59 (2.11)
350	9.67 (1.04)	9.37 (5.75)	10.13 (2.72)	10.17 (2.49)	6.53 (5.14)	9.67 (0.31)	9.26 (2.55)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.13. Organic matter (%) 0 to 5 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	2.20 (0.47)	4.99 (0.11)	1.88 (0.07)	2.50 (0.40)	2.68 (1.14)	2.85 (0.47)	2.85 (1.17)
6	2.19 (0.70)	6.30 (1.55)	2.52 (0.29) ▪9	3.41 (0.31)	2.73 (0.38)	3.85 (1.69)	3.50 (1.56)
16	2.68 (0.60)	7.65 (0.71)	2.85 (1.11)	3.97 (1.47)	3.20 (0.84)	4.29 (2.15)	4.11 (2.07)
25	3.24 (1.49)	7.81 (0.40)	2.81 (0.11)	3.89 (1.43)	3.57 (1.25)	5.98 (1.36) ▪28	4.55 (2.09) ▪29
35	4.11 (1.46)	7.22 (0.31)	3.07 (0.54)	5.78 (2.32)	4.77 (1.00)	6.67 (0.25)	5.27 (2.01)
50	4.23 (3.05)	7.56 (1.47)	2.47 (0.11)	3.28 (0.93)	3.07 (0.30)	5.16 (1.24)	4.30 (2.26)
65	2.99 (0.63)	7.44 (1.43)	3.89 (1.55)	5.55 (3.86)	3.16 (1.50)	6.17 (1.78)	4.87 (2.44)
350	3.25 (0.51)	3.55 (2.32)	4.57 (0.71)	4.32 (1.33)	3.19 (0.59)	5.01 (1.75)	3.98 (1.12)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.14. Total inorganic carbon (%) 0 to 5 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland		Overall	
0	0.26 (0.21)	0.06 (0.32)	0.33 (0.12)	0.78 (0.35)	0.03 (0.01)	0.15 (0.08)		0.27 (0.30)	
6	0.38 (0.11)	0.06 (0.16)	0.05 (0.01)	0.35 (0.27)	0.02 (0.01)	0.13 (0.04)		0.17 (0.18)	
16	0.44 (0.05)	0.07 (0.03)	0.27 (0.38)	0.62 (0.51)	0.03 (0.01)	0.04 (0.02)	▪16	0.24 (0.32)	
25	0.20 (0.23)	0.05 (0.35)	0.22 (0.20)	0.26 (0.37)	0.03 (0.00)	0.04 (0.02)		0.13 (0.19)	▪32
35	0.20 (0.24)	0.04 (0.27)	0.09 (0.10)	0.35 (0.49)	0.03 (0.01)	0.05 (0.02)		0.13 (0.23)	
50	0.19 (0.20)	0.07 (0.51)	0.21 (0.32)	0.46 (0.38)	0.03 (0.01)	0.04 (0.02)		0.17 (0.24)	
65	0.16 (0.11)	0.07 (0.37)	0.16 (0.16)	0.07 (0.01)	0.03 (0.01)	0.04 (0.01)		0.09 (0.09)	
350	0.13 (0.16)	0.04 (0.49)	0.12 (0.03)	0.10 (0.10)	0.03 (0.01)	0.06 (0.04)		0.08 (0.08)	

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.15. Total organic carbon (%) 0 to 5 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill		Highway	McNeil	Remount Lowland		Overall	
0	1.10 (0.24)	2.49 (0.06)	0.94 (0.04)		1.25 (0.20)	1.34 (0.57)	1.43 (0.23)		1.43 (0.59)	
6	1.09 (0.35)	3.15 (0.77)	1.26 (0.15)	▪11	1.71 (0.15)	1.37 (0.19)	1.93 (0.85)		1.75 (0.78)	
16	1.34 (0.30)	3.82 (0.35)	1.43 (0.56)		1.99 (0.74)	1.60 (0.42)	2.14 (1.07)		2.05 (1.04)	
25	1.62 (0.75)	3.91 (0.20)	1.40 (0.06)		1.95 (0.72)	1.78 (0.62)	2.99 (0.68)	▪28	2.28 (1.05)	▪29
35	2.06 (0.73)	3.61 (0.15)	1.53 (0.27)		2.89 (1.16)	2.39 (0.50)	3.34 (0.13)		2.64 (1.00)	
50	2.12 (1.52)	3.78 (0.74)	1.24 (0.06)		1.64 (0.46)	1.54 (0.15)	2.58 (0.62)		2.15 (1.13)	
65	1.50 (0.32)	3.72 (0.72)	1.94 (0.77)		2.78 (1.93)	1.58 (0.75)	3.09 (0.89)		2.43 (1.22)	
350	1.63 (0.26)	1.78 (1.16)	2.28 (0.35)		2.16 (0.66)	1.59 (0.30)	2.51 (0.88)		1.99 (0.56)	

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.16. Reaction (pH) 0 to 5 cm with distance from pipeline centre.

Distance (m)	Coulee		Coulee Upland		Hill		Highway	McNeil	Remount Lowland		Overall	
0	7.70 (0.10)		7.07 (0.80)		7.90 (0.26)		7.77 (0.15)	6.77 (0.15)	7.53 (0.12)		7.46 (0.45)	
6	7.77 (0.06)		6.57 (0.17)		7.67 (0.06)	▪15	7.77 (0.23)	6.97 (0.25)	7.47 (0.06)		7.37 (0.49)	
16	7.77 (0.15)		6.53 (0.15)		7.30 (0.46)		7.53 (0.64)	6.67 (0.21)	6.63 (0.21)	▪21	7.07 (0.59)	
25	7.27 (0.40)		5.93 (0.15)	▪28	7.40 (0.35)		7.33 (0.70)	6.87 (0.06)	6.20 (0.44)		6.83 (0.69)	▪27
35	7.13 (0.35)	▪35	5.80 (0.23)		7.33 (0.23)		7.23 (0.65)	6.80 (0.00)	6.30 (0.44)		6.77 (0.65)	
50	7.03 (0.71)		5.97 (0.64)		7.17 (0.80)		7.50 (0.53)	6.77 (0.06)	6.70 (0.30)		6.86 (0.66)	
65	7.37 (0.42)		5.97 (0.70)		7.40 (0.17)		7.30 (0.44)	6.30 (0.36)	6.33 (0.15)		6.78 (0.66)	
350	7.20 (0.52)		6.40 (0.65)		7.27 (0.15)		7.10 (0.56)	6.27 (0.45)	6.33 (0.06)		6.76 (0.56)	

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.17. Electrical conductivity (dS/m) 0 to 5 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland		Overall	
0	0.50 (0.08)	0.50 (0.26)	0.61 (0.26)	0.65 (0.23)	0.34 (0.04)	0.51 (0.03)		0.52 (0.16)	
6	0.52 (0.11)	0.35 (0.31)	0.52 (0.28)	0.46 (0.13)	0.26 (0.06)	0.76 (0.09)		0.48 (0.20)	
16	0.55 (0.07)	0.42 (0.23)	0.48 (0.05)	0.57 (0.07)	0.25 (0.04)	0.34 (0.04)	▪21	0.43 (0.13)	▪20
25	0.50 (0.23)	0.28 (0.23)	0.52 (0.36)	0.45 (0.13)	0.32 (0.06)	0.31 (0.12)		0.40 (0.19)	
35	0.40 (0.17)	0.38 (0.13)	0.61 (0.36)	0.55 (0.04)	0.33 (0.03)	0.33 (0.16)		0.43 (0.19)	
50	0.35 (0.03)	0.27 (0.07)	0.40 (0.26)	0.63 (0.02)	0.23 (0.03)	0.46 (0.15)		0.39 (0.17)	
65	0.43 (0.02)	0.46 (0.13)	0.50 (0.31)	0.57 (0.12)	0.20 (0.03)	0.37 (0.05)		0.42 (0.21)	
350	0.32 (0.11)	0.24 (0.04)	0.57 (0.23)	0.48 (0.19)	0.25 (0.17)	0.28 (0.05)		0.36 (0.18)	

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.18. Saturation (%) 0 to 5 cm with distance from pipeline centre.

Distance (m)	Coulee		Coulee Upland	Hill	Highway	McNeil		Remount Lowland	Overall	
0	45.00 (6.93)		63.33 (3.51)	49.00 (3.46)	59.67 (2.52)	51.67 (2.52)		55.00 (5.00)	53.94 (7.32)	
6	42.33 (6.03)		72.67 (14.84)	54.00 (2.65)	66.33 (5.86)	52.33 (2.52)		64.00 (6.56)	58.61 (11.17)	
16	47.00 (4.58)		80.33 (2.52)	52.67 (4.04)	68.67 (10.50)	59.67 (2.08)	▪18	58.33 (8.50)	61.11 (12.70)	
25	50.67 (6.81)	▪34	76.00 (2.52)	55.67 (2.31)	62.33 (8.39)	64.33 (2.52)		68.33 (15.31)	62.89 (11.18)	▪28
35	58.00 (8.66)		75.00 (5.86)	58.00 (4.58)	77.00 (14.18)	63.00 (5.57)		74.00 (6.56)	67.50 (11.89)	
50	55.00 (20.07)		75.67 (10.50)	57.67 (3.51)	55.67 (7.51)	57.33 (4.16)		67.33 (9.24)	61.44 (11.76)	
65	49.33 (6.43)		75.33 (8.39)	62.67 (14.84)	72.33 (23.97)	57.33 (10.12)		71.67 (15.01)	64.78 (15.38)	
350	53.67 (7.02)		57.33 (14.18)	77.33 (2.52)	64.33 (6.81)	64.67 (5.51)		65.33 (6.43)	63.78 (9.17)	

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.19. Soluble magnesium (mg/kg) 0 to 5 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland		Overall
0	7.93 (2.68)	8.13 (3.15)	6.23 (2.50)	15.43 (6.90)	5.57 (1.36)	12.10 (0.89)		9.23 (4.52)
6	7.30 (3.50)	8.03 (8.46)	9.50 (5.04)	10.07 (1.95)	4.40 (1.13)	20.00 (4.22)		9.88 (5.70)
16	8.83 (1.99)	10.03 (5.40)	8.83 (2.12)	14.43 (3.73)	4.87 (1.25)	7.67 (1.57)	▪19	9.11 (3.72)
25	11.10 (8.71)	5.53 (6.90)	11.23 (9.24)	9.20 (3.05)	6.53 (1.14)	7.83 (5.53)		8.57 (5.47)
35	7.63 (4.02)	10.63 (1.95)	13.57 (7.78)	16.57 (6.42)	7.10 (1.35)	8.37 (5.09)		10.64 (6.02)
50	7.00 (3.59)	6.13 (3.73)	6.37 (3.15)	13.27 (6.60)	4.03 (0.67)	10.53 (4.00)		7.89 (4.52)
65	7.33 (2.42)	16.57 (3.05)	11.23 (8.46)	14.07 (3.29)	3.03 (0.21)	8.63 (1.29)		10.14 (9.08)
350	6.60 (3.35)	4.70 (6.42)	17.23 (5.40)	11.97 (6.18)	5.23 (4.45)	5.80 (1.71)		8.59 (5.84)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.20. Soluble sodium (mg/kg) 0 to 5 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	2.33 (1.53)	1.67 (18.19)	29.33 (43.89)	5.67 (5.51)	1.67 (1.15)	5.33 (1.15)	7.67 (18.25)
6	1.67 (1.15)	1.33 (23.09)	14.67 (21.94)	1.67 (0.58)	2.00 (0.00)	2.67 (0.58)	▪7 4.00 (9.01)
16	1.33 (0.58)	1.67 (3.00)	5.67 (4.73)	1.33 (0.58)	1.33 (0.58)	2.00 (0.00)	2.22 (2.32)
25	1.00 (0.00)	1.67 (5.51)	5.67 (5.51)	1.33 (0.58)	1.33 (0.58)	2.33 (0.58)	2.22 (2.53)
35	1.00 (0.00)	1.67 (0.58)	15.33 (22.23)	2.33 (1.53)	1.33 (0.58)	2.33 (0.58)	4.00 (9.27)
50	1.33 (0.58)	1.67 (0.58)	13.00 (18.19)	1.33 (0.58)	1.33 (0.58)	3.00 (2.65)	3.61 (7.68)
65	1.00 (0.00)	1.67 (0.58)	15.33 (23.09)	1.67 (1.15)	1.00 (0.00)	2.00 (0.00)	3.78 (9.56)
350	1.00 (0.00)	1.33 (1.53)	8.00 (3.00)	1.33 (0.58)	1.33 (0.58)	1.33 (0.58)	2.39 (2.81)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.21. Ammonium (mg/kg) 5 to 15 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	1627 (205)	2777 (455)	1597 (315)	2533 (649)	2140 (122)	2453 (352)	2188 (554)
6	1527 (256)	2533 (414)	1677 (283)	2280 (122)	2283 (196)	2570 (207)	2145 (459)
16	1723 (455)	2570 (199)	1717 (75)	2223 (220)	2133 (67)	2583 (228)	2158 (411)
25	1833 (235)	2557 (649)	1797 (137)	2480 (98)	2273 (100)	2523 (277)	2244 (370)
35	2293 (91)	2487 (122)	1777 (268)	2330 (527)	2277 (165)	2610 (262)	2296 (363)
50	1732 (768)	2527 (220)	2033 (455)	2427 (283)	2257 (207)	2683 (494)	2276 (499)
65	1412 (523)	2607 (98)	2187 (414)	2693 (280)	2317 (172)	2917 (489)	2355 (587)
350	2113 (155)	2603 (527)	4237 (199)	1980 (320)	2183 (108)	2737 (405)	2642 (819)

Numbers are means with standard deviations in brackets.

Table 2.22. Cation exchange capacity (meq/100g) 5 to 15 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	11.60 (1.50)	19.80 (3.22)	11.37 (2.28)	18.10 (4.61)	15.23 (0.90)	17.50 (2.46)	15.60 (3.96)
6	10.90 (1.85)	18.10 (2.93)	11.97 (2.01)	16.23 (0.84)	16.30 (1.35)	18.37 (1.46)	15.31 (3.28)
16	12.30 (3.30)	18.30 (1.40)	12.27 (0.55)	15.87 (1.62)	15.23 (0.49)	18.47 (1.62)	15.41 (2.94)
25	13.07 (1.68)	18.27 (4.61)	12.83 (0.99)	17.67 (0.68)	16.23 (0.74)	18.03 (1.96)	16.02 (2.64)
35	16.37 (0.67)	17.73 (0.84)	12.67 (1.92)	16.57 (3.76)	16.27 (1.15)	18.67 (1.86)	16.38 (2.59)
50	12.33 (5.49)	18.03 (1.62)	14.50 (3.22)	17.33 (2.02)	16.07 (1.52)	19.13 (3.54)	16.23 (3.57)
65	10.07 (3.76)	18.57 (0.68)	15.60 (2.93)	19.23 (2.00)	16.53 (1.21)	20.80 (3.47)	16.80 (4.18)
350	15.07 (1.14)	18.60 (3.76)	30.23 (1.40)	14.13 (2.31)	15.60 (0.79)	19.53 (2.91)	18.86 (5.85)

Numbers are means with standard deviations in brackets.

Table 2.23. Total nitrogen (%) 5 to 15 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	0.14 (0.06)	0.26 (0.11)	0.11 (0.09)	0.21 (0.09)	0.12 (0.02)	0.14 (0.05)	0.16 (0.09)
6	0.10 (0.04)	0.14 (0.07)	0.14 (0.07)	0.16 (0.08)	0.28 (0.25)	0.19 (0.14)	0.17 (0.12)
16	0.22 (0.10)	0.13 (0.04)	0.10 (0.01)	0.16 (0.04)	0.28 (0.13)	0.22 (0.06)	0.18 (0.09)
25	0.16 (0.06)	0.20 (0.09)	0.17 (0.10)	0.14 (0.05)	0.11 (0.12)	0.19 (0.08)	0.16 (0.08)
35	0.16 (0.09)	0.21 (0.08)	0.16 (0.06)	0.19 (0.06)	0.15 (0.09)	0.17 (0.07)	0.17 (0.06)
50	0.13 (0.07)	0.28 (0.04)	0.14 (0.11)	0.22 (0.15)	0.17 (0.06)	0.19 (0.10)	0.19 (0.12)
65	0.12 (0.05)	0.24 (0.05)	0.17 (0.07)	0.26 (0.02)	0.18 (0.06)	0.18 (0.05)	0.19 (0.07)
350	0.14 (0.02)	0.15 (0.06)	0.16 (0.04)	0.14 (0.01)	0.29 (0.12)	0.19 (0.05)	0.18 (0.07)

Numbers are means with standard deviations in brackets.

Table 2.24. Organic matter (%) 5 to 15 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	1.88 (0.34)	4.57 (0.32)	1.78 (0.10)	2.50 (0.39)	2.54 (0.45)	2.01 (0.10)	2.55 (1.06)
6	1.97 (0.75)	3.45 (1.25)	1.54 (0.34)	2.89 (0.44)	2.55 (0.30)	2.14 (0.28)	2.42 (0.75)
16	2.42 (1.10)	3.40 (0.44)	1.75 (0.10)	2.57 (0.73)	3.18 (1.23)	2.54 (0.70)	2.64 (0.86)
25	2.57 (0.69)	3.49 (0.39)	1.64 (0.17)	2.88 (0.58)	2.26 (0.09)	2.76 (0.47)	2.60 (0.78)
35	3.08 (0.41)	3.37 (0.44)	2.51 (1.68)	2.93 (1.25)	2.53 (0.46)	2.90 (0.67)	2.89 (0.89)
50	2.31 (1.11)	3.26 (0.73)	2.12 (0.32)	2.14 (0.51)	2.45 (0.38)	3.03 (1.10)	2.55 (0.79)
65	1.83 (0.58)	3.49 (0.58)	2.76 (1.25)	3.74 (1.27)	3.29 (0.87)	2.55 (0.72)	2.94 (1.03)
350	2.30 (0.20)	2.08 (1.25)	3.13 (0.44)	2.42 (0.56)	4.16 (1.87)	2.88 (0.32)	2.83 (1.00)

Numbers are means with standard deviations in brackets.

Table 2.25. Total organic carbon (%) 5 to 15 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	0.94 (0.17)	2.28 (0.16)	0.89 (0.05)	1.25 (0.19)	1.27 (0.23)	1.00 (0.05)	1.27 (0.53)
6	0.99 (0.38)	1.72 (0.63)	0.77 (0.17)	1.45 (0.22)	1.28 (0.15)	1.07 (0.14)	1.21 (0.38)
16	1.21 (0.55)	1.70 (0.22)	0.88 (0.05)	1.28 (0.37)	1.59 (0.61)	1.27 (0.35)	1.32 (0.43)
25	1.28 (0.35)	1.75 (0.19)	0.82 (0.09)	1.44 (0.29)	1.13 (0.05)	1.38 (0.24)	1.30 (0.39)
35	1.54 (0.21)	1.68 (0.22)	1.25 (0.84)	1.47 (0.62)	1.27 (0.23)	1.45 (0.33)	1.44 (0.45)
50	1.16 (0.56)	1.63 (0.37)	1.06 (0.16)	1.07 (0.25)	1.23 (0.19)	1.51 (0.55)	1.28 (0.39)
65	0.91 (0.29)	1.75 (0.29)	1.38 (0.63)	1.87 (0.64)	1.64 (0.43)	1.27 (0.36)	1.47 (0.51)
350	1.15 (0.10)	1.04 (0.62)	1.56 (0.22)	1.21 (0.28)	2.08 (0.94)	1.44 (0.16)	1.41 (0.50)

Numbers are means with standard deviations in brackets.

Table 2.26. Soluble potassium (mg/kg) 5 to 15 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	8.67 (2.08)	23.67 (3.51)	4.00 (0.00)	7.00 (0.00)	7.00 (0.00)	2.67 (0.58)	8.83 (7.27)
6	9.33 (4.93)	10.00 (6.93)	3.00 (1.00)	4.67 (0.58)	4.33 (2.52)	2.33 (0.58)	5.61 (3.78)
16	9.33 (5.03)	14.33 (9.61)	6.00 (3.46)	6.33 (2.31)	4.00 (1.00)	3.00 (2.65)	7.17 (4.62)
25	7.33 (5.86)	12.67 (0.00)	4.33 (3.21)	6.33 (4.04)	5.67 (1.53)	5.00 (4.36)	6.89 (4.44)
35	16.33 (12.34)	12.67 (0.58)	4.00 (2.65)	8.00 (6.24)	5.00 (2.00)	5.33 (4.16)	8.56 (7.19)
50	7.67 (4.04)	10.33 (2.31)	5.33 (3.51)	4.00 (2.65)	4.33 (0.58)	7.67 (8.96)	6.56 (4.36)
65	11.00 (7.94)	13.67 (4.04)	9.00 (6.93)	6.67 (2.31)	7.00 (2.65)	8.00 (5.20)	9.22 (5.28)
350	3.67 (2.52)	3.33 (6.24)	13.67 (9.61)	6.67 (1.53)	4.00 (2.65)	4.33 (3.21)	5.94 (5.30)

Numbers are means with standard deviations in brackets.

Table 2.27. Carbon to nitrogen ratio 5 to 15 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	7.40 (1.80)	9.23 (6.15)	15.37 (15.20)	6.40 (1.64)	10.90 (0.62)	7.80 (2.21)	9.52 (6.20)
6	9.80 (0.82)	14.73 (2.54)	6.60 (2.75)	9.63 (2.83)	7.13 (4.36)	7.50 (3.70)	9.23 (4.72)
16	6.03 (4.01)	17.53 (1.16)	8.83 (1.00)	7.77 (1.69)	7.03 (4.80)	6.40 (2.95)	8.93 (6.32)
25	8.17 (0.78)	8.67 (1.64)	5.70 (2.43)	10.20 (1.95)	25.70 (24.58)	8.10 (2.66)	11.09 (10.97)
35	12.80 (7.98)	7.87 (2.83)	7.50 (2.27)	7.30 (1.71)	9.50 (3.62)	8.63 (1.40)	8.93 (3.79)
50	9.27 (0.81)	7.00 (1.69)	▪50 10.43 (6.15)	6.83 (4.10)	7.77 (2.81)	8.17 (2.80)	8.24 (3.30)
65	8.43 (1.93)	7.57 (1.95)	8.53 (2.54)	6.93 (1.97)	9.83 (4.15)	7.00 (1.51)	8.05 (2.37)
350	8.53 (0.99)	6.93 (1.71)	9.57 (1.16)	8.67 (1.53)	7.53 (3.71)	8.13 (2.66)	8.23 (1.98)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.28. Total inorganic carbon (%) 5 to 15 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland		Overall
0	0.38 (0.26)	0.13 (0.16)	0.41 (0.19)	0.80 (0.22)	0.15 (0.12)	0.48 (0.14)		0.39 (0.28)
6	0.44 (0.10)	0.04 (0.78)	0.27 (0.22)	1.22 (0.39)	0.11 (0.14)	0.03 (0.01)	▪6	0.35 (0.46)
16	0.52 (0.19)	0.03 (0.21)	0.39 (0.44)	1.06 (0.96)	0.02 (0.01)	0.02 (0.01)		0.34 (0.53)
25	0.17 (0.19)	0.03 (0.22)	0.43 (0.37)	0.61 (0.84)	0.04 (0.02)	0.02 (0.01)		0.22 (0.40)
35	0.19 (0.19)	0.03 (0.39)	0.27 (0.43)	0.50 (0.81)	0.03 (0.02)	0.03 (0.01)		0.18 (0.37)
50	0.20 (0.16)	0.04 (0.96)	0.19 (0.16)	0.76 (0.67)	0.02 (0.01)	0.03 (0.01)		0.21 (0.36)
65	0.44 (0.13)	0.04 (0.84)	0.53 (0.78)	0.33 (0.44)	0.02 (0.01)	0.04 (0.02)		0.23 (0.38)
350	0.39 (0.63)	0.21 (0.81)	0.40 (0.21)	0.40 (0.66)	0.02 (0.01)	0.03 (0.01)		0.24 (0.38)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.29. Reaction (pH) 5 to 15 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland		Hill	Highway	McNeil		Remount Lowland		Overall	
0	7.80 (0.17)	7.23 (0.75)		8.03 (0.25)	7.87 (0.23)	7.40 (0.10)		7.87 (0.06)		7.70 (0.33)	
6	7.80 (0.10)	6.57 (0.29)	▪9	7.80 (0.20)	7.90 (0.10)	7.27 (0.35)		7.40 (0.20)	▪14	7.46 (0.50)	
16	7.80 (0.30)	6.40 (0.15)		7.73 (0.15)	7.60 (0.69)	6.83 (0.06)	▪17	6.57 (0.21)		7.16 (0.66)	▪19
25	7.37 (0.25)	6.23 (0.23)		7.57 (0.67)	7.50 (0.66)	7.00 (0.26)		6.70 (0.36)		7.06 (0.62)	
35	7.20 (0.40)	6.20 (0.10)		7.60 (0.61)	7.33 (0.71)	6.80 (0.10)		6.77 (0.31)		6.98 (0.61)	
50	7.43 (0.57)	6.27 (0.69)		7.53 (0.75)	7.70 (0.53)	6.87 (0.21)		7.13 (0.31)		7.16 (0.65)	
65	7.73 (0.15)	6.33 (0.66)		7.57 (0.29)	7.40 (0.52)	6.57 (0.12)		6.73 (0.23)		7.06 (0.62)	
350	7.17 (0.47)	7.00 (0.71)		7.77 (0.15)	7.40 (0.46)	6.60 (0.00)		6.77 (0.06)		7.12 (0.49)	

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.30. Electrical conductivity (dS/m) 5 to 15 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	0.48 (0.03)	0.58 (0.46)	0.65 (0.32)	0.53 (0.06)	0.57 (0.01)	0.49 (0.04)	0.55 (0.13)
6	0.77 (0.59)	0.26 (0.23) ▪6	0.49 (0.21)	0.45 (0.08)	0.39 (0.16) ▪10	0.41 (0.05) ▪15	0.46 (0.27) ▪13
16	0.50 (0.09)	0.27 (0.33)	0.46 (0.11)	0.43 (0.06)	0.23 (0.03)	0.25 (0.04)	0.36 (0.13)
25	0.43 (0.19)	0.28 (0.06)	0.44 (0.30)	0.41 (0.11)	0.30 (0.10)	0.24 (0.02)	0.35 (0.16)
35	0.49 (0.04)	0.26 (0.08)	0.62 (0.58)	0.43 (0.05)	0.28 (0.03)	0.30 (0.01)	0.40 (0.24)
50	0.39 (0.08)	0.22 (0.06)	0.56 (0.46)	0.47 (0.08)	0.29 (0.05)	0.37 (0.06)	0.38 (0.20)
65	0.46 (0.12)	0.27 (0.11)	0.47 (0.23)	0.51 (0.11)	0.25 (0.04)	0.26 (0.05)	0.37 (0.15)
350	0.34 (0.13)	0.33 (0.05)	0.55 (0.33)	0.47 (0.14)	0.19 (0.03)	0.27 (0.03)	0.36 (0.19)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.31. Saturation (%) 5 to 15 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	41.33 (3.51)	64.00 (1.53)	46.00 (3.46)	60.33 (5.51)	50.00 (1.73)	49.00 (3.61)	51.78 (8.73)
6	39.33 (7.51)	57.00 (11.27)	▪6 46.00 (4.00)	61.67 (5.86)	50.67 (1.15)	51.67 (2.31)	51.06 (8.41)
16	41.67 (8.08)	58.67 (3.61)	48.33 (0.58)	60.67 (4.73)	50.33 (1.53)	52.00 (5.29)	51.94 (7.57)
25	46.33 (0.58)	57.00 (5.51)	50.00 (1.73)	62.33 (3.51)	52.67 (3.06)	58.33 (13.05)	54.44 (7.72)
35	52.67 (2.08)	54.33 (5.86)	47.67 (0.58)	58.33 (2.08)	51.33 (3.06)	55.00 (7.81)	53.22 (5.08)
50	44.33 (10.79)	55.00 (4.73)	51.67 (1.53)	51.67 (2.52)	53.00 (2.65)	55.00 (10.15)	51.78 (6.49)
65	43.00 (10.58)	56.33 (3.51)	63.00 (11.27)	61.33 (6.66)	54.67 (8.02)	62.67 (8.02)	56.83 (10.04)
350	50.33 (6.66)	53.00 (2.08)	86.00 (3.61)	60.67 (3.21)	49.67 (2.52)	59.33 (3.21)	59.83 (13.29)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.32. Soluble calcium (mg/kg) 5 to 15 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland		Hill	Highway	McNeil		Remount Lowland		Overall	
0	23.23 (4.13)	46.33 (7.25)		19.73 (7.59)	39.33 (3.74)	35.00 (1.75)		23.43 (1.17)		31.18 (10.52)	
6	40.90 (37.58)	13.60 (11.66)	▪6	21.47 (5.16)	39.67 (5.15)	24.97 (10.99)	▪11	25.77 (5.51)		27.73 (17.03)	
16	26.40 (13.40)	14.77 (20.04)		26.30 (3.73)	35.83 (12.80)	13.53 (2.32)		12.80 (4.85)	▪16	21.61 (11.18)	▪17
25	27.23 (16.30)	14.73 (3.74)		21.03 (8.64)	32.80 (12.95)	20.37 (9.82)		11.83 (4.85)		21.33 (11.35)	
35	29.93 (7.05)	14.83 (5.15)		14.30 (4.45)	32.60 (3.82)	17.43 (2.71)		14.90 (1.65)		20.67 (8.73)	
50	19.40 (6.48)	11.20 (12.80)		16.83 (7.25)	33.00 (9.11)	18.27 (5.16)		19.97 (2.70)		19.78 (8.42)	
65	24.60 (9.80)	14.87 (12.95)		30.40 (11.66)	42.43 (7.80)	13.90 (1.67)		14.30 (3.72)		23.42 (12.47)	
350	22.07 (15.51)	18.47 (3.82)		39.67 (20.04)	35.73 (11.15)	9.60 (1.65)		15.13 (2.92)		23.44 (14.85)	

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.33. Soluble magnesium (mg/kg) 5 to 15 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland		Hill	Highway	McNeil		Remount Lowland		Overall	
0	7.77 (1.89)	12.10 (2.31)		6.23 (2.01)	13.43 (1.76)	12.23 (1.59)		10.70 (0.95)		10.41 (2.96)	
6	13.50 (13.99)	4.27 (4.95)	▪6	7.03 (1.02)	11.43 (1.45)	8.47 (3.89)	▪12	8.73 (1.21)	▪14	8.91 (5.89)	
16	7.70 (3.20)	4.57 (9.93)		9.10 (3.25)	11.43 (3.37)	4.03 (0.75)		5.17 (1.42)		7.00 (3.45)	▪17
25	7.07 (2.63)	4.43 (1.76)		6.50 (2.61)	10.90 (4.16)	5.30 (1.83)		4.90 (2.00)		6.52 (3.11)	
35	9.50 (1.95)	4.53 (1.45)		5.47 (1.43)	9.83 (2.29)	5.07 (0.67)		6.63 (0.40)		6.84 (2.54)	
50	7.40 (5.20)	3.40 (3.37)		6.00 (2.31)	9.13 (2.27)	5.20 (1.41)		7.60 (0.26)		6.46 (2.88)	
65	7.97 (6.04)	4.47 (4.16)		11.40 (4.95)	12.80 (3.86)	3.93 (0.45)		6.03 (1.45)		7.77 (4.61)	
350	7.00 (3.58)	5.97 (2.29)		16.93 (9.93)	11.03 (3.38)	2.87 (0.46)		5.77 (0.65)		8.26 (6.08)	

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.34. Soluble sodium (mg/kg) 5 to 15 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	4.00 (2.00)	3.33 (49.94)	40.00 (44.24)	7.67 (2.89)	4.33 (2.31)	12.00 (5.29)	11.89 (20.31)
6	9.00 (13.00)	2.00 (17.35)	▪9 17.33 (24.83)	2.33 (0.58)	3.67 (1.53)	3.33 (1.53)	6.28 (11.16)
16	4.00 (3.61)	1.00 (14.50)	7.00 (4.58)	2.00 (0.00)	1.67 (0.58)	2.33 (0.58)	▪19 3.00 (2.89)
25	1.33 (0.58)	1.67 (2.89)	13.00 (17.35)	2.00 (0.00)	1.33 (0.58)	3.67 (2.08)	3.83 (7.38)
35	1.67 (0.58)	1.00 (0.58)	41.67 (66.97)	1.67 (0.58)	1.33 (0.58)	2.67 (1.15)	8.33 (27.63)
50	0.67 (0.58)	1.33 (0.00)	32.33 (49.94)	1.67 (0.58)	1.33 (0.58)	2.33 (0.58)	6.61 (20.83)
65	1.33 (0.58)	1.33 (0.00)	13.00 (17.35)	2.67 (1.15)	1.00 (0.00)	2.33 (0.58)	3.61 (7.40)
350	2.33 (0.58)	1.67 (0.58)	23.67 (14.50)	1.67 (0.58)	1.00 (0.00)	2.33 (0.58)	5.44 (9.77)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.35. Soil physical properties for areas of the pipeline right of way areas for 0 to 5 cm and 5 to 15 cm.

	0 to 5 cm					5 to 15 cm		
Area	Sand (%)	Silt (%)		Clay (%)		Sand (%)	Silt (%)	Clay (%)
Storage	44.4 (9.5)	41.9 (8.3)	a	13.6 (2.1)	a	48.0 (11.6)	37.1 (8.9)	14.9 (3.9)
Trench	46.2 (9.9)	38.4 (8.1)	b	15.4 (3.9)	b	45.0 (11.2)	38.5 (8.0)	16.5 (4.7)
Work	45.5 (11.8)	41.0 (9.9)	ab	13.5 (3.0)	a	46.5 (13.2)	38.7 (9.8)	14.8 (4.6)

Numbers are means with standard deviations in brackets.
Different letters within rows denote significant differences between areas of ROW at $p<0.05$.

Table 2.36. Sand (%) 0 to 5 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland		Hill	Highway	McNeil	Remount Lowland	Overall
0	59.4 (5.6)	33.5 (0.2)		51.0 (1.0)	37.0 (4.0)	52.3 (1.5)	44.0 (7.4)	46.2 (9.9)
6	65.4 (8.6)	33.3 (4.6)		48.3 (2.5)	39.5 (8.2)	51.6 (1.8)	38.2 (4.5)	46.1 (11.8)
16	58.9 (3.3)	35.5 (4.3)		47.5 (2.3)	37.1 (3.0)	48.4 (4.3)	35.5 (5.3)	43.8 (9.4)
25	56.9 (6.4)	35.5 (4.0)		50.9 (3.4)	41.7 (6.1)	53.7 (2.2)	37.3 (5.1)	46.0 (9.3)
35	48.3 (6.1)	35.2 (8.2)		50.0 (7.2)	37.0 (4.2)	47.0 (3.8)	35.0 (5.2)	42.1 (7.9)
50	54.8 (21.7)	38.0 (3.0)	▪50	47.7 (0.2)	39.9 (7.6)	53.6 (3.5)	32.7 (2.1)	44.4 (11.7)
65	62.6 (15.4)	36.9 (6.1)		49.3 (4.6)	39.9 (7.7)	53.6 (3.5)	33.5 (5.3)	46.0 (12.3)
350	46.6 (8.7)	39.9 (4.2)		24.2 (4.3)	43.1 (8.9)	50.9 (2.3)	36.3 (3.8)	40.2 (10.0)

Numbers are means with standard deviations in brackets.
▪Significant distance of effect ($p < 0.05$).

Table 2.37. Silt (%) 0 to 5 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland		Hill	Highway	McNeil	Remount Lowland		Overall
0	28.1 (3.9)	50.9 (1.9)		37.3 (2.1)	43.3 (6.8)	34.2 (1.3)	36.6 (4.1)		38.4 (8.1)
6	24.8 (6.3)	51.2 (3.5)		40.7 (3.5)	45.5 (9.2)	34.3 (2.4)	46.6 (3.3)	▪6	40.5 (10.0)
16	28.9 (1.9)	51.0 (1.3)		41.8 (2.9)	46.8 (1.7)	38.5 (3.0)	47.5 (6.4)		42.4 (8.0)
25	31.3 (5.8)	51.8 (6.8)		40.0 (2.6)	43.3 (7.1)	34.3 (3.2)	45.8 (4.2)		41.1 (8.1)
35	37.9 (6.2)	50.7 (9.2)		41.0 (4.6)	47.9 (4.5)	40.5 (2.5)	48.0 (1.4)		44.3 (5.8)
50	34.4 (17.6)	46.3 (1.7)	▪56	39.9 (1.9)	42.9 (7.6)	34.6 (4.2)	48.3 (0.8)		41.1 (8.7)
65	26.8 (10.4)	47.7 (7.1)		39.0 (3.5)	42.7 (7.2)	34.1 (2.9)	47.4 (3.0)		39.6 (9.0)
350	38.0 (4.5)	43.8 (4.5)		42.5 (1.3)	42.7 (8.1)	37.4 (2.6)	47.8 (1.3)		42.0 (5.1)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.38. Clay (%) 0 to 5 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil		Remount Lowland	Overall
0	12.5 (1.9)	15.6 (2.1)	11.7 (1.2)	19.7 (2.9)	13.5 (2.2)		19.4 (3.8)	15.4 (3.9)
6	9.8 (2.4)	15.5 (1.2)	11.0 (1.0)	15.0 (1.0)	14.1 (0.8)		15.2 (1.3)	13.4 (2.6)
16	12.1 (1.6)	13.5 (3.2)	10.7 (0.6)	16.1 (1.4)	13.1 (1.4)		17.0 (1.7)	13.7 (2.5)
25	11.8 (1.1)	12.7 (2.9)	9.1 (1.0)	15.0 (1.0)	12.0 (1.0)	▪25	16.9 (2.0)	12.9 (3.1)
35	13.8 (0.3)	14.1 (1.0)	9.0 (2.6)	15.1 (0.5)	12.5 (1.4)		17.0 (4.0)	13.6 (3.2)
50	10.8 (4.2)	15.7 (1.4)	12.3 (2.1)	17.3 (0.7)	11.8 (1.1)		19.1 (2.5)	14.5 (3.6)
65	10.6 (5.0)	15.3 (1.0)	11.7 (1.2)	17.4 (0.7)	12.3 (0.8)		19.1 (2.7)	14.4 (3.8)
350	15.4 (4.8)	16.3 (0.5)	33.3 (3.2)	14.1 (1.3)	11.7 (0.6)		15.9 (2.7)	17.8 (7.7)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.39. Sand (%) 5 to 15 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland		Hill	Highway	McNeil	Remount Lowland		Overall
0	62.1 (3.1)	32.7 (0.6)		51.0 (5.3)	34.8 (2.7)	50.4 (2.3)	39.3 (6.1)		45.0 (11.2)
6	67.5 (12.6)	33.2 (10.5)		54.0 (2.0)	38.7 (14.2)	52.9 (3.5)	45.5 (5.5)		48.6 (13.5)
16	60.9 (7.5)	35.0 (7.2)	▪22	50.7 (3.1)	33.7 (5.5)	55.5 (0.5)	39.3 (2.3)		45.9 (11.3)
25	56.7 (1.9)	37.2 (2.7)		50.2 (3.4)	36.9 (8.7)	50.7 (2.2)	36.3 (4.0)		44.7 (9.3)
35	51.1 (6.1)	37.1 (14.2)		54.3 (2.9)	40.7 (11.4)	49.3 (6.1)	37.0 (5.6)		44.9 (8.9)
50	62.9 (19.2)	36.0 (5.5)		50.3 (0.6)	46.2 (6.8)	55.3 (2.9)	34.7 (1.5)	▪57	47.6 (12.6)
65	70.5 (18.7)	33.6 (8.7)		42.9 (10.5)	43.7 (7.0)	54.1 (4.3)	33.2 (5.5)		46.3 (15.6)
350	48.5 (13.7)	39.3 (11.4)		25.9 (7.2)	45.0 (12.5)	49.9 (2.1)	33.0 (3.6)		40.3 (11.4)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.40. Silt (%) 5 to 15 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	25.2 (1.5)	49.7 (1.7)	37.5 (4.8)	43.1 (1.2)	36.1 (2.5)	39.1 (3.8)	38.5 (8.0)
6	22.6 (9.2)	49.8 (7.0)	35.5 (1.9)	42.6 (11.1)	33.7 (4.2)	35.8 (2.1)	36.7 (10.1)
16	27.3 (6.5)	48.7 (5.9)	38.8 (1.6)	47.9 (1.3)	31.5 (0.2)	40.3 (2.4)	39.1 (8.4)
25	31.3 (1.2)	45.7 (1.2)	▪25 40.0 (2.9)	45.2 (5.6)	36.5 (2.1)	44.6 (2.6)	▪25 40.5 (6.1)
35	34.6 (3.8)	45.2 (11.1)	35.0 (2.0)	43.1 (9.9)	38.6 (6.6)	42.5 (1.3)	39.8 (6.1)
50	26.5 (14.3)	46.3 (1.3)	37.5 (1.7)	32.7 (7.2)	32.3 (2.6)	44.0 (3.6)	36.6 (9.1)
65	20.0 (13.3)	48.2 (5.6)	43.5 (7.0)	38.3 (7.1)	34.7 (4.4)	42.6 (3.4)	37.9 (11.1)
350	34.7 (9.7)	40.8 (9.9)	36.8 (5.9)	40.6 (11.4)	35.9 (2.7)	44.8 (3.7)	38.9 (6.9)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.41. Clay (%) 5 to 15 cm with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	12.7 (2.2)	17.7 (1.2)	11.5 (0.5)	22.1 (3.4)	13.5 (0.9)	21.5 (2.3)	16.5 (4.7)
6	9.9 (3.4)	17.0 (4.5)	10.5 (0.5)	18.7 (3.4)	13.3 (0.7)	18.7 (3.4)	14.7 (4.3)
16	11.7 (1.0)	16.3 (2.1)	10.5 (1.5)	18.4 (4.3)	13.0 (0.4)	20.4 (2.4)	15.1 (4.1)
25	12.0 (1.0)	17.1 (3.4)	9.8 (0.7)	▪25 17.9 (3.2)	12.9 (0.5)	19.1 (4.3)	14.8 (4.1)
35	14.3 (2.3)	17.7 (3.4)	10.7 (1.5)	16.3 (2.0)	12.1 (0.8)	20.5 (4.3)	15.3 (4.0)
50	10.6 (4.8)	17.7 (4.3)	12.1 (1.2)	21.1 (3.8)	12.5 (0.8)	21.3 (3.8)	15.9 (5.2)
65	9.5 (5.7)	18.2 (3.2)	13.7 (4.5)	18.1 (3.1)	11.1 (0.2)	24.2 (4.2)	15.8 (6.0)
350	16.9 (4.2)	19.9 (2.0)	37.3 (2.1)	14.4 (2.0)	14.1 (0.8)	22.2 (5.0)	20.8 (8.5)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.42. Soil textures found at each site (%).

Texture	Coulee	Coulee Upland	Highway	Hill	McNeil	Remount Lowland
0-5 cm						
Clay Loam	-	-	-	8	-	-
Loam	38	46	79	63	50	88
Loamy Sand	8	-	-	-	-	-
Sandy Loam	54	-	4	25	50	4
Silt Loam	-	54	17	-	-	8
Silty Clay Loam	-	-	-	4	-	-
5-15 cm						
Clay Loam	-	-	-	8	-	8
Loam	17	79	75	42	46	92
Loamy Sand	8	-	-	-	-	-
Sand	4	-	-	-	-	-
Sandy Clay	-	-	4	-	-	-
Sandy Loam	71	-	8	42	54	-
Silt Loam	-	21	13	4	-	-
Silty Clay Loam	-	-	-	4	-	-

Table 2.43. Soil penetration resistance and max depth for areas of the pipeline right of way (site:area interaction).

Site	Area	5 cm (MPa)		10 cm (MPa)		15 cm (MPa)	20 cm (MPa)	Max Depth (cm)	
Coulee	Storage	3.6 (0.8)		4.8 (1.5)		3.8 (0.6)	3.3 (0.2)	14 (5)	
	Trench	3.5 (1.1)		4.2 (2.1)		2.9	4.6	12 (7)	
	Work	3.6 (1.1)		4.3 (0.8)		3.6	3.3	12 (5)	
Coulee Upland	Storage	2.3 (0.4)	a	2.9 (0.3)	a	3.1 (0.2)	3.0 (0.1)	20 (0)	a
	Trench	4.0 (0.7)	b	4.9 (0.2)	b	4.7 (0.3)	-	10 (4)	b
	Work	2.6 (0.2)	a	3.1 (0.2)	a	3.1 (0.1)	3.0 (0.1)	18 (1)	a
Hill	Storage	3.6 (0.6)		4.2		4.9	4.0	10 (5)	ab
	Trench	3.9 (0.7)		3.3 (1.7)		4.6	4.3	9 (3)	a
	Work	3.0 (0.5)		3.3 (0.7)		3.4	3.1 (0.6)	19 (2)	b
Highway	Storage	3.2 (0.6)		4.0 (0.4)		4.0 (0.5)	3.6 (0.6)	10 (4)	
	Trench	3.6 (0.9)		3.1 (0.6)		3.1 (0.3)	3.0	9 (2)	
	Work	2.8 (0.5)		4.2 (0.5)		4.0 (0.3)	3.8 (0.3)	15 (2)	
McNeil	Storage	1.8 (0.0)	a	2.0 (0.1)	a	2.4 (0.1)	2.3 (0.1)	20 (0)	a
	Trench	4.8 (1.0)	b	4.7 (1.0)	b	3.3	-	11 (1)	b
	Work	3.7 (0.5)	b	3.7 (0.1)	b	3.6 (0.1)	3.0 (0.5)	14 (2)	b
Remount Lowland	Storage	3.6 (0.9)		5.0 (1.0)		4.3 (0.7)	4.9 (0.5)	14 (2)	ab
	Trench	3.5 (0.7)		3.9 (1.2)		2.6	5.6	10 (2)	a
	Work	3.1 (0.5)		4.6 (0.7)		4.8 (0.3)	4.6 (0.3)	17 (2)	b

Numbers are means with standard deviations in brackets.

Different letters within columns for ROW areas for a given site denote significant differences at p<0.05.

Table 2.44. Penetration resistance (MPa) at 5 cm depth with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	3.3 (1.1)	4.0 (0.8)	3.9 (0.8)	3.5 (1.2)	4.8 (1.0)	3.5 (0.9)	3.9 (1.1)
3	3.6 (1.2)	3.1 (0.9)	3.9 (1.0)	3.3 (1.1)	3.2 (1.1)	3.6 (0.8)	3.4 (1.0)
6	3.6 (1.8)	2.0 (0.6) ▪6	3.9 (0.7)	2.8 (1.0)	4.0 (0.5)	3.3 (0.7)	3.3 (1.2)
11	3.6 (0.8)	2.6 (0.4)	2.5 (0.6)	2.6 (0.9)	3.6 (0.7)	3.1 (1.0)	3.0 (0.9)
16	3.7 (1.5)	2.5 (0.7)	2.2 (0.5) ▪19	2.6 (1.1)	2.2 (0.2)	2.3 (0.8) ▪16	2.6 (1.0)
21	3.5 (0.6)	1.8 (0.2)	1.6 (0.3)	2.5 (0.9) ▪24	2.0 (0.2) ▪23	2.5 (0.5)	2.3 (0.8) ▪22
25	3.0 (0.6)	2.0 (0.5)	2.0 (0.6)	1.9 (0.7)	1.7 (0.3)	3.0 (0.6)	2.3 (0.8)
30	2.4 (0.3)	2.4 (0.5)	1.7 (0.4)	2.3 (1.0)	1.5 (0.2)	3.1 (1.2)	2.2 (0.8)
35	2.1 (0.5) ▪35	2.8 (1.1)	1.6 (0.3)	2.5 (1.0)	1.8 (0.2)	2.5 (0.5)	2.2 (0.8)
40	2.7 (0.7)	2.4 (0.4)	1.8 (0.4)	2.3 (0.8)	1.7 (0.3)	2.4 (0.6)	2.2 (0.6)
45	2.3 (0.5)	2.7 (0.6)	2.2 (0.8)	1.6 (0.5)	1.6 (0.3)	2.1 (0.3)	2.1 (0.7)
50	2.6 (0.9)	2.6 (0.6)	1.4 (0.3)	2.1 (1.1)	1.6 (0.4)	2.5 (0.6)	2.1 (0.8)
65	2.3 (0.6)	2.8 (0.8)	2.3 (0.7)	2.2 (0.5)	2.0 (0.4)	2.4 (0.5)	2.3 (0.6)
350	2.3 (1.2)	3.7 (1.1)	1.7 (0.2)	1.5 (0.5)	2.1 (0.2)	1.7 (0.3)	2.1 (1.0)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.45. Penetration resistance (MPa) at 10 cm depth with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	4.0 (1.6)	4.9 (0.6)	2.8 (1.4)	3.1 (0.6)	4.5 (0.9)	3.6 (1.3)	4.0 (1.3)
3	3.9 (0.9)	4.0 (0.6)	3.3 (0.7)	4.9 (1.3)	3.2 (1.0)	5.4 (1.4)	4.1 (1.3)
6	4.1 (2.0)	2.8 (0.6) ▪7	4.2 (0.7)	4.4 (0.6)	4.0 (2.6)	5.1 (1.5)	4.1 (1.4)
11	4.8 (0.8)	3.0 (0.4)	3.4 (0.9)	3.7 (0.8)	4.2 (0.7)	4.6 (0.9)	3.9 (1.0)
16	3.2 (1.7)	2.8 (0.9)	2.7 (1.2) ▪19	3.8 (0.8)	2.5 (0.5)	3.7 (1.0) ▪16	3.0 (1.1)
21	4.7 (1.6)	2.2 (0.3)	2.6 (1.1)	3.8 (0.9) ▪24	2.0 (0.3) ▪24	3.4 (0.8)	3.1 (1.3) ▪21
25	4.1 (1.4)	2.2 (0.5)	2.9 (1.3)	3.4 (0.6)	1.8 (0.4)	4.5 (0.7)	3.2 (1.3)
30	3.5 (1.2)	3.3 (0.9)	2.5 (0.6)	3.2 (0.9)	2.1 (0.3)	4.3 (1.4)	3.2 (1.2)
35	3.0 (0.8) ▪35	3.7 (1.3)	2.1 (0.7)	3.6 (1.4)	2.2 (0.4)	4.1 (0.9)	3.1 (1.2)
40	3.6 (0.9)	3.1 (0.7)	2.5 (0.8)	3.9 (0.7)	1.9 (0.4)	3.5 (0.6)	3.1 (1.0)
45	3.4 (0.7)	3.8 (0.7)	2.9 (0.6)	2.7 (0.6)	1.8 (0.4)	2.7 (0.6)	2.9 (0.9)
50	3.5 (1.1)	4.4 (0.6)	2.2 (0.7)	3.2 (0.9)	1.9 (0.5)	3.3 (1.2)	3.1 (1.2)
65	3.5 (0.6)	3.9 (1.0)	3.0 (0.6)	3.1 (0.6)	2.0 (0.3)	3.4 (1.0)	3.2 (0.9)
350	3.7 (1.4)	5.5 (0.8)	2.3 (0.6)	2.5 (0.7)	2.3 (0.3)	2.7 (0.7)	3.0 (1.3)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.46. Penetration resistance (MPa) at 15 cm depth with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	2.9 (0.6)	4.7 (0.6)	4.6	3.1 (0.5)	3.3 (1.5)	2.6	3.6 (1.1)
3	4.3 (0.5)	4.3 (0.5)	2.9 (0.8)	4.7 (0.9)	3.5 (1.2)	5.5 (1.3)	4.0 (1.2)
6	4.6 (1.7)	3.0 (0.6)	4.1 (1.0)	4.1 (0.6)	-	5.4 (1.0)	4.1 (1.2)
11	3.9 (0.4)	3.1 (0.4)	3.4 (0.9)	3.3 (0.6)	5.2 (0.9)	5.0 (0.7)	3.9 (1.1)
16	3.3 (1.9)	2.7 (0.7)	3.3 (1.8)	4.0 (0.6)	3.2 (0.6)	4.1 (0.9)	3.4 (1.2)
21	3.5 (0.9)	2.5 (0.4)	2.5 (1.2)	3.7 (0.9)	2.3 (0.4)	3.7 (0.9)	2.9 (1.0)
25	4.1 (1.3)	2.4 (0.5)	3.0 (1.6)	3.6 (0.9)	2.2 (0.5)	4.5 (0.7)	3.3 (1.3)
30	3.6 (1.0)	3.6 (0.6)	2.9 (0.5)	3.6 (0.4)	2.6 (0.5)	4.3 (1.0)	3.4 (0.9)
35	3.0 (0.6)	3.8 (1.1)	2.4 (0.5)	3.6 (1.3)	2.6 (0.5)	4.2 (0.9)	3.3 (1.1)
40	3.6 (1.6)	3.1 (0.6)	3.1 (1.3)	3.6 (0.8)	2.1 (0.5)	4.1 (0.7)	3.3 (1.2)
45	3.7 (0.7)	3.7 (0.6)	2.6 (0.4)	2.8 (0.5)	2.1 (0.6)	3.1 (0.7)	3.0 (0.8)
50	4.0 (1.1)	4.3 (0.6)	2.8 (0.7)	3.5 (0.6)	2.1 (0.6)	3.2 (1.1)	3.3 (1.1)
65	3.9 (1.1)	3.9 (0.8)	2.7 (0.6)	3.3 (0.6)	2.3 (0.5)	3.8 (0.9)	3.3 (1.0)
350	3.8 (1.3)	4.2 (2.5)	2.8 (0.9)	2.6 (0.6)	2.6 (0.6)	3.2 (0.7)	3.1 (1.1)

Numbers are means with standard deviations in brackets.

Table 2.47. Penetration resistance (MPa) at 20 cm depth with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	4.6 (0.9)	-	4.3	3.0	-	5.6	4.5 (1.0)
3	3.6 (0.5)	5.3 (2.1)	2.8 (0.6)	4.0 (0.3)	3.5 (1.6)	4.6 (2.4)	3.6 (1.3)
6	-	3.1 (0.7)	3.8 (1.1)	4.0 (0.4)	-	5.1 (1.8)	3.8 (1.3)
11	4.1 (0.2)	3.1 (0.3)	2.9 (0.8)	3.3 (0.8)	3.4 (2.0)	5.0 (0.8)	3.6 (1.1)
16	3.7 (1.7)	2.7 (0.5)	3.4 (1.9)	3.8 (0.8)	3.0 (0.5)	4.2 (0.9)	3.4 (1.2)
21	2.8 (1.3)	2.5 (0.4)	2.3 (1.1)	3.2 (0.7)	2.3 (0.3)	3.6 (0.7)	2.8 (0.9)
25	3.8 (1.2)	2.4 (0.4)	2.7 (1.3)	3.5 (1.2)	2.1 (0.6)	4.8 (0.8)	3.2 (1.3)
30	3.5 (0.8)	3.5 (0.7)	2.6 (0.6)	3.6 (0.6)	2.5 (0.4)	4.6 (1.1)	3.4 (1.0)
35	3.0 (0.6)	3.7 (1.1)	2.5 (0.5)	3.5 (1.1)	2.5 (0.2)	4.1 (1.0)	3.2 (1.0)
40	2.7 (1.4)	3.2 (0.9)	3.0 (1.1)	3.5 (0.6)	2.1 (0.4)	4.1 (0.8)	3.1 (1.1)
45	3.7 (0.4)	3.4 (0.5)	2.4 (0.5)	2.9 (0.8)	2.1 (0.5)	3.2 (0.8)	2.9 (0.8)
50	3.7 (1.2)	3.9 (0.8)	2.8 (0.8)	3.5 (0.9)	1.9 (0.8)	3.1 (0.9)	3.1 (1.1)
65	3.8 (1.0)	3.9 (0.7)	2.6 (0.6)	3.2 (0.7)	2.4 (0.4)	3.8 (0.9)	3.3 (0.9)
350	3.5 (0.9)	3.0 (2.9)	3.2 (1.3)	2.1 (0.6)	2.6 (0.7)	3.1 (0.7)	2.9 (1.1)

Numbers are means with standard deviations in brackets.

Table 2.48. Max penetration depth (cm) with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	12 (6)	10 (4)	9 (4)	9 (4)	11 (3)	10 (3)	10 (4)
3	11 (7)	12 (5)	15 (7) ▪5	14 (5)	17 (5)	13 (6)	14 (6)
6	10 (3)	20 (0) ▪7	19 (2)	15 (5)	8 (2)	17 (4) ▪9	15 (5)
11	12 (5)	20 (0)	20 (0)	18 (4)	13 (6)	20 (1)	17 (5)
16	12 (6)	19 (3)	20 (0)	13 (6)	20 (0)	20 (0)	17 (5)
21	16 (5)	20 (0)	20 (0)	16 (5)	20 (0) ▪22	20 (0)	19 (3) ▪21
25	18 (4)	20 (0)	20 (0)	20 (1)	20 (0)	20 (2)	20 (2)
30	19 (2)	20 (0)	20 (0)	20 (0) ▪30	20 (0)	20 (0)	20 (1)
35	20 (0) ▪35	20 (0)	20 (0)	20 (0)	20 (0)	20 (0)	20 (0)
40	20 (1)	20 (0)	20 (0)	20 (0)	20 (0)	20 (1)	20 (1)
45	20 (1)	20 (0)	20 (0)	20 (0)	20 (0)	20 (0)	20 (1)
50	19 (3)	19 (2)	20 (0)	19 (4)	20 (0)	20 (0)	19 (2)
65	20 (2)	20 (0)	20 (0)	20 (0)	20 (0)	20 (0)	20 (1)
350	20 (0)	13 (6)	20 (0)	19 (3)	20 (0)	20 (0)	19 (4)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.49. Ground cover (%) for areas of the pipeline right of way 2012 (site:area interaction).

		Live		Litter		Bare ground	
Coulee	Storage	15 (5)		74 (12)	a	11 (12)	a
	Trench	7 (6)		13 (11)	b	80 (16)	b
	Work	13 (2)		41 (3)	c	45 (3)	c
Coulee Upland	Storage	19 (4)	a	79 (4)	a	2 (2)	
	Trench	9 (1)	b	91 (2)	b	0 (1)	
	Work	14 (2)	ab	77 (7)	a	9 (8)	
Hill	Storage	15 (4)	a	62 (10)		23 (7)	
	Trench	13 (4)	a	32 (18)		55 (22)	
	Work	24 (3)	b	53 (4)		21 (8)	
McNeil	Storage	24 (1)	a	55 (20)		21 (21)	
	Trench	10 (1)	b	47 (1)		43 (2)	
	Work	15 (2)	c	71 (4)		14 (5)	
Remount Lowland	Storage	20 (1)	a	66 (5)	a	13 (5)	b
	Trench	10 (4)	b	38 (10)	b	48 (6)	a
	Work	27 (4)	a	54 (3)	ab	19 (4)	b

Numbers are means with standard deviations in brackets.

Different letters within columns for ROW areas for a given site denote significant differences at $p<0.05$.

Table 2.50. Ground cover (%) for areas of the pipeline right of way 2013.

	Live		Litter		Bare ground	
Storage	18 (5)	a	70 (10)	a	11 (12)	a
Trench	11 (3)	b	58 (25)	b	31 (25)	b
Work	18 (6)	a	67 (15)	ab	14 (15)	ab

Numbers are means with standard deviations in brackets.

Different letters within columns denote significant differences between areas of ROW at $p<0.05$.

Table 2.51. 2012 live vegetation ground cover (%) with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	4.5 (2.1)	8.3 (2.3)	14.3 (6.7)	12.0 (3.0)	6.4 (4.2)	9.3 (4.0)	9.0 (4.8)
1	12.5 (6.6)	8.8 (4.0)	12.1 (6.7)	12.3 (4.5)	13.0 (7.0)	10.5 (4.7)	11.4 (5.5)
2	11.0 (4.8)	9.8 (2.6)	18.5 (8.8)	10.0 (1.7)	11.5 (3.0)	9.7 (2.6)	12.0 (5.5)
3	9.0 (5.5)	12.7 (8.8)	19.5 (9.3) ▪3	21.0 (2.6)	13.5 (7.0)	21.7 (7.2)	16.2 (8.3)
4	7.8 (2.6) ▪4	17.0 (9.8)	20.5 (8.6)	21.3 (1.5)	17.3 (4.4)	30.8 (9.8) ▪4	19.6 (9.7) ▪4
5	10.4 (4.8)	16.7 (10.3) ▪6	18.5 (6.5)	19.0 (3.6)	16.2 (5.7)	33.1 (9.9)	19.2 (10.1)
7	12.4 (3.4)	15.7 (4.8)	22.2 (9.2)	21.7 (4.7) ▪8	17.7 (9.4)	28.8 (12.2)	19.8 (9.4)
9	13.4 (3.1)	19.7 (3.1)	19.7 (8.6)	26.7 (15.9)	26.5 (21.5)	15.2 (6.9)	19.8 (11.7)
11	15.2 (8.3)	17.3 (7.1)	20.0 (5.1)	33.3 (22.4)	16.3 (11.3)	14.0 (4.9)	18.1 (10.3)
13	21.2 (18.1)	20.7 (5.2)	17.7 (6.2)	23.3 (5.0)	17.0 (7.1)	28.5 (20.2)	21.2 (12.3)
15	15.3 (9.1)	17.5 (9.3)	20.2 (10.5)	23.7 (12.7)	20.7 (4.2)	21.0 (10.2)	19.4 (8.9)
20	21.3 (10.8)	13.2 (4.9)	26.8 (6.5)	23.0 (13.0)	31.3 (19.4) ▪20	22.5 (7.7)	23.0 (11.9)
30	25.9 (18.0) ▪30	16.5 (8.9)	18.2 (7.1)	32.3 (21.6)	33.2 (18.2)	26.5 (9.8)	24.8 (14.4) ▪30
40	18.5 (11.8)	23.7 (6.7)	19.3 (8.1)	19.0 (3.6)	31.0 (8.0)	30.4 (11.1)	24.1 (9.9)
50	21.3 (13.7)	23.0 (4.6)	20.5 (6.0)	20.3 (4.5)	14.7 (7.3)	27.0 (12.7)	21.2 (9.4)
100	22.2 (4.8)	20.7 (9.2)	25.4 (10.5)	24.0 (14.0)	28.7 (11.6)	27.0 (8.9)	24.8 (9.4)
150	24.8 (11.0)	21.0 (14.5)	18.0 (4.3)	28.0 (14.7)	24.5 (14.3)	31.0 (16.1)	24.6 (13.0)
200	18.1 (5.8)	25.2 (5.8)	27.0 (6.1)	20.7 (6.0)	26.7 (11.3)	23.6 (10.7)	23.7 (8.3)
250	23.0 (15.3)	15.3 (4.5)	18.7 (4.0)	19.0 (2.6)	16.6 (1.7)	24.0 (9.7)	19.4 (8.3)
300	29.8 (14.7)	16.5 (6.7)	22.7 (12.0)	31.0 (1.7)	21.3 (10.6)	28.3 (16.2)	24.4 (12.0)
350	16.0 (5.3)	20.7 (10.1)	20.3 (3.5)	23.7 (10.8)	21.3 (9.0)	20.2 (5.7)	20.0 (7.3)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.52. 2012 litter cover (%) with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	25.5 (13.4)	91.2 (2.8)	11.0 (5.2)	14.7 (10.1)	47.8 (46.0)	35.0 (27.2)	39.7 (36.7)
1	15.8 (8.9)	90.7 (5.1)	43.1 (27.8)	36.3 (27.4)	46.0 (38.1)	39.5 (27.4)	48.0 (33.1)
2	32.8 (29.5)	88.5 (4.1)	32.7 (16.4)	16.3 (17.1)	68.5 (34.1)	57.4 (32.1)	53.6 (33.1)
3	30.3 (25.2)	83.7 (10.2)	56.8 (37.9)	69.7 (5.0) ▪3	66.2 (32.7)	68.8 (7.0) ▪3	64.0 (27.5)
4	18.0 (4.3)	79.2 (12.0)	60.0 (15.3) ▪4	44.0 (28.9)	80.7 (4.1)	60.8 (13.5)	60.9 (23.9) ▪4
5	38.4 (37.2)	56.3 (28.6) ▪5	59.7 (17.2)	63.5 (11.5)	59.0 (29.0)	63.4 (9.8)	56.7 (24.3)
7	46.0 (27.7)	73.8 (21.7)	67.3 (8.3)	25.7 (31.5)	72.8 (13.0)	49.3 (22.8)	59.0 (24.6)
9	52.1 (26.1) ▪10	77.2 (4.4)	68.8 (11.4)	54.3 (3.2)	65.5 (19.8)	41.6 (36.0)	60.7 (23.2)
11	57.2 (29.0)	82.0 (7.4)	62.5 (20.8)	47.7 (20.3)	75.2 (14.8)	68.0 (27.8)	67.0 (22.4)
13	65.8 (25.6)	75.3 (5.5)	46.8 (22.7)	40.2 (22.5)	63.8 (25.8)	49.1 (25.2)	58.3 (23.8)
15	52.3 (36.6)	81.4 (9.8)	72.3 (10.6)	59.3 (11.2)	52.5 (23.9)	71.8 (9.5)	65.5 (22.0)
20	50.1 (32.1)	86.3 (4.4)	67.5 (6.5)	67.3 (7.2)	65.7 (18.0)	70.4 (7.2)	67.9 (18.9)
30	51.0 (27.3)	82.2 (9.2)	67.0 (20.4)	58.3 (20.8)	65.0 (19.5)	69.1 (7.5)	66.1 (19.7)
40	47.3 (33.3)	74.8 (6.0)	72.5 (11.0)	38.7 (30.7)	67.0 (8.4)	66.0 (12.9)	63.1 (21.0)
50	66.8 (10.6)	74.8 (7.0)	74.0 (6.9)	66.3 (2.1)	82.0 (5.8)	68.6 (12.3)	72.6 (9.6)
100	70.8 (4.4)	68.5 (15.2)	63.0 (8.8)	71.7 (15.0)	70.3 (12.4)	68.2 (10.0)	68.6 (10.8)
150	71.2 (13.0)	69.5 (13.2)	73.5 (6.1)	56.3 (6.1)	66.8 (17.7)	63.7 (14.9)	67.3 (13.3)
200	61.0 (26.1)	62.0 (15.2)	68.0 (7.0)	62.0 (14.8)	70.8 (11.8)	65.7 (30.8)	65.0 (19.1)
250	66.8 (18.9)	78.3 (3.9)	79.5 (5.9)	71.7 (3.1)	80.6 (2.6)	73.3 (10.3)	75.2 (10.1)
300	58.8 (19.6)	64.7 (23.1)	67.5 (9.7)	57.5 (9.0)	63.6 (8.9)	66.4 (13.4)	63.3 (14.9)
350	70.2 (9.6)	69.8 (12.8)	76.7 (4.7)	59.7 (18.9)	75.3 (9.5)	70.9 (17.4)	70.4 (12.9)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.53. 2012 bare ground cover (%) with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	70.0 (11.3)	0.3 (0.6)	74.7 (6.4)	73.3 (7.6)	45.4 (49.8)	55.3 (30.7)	51.2 (37.3)
1	71.8 (14.9)	0.5 (1.2)	44.8 (31.2)	51.0 (30.3)	41.0 (45.1)	44.8 (29.3)	39.6 (34.6)
2	56.1 (33.1)	1.7 (3.6)	48.8 (20.1)	73.2 (15.8)	19.7 (33.9)	32.2 (30.3)	34.1 (32.5)
3	56.0 (18.4)	3.7 (8.0)	23.7 (34.9)	9.3 (2.9)	20.3 (34.3)	8.0 (8.4) ▪3	18.9 (26.9) ▪3
4	72.3 (2.1)	3.2 (5.2)	19.3 (14.7) ▪4	34.3 (30.2)	2.0 (2.1) ▪4	8.5 (12.7)	19.0 (25.7)
5	51.2 (36.7)	26.8 (35.4)	21.7 (20.1)	16.7 (12.7) ▪5	24.8 (29.8)	2.6 (1.7)	23.8 (28.5)
7	38.8 (28.2)	10.5 (25.2)	10.4 (8.4)	50.5 (28.8)	9.5 (6.9)	21.3 (11.5)	20.5 (22.4)
9	34.0 (29.2)	3.0 (3.5)	11.3 (8.5)	16.3 (9.1)	7.3 (8.5)	43.2 (39.3)	19.0 (25.0)
11	19.3 (36.1) ▪11	0.7 (1.0)	10.2 (12.8)	17.3 (22.4)	8.5 (6.2)	18.0 (27.8)	11.9 (20.8)
13	13.0 (25.7)	4.0 (9.8)	35.0 (19.9)	35.3 (25.7)	19.3 (28.3)	9.9 (7.7)	18.0 (22.2)
15	32.3 (38.8)	0.8 (2.0)	7.3 (9.9)	9.7 (8.7)	26.6 (25.0)	6.1 (4.3)	14.2 (22.5)
20	27.3 (31.2)	0.3 (0.8)	4.3 (3.8)	6.2 (5.3)	2.0 (1.9)	7.0 (6.9)	8.0 (16.0) ▪22
30	22.0 (28.5)	1.3 (1.5)	10.3 (16.7)	5.7 (6.7)	0.7 (1.0)	3.4 (5.8)	7.4 (15.5)
40	33.3 (40.1)	0.7 (0.8)	4.8 (5.2)	38.7 (32.5)	1.7 (1.5)	2.2 (1.6)	11.3 (23.4)
50	10.3 (11.9)	1.7 (2.9)	2.8 (1.7)	7.3 (5.9)	3.2 (3.7)	3.7 (3.5)	4.6 (6.3)
100	4.7 (1.2)	10.7 (18.9)	8.6 (15.0)	3.3 (0.6)	0.5 (0.5)	4.7 (2.9)	5.5 (10.2)
150	4.0 (2.5)	3.7 (3.6)	5.0 (5.3)	13.3 (8.1)	4.3 (3.4)	5.3 (3.0)	5.3 (4.7)
200	15.2 (25.1)	6.8 (9.0)	2.3 (3.2)	10.0 (4.4)	1.0 (2.0)	10.8 (23.0)	7.7 (15.1)
250	2.2 (2.5)	4.0 (4.5)	1.7 (2.1)	4.3 (3.2)	2.5 (1.9)	2.7 (3.9)	2.9 (3.1)
300	4.0 (3.4)	16.2 (19.7)	9.7 (11.9)	8.3 (7.8)	10.0 (11.5)	3.9 (5.2)	8.8 (11.6)
350	4.2 (2.7)	2.9 (2.9)	1.7 (1.5)	12.7 (7.5)	2.5 (2.8)	1.5 (1.9)	3.8 (4.5)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.54. 2013 live vegetation ground cover (%) with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	8.0 (2.8)	11.8 (2.3)	16.8 (7.3)	16.0 (8.5)	8.2 (3.0)	17.3 (4.2)	12.6 (5.9)
1	6.8 (1.7)	12.7 (4.9)	9.8 (4.1)	14.0 (1.0)	9.3 (2.4)	10.2 (4.4)	10.4 (4.0)
2	10.3 (4.6)	12.5 (3.3)	10.5 (3.1)	13.0 (1.7)	13.0 (3.2)	13.7 (3.7)	12.2 (3.4)
3	8.0 (2.2)	14.3 (5.4)	16.4 (6.6)	27.0 (16.7) ▪3	13.7 (4.0)	15.0 (4.7)	15.1 (7.7)
4	9.0 (3.4)	24.8 (3.3)	19.3 (14.3) ▪4	23.7 (10.1)	19.5 (10.5)	36.7 (15.8)	22.9 (13.2)
5	10.4 (2.5)	18.0 (9.0)	17.7 (13.3)	26.0 (4.4)	18.3 (8.0)	23.2 (8.4)	18.5 (9.3)
7	10.0 (2.4)	17.2 (3.3)	16.7 (9.1)	24.7 (8.1)	17.3 (13.0)	32.0 (20.8)	19.5 (13.0)
9	16.8 (11.9)	20.0 (5.4)	13.8 (5.9)	30.0 (18.0)	19.2 (10.6)	25.2 (15.8)	20.1 (11.5)
11	18.2 (8.8)	18.1 (8.1)	12.7 (4.2)	29.3 (12.1)	16.0 (7.0)	18.2 (7.3)	17.8 (8.2)
13	11.3 (4.8)	17.8 (3.3)	13.2 (6.9)	26.0 (17.1)	19.8 (6.0)	14.8 (9.6)	16.4 (8.3)
15	12.8 (4.2)	16.5 (2.7)	18.7 (9.9)	23.0 (16.6)	21.0 (10.3)	27.8 (20.6)	19.7 (12.0)
20	14.3 (6.5)	16.8 (2.2)	19.0 (10.5)	15.7 (7.2)	18.5 (6.6)	14.7 (11.1)	16.6 (7.6)
30	20.2 (5.1) ▪26	19.8 (8.0)	15.8 (7.0)	22.7 (2.5)	42.7 (24.7)	25.7 (15.1)	24.6 (15.4)
40	17.5 (7.1)	24.2 (6.6)	16.8 (8.7)	17.0 (5.6)	38.5 (26.8)	36.5 (14.7)	25.8 (16.2)
50	16.2 (7.7)	28.8 (17.7) ▪50	13.3 (5.5)	19.0 (9.6)	21.7 (9.4) ▪81	30.0 (19.6)	21.7 (13.6) ▪68
100	18.8 (5.1)	25.3 (10.0)	22.8 (9.7)	17.7 (7.5)	62.5 (31.2)	36.2 (13.4)	32.4 (22.2)
150	14.4 (3.8)	25.5 (13.9)	21.0 (9.8)	23.7 (2.3)	26.0 (13.9)	26.3 (13.8)	23.1 (11.4)
200	21.4 (13.1)	19.5 (7.2)	27.7 (19.1)	25.7 (2.1)	33.3 (16.8)	18.4 (6.7)	23.9 (12.3)
250	25.6 (16.4)	21.1 (5.1)	18.0 (7.0)	22.0 (5.6)	26.0 (10.6)	19.2 (7.0)	22.3 (9.3)
300	18.8 (4.0)	16.5 (5.8)	22.3 (9.3)	30.3 (10.0)	37.0 (26.4)	20.0 (4.8)	23.9 (14.5)
350	16.8 (2.7)	28.8 (10.6)	24.3 (2.5)	24.7 (7.0)	18.7 (3.8)	24.5 (8.6)	23.3 (7.9)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.55. 2013 litter cover (%) with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	63.0 (24.0)	85.8 (4.8)	11.7 (11.5)	36.7 (30.6)	74.3 (22.5)	69.7 (6.5)	59.2 (30.4)
1	46.3 (38.2)	87.0 (5.6)	45.2 (33.5)	42.7 (30.3)	73.7 (27.3)	37.5 (25.4)	57.2 (31.7)
2	50.0 (28.2)	87.0 (3.0)	49.8 (22.6)	23.7 (18.5)	85.0 (7.3)	44.2 (32.0)	60.2 (29.2)
3	53.3 (24.9)	80.8 (3.2)	64.7 (24.8) ▪3	62.0 (13.7)	84.9 (5.1)	73.2 (15.1)	71.6 (18.4)
4	35.5 (31.5)	73.0 (5.4) ▪4	72.1 (18.3)	29.3 (26.6)	78.0 (9.7)	59.1 (12.4)	62.0 (23.4)
5	60.9 (29.0)	76.5 (7.3)	71.8 (13.8)	41.8 (26.8)	73.7 (14.8)	67.7 (13.8)	67.8 (18.9) ▪5
7	39.7 (28.6)	71.5 (25.9)	76.8 (11.7)	47.0 (22.0)	81.2 (13.8)	59.2 (20.2)	64.7 (24.3)
9	67.2 (17.7)	79.7 (5.9)	69.5 (29.8)	54.5 (15.3)	72.5 (15.4)	60.3 (15.3)	68.5 (18.4)
11	57.9 (19.5)	81.7 (8.2)	79.8 (7.2)	34.8 (17.4)	74.3 (17.5)	75.3 (11.4) ▪11	70.3 (19.0)
13	64.5 (31.4)	82.2 (3.3)	48.2 (37.7)	38.3 (15.6)	74.2 (5.2)	68.9 (24.3)	64.9 (26.1)
15	64.3 (25.5)	83.0 (3.2)	73.0 (10.4)	69.0 (9.7)	76.9 (10.6)	69.1 (19.5)	72.9 (15.6)
20	55.3 (32.3)	82.4 (2.4)	69.4 (17.8)	78.7 (6.4) ▪22	78.7 (8.8)	82.0 (12.6)	74.0 (18.8)
30	38.3 (30.5)	78.4 (10.0)	70.3 (8.1)	69.7 (7.3)	54.9 (26.1)	73.4 (15.7)	63.7 (22.9)
40	55.9 (28.2)	73.1 (5.2)	74.8 (10.2)	64.8 (3.5)	60.7 (26.4)	61.3 (12.3)	65.1 (18.2)
50	65.6 (17.7)	70.1 (17.8)	80.8 (7.1)	75.5 (9.7)	76.3 (9.4) ▪99	69.0 (19.2)	72.6 (14.6)
100	71.4 (5.0) ▪100	71.9 (8.9)	65.0 (16.2)	80.2 (9.3)	35.5 (31.1)	63.3 (13.6)	62.8 (21.4)
150	68.6 (36.9)	68.1 (10.5)	77.4 (11.7)	70.5 (2.5)	69.8 (14.2)	73.2 (13.8)	71.0 (17.3)
200	71.5 (8.2)	70.8 (10.4)	65.8 (26.1)	36.5 (30.9)	62.5 (15.6)	80.2 (5.6)	67.1 (18.5)
250	61.8 (11.4)	72.5 (8.5)	81.3 (6.4)	57.5 (26.2)	63.6 (32.1)	78.8 (7.1)	69.5 (18.6)
300	71.8 (9.7)	71.8 (9.4)	67.0 (11.1)	59.0 (9.5)	51.5 (23.5)	73.2 (8.2)	66.1 (15.2)
350	66.8 (15.6)	65.2 (11.1)	73.3 (6.4)	67.3 (6.7)	69.3 (15.0)	69.8 (14.4)	68.2 (11.7)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.56. 2013 bare ground cover (%) with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	27.5 (24.7)	2.3 (4.0)	71.5 (11.8)	47.2 (33.6)	16.7 (21.8)	12.0 (6.9)	27.7 (29.0)
1	47.0 (37.7)	0.3 (0.8)	45.0 (35.3)	42.0 (31.8)	16.3 (29.1)	49.2 (25.7)	31.6 (32.4)
2	39.8 (32.2)	0.5 (0.8)	39.0 (25.2)	63.0 (19.9)	1.0 (2.4)	42.1 (29.7)	27.2 (29.8)
3	35.6 (30.2)	3.2 (6.0)	18.6 (24.0)	11.0 (3.0)	0.3 (0.8)	7.5 (11.8)	11.4 (18.6)
4	38.3 (34.5)	2.2 (4.4)	7.2 (6.7) ▪4	47.0 (28.8)	1.8 (2.1)	2.2 (3.2) ▪4	12.1 (21.6) ▪4
5	27.2 (28.1)	5.2 (7.9)	5.3 (5.0)	31.7 (30.5)	8.0 (11.9)	6.5 (6.3)	11.9 (17.5)
7	49.8 (28.1)	11.3 (27.8)	5.2 (4.2)	27.5 (14.9)	1.5 (1.8)	7.3 (4.3)	15.1 (22.9)
9	11.6 (6.8) ▪9	0.3 (0.8)	15.2 (29.4)	14.3 (13.1)	6.8 (9.4)	6.7 (6.8)	8.6 (14.3)
11	17.7 (15.4)	0.2 (0.4)	4.5 (5.5)	31.3 (28.0)	8.5 (12.2)	3.8 (4.5)	9.2 (14.2)
13	23.6 (30.6)	0.0 (0.0)	38.0 (34.1)	32.2 (30.8)	5.5 (6.0)	13.8 (23.6)	17.6 (25.9)
15	20.7 (27.2)	0.3 (0.8)	7.0 (7.7)	6.0 (5.3) ▪18	1.3 (2.3)	1.6 (1.5)	6.2 (13.5)
20	30.1 (34.6)	0.6 (1.4)	7.2 (12.6)	3.7 (4.0)	1.5 (3.2)	1.7 (1.9)	7.8 (18.3)
30	40.1 (35.8)	1.5 (2.5)	7.7 (13.1)	6.0 (9.5)	0.7 (1.0)	0.7 (1.0)	9.7 (21.3)
40	24.2 (32.3)	1.9 (2.4)	2.0 (2.4)	14.7 (11.2)	0.5 (0.8)	0.7 (1.2)	6.7 (16.1)
50	16.4 (21.4)	0.8 (1.3)	2.8 (2.6)	2.0 (2.6)	1.0 (1.3)	0.3 (0.5)	4.1 (10.4)
100	5.6 (3.2)	2.3 (2.3)	9.8 (19.8)	0.8 (1.0)	0.2 (0.4)	0.0 (0.0)	3.0 (8.2)
150	16.4 (36.7)	3.8 (4.4)	1.3 (2.5)	4.7 (2.5)	1.2 (2.0)	0.5 (0.8)	4.5 (14.9)
200	2.4 (3.3)	4.8 (4.2)	0.0 (0.0)	36.5 (29.6)	2.9 (6.0)	0.3 (0.5)	5.9 (13.7)
250	7.4 (11.3)	4.8 (6.7)	0.7 (1.2)	17.5 (27.3)	10.0 (24.0)	0.8 (2.0)	6.4 (14.5)
300	5.0 (5.2)	8.8 (5.8)	10.2 (14.6)	4.0 (4.0)	4.5 (5.5)	3.5 (4.8)	5.8 (6.5)
350	5.0 (4.1)	2.8 (3.0)	0.0 (0.0)	3.7 (1.2)	0.0 (0.0)	0.8 (2.0)	2.2 (3.0)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.57. Native species cover (%) for areas of the pipeline right of way 2012 (site:area interaction).

Site	Area	Native	
Coulee	Storage	32 (18)	
	Trench	7 (6)	
	Work	13 (2)	
Coulee Upland	Storage	23 (5)	a
	Trench	12 (2)	b
	Work	18 (1)	ab
Hill	Storage	20 (7)	
	Trench	24 (9)	
	Work	32 (4)	
McNeil	Storage	27 (1)	a
	Trench	13 (2)	b
	Work	19 (2)	c
Remount Lowland	Storage	25 (5)	a
	Trench	13 (4)	a
	Work	40 (6)	b

Numbers are means with standard deviations in brackets.

Different letters within columns for ROW areas for a given site denote significant differences at $p<0.05$.

Table 2.58. Non native and native species cover (%) for areas of the pipeline right of way 2012 and 2013.

	2012	2013		
Area	Non Native	Native		Non Native
Storage	0.6 (1.0)	24 (8)	a	2 (6)
Trench	0.3 (0.5)	15 (6)	b	2 (5)
Work	0.2 (0.4)	24 (7)	a	1 (2)

Numbers are means with standard deviations in brackets.

Different letters within columns denote significant differences between areas of ROW at $p<0.05$.

Table 2.59. 2012 native species cover (%) with distance from pipeline centre.

Distance (m)	Coulee		Coulee Upland		Hill	Highway		McNeil		Remount Lowland		Overall	
0	7.5 (1.4)		11.8 (3.0)		33.5 (29.0)	13.0 (4.4)		9.0 (5.0)		14.4 (5.6)		14.4 (13.2)	
1	12.0 (7.8)		11.9 (4.5)		19.1 (11.9)	13.7 (4.8)		16.3 (7.3)		12.6 (4.6)		14.5 (7.4)	
2	13.4 (4.8)		13.5 (3.5)		23.5 (9.3)	14.3 (4.0)		15.3 (3.2)		15.3 (3.3)		16.2 (6.1)	
3	11.8 (7.0)		16.1 (10.6)		24.2 (9.3)	29.7 (8.3)		18.7 (7.6)		30.6 (10.8)		21.7 (10.8)	
4	10.3 (3.7)		23.5 (12.3)		27.4 (13.0)	23.0 (3.0)		22.9 (5.5)		43.0 (15.2)	▪4	26.2 (13.9)	▪4
5	14.2 (9.7)		20.7 (11.2)		25.6 (9.9)	22.8 (5.8)		21.6 (7.5)		38.6 (12.3)		24.3 (12.0)	
7	13.8 (5.0)		19.5 (4.3)		27.9 (9.6)	28.2 (9.5)	▪8	21.3 (10.1)		39.0 (11.6)		25.0 (11.6)	
9	17.5 (8.5)		26.7 (6.9)		26.0 (11.8)	31.2 (18.7)		25.9 (22.7)		20.0 (13.0)		24.1 (13.8)	
11	19.8 (11.5)		19.2 (7.2)		25.4 (10.1)	44.3 (32.4)		24.9 (16.5)		30.3 (37.0)		25.8 (20.4)	
13	26.6 (19.7)		22.7 (6.7)		21.9 (9.7)	30.7 (6.1)		20.3 (8.4)		39.5 (16.6)		26.6 (13.7)	
15	20.9 (8.6)		18.8 (8.5)		29.2 (23.6)	27.0 (14.6)		23.3 (6.1)		29.4 (18.9)		24.6 (14.3)	
20	24.9 (14.1)	▪21	19.8 (5.7)		24.9 (11.8)	25.3 (16.6)		30.7 (16.6)	▪25	33.4 (10.3)		26.6 (12.5)	
30	29.2 (11.6)		26.9 (13.5)	▪35	24.3 (10.4)	39.2 (16.0)		38.3 (19.3)		37.3 (15.7)		31.9 (14.6)	
40	27.5 (16.1)		27.6 (9.0)		27.8 (13.5)	23.7 (4.0)		39.4 (11.8)		40.1 (11.4)		31.7 (12.8)	
50	24.5 (13.5)		26.6 (4.9)		26.2 (7.6)	34.7 (8.5)		20.9 (9.6)		36.6 (16.4)		27.7 (11.5)	
100	28.1 (4.4)		29.8 (11.0)		35.8 (12.6)	28.5 (15.2)		32.8 (12.5)		39.9 (9.3)		32.9 (10.9)	▪68
150	32.8 (15.4)		25.8 (13.2)		23.8 (5.7)	40.0 (32.6)		32.4 (12.3)		41.3 (19.3)		32.5 (16.5)	
200	25.0 (7.3)		30.3 (6.5)		34.8 (4.3)	25.0 (6.2)		26.8 (11.2)		32.8 (13.6)		29.1 (9.3)	
250	31.4 (16.1)		22.6 (4.5)		22.8 (9.2)	22.2 (1.6)		22.8 (9.7)		34.3 (7.2)		26.6 (10.0)	
300	33.6 (15.2)		18.9 (4.1)		24.8 (9.3)	44.7 (8.5)		27.4 (12.2)		32.3 (17.4)		29.2 (13.6)	
350	21.6 (7.1)		25.8 (11.8)		23.2 (4.3)	31.8 (9.7)		25.5 (9.7)		30.8 (10.5)		26.5 (9.4)	

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.60. 2012 non native species cover (%) with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	0.0 (0.0)	0.0 (0.0)	0.5 (0.9)	4.5 (7.8)	0.0 (0.0)	0.0 (0.0)	0.8 (3.0)
1	1.5 (2.4)	0.3 (0.6)	0.3 (0.8)	1.0 (1.7)	0.0 (0.0)	0.0 (0.0)	0.4 (1.1)
2	0.9 (1.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.2)	0.1 (0.5)
3	0.5 (1.0)	1.5 (2.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.4 (1.2)
4	0.0 (0.0)	0.2 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.1)
5	0.4 (0.9)	1.1 (1.3)	0.0 (0.0)	0.0 (0.0)	0.2 (0.4)	0.0 (0.0)	0.3 (0.7)
7	0.0 (0.0)	0.1 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.1)
9	0.6 (0.8)	0.0 (0.0)	0.5 (1.2)	0.0 (0.0)	0.0 (0.0)	2.0 (4.9)	0.6 (2.2)
11	0.6 (1.0)	1.9 (4.0)	3.0 (5.6)	0.0 (0.0)	0.0 (0.0)	2.8 (4.5)	1.5 (3.5)
13	0.0 (0.0)	1.3 (2.6)	0.3 (0.8)	0.0 (0.0)	1.5 (3.7)	0.0 (0.0)	0.6 (1.9)
15	0.3 (0.8)	4.2 (8.4)	0.0 (0.0)	0.0 (0.0)	2.0 (4.0) ▪15	1.7 (4.1)	1.5 (4.3)
20	0.0 (0.0)	0.7 (1.6)	5.9 (13.8)	0.8 (1.4)	2.8 (6.9)	4.2 (10.2)	2.5 (7.7)
30	0.0 (0.0)	0.0 (0.0)	0.2 (0.4)	6.0 (10.4)	0.3 (0.6)	0.0 (0.0)	0.6 (3.1)
40	0.0 (0.0)	0.1 (0.2)	0.2 (0.4)	0.2 (0.3)	0.7 (1.4)	0.0 (0.0)	0.2 (0.6)
50	0.0 (0.0)	0.1 (0.2)	0.0 (0.0)	0.0 (0.0)	0.3 (0.6)	0.0 (0.0)	0.1 (0.3)
100	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.3 (1.0)	0.0 (0.0)	0.2 (0.6)
150	0.4 (0.9)	0.0 (0.0)	0.1 (0.3)	0.0 (0.0)	1.0 (2.0)	0.0 (0.0)	0.3 (1.0)
200	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.6 (5.2)	0.0 (0.0)	0.5 (2.4)
250	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
300	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.7 (1.6)	1.3 (3.3)	0.4 (1.6)
350	0.0 (0.0)	0.0 (0.0)	0.3 (0.6)	0.0 (0.0)	0.2 (0.3)	0.0 (0.0)	0.1 (0.2)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.61. 2013 native species cover (%) with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	10.8 (6.0)	14.8 (2.7)	32.8 (11.1)	16.2 (6.4)	12.8 (5.3)	26.0 (12.1)	18.4 (10.2)
1	8.5 (2.4)	14.8 (5.5)	16.3 (6.3)	16.3 (3.0)	16.5 (5.9)	14.1 (5.5)	14.6 (5.5)
2	13.0 (6.9)	14.2 (5.0)	18.0 (2.4)	18.5 (3.3)	20.2 (10.4)	21.4 (7.3)	17.7 (6.9)
3	10.4 (4.4)	16.6 (7.7)	23.7 (10.8)	32.2 (19.1) ▪3	19.4 (9.4)	20.6 (6.2)	20.0 (10.5)
4	11.6 (5.0)	29.4 (5.3)	28.3 (14.7)	26.9 (9.6)	27.7 (14.1)	45.8 (17.6) ▪4	29.5 (15.2) ▪4
5	19.0 (10.9)	19.4 (7.7)	24.3 (13.0)	30.3 (5.9)	29.8 (13.8)	32.0 (8.4)	25.6 (11.2)
7	14.3 (2.9)	23.6 (7.4)	27.2 (9.4)	28.0 (8.2)	32.1 (15.3)	45.3 (19.1)	28.9 (14.8)
9	18.7 (12.9)	25.3 (7.2)	18.3 (6.0)	33.2 (18.2)	29.0 (18.6)	34.1 (16.1)	26.0 (13.9)
11	25.3 (5.0)	21.7 (8.8)	18.7 (6.7)	32.5 (11.8)	26.3 (14.4)	24.8 (17.2)	24.2 (11.2)
13	15.2 (4.9)	21.4 (6.4)	19.2 (5.3)	29.3 (17.7)	27.0 (9.2)	31.3 (9.8)	23.4 (9.8)
15	17.3 (1.5)	20.0 (4.8)	29.8 (10.5)	28.0 (19.9)	26.3 (11.7)	37.0 (15.5)	26.3 (12.3)
20	17.4 (8.2) ▪29	22.0 (3.0)	23.3 (9.9)	18.3 (8.4)	25.3 (10.1)	27.4 (20.8)	22.6 (11.3)
30	26.8 (8.2)	25.9 (9.4)	21.3 (4.8)	24.3 (2.6)	45.6 (18.8)	32.3 (13.6)	29.8 (13.5)
40	28.3 (18.6)	32.8 (7.2) ▪40	21.9 (8.4)	20.0 (6.7)	47.3 (31.6)	43.3 (13.4)	33.4 (19.0)
50	21.6 (6.9)	34.0 (19.0)	19.3 (3.6)	21.8 (9.8)	31.8 (8.3) ▪89	36.7 (19.2)	28.1 (13.8)
100	23.0 (5.6)	30.2 (11.0)	27.6 (11.3)	22.2 (8.0)	80.0 (37.0)	43.3 (13.8)	40.0 (27.4)
150	18.1 (3.1)	29.2 (14.1)	25.8 (11.5)	27.3 (0.8)	32.2 (13.6)	38.8 (14.6)	29.2 (12.8)
200	25.9 (13.7)	23.7 (6.1)	37.3 (17.2)	29.3 (5.1)	42.6 (20.8)	30.5 (6.2)	31.4 (13.8)
250	33.3 (20.9)	25.3 (6.3)	22.0 (6.7)	24.7 (5.5)	37.8 (22.8)	27.0 (9.0)	29.2 (14.6)
300	23.0 (4.6)	23.0 (6.5)	25.8 (9.0)	36.0 (11.8)	45.2 (25.6)	25.8 (3.9)	29.8 (15.0)
350	20.3 (2.9)	36.6 (11.6)	38.3 (17.1)	26.7 (7.3)	32.0 (10.6)	31.2 (8.8)	30.7 (10.9)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.62. 2013 non native species cover (%) with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	1.0 (1.4)	0.0 (0.0)	0.3 (0.6)	5.5 (9.5)	1.3 (2.0)	0.0 (0.0)	1.4 (3.8)
1	0.5 (0.7)	1.1 (1.3)	0.0 (0.0)	0.8 (1.4)	0.0 (0.0)	0.0 (0.0)	0.4 (0.8)
2	0.6 (0.9)	2.5 (2.7)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.6 (1.5)
3	1.0 (2.0)	1.8 (3.6)	0.3 (0.8)	0.8 (1.4)	0.0 (0.0)	0.3 (0.8)	0.7 (1.8)
4	0.6 (1.3)	3.0 (3.6)	0.0 (0.0)	0.2 (0.3)	0.0 (0.0)	0.3 (0.6)	0.7 (1.9)
5	1.0 (2.2)	1.8 (4.0)	1.1 (2.4)	0.0 (0.0)	0.2 (0.4)	0.0 (0.0)	0.7 (2.2)
7	0.2 (0.4)	0.4 (1.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.5)
9	1.4 (3.1)	1.4 (2.2)	0.3 (0.4)	0.0 (0.0)	0.7 (1.6)	0.5 (1.2)	0.8 (1.7)
11	0.7 (1.0)	0.8 (1.3)	0.7 (1.6)	0.0 (0.0)	0.8 (1.6)	3.7 (9.0)	1.2 (3.9)
13	0.3 (0.6)	4.6 (6.3)	1.0 (2.4)	0.0 (0.0)	0.2 (0.4)	0.0 (0.0)	1.1 (3.2)
15	1.8 (3.6)	6.3 (10.8)	1.2 (2.4)	0.2 (0.3)	1.1 (1.6)	0.0 (0.0)	1.9 (5.1)
20	3.8 (8.9)	4.6 (8.6)	0.7 (1.6)	0.0 (0.0)	0.5 (0.6)	1.3 (3.3)	2.0 (5.4)
30	0.6 (1.4)	1.0 (1.6)	0.0 (0.0)	2.7 (4.6)	0.5 (0.8)	0.0 (0.0)	0.6 (1.6)
40	0.1 (0.2)	0.0 (0.0)	0.7 (1.0)	0.0 (0.0)	0.9 (1.1)	0.0 (0.0)	0.3 (0.7)
50	0.0 (0.0)	0.3 (0.8)	▪86 0.5 (1.2)	0.0 (0.0)	1.1 (1.2)	0.0 (0.0)	0.3 (0.8)
100	0.0 (0.0)	0.3 (0.8)	0.0 (0.0)	0.2 (0.3)	0.6 (1.2)	0.2 (0.4)	0.2 (0.7)
150	1.0 (2.2)	0.0 (0.0)	0.5 (0.6)	0.0 (0.0)	1.0 (0.9)	0.0 (0.0)	0.4 (1.0)
200	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.9 (1.6)	0.5 (0.8)	0.3 (0.8)
250	0.6 (1.1)	0.0 (0.0)	0.2 (0.3)	0.0 (0.0)	0.0 (0.0)	0.5 (0.8)	0.2 (0.6)
300	0.4 (0.9)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.4)	1.2 (2.9)	0.3 (1.3)
350	0.0 (0.0)	0.0 (0.0)	1.7 (2.9)	1.0 (1.7)	0.8 (1.0)	0.0 (0.0)	0.4 (1.2)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.63. Grass species cover (%) with distance from pipeline centre in 2012.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	7.5 (1.4)	11.8 (3.0)	11.3 (4.3)	10.8 (7.5)	8.7 (5.5)	14.4 (5.6)	10.6 (5.0)
1	10.4 (6.9)	12.3 (4.2)	14.3 (6.1)	13.8 (4.5)	16.2 (7.4)	12.6 (4.6)	13.4 (5.6)
2	10.0 (4.1)	12.8 (2.5)	16.3 (10.9)	14.3 (4.0)	14.8 (2.8)	14.5 (3.3)	14.0 (5.5)
3	7.1 (1.4)	16.4 (9.2)	20.6 (10.7)	29.2 (8.2)	18.3 (7.9)	29.8 (11.1)	20.2 (11.0)
4	9.8 (3.9)	22.3 (12.8)	23.0 (12.0) ▪4	23.0 (3.0) ▪4	15.3 (3.0)	41.8 (14.9) ▪4	23.3 (14.1)
5	9.4 (3.6)	19.2 (11.0)	22.1 (9.7)	22.5 (6.4)	16.0 (5.6)	34.8 (12.3)	20.8 (11.5)
7	13.0 (5.8)	18.5 (4.5)	24.1 (10.3)	27.5 (10.2)	12.4 (4.4)	33.7 (11.2)	21.2 (10.9)
9	13.6 (6.4)	24.0 (7.8)	24.2 (10.6)	29.8 (18.0)	13.3 (4.7)	15.7 (12.1)	19.4 (10.8)
11	16.2 (8.2)	18.0 (7.5)	25.9 (6.0)	31.7 (15.8)	17.1 (9.4)	17.6 (6.7)	20.1 (9.3)
13	21.8 (17.5)	17.3 (9.8)	18.5 (7.6)	25.0 (11.0)	13.8 (6.9)	29.2 (11.4)	20.6 (11.6)
15	15.9 (8.5) ▪17	17.5 (9.3)	17.6 (5.4)	25.0 (13.5)	18.9 (8.0)	28.0 (16.8)	20.1 (10.7)
20	19.8 (13.3)	15.3 (7.1)	26.3 (10.3)	23.7 (14.6)	18.7 (5.7)	30.1 (9.1)	22.2 (10.5)
30	15.9 (6.1)	26.3 (12.9) ▪33	17.9 (6.0)	33.2 (20.4)	18.0 (7.1)	31.3 (19.3)	22.9 (13.1)
40	24.2 (16.0)	25.6 (8.6)	23.8 (12.0)	18.8 (7.3)	20.1 (7.6)	32.0 (8.9)	24.6 (10.8)
50	21.5 (15.1)	22.3 (6.1)	18.8 (9.9)	27.8 (12.3)	12.2 (5.9)	24.9 (12.9)	20.7 (11.0)
100	24.2 (6.9)	25.4 (12.0)	27.5 (11.6)	18.8 (8.3)	12.2 (4.2)	27.4 (6.3)	22.7 (9.8)
150	24.6 (16.4)	17.3 (2.8)	22.9 (6.2)	35.3 (26.2)	17.6 (5.2)	30.3 (15.0)	23.7 (13.1)
200	18.7 (10.1)	25.8 (5.3)	26.5 (6.6)	23.0 (4.6)	17.3 (1.4)	28.3 (10.1)	23.1 (7.9)
250	24.4 (20.0)	19.1 (2.8)	20.7 (12.0)	22.2 (1.6)	16.3 (3.7)	27.1 (10.1)	21.6 (10.2)
300	28.8 (19.3)	17.6 (3.0)	22.3 (8.8)	38.5 (10.4)	12.1 (6.3)	25.1 (14.5)	22.6 (13.3)
350	19.6 (9.4)	18.6 (4.0)	21.5 (4.8)	31.3 (10.2)	14.7 (5.0)	27.8 (10.9)	22.3 (9.1)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.64. 2012 forb species cover (%) with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	0.0 (0.0)	0.0 (0.0)	22.7 (32.5)	6.7 (11.6)	0.3 (0.8)	0.0 (0.0)	4.5 (13.9)
1	3.1 (4.1)	0.0 (0.0)	5.1 (8.4)	0.8 (1.5)	0.1 (0.2)	0.0 (0.0)	1.5 (4.2)
2	4.3 (3.3)	0.8 (1.3)	7.3 (5.6)	0.0 (0.0)	0.5 (1.0)	0.8 (1.0)	2.4 (3.8)
3	5.1 (7.3)	1.2 (1.5)	3.6 (3.5)	0.5 (0.5)	0.4 (0.8)	0.8 (0.8)	1.9 (3.3)
4	0.5 (1.0)	1.3 (1.4)	4.4 (5.3)	0.0 (0.0)	7.6 (6.3)	1.3 (1.3)	2.9 (4.4)
5	5.2 (11.1)	2.6 (1.8)	3.5 (4.0)	0.3 (0.6)	5.8 (3.7)	3.8 (3.9)	3.8 (5.1)
7	0.8 (1.8)	1.1 (0.9)	3.8 (4.2)	0.7 (1.2)	8.9 (10.5)	5.3 (4.9)	3.8 (5.9)
9	4.5 (9.2)	2.7 (3.2)	2.3 (3.2)	1.3 (1.5)	12.7 (25.1)	6.3 (4.4)	5.3 (11.6)
11	4.2 (5.6)	3.1 (5.5)	2.5 (3.1)	12.7 (17.2)	7.8 (8.3)	15.6 (32.6)	▪11 7.2 (15.2)
13	4.8 (6.4)	6.6 (7.7)	▪13 3.8 (4.1)	5.7 (5.1)	8.0 (10.3)	10.3 (17.1)	6.6 (9.4)
15	5.3 (6.4)	5.4 (9.6)	11.6 (23.1)	2.0 (1.5)	6.4 (8.3)	3.1 (2.0)	6.0 (11.2)
20	5.1 (2.0)	5.2 (6.7)	4.5 (5.9)	2.5 (1.5)	14.8 (21.7) ▪26	7.5 (5.4)	7.0 (10.4)
30	13.3 (13.8)	0.7 (1.6)	6.6 (8.4)	12.0 (11.3)	20.6 (18.0)	5.9 (8.6)	9.6 (12.5)
40	3.3 (6.3)	2.1 (2.2)	4.2 (5.6)	5.0 (4.0)	20.0 (12.3)	8.1 (9.3)	7.3 (9.5)
50	3.0 (3.8)	4.4 (6.6)	7.3 (6.2)	6.8 (7.9)	9.1 (9.1)	11.7 (16.4)	7.1 (9.1)
100	3.9 (4.7)	4.4 (8.0)	8.3 (7.4)	9.7 (10.3)	21.8 (16.0)	12.5 (8.3)	10.4 (11.1)
150	8.6 (2.8)	8.4 (12.4)	1.0 (0.9)	4.7 (6.4)	15.8 (10.8)	10.9 (15.7)	9.1 (10.7)
200	6.3 (4.6)	4.5 (9.6)	8.3 (7.3)	2.0 (3.5)	12.2 (10.6)	4.5 (4.5)	6.5 (7.7)
250	7.0 (7.1)	3.5 (3.7)	2.2 (3.3)	0.0 (0.0)	6.6 (9.8)	7.2 (12.8)	5.0 (7.9)
300	4.8 (5.4)	1.3 (1.2)	2.5 (0.5)	6.2 (5.3)	16.0 (13.4)	8.5 (16.5)	7.1 (10.7)
350	2.0 (3.9)	7.3 (9.5)	2.0 (2.6)	0.5 (0.9)	11.0 (8.3)	3.0 (4.8)	4.3 (6.5)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.65. 2013 grass species cover (%) with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	10.8 (6.0)	14.8 (2.7)	19.7 (12.2)	9.8 (7.8)	11.3 (6.1)	25.5 (12.6)	14.9 (9.1)
1	8.8 (2.9)	15.6 (5.0)	15.1 (6.7)	15.3 (4.3)	13.7 (6.1)	13.9 (5.7)	13.9 (5.5)
2	9.8 (2.7)	13.5 (2.8)	14.5 (4.0)	16.8 (2.0)	20.2 (10.4)	20.2 (7.6)	16.1 (6.8)
3	8.6 (3.5)	17.1 (7.5)	20.4 (9.6)	31.5 (18.1) ▪3	18.9 (9.6)	19.2 (7.0)	18.8 (10.1)
4	11.5 (5.1)	28.3 (4.8)	23.6 (7.1)	25.7 (9.1)	25.5 (13.8)	40.0 (20.4) ▪4	26.7 (13.8)
5	13.4 (5.6)	18.2 (6.8)	21.4 (13.5)	26.8 (6.2)	18.1 (2.5)	27.7 (10.0)	20.6 (9.2)
7	12.1 (3.3)	22.9 (7.6)	25.7 (8.6)	27.3 (8.8)	15.7 (5.4)	38.1 (17.1)	23.6 (12.5)
9	12.0 (2.2)	20.3 (6.2)	16.0 (4.1)	31.7 (17.0)	18.4 (7.5)	29.5 (14.1)	20.6 (10.7)
11	17.7 (6.7)	20.8 (8.0)	15.1 (5.5)	18.8 (16.2)	18.4 (7.9)	26.4 (13.6)	19.6 (9.5)
13	14.8 (5.2)	18.8 (5.8)	15.9 (4.6)	27.5 (19.1)	17.6 (8.7)	25.7 (12.1)	19.4 (9.5)
15	15.4 (2.9)	16.9 (3.8)	18.8 (9.3)	24.2 (14.2)	20.3 (9.7)	32.8 (13.0)	21.1 (10.4)
20	13.3 (8.0)	18.5 (7.3)	21.3 (10.3)	16.2 (5.5)	21.2 (10.2)	21.9 (14.1)	19.0 (9.7)
30	19.3 (7.6) ▪28	23.4 (8.7)	16.8 (4.1)	16.3 (6.7)	22.0 (7.7)	25.0 (9.4)	20.8 (7.7)
40	21.8 (7.7)	31.2 (6.3) ▪40	18.8 (6.4)	16.7 (3.8)	19.3 (5.2)	30.8 (13.0)	23.7 (9.3)
50	15.9 (9.2)	28.1 (19.2)	13.3 (4.1)	19.8 (6.4)	25.3 (7.6) ▪87	24.8 (7.4)	21.3 (11.2)
100	19.6 (4.8)	25.0 (11.3)	21.1 (8.0)	16.3 (2.9)	30.9 (12.8)	31.5 (17.4)	25.1 (11.9)
150	15.0 (4.9)	21.7 (10.3)	24.3 (10.6)	22.5 (4.3)	20.2 (6.5)	29.8 (15.7)	22.3 (10.3)
200	18.3 (8.4)	20.4 (3.3)	30.2 (20.5)	27.3 (2.1)	31.3 (10.1)	21.7 (7.9)	24.3 (9.9)
250	25.9 (17.7)	21.3 (6.9)	20.3 (5.5)	23.3 (7.1)	26.8 (8.2)	22.3 (8.0)	23.6 (9.4)
300	18.9 (6.6)	21.0 (6.3)	24.3 (8.4)	26.7 (3.8)	21.3 (16.6)	21.9 (3.1)	21.8 (8.7)
350	18.3 (5.3)	22.9 (6.8)	38.2 (17.3)	26.7 (7.3)	22.3 (10.2)	27.9 (8.4)	25.3 (9.9)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.66. 2013 forb species cover (%) with distance from pipeline centre.

Distance (m)	Coulee	Coulee Upland	Hill	Highway	McNeil	Remount Lowland	Overall
0	1.0 (1.4)	0.0 (0.0)	13.5 (16.9)	11.8 (20.5)	2.8 (5.5)	0.5 (0.9)	4.8 (10.6)
1	0.3 (0.3)	0.3 (0.6)	1.2 (1.6)	1.8 (2.8)	2.8 (6.5)	0.2 (0.4)	1.1 (3.0)
2	3.9 (3.9)	3.2 (2.8)	3.5 (3.9)	1.7 (2.9)	0.0 (0.0)	1.3 (1.7)	2.2 (2.9)
3	2.8 (1.6)	1.4 (1.7)	3.6 (2.9)	1.5 (1.3)	0.5 (1.2)	1.8 (1.3)	1.9 (2.0)
4	0.8 (1.5)	4.2 (3.3)	4.8 (7.9)	1.3 (1.0)	2.2 (2.2)	6.0 (5.8)	3.5 (4.7)
5	6.6 (14.8)	3.1 (4.5)	3.9 (5.0)	3.5 (5.6)	11.9 (11.7)	4.3 (3.6)	5.7 (8.5)
7	2.4 (4.3)	1.1 (1.6)	1.5 (1.8)	0.7 (1.2)	16.4 (13.2)	7.3 (11.9)	5.4 (9.4)
9	8.1 (11.4)	6.4 (6.6)	2.5 (3.0)	1.5 (1.8)	11.3 (16.5)	5.1 (5.3)	6.1 (9.2)
11	8.3 (4.4)	1.7 (1.5)	4.3 (6.3)	13.7 (10.1)	8.7 (10.0)	2.0 (1.7)	5.8 (6.9)
13	0.7 (1.1)	7.3 (6.1)	4.3 (3.4)	1.8 (2.0)	9.6 (10.2)	5.6 (7.7)	5.1 (6.5)
15	3.8 (4.0)	9.3 (11.5)	12.4 (14.5)	4.0 (5.6)	7.2 (8.5)	4.2 (3.3)	7.1 (9.1)
20	7.9 (5.2)	8.1 (16.7)	2.6 (2.4)	2.2 (2.9)	4.6 (2.2)	6.8 (6.9)	5.7 (7.9)
30	8.2 (5.9)	3.5 (5.2)	4.5 (4.8)	10.7 (8.9)	24.1 (21.7)	7.3 (12.7)	9.6 (13.0)
40	6.6 (14.4)	1.6 (1.7)	3.8 (3.6)	3.4 (3.2)	28.9 (31.4)	12.5 (14.4)	▪46 10.0 (17.8)
50	5.7 (6.5)	6.3 (6.1)	6.7 (4.9)	2.2 (3.3)	7.7 (4.0)	▪88 11.8 (14.2)	7.1 (7.6)
100	3.4 (3.7)	5.5 (7.3)	6.5 (5.7)	6.0 (5.2)	49.7 (32.3)	11.9 (10.2)	15.2 (22.6)
150	4.1 (5.1)	7.5 (13.8)	2.0 (2.7)	4.8 (5.0)	13.3 (11.7)	9.1 (8.1)	7.4 (9.4)
200	7.6 (5.4)	3.3 (5.4)	7.2 (7.7)	2.0 (3.5)	12.2 (11.5)	9.3 (5.0)	7.4 (7.4)
250	8.0 (10.8)	4.1 (4.6)	1.8 (1.5)	1.3 (2.3)	10.9 (19.2)	5.3 (7.0)	5.9 (10.3)
300	4.5 (3.4)	2.0 (1.3)	1.5 (1.3)	9.3 (8.1)	24.0 (25.7)	5.0 (2.5)	8.3 (14.0)
350	2.0 (2.7)	13.7 (11.5)	1.8 (2.8)	1.0 (1.7)	10.5 (6.6)	3.3 (4.9)	5.8 (8.0)

Numbers are means with standard deviations in brackets.

▪Significant distance of effect ($p < 0.05$).

Table 2.67. Overall changes to soil properties and vegetation on ROW 4 years after pipeline disturbance.

	Storage		Trench		Work	
Soil 0 to 5 cm						
Organic Matter (%)	3.66 (1.47)	a	2.85 (1.17)	b	3.95 (2.17)	a
Total Organic Carbon (%)	1.83 (0.74)	a	1.43 (0.59)	b	1.97 (1.08)	a
Saturation (%)	60.61 (9.43)	a	53.94 (7.32)	b	59.11 (14.12)	a
Silt	41.9 (8.3)	a	38.4 (8.1)	b	41.0 (9.9)	ab
Clay	13.6 (2.1)	a	15.4 (3.9)	b	13.5 (3.0)	a
Soil 5 to 15 cm						
Electrical Conductivity (dS/m)	0.39 (0.14)	a	0.55 (0.13)	b	0.43 (0.28)	ab
Ground Cover 2013						
Live	18 (5)	a	11 (3)	b	18 (6)	a
Litter	70 (10)	a	58 (25)	b	67 (15)	ab
Bare Ground	11 (12)	a	31 (25)	b	14 (15)	ab
Native Cover 2013	24 (8)	a	15 (6)	b	24 (7)	a

Numbers are means with standard deviations in brackets.

Different letters within rows denote significant differences between areas of ROW at $p<0.05$.

Table 2.68. Overall changes to soil properties and vegetation on ROW 4 years after pipeline disturbance.

Property	Range of Distance of Effect (m)	Change in Property After Distance of Effect
Soil 0 to 5 cm		
Carbon to Nitrogen Ratio	24	Increase
Organic Matter (%)	9 to 28	Increase
Total Inorganic Carbon (%)	16	Decrease
Total Organic Carbon (%)	11 to 28	Increase
Reaction (pH)	15 to 35	Decrease
Electrical Conductivity (dS/m)	21	Decrease
Saturation (%)	18 to 34	Increase
Soluble Magnesium (mg/kg)	19	Decrease
Soluble Sodium (mg/kg)	7	Decrease
Soil 5 to 15 cm		
Carbon to Nitrogen Ratio	50	Decrease
Total Inorganic Carbon (%)	6	Decrease
Reaction (pH)	9 to 17	Decrease
Electrical Conductivity (dS/m)	6 to 15	Decrease
Saturation (%)	6	Decrease
Soluble Calcium (mg/kg)	6 to 16	Decrease
Soluble Magnesium (mg/kg)	6 to 14	Decrease
Soluble Sodium (mg/kg)	9 to 19	Decrease
Penetration Resistance		
5 cm (MPa)	6 to 35	Decrease
10 cm (MPa)	6 to 35	Decrease
Max Penetration Depth (cm)	5 to 35	Increase
Ground Cover		
Live 2012	3 to 30	Increase
Litter 2012	3 to 10	Site specific
Bare Ground 2012	3 to 11	Decrease
Live 2013	3 to 81	Increase
Litter 2013	3 to 100	Site Specific
Bare Ground 2013	4 to 18	Decrease
Native Cover 2012	4 to 35	Increase
Non Native Cover 2012	15	Increase
Native Cover 2013	3 to 89	Increase
Non Native Cover 2013	86	Decrease
Grass Cover 2012	4 to 33	Increase
Forb Cover 2012	11 to 26	Increase
Grass Cover 2013	4 to 40	Increase
Forb Cover 2013	46 to 88	Increase

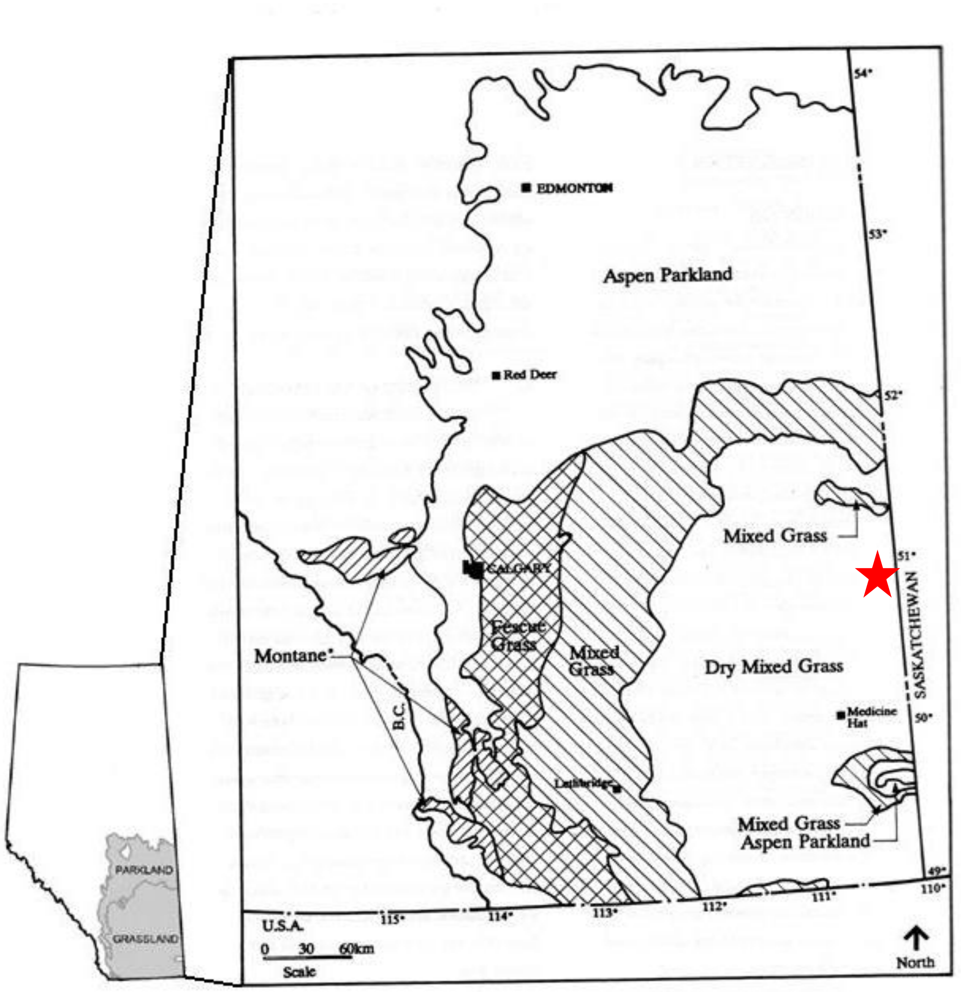

Figure 2.1. Map of Alberta showing grassland ecoregions and study location. Adapted from Kerr et al. 1993.

Figure 2.2. Location of research sites (Coulee, Coulee Upland, Highway, Remount Lowland, Hill, McNeil) along the TransCanada Keystone pipeline (Google Earth, 2013)

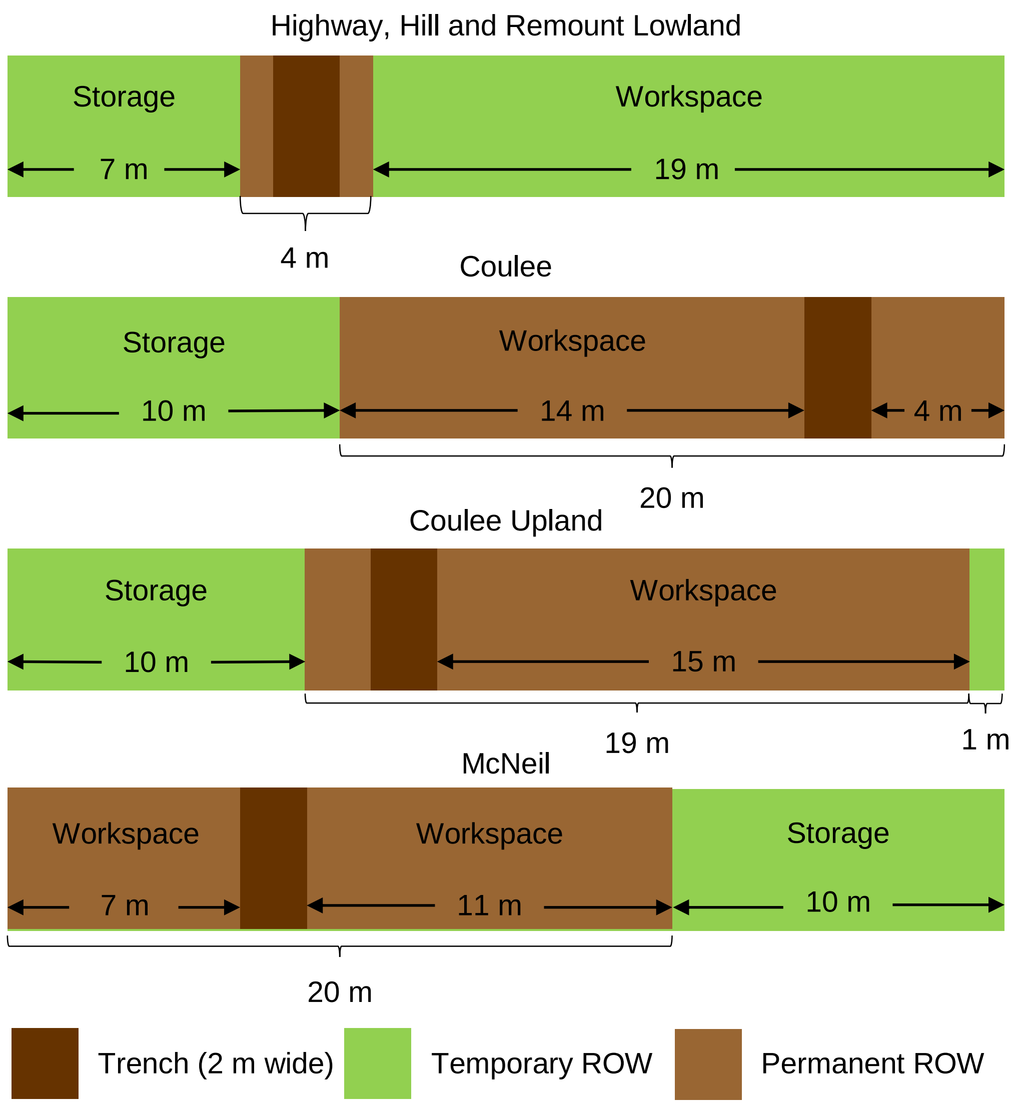

Figure 2.3. Layout of pipeline ROW for the study sites, each ROW is 30 m wide.

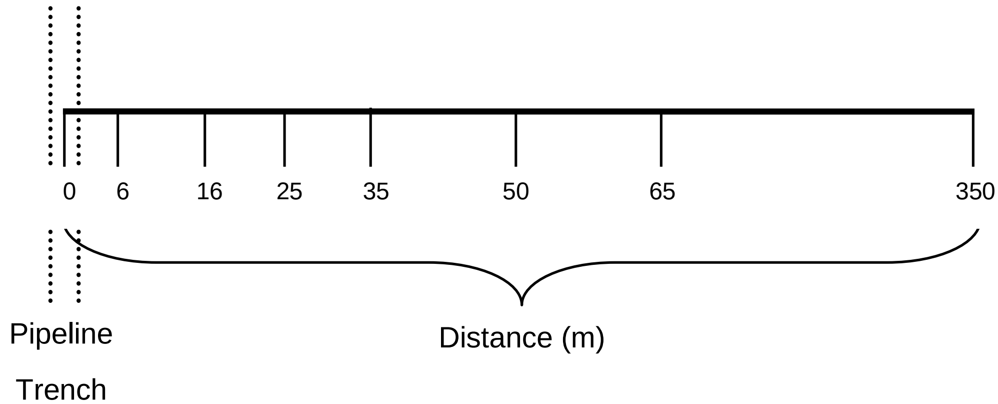

Figure 2.4. Sampling strategy for soil sampling.

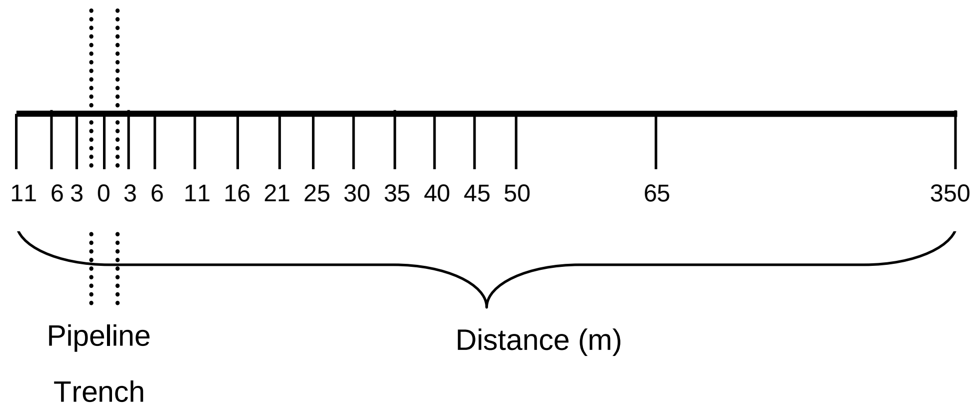

Figure 2.5. Sampling strategy for soil penetration resistance.

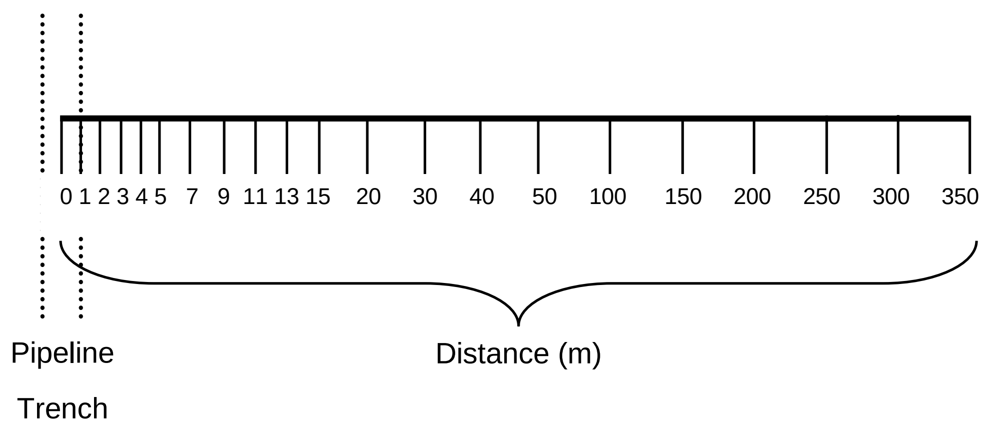

Figure 2.6. Sampling strategy for vegetation assessments.

CHAPTER III. EFFECTS OF PIPELINE CONSTRUCTION ON *HALIMOLOBOS VIRGATA* AND ITS HABITAT IN NATIVE MIXED GRASS PRAIRIE IN SOUTHERN ALBERTA

1. INTRODUCTION

Halimolobos virgata (Nutt.) O.E. Schulz (slender mouse ear cress) is native to Canada and the United States; Canadian populations are only found in Alberta and Saskatchewan (Environment Canada 2010). *Halimolobos virgata* is a member of the *Brassicaceae* (mustard) family and the only *Halimolobos* species in Alberta (Alberta Sustainable Resource Development 2005). It is mainly found in the Mixed Grass Ecoregion with growing season water deficits (Alberta Sustainable Resource Development and Alberta Conservation Association 2009, Environment Canada 2010). Its habitat is subxeric (moderate dry) to occasionally xeric (very dry) on flat to very gently undulating sand plains (Alberta Sustainable Resource Development 2005). *Halimolobos virgata* may require disturbance; most known locations in Alberta were lightly grazed (Alberta Sustainable Resource Development 2005). Modest disturbances expose sand and create depressions that collect soil water which may assist seedling establishment.

In 1992, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated *Halimolobos virgata* as endangered, (Environment Canada 2010). In 2000 it was reassessed as threatened due to an updated status report with new information on locations (Alberta Sustainable Resource Development and Alberta Conservation Association 2009, Environment Canada 2010). In 2003 it was listed as threatened under the species at risk act. *Halimolobos virgata* is threatened by habitat degradation and loss from anthropogenic and natural processes including drought, alteration or lack of grazing and fire regimes, oil and gas activities, cultivation, competition from non native species, urban development and military and industrial activities.

Pipeline construction can impact soil properties. Mixing topsoil and subsoil can alter pH, electrical conductivity, organic matter, soluble salts and texture on a pipeline right of way (ROW) (de Jong and Button 1973, Naeth 1985, Naeth et al. 1987, Culley and Dow 1988, Ivey and McBride 1999, Soon et al. 2000a, Soon et al. 2000b, Shi et al. 2013). Changes may persist with time (Naeth 1985, Naeth et al. 1987), affecting soil and plant productivity temporarily or permanently (de Jong and Button 1973). Plant communities may be affected by introduction of non native species (Sousa 1984, Hansen and Clevenger 2005) and altering light, temperature and soil water content (de Jong and Button 1973, Naeth et al. 1988, Naeth et al. 1993, Parendes and Jones 2000, Hansen and Clevenger 2005).

Guidelines were developed in 2008 for Saskatchewan, Alberta and Manitoba to protect prairie plant species at risk and their critical habitat (Environment Canada 2008). Currently there are no provincial regulatory requirements for set backs on provincial, municipal or private lands from plant species at risk. Threats to at risk species and critical habitat can be mitigated by best management practices and recommendations in federal recovery plans (Environment Canada 2012b). Guidelines state pipeline construction cannot occur within 300 m of endangered or threatened plant species on federal lands; set back distance is the same for all sizes and types of pipelines and does not include seasonal lifting. Set backs, or distance from the pipeline ROW edge, reduce direct mortality of plant species and cumulative edge effects with potential to destroy their habitat. Studies addressing set backs for different activities are limited; therefore they are based on interpretation of related research and require more direct research.

2. OBJECTIVES AND HYPOTHESES

2.1 Objectives

The objectives of this research program were to determine important components of *Halimolobos virgata* habitat, effects pipeline construction and management may have had on individual *Halimolobos virgata* plants and their habitat and whether a 300 m set back from a pipeline ROW is appropriate for *Halimolobos virgata*.

2.2 Hypotheses

The following hypotheses were addressed in this research.

- *Halimolobos virgata* habitat will not be impacted off ROW since effects of pipeline construction and operation are most intense on the ROW. Therefore *Halimolobos virgata* plants will not be impacted and will require no set back distance from pipeline ROW.

- Pipeline disturbance may create habitat on ROW as *Halimolobos virgata* habitat generally includes soil disturbance.

3. MATERIALS AND METHODS

3.1 Research Site Location

Research sites were located near Bindloss in southeastern Alberta, in the Dry Mixed Grass Subregion of the Grassland Natural Region (Figure 3.1). They were located between the South Saskatchewan and the Red Deer Rivers, 150 km north of Medicine Hat, Alberta and 20 km west of the Alberta-Saskatchewan border, within the Bindloss Plain Ecodistrict (Adams et al. 2013). Climate is continental with low precipitation, short warm summers and long cold winters (Alberta Environmental Protection 1997). Mean summer and winter temperatures are 16 °C and -10 °C, respectively. Mean annual precipitation is 306 mm, of which 80 % falls as rain (Environment Canada 2012a).

The region is characterized by gently undulating topography with hummocky and dissected uplands (Pettapiece 1986, Natural Regions Committee 2006). Surficial deposits are glaciofluvial and eolian (Pettapiece 1986, Adams et al. 2013), typically cobbles and gravel and loamy sand or sand lenses and bands. Soils are primarily Orthic Brown Chernozems and Solonetzes; comprising 60 and 25 %, of the area respectively (Natural Regions Committee 2006, Shorthouse and Floate 2010). Major soil series of the area are Bingville, Cavendish, Purple Springs, Vendisant, Antelope and Chin. These are primarily Orthic Brown Chernozems, Rego Brown Chernozems or Orthic Regosols with sandy to loamy textures.

The Dry Mixed Grass Subregion is characterized by a mix of drought tolerant grasses of both short and medium heights (Alberta Environmental Protection 1997, Natural Regions Committee 2006). In the area 85 to 95 % of the vegetation is comprised of grasses and sedges (Rowe and Coupland 1984, Coupland 1992). Several of the plant species at risk in the study area include *Halimolobos* *virgata* (Nutt.) O.E. Schulz (slender mouse ear cress), *Yucca glauca* Nutt. (soap weed), *Cryptantha minima* Rydb. (tiny cryptanthe), *Iris missouriensis* Nutt. (western blue flag), *Tripterocalyx micranthus* (Torrey) Hooker (small flowered sand verbena) and *Tradescantia occidentalis* (Britton Smyth) (western spiderwort) (Environment Canada 2009).

3.2 Study Site Selection

Two study sites, Hill and Coulee, were selected along the TransCanada Keystone pipeline which was constructed and reclaimed February to May 2009 on non federal land (Figure 3.2). The Keystone pipeline is 76.2 cm in diameter and 3,460 km in length, transporting crude oil from Hardisty, Alberta to United States markets at Wood River and Patoka, Illinois and Cushing, Oklahoma (TransCanada 2012). The pipeline was buried with minimum cover of 1.2 m depending on land use.

Study sites were selected based on previous occurrences of *Halimolobos virgata* within 300 m of the pipeline ROW. Occurrence information was gathered from Alberta Conservation Information Management System and previous research conducted by Candace Nemirsky for her MSc program in 2009 and 2010 (Nemirsky 2011).

Coulee was located north of Secondary 555 near Bindloss, Alberta. It has steep slopes that required extensive grading due to the large diameter pipeline; the coulee runs in a northeast to southwest direction and the pipeline runs northwest to southeast. The Keystone pipeline passed through approximately 500 m of habitat with known occurrences of *Halimolobos virgata* (Nemirsky 2011).

Hill was located south of Secondary 555 in the Remount Community pasture, 3.5 km south east of Coulee. *Halimolobos virgata* was found at the bottom of a hill near an intermittent water course at the edge of a saline drainage way (Jaques Whitford AXYS Ltd. 2008). Drainage is northeast to southwest with the pipeline traversing southeast to northwest. The pipeline is within the Alberta Ethane Gathering System (AEGS) pipeline easement with two pipelines built between 1976 and 2000 (Nemirsky 2011). The Keystone pipeline directly passed through 200 m of known habitat.

3.3 Halimolobos Virgata Surveys

Halimolobos virgata surveys were conducted using GPS coordinates of individual plants found in prior years by the Alberta Conservation Information Management System and Candace Nemirsky. Following landowner permission, a Garmin etrex 10 was used to find prior locations of prior *Halimolobos* virgata. Detailed ground surveys were conducted in a 100 x 100 m area around each of these GPS points. Using transects 5 m apart, in a north to south direction, surveyors visually scanned the ground as they progressed along the transect, slightly overlapping the area scanned by adjacent surveyors. In areas with several prior *Halimolobos virgata* occurrences resulting in the 100 x 100 m survey areas being overlapped, larger survey polygons were created to encompass all 100 x 100 m survey areas to conduct effective and efficient surveys. Surveys were conducted May 15 to 16, 2012 and May 22 to 24, 2013 during the blooming period of *Halimolobos virgata* making it easier for surveyors to find individual plants among the grass.

Halimolobos virgata plants were identified according to Kershaw (2001), Alberta Sustainable Resource Development and Alberta Conservation Association (2009) and notes from a professional botanist (Bradley 2012). For each plant found, GPS location, distance from pipeline centre, elevation, height, number of siliques, number of flowers and number of nearby rosettes were recorded. In 2013 slope and aspect were recorded for each plant, using a Suunto clinometer and Brunton Type 15 compass, respectively.

3.4 Soil Sampling, Measurements and Analyses

Soil sampling and penetration resistance measurements were conducted May 30, 2013. Two GPS coordinates were randomly selected from each year for individual *Halimolobos virgata* plant occurrences at the Hill research site from 2009 to 2013 to represent sampling locations. There was only one occurrence in 2010, resulting in nine sampling locations. GPS coordinates from 2009 to 2011 were from Nemirsky (2011). For sampling points representing 2013 *Halimolobos virgata* plant occurrences, the individual plant was relocated using a Garmin etrex 10 GPS. The GPS was used to locate the coordinates for the remaining sampling locations; as these did not have a current *Halimolobos virgata* plant, the sampling location was marked with a pin flag. Penetration resistance measurements and soil samples were taken at three sampling points surrounding the plant or pin flag, approximately 10 cm away from the plant stem (Figure 3.3) to minimize plant root damage and maintain consistently located readings.

Penetration resistance was measured using a Rimik CP40II cone penetrometer with 130 mm^2 cone. Penetration resistance measurements were recoded at each sampling location before soil sampling occurred. The penetrometer was programmed to take measurements at 1 cm increments to a maximum depth of 20 cm; 5, 10, 15 and 20 cm depths were maintained for statistical analyses. After each insertion data were inspected for errors; measurements with an error were discarded and a new measurement taken. Errors were a result of too fast or too slow insertion, rocks or interference from surrounding vegetation. Vegetation was trimmed to approximately 2 cm when interference occurred. Five measurements were taken at each of the three sampling points per sampling location for a total of 135 measurements.

Soil was sampled with a 5 cm Dutch auger at 0 to 5 and 5 to 15 cm depth increments. Samples were placed in plastic bags and stored in a cooler with ice until taken to a commercial laboratory. One sample was collected from each of three points per sampling location (total 54). Particle size (sand, silt, clay) was determined by hydrometer method (Carter 1993); electrical conductivity, pH, sodium adsorption ratio, saturation and soluble salts (calcium, magnesium, sodium, potassium) by saturated paste (Carter 1993); cation exchange capacity by ammonium extraction (McKeague 1978) and total carbon, total organic carbon and total nitrogen by combustion (Nelson and Sommers 1996).

3.5 Vegetation Assessments

Vegetation assessments were conducted May 22, 2013 during the rare plant surveys. A circle with a 20 cm diameter was used to determine ocular estimates of percent ground cover (bare ground, litter, live vegetation, manure, scat, rocks, lichen, mushrooms, woody debris) and percent species composition around each *Halimolobos virgata* plant. The circle was placed so each stem was in the centre, when two plants were adjacent, vegetation assessment was conducted for the pair. A total of 57 quadrats were assessed.

3.6 Statistical Analyses

Statistical analyses were conducted using R version 3.0.1 (R Core Team 2013). Shapiro-Wilks test for normality (Shapiro and Wilk 1965) was performed on the data; data did not meet assumptions of normality. Spearman's rank correlation was used to test for correlation between *Halimolobos virgata* height or silique number and ground cover, distance from pipeline ROW, elevation, aspect or slope (Steel et al. 1997). An alpha value of 0.050 was used to balance Type I and Type II error. Descriptive statistics were calculated for chemical and physical soil properties, penetration resistance and species cover and frequency; these data were not statistically analyzed due to the small sample size.

4. RESULTS

4.1 *Halimolobos Virgata*

In May 2012, 29 *Halimolobos virgata* plants were found at Hill and none at Coulee. Plants were in bloom with developing siliques. Plant heights were 6.4 to 41.6 cm (mean 22.8 cm). Only 20 plants had siliques; number was 0 to 17 (mean 4.5). *Halimolobos virgata* was found 7.8 to 92.7 m (mean 46 m) from pipeline centre (Figure 3.4). Two plants were on ROW, two on ROW edge, 25 off ROW.

In May 2013, 182 *Halimolobos virgata* was found at Hill and none at Coulee. Growth stages were just in bloom to well developed siliques. Plant heights were 2 to 44 cm (mean 24.2 cm). After seven days of rain and high temperatures *Halimolobos virgata* grew several cm; random measurements of heights were 60 cm. Number of siliques were 0 to 125 on 122 of 182 plants (mean 8.3). Plants were found 4.2 to 107.5 m from the pipeline centre (Figure 3.5) (mean 52.8 m). Eleven plants were located on ROW, eight on the edge and 162 off ROW.

There was no correlation between the distance from the pipeline centre and *Halimolobos virgata* plant height (2012 $P=0.722$, 2013 $P=0.366$) or silique number (2012 $P=0.247$, 2013 $P=0.497$). With the combined data from both study years there was no correlation between the distance from the pipeline centre and *Halimolobos virgata* plant height ($P=0.432$) or its silique number ($P=0.778$) (Figures 3.6, 3.7).

4.1 Habitat Properties

4.2.1 Soil chemical properties

Soil next to *Halimolobos virgata* plants had similar total nitrogen, organic matter, total inorganic carbon, organic carbon and pH at 0 to 5 and 5 to 15 cm to that of surrounding habitat (Tables 3.1, 3.2). With depth total nitrogen, organic matter and organic carbon decreased and total inorganic carbon and pH increased.

Soil potassium, magnesium, calcium, saturation, cation exchange capacity and ammonium near *Halimolobos virgata* plants were lower and less variable than surrounding habitat (Tables 3.1, 3.2). Ammonium, cation exchange capacity, saturation, calcium and potassium decreased with depth. Sodium adsorption ratio and sodium near plants were more variable with a greater range than surrounding habitat, many values from plant locations exceeded maximums from surrounding habitat. Sodium adsorption ratio and sodium increased with depth. Electrical conductivity means and minimums near *Halimolobos virgata* plants were similar to surrounding habitat, with greater ranges and more variability, decreasing with depth. Soil 0 to 5 cm near *Halimolobos virgata* plants had a greater range of carbon to nitrogen ratio than surrounding habitat, with less range and variability near plants at 5 to 15 cm. Values decreased with depth.

4.2.2 Soil physical properties

Soil near *Halimolobos virgata* plants had 52.6 % sand, 38.3 % silt and 9.1 % clay at 0 to 5 cm (Table 3.3). Sand and clay increased and silt decreased slightly with depth. Texture was loam or sandy loam. Soil near *Halimolobos virgata* plants had more sand and less clay and silt at both depths than the surrounding habitat.

Halimolobos virgata locations had a similar penetration resistance ranges as the surrounding area, with slightly lower means (Table 3.4). Penetration resistance generally increased with depth. At 10, 15 and 20 cm there was considerable variability in penetration resistance between plant locations. At 5 cm penetration only 2011 plant locations exceeded the overall average of 1.9 MPa, at 3.0 MPa.

4.2.3 Aspect, elevation and slope

Halimolobos virgata was found 75 % of the time on west to northwest facing slopes with an equal distribution between 260 and 335 degrees. Plants were on south (180 degrees) and north (360 degrees) facing slopes, 10 and 15 % of the time, respectively. There was a correlation between aspect and *Halimolobos virgata* height (P=<0.001) and aspect and silique number (P=<0.001) (Figures 3.8, 3.9). Height and silique number decreased with increasing degree of aspect.

Elevation for individual plants was 611 to 617 m (mean 614 m) in 2012 and 607 to 626 m (mean 615 m) in 2013. With years combined there was no correlation between elevation and *Halimolobos virgata* silique number (P=0.644) (Figure 3.10). In 2012 there was no correlation between elevation and height (P=0.627) (Figure 3.11); in 2013 height decreased with increasing elevation (P=0.003) (Figure 3.12). Slope was 7 to 24 % (mean 14 %). Plant height (P=0.044) and silique number (P=<0.001) decreased with increasing slope (Figures 3.13, 3.14).

4.2.4 Vegetation

Bare ground was 0 to 92 % (mean 21.1 %), litter 5 to 95 % (mean 64.1 %), lichen was 24.5 % and woody debris 21.1 % (Table 3.5). There was no correlation between bare ground or litter and *Halimolobos virgata* height (P= 0.084, P=0.218) (Figures 3.15, 3.16) or silique number (P=0.529, P=0.480) (Figures 3.17, 3.18). Live vegetation was 3 to 25 % (mean 11.5 %). *Halimolobos virgata* height increased with increasing live vegetation (P=0.002) (Figure 3.19), with no correlation between live vegetation and silique number (P=0.179) (Figure 3.20).

Halimolobos virgata was most commonly associated with *Stipa comata,* unknown forbs, *Agropyron smithii* and *Bouteloua gracilis* (HBK) Lag. (blue grama) (Table 3.6). Associated species were mostly native; introduced species frequency was 5.3 %, comprised of *Taraxacum officinale* Weber (dandelion) and *Tragopogon dubius* Scop. (goat beard). *Stipa comata, Carex* species, *Bouteloua gracilis* and *Agropyron smithii* contributed the most individual species cover (Table 3.7).

5. DISCUSSION

5.1 *Halimolobos Virgata* Habitat

Similarity of total nitrogen, inorganic carbon and organic carbon, organic matter and pH at 0 to 15 cm in surrounding habitat and next to *Halimolobos virgata* indicate these properties are unlikely key factors in *Halimolobos virgata* habitat.

Organic matter at 5 to 15 cm was lower near plants than surrounding areas; potentially indicating in the top 5 cm it is important to *Halimolobos virgata* establishment and growth. High variability and ranges for sodium adsorption ratio, sodium, electrical conductivity and carbon to nitrogen ratio at 0 to 15 cm near *Halimolobos virgata* plants relative to surrounding habitat may indicate wide tolerances, and therefore unlikely key habitat properties. Potassium, magnesium, calcium, percent saturation, cation exchange capacity and ammonia may be key habitat properties as values were lower with less variability near plants than the surrounding habitat at 0 to 15 cm. Maximum values for potassium, magnesium, calcium, percent saturation, cation exchange capacity and ammonia near *Halimolobos virgata* plants were $\leq$ half those in surrounding habitat. This may indicate *Halimolobos virgata* does not have a tolerance for high values of these properties, making them potentially important habitat properties.

Potential habitat properties may vary with populations. Nemirsky (2011) identified electrical conductivity, total carbon, total nitrogen, total organic carbon, calcium, magnesium, sodium, potassium, pH, base saturation and sodium adsorption ratio all potential factors that differed between *Halimolobos virgata* occupied locations and locations with undetected *Halimolobos virgata* plants. Soil properties naturally vary at a regional scale and with topography (Schimel et al. 1985, Aguilar and Heil 1988, Hook and Burke 2000); the differences in soil chemical properties considered to be potential habitat properties may be a result of natural variation in surrounding habitat of different *Halimolobos virgata* populations.

Other researchers found soil texture near *Halimolobos virgata* plants was sandy loam or sand (Alberta Sustainable Resource Development 2005, Alberta Sustainable Resource Development and Alberta Conservation Association 2009, Nemirsky 2011, Environment Canada 2012b). In this study surrounding habitat generally had less sand, and more silt and clay resulting in a greater range of soil textures (loam, clay loam, silt loam, silty clay loam, sandy loam and sand). The restriction to two soil textures (loam, sandy loam) in this study may indicate *Halimolobos virgata* establishment is affected by soil water content as soil texture impacts soil water retention (Rawls et al. 1991).

Soil strength in the upper 5 cm of soil is likely an important habitat property. Soil strength and compaction can be measured indirectly by soil penetration resistance (Brady and Weil 2008). In this study soil penetration resistance was lower in the upper 5 cm near plants than in the surrounding habitat and were similar to values from Nemirsky (2011). Lower penetration resistance could indicate *Halimolobos virgata* requires greater soil water content for germination and or initial root growth as soil penetration decreases with increased water content (Masle and Passioura 1987, Laboski et al. 1998).

Halimolobos virgata has been found in Alberta at elevations of 606 to 724 m (Nemirsky 2011), similar to this study. In this study a differences in effect of elevation on *Halimolobos virgata* height between years is likely a result of precipitation as elevation for individual plants is a direct representation of the plant location on a hill. More precipitation fell prior to *Halimolobos virgata* surveys in 2012 than 2013 (Government of Canada 2014) as was apparent from very green and lush vegetation in 2012 and brown and very dry vegetation in 2013 (Table A73). Greater soil water in 2012 did not stress plants further up slope resulting in no correlation in elevation and height in 2012, unlike 2013 where plants with greater elevation had some water stress resulting in shorter plants.

Halimolobos virgata was previously not found on slopes > 8 % (Alberta Sustainable Resource Development 2005, Nemirsky 2011); in one study slopes had a southerly aspect. In this study 90 % of plants on a southerly aspect were on slopes < 8 %; plants on other aspects were on slopes > 8 %, 90 % of the time. This may indicate water content affects *Halimolobos virgata* establishment and growth as aspect can have a significant impact on soil water (Ayyad and Dix 1964, Bennie et al. 2008) with south facing slopes having less than north facing slopes. Greater slope angles are associated with lower infiltration (Cerdà and García-Fayos 1997), which may mean steeper slopes on southerly aspects do not have sufficient soil water to support *Halimolobos virgata*.

Litter is important for conserving soil water, as it reduces evaporation from soil by intercepting solar radiation and decreasing surface temperature (Willms et al. 1993). Thus increasing bare ground can cause reduced plant height, which was not the case in this study. However from photo documentation, *Halimolobos virgata* plants on a south aspect slope were generally surrounded by more litter cover and standing litter. Ground cover varied substantially. Bare ground was often associated with disturbed soil from burrowing animals and insects; size of disturbance or plant location within the disturbance impacted bare ground. Increased bare ground can impact soil water content and therefore plant size. Bare ground was mainly a result of a disturbance which reduced competition between plants, likely preventing *Halimolobos virgata* height from being impacted by bare ground (Hobbs and Huenneke 1992). *Halimolobos virgata* is typically found with light disturbance (Alberta Sustainable Resource Development 2005), likely allowing seedlings to establish as the species is an early colonizer with high resistance to stress but low competitive ability (Nemirsky 2011). Live vegetation cover impacted *Halimolobos virgata* height. As cover and competition for light from surrounding plants increased, plant height increased (Lovett Doust 1988)

In this study *Halimolobos virgata* was associated with similar native species as in other studies (Alberta Sustainable Resource Development and Alberta Conservation Association 2009, Nemirsky 2011). It was not often associated with non native species, likely a result of its low competitive ability. Other studies found it associated with *Agropyron pectiniforme* R. & S. (crested wheat grass) (Alberta Sustainable Resource Development 2005). In this study it was found up to the edge of an old pipeline ROW seeded with *Agropyron pectiniforme* but not growing among large bunches of grass; supporting its low competitive ability.

Overall many habitat factors indicated *Halimolobos virgata* is sensitive to soil water content and favours habitat with low competition and light disturbance. Results supported those of Nemirsky (2011), who characterized the micro habitat of *Halimolobos virgata* as a rim niche, where *Halimolobos virgata* may be forced by low competitive ability and need for more soil water.

5.2 Pipeline Impacts on *Halimolobos Virgata* and Habitat

Halimolobos virgata height and silique number were not directly impacted by distance to pipeline. Although the plants that did grow on the ROW had heights and silique numbers well within the off ROW range, reduced number of plants on the ROW indicates pipeline construction may negatively impact *Halimolobos virgata* habitat.

In this study *Halimolobos virgata* may not have tolerated elevated potassium, magnesium, calcium, percent saturation, cation exchange capacity and ammonia. Off ROW there were no impacts to these properties when steep terrain and extensive grading were not a factor for 0 to 15 cm (Chapter II). On ROW calcium, potassium, magnesium and present saturation were impacted by construction on trench and storage areas, although results were not consistent at all sites. When significant distance of effect or differences between areas of the ROW were found it was likely a result of salt rich parent material or subsoil mixed with top soil. The impact pipeline construction will have on *Halimolobos virgata* habitat via soil chemical properties will vary with location and parent material; however it is hypothesized that with typical construction impacts will be confined to the ROW. Pipeline construction changed texture in the upper 5 cm of the trench, but depending on original texture the decrease in silt and increase in clay by a few % may not be enough to impact *Halimolobos virgata* habitat. No trends were found to indicate *Halimolobos virgata* inhabited different micro habitats in different years after pipeline construction, in regards to soil properties.

The greatest impact pipeline construction had on *Halimolobos virgata* habitat was compaction. Significant distance of effects for penetration resistance, an indirect measure of compaction and soil strength, were found at 5 and 10 cm at varying distance from the pipeline centre (Chapter II). The distance likely varied as a result of terrain and construction conditions. Distance of effect only exceeded the edge of the ROW when steep terrain and extensive grading was a factor. Several properties measured in this study indicate soil water content is important for *Halimolobos virgata.* Compaction reduces the volume of large pores and soil water retention (Richard et al. 2001) which could negatively impact *Halimolobos virgata* habitat on the ROW. Increased soil strength as a result of compaction from equipment is a concern for *Halimolobos virgata* establishment; the average penetration resistance near *Halimolobos virgata* plants was 1 to 2 MPa less than penetration resistance values found before the significant distance of effect.

Pipeline disturbance impacts to ground cover were confined to the ROW when steep terrain was not a factor. Whether construction impacts on *Halimolobos virgata* will depend on slope and aspect of the pipeline. If the pipeline crosses habitat on a non south facing slope changes to ground cover would likely not be negative as *Halimolobos virgata* can grow on north to west facing slopes with a wider range of bare ground and litter cover. Increased bare ground and decreased competition as a result of pipeline construction could initially provide an opening for *Halimolobos virgata*. However, reduced litter on a slope with greater evaporation or on a steeper slope with decreased infiltration could impact soil water content and therefore negatively impact *Halimolobos virgata* habitat.

Fencing the ROW after construction may impact *Halimolobos virgata* habitat. Litter increased with fencing; at one site litter was higher on the fenced ROW than in grazed off ROW areas (Chapter II). Plant communities and plant heights were different between fenced ROW and grazed off ROW areas. Many studies found *Halimolobos virgata* populations in areas with light to moderate grazing (Alberta Sustainable Resource Development 2005, Alberta Sustainable Resource Development and Alberta Conservation Association 2009, Environment Canada 2012b). Grazing may provide micro habitats for *Halimolobos virgata* by reducing competition from native and aggressive plant species and light disturbance from hoofs could create slight depressions in bare soil for seed germination and plant establishment (Alberta Sustainable Resource Development and Alberta Conservation Association 2009, Environment Canada 2012b). No grazing is considered a threat to *Halimolobos virgata* habitat (Environment Canada 2012b). Prairie plants evolved with grazing, so no grazing could alter natural ecological processes, leading to habitat degradation or loss.

Disturbances like pipelines can increase invasibility of communities (Hobbs and Huenneke 1992) increasing non native plant species on the ROW relative to undisturbed soil (Kerr et al. 1993, Ostermann 2001, Nemirsky 2011). The low frequency of non native plant species associated with *Halimolobos virgata* and the lack of *Halimolobos virgata* on an old ROW revegetated with *Agropyron pectiniforme* indicate pipeline construction could negatively impact *Halimolobos virgata* if the pipeline is a source of non native species. Especially if the non native species introduced are aggressive early colonizers capable of out competing *Halimolobos virgata*. Long term impacts of non native species on *Halimolobos virgata* is not known (Environment Canada 2012b). Continual management after construction may prevent *Halimolobos virgata* habitat from being negatively impacted by non native plant species (Chapter II), however there is always the potential for *Halimolobos virgata* and its habitat to be directly impacted by non native control methods.

Halimolobos virgata has been found up to the edge of the pipeline ROW but not on it (Environment Canada 2012b). Researchers speculated that pipeline construction disturbance either degraded the habitat or buried plant seeds too deeply for emergence. In 2010 Nemirsky (2011) found 16 *Halimolobos virgata* plants growing on ROW under an erosion control mat at Coulee. The following year the mat was removed and *Halimolobos virgata* has not been found on ROW since. The erosion control mat likely provided a micro habitat for *Halimolobos virgata* by reducing competition and conserving soil water (Nemirsky 2011). *Halimolobos virgata* seeds were not buried too deep for emergence but pipeline disturbance created unsuitable habitat. In this study *Halimolobos virgata* was found on non trench areas of the ROW; the low count on ROW indicates pipeline disturbance may negatively impact habitat. Further studies are needed to determine long term effects of ROW disturbance and whether *Halimolobos virgata* can re establish.

6. CONCLUSIONS

Halimolobos virgata appears to utilize micro habitats with different soil chemical and physical properties and soil water content than the surrounding habitat. Soil texture, strength and water content are likely the most important components of its habitat. *Halimolobos virgata* favours habitat with light disturbance and is likely out competed by non native species.

Pipeline disturbances do not impact *Halimolobos virgata* and its habitat off ROW with typical construction methods. Disturbance on the ROW may negatively impact *Halimolobos virgata* habitat for up to five growing seasons after construction, mainly through soil compaction.

No set back distance is recommended between *Halimolobos virgata* and pipeline disturbance. However, since the pipeline ROW could negatively impact *Halimolobos virgata* habitat, the pipeline route and construction should be carefully planned. Avoidance of important growth and reproductive times for *Halimolobos virgata* and weather conditions that would result in greater compaction are important.

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Table 3.1. Soil chemical properties in 0 to 5 cm for *Halimolobos virgata* occurrence locations and surrounding habitat (Hill site).

	Halimolobos virgata			Surrounding Habitat		
Property	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Ammonium Nitrogen (mg/kg)	1896 (334)	1260	2510	2321 (858)	1490	4780
Cation Exchange Capacity (meq/100g)	13.51 (2.38)	9.00	17.90	16.58 (6.13)	10.60	34.10
Carbon:Nitrogen Ratio	9.90 (4.21)	3.80	24.50	10.16 (2.95)	4.10	16.60
Total Nitrogen (%)	0.16 (0.07)	0.06	0.36	0.16 (0.06)	0.07	0.29
Organic Matter (%)	2.84 (1.01)	1.21	5.59	3.01 (1.03)	1.80	5.36
Total Inorganic Carbon (%)	0.25 (0.28)	0.03	0.88	0.18 (0.19)	0.02	0.70
Total Organic Carbon (%)	1.42 (0.50)	0.60	2.79	1.50 (0.51)	0.90	2.68
Hydrogen Ion Activity (pH)	7.76 (0.38)	6.90	8.90	7.43 (0.39)	6.40	8.20
Electrical Conductivity (dS/m)	0.63 (0.35)	0.34	2.03	0.53 (0.24)	0.19	1.00
Sodium Adsorption Ratio	2.26 (4.93)	0.05	24.00	0.76 (1.59)	0.05	7.80
Saturation (%)	53.19 (5.46)	42.00	64.00	58.38 (9.73)	47.00	80.00
Soluble Calcium (mg/kg)	24.29 (9.32)	8.10	44.80	31.7 (16.61)	8.10	69.30
Soluble Magnesium (mg/kg)	8.14 (2.79)	3.60	14.10	10.53 (6.15)	3.30	23.00
Soluble Sodium (mg/kg)	28.59 (53.32)	1.00	251.00	13.38 (19.66)	2.00	80.00
Soluble Potassium (mg/kg)	11.63 (5.35)	1.00	28.00	13.42 (11.71)	5.00	59.00

Standard deviations are in brackets.

Table 3.2. Soil chemical properties in 5 to 15 cm for *Halimolobos virgata* occurrence locations and surrounding habitat (Hill site).

	Halimolobos virgata			Hill		
Property	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Ammonium Nitrogen (mg/kg)	1599 (261)	1180	2150	2128 (870)	1410	4460
Cation Exchange Capacity (meq/100g)	11.42 (1.88)	8.40	15.40	15.18 (6.21)	10.00	31.80
Carbon:Nitrogen Ratio	7.76 (4.32)	1.80	24.30	9.07 (5.82)	2.90	32.70
Total Nitrogen (%)	0.13 (0.09)	0.03	0.49	0.14 (0.07)	0.03	0.28
Organic Matter (%)	1.60 (0.37)	0.74	2.22	2.15 (0.85)	1.23	4.44
Total Inorganic Carbon (%)	0.42 (0.32)	0.01	0.93	0.36 (0.35)	0.01	1.43
Carbon Total Organic (%)	0.80 (0.19)	0.37	1.11	1.08 (0.43)	0.62	2.22
Hydrogen Ion Activity (pH)	8.05 (0.4)	7.20	8.70	7.7 (0.41)	6.80	8.30
Electrical Conductivity (dS/m)	0.86 (0.77)	0.26	3.77	0.53 (0.3)	0.21	1.28
Sodium Adsorption Ratio	5.46 (7.33)	0.10	23.90	1.68 (2.76)	0.20	9.70
Percent Saturation (%)	48.19 (6.12)	38.00	67.00	54.83 (13.69)	42.00	90.00
Soluble Calcium (mg/kg)	18.06 (9.14)	7.30	35.70	23.72 (11.37)	9.60	62.70
Soluble Magnesium (mg/kg)	6.41 (3.23)	2.90	18.40	8.58 (5.22)	3.80	28.00
Soluble Sodium (mg/kg)	69.26 (118.70)	1.00	544.00	23.5 (32.57)	2.00	119.00
Soluble Potassium (mg/kg)	5.59 (3.10)	1.00	13.00	6.17 (5.23)	2.00	24.00

Standard deviations are in brackets.

Table 3.3. Sand silt and clay in soil of *Halimolobos virgata* occurrence locations and surrounding habitat (Hill site).

	Halimolobos Virgata			Surrounding Habitat		
	Mean (%)	Minimum (%)	Maximum (%)	Mean (%)	Minimum (%)	Maximum (%)
0 to 5 cm						
Sand	52.6 (5.1)	43	65	46.1 (9.1)	19.6	58
Silt	38.3 (4.2)	28.4	45	40.3 (2.9)	35	45
Clay	9.1 (2.3)	6	15	13.6 (7.9)	6	37
5 to 15 cm						
Sand	56.3 (6)	42	69	47.4 (10)	17.6	56
Silt	33.8 (4.2)	25.6	42	38.1 (4.2)	32	50
Clay	9.9 (3)	5.4	16	14.5 (9)	9	39

Standard deviations are in brackets.

Table 3.4. Soil penetration resistance at 5, 10, 15 and 20 cm for *Halimolobos virgata* location and surrounding habitat (Hill site).

	Penetration Resistance Depth (MPa)											
	5 cm			10 cm			15 cm			20 cm		
Sampling Location	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
2009	1.5 (0.4)	1.0	2.6	2.0 (0.6)	1.1	3.2	2.6 (0.8)	1.0	4.3	2.8 (0.8)	1.1	4.4
2010	1.7 (0.3)	1.2	2.3	3.1 (0.7)	1.8	4.5	3.8 (0.9)	2.2	5.2	3.8 (1.1)	1.9	5.5
2011	3.0 (1.1)	1.1	5.3	3.7 (1.1)	1.6	6.2	3.2 (1.1)	1.6	5.6	3.3 (0.8)	1.8	4.6
2012	1.3 (0.5)	0.4	2.5	1.9 (0.9)	0.4	3.6	2.4 (1.5)	0.6	5.9	3.0 (1.9)	0.4	6.4
2013	1.6 (0.3)	1.0	2.3	2.0 (0.8)	0.9	3.9	2.1 (0.8)	0.7	3.6	2.0 (0.8)	0.6	3.9
Mean	1.9 (0.9)	0.4	5.3	2.5 (1.1)	0.4	6.2	2.7 (1.2)	0.6	5.9	2.9 (1.3)	0.4	6.4
Surrounding Habitat	2.5 (1.1)	0.7	5.5	2.9 (1.0)	0.7	5.9	3.0 (1.1)	0.5	6.5	2.8 (1.1)	0.6	6.5

Standard deviations are in brackets.
Min = minimum, Max = maximum.

Table 3.5. Ocular ground cover.

Cover	Mean (%)	Maximum (%)	Minimum (%)
Live Vegetation	11.5 (5.2)	3	25
Litter	64.1 (27.2)	5	95
Bare Ground	21.1 (27.1)	0	92
Lichen	1.6 (4.7)	0	25
Woody Debris	1.5 (4.2)	0	25
Other	0.2 (1.6)	0	12

Standard deviations are in brackets.

Table 3.6. Frequency of plant species associated with *Halimolobos virgata*.

Scientific Name	Common Name	Status	Frequency (%)
Grass and Grass Like Species			
Agropyron smithii Rydb.	western wheat grass	Native	24.6
Agropyron species	wheat grass	Native	5.3
Bouteloua gracilis (HBK) Lag.	blue grama	Native	21.1
Carex species	sedge	Native	19.3
Stipa comata Trin. and Rupr. var. *comate*	needle and thread grass	Native	59.6
Forb Species			
Androsace septentrionalis (L.)	fairy candelabra	Native	1.8
Arabis species	Rock cress	Native	3.5
Artemisia cana Pursh	sage bush	Native	8.8
Artemisia frigida Willd.	pasture sage	Native	10.5
Astragalus species	milk vetch	Native	1.8
Hedeoma hispidum Pursh	pennyroyal	Native	1.8
Opuntia polycantha Haw.	prickly pear	Native	3.5
Phlox hoodii Richards	moss phlox	Native	5.3
Selaginella densa Rydb.	little club moss	Native	3.5
Sphaeralcea coccinea (Pursh) Rydb.	scarlet mallow	Native	1.8
Taraxacum officinale Weber	dandelion	Non Native	3.5
Tragopogon dubius Scop.	goat beard	Non Native	1.8
Unknown forbs			26.3

Status is according to (Moss 1994).

Table 3.7. Ocular plant species cover.

Scientific Name	Common Name	Mean (%)	Minimum (%)	Maximum (%)
Grass and Grass Like Species				
Agropyron smithii Rydb.	western wheat grass	0.76 (2.47)	0.00	15.00
Agropyron species	wheat grass	0.02 (0.09)	0.00	0.50
Bouteloua gracilis (HBK) Lag.	blue grama	0.97 (2.19)	0.00	10.00
Carex species	sedge	1.61 (5.16)	0.00	27.00
Stipa comata Trin. and Rupr. var. comate	needle and thread grass	2.11 (3.39)	0.00	18.00
Forb Species				
Androsace septentrionalis (L.)	fairy candelabra	0.04 (0.26)	0.00	2.00
Arabis species	Rock cress	0.14 (0.77)	0.00	5.00
Artemisia cana Pursh	sage bush	0.68 (3.38)	0.00	24.00
Artemisia frigida Willd.	pasture sage	0.51 (1.91)	0.00	12.00
Astragalus species	milk vetch	0.04 (0.26)	0.00	2.00
Halimolobos virgata (Nutt.) O.E. Schulz	slender mouse ear cress	8.17 (5.38)	1.50	27.00
Hedeoma hispidum Pursh	pennyroyal	0.00 (0.00)	0.00	0.01
Opuntia polycantha Haw.	prickly pear	0.25 (1.31)	0.00	8.00
Phlox hoodii Richards	moss phlox	0.13 (0.74)	0.00	5.00
Selaginella densa Rydb.	little club moss	0.15 (0.94)	0.00	7.00
Sphaeralcea coccinea (Pursh) Rydb.	scarlet mallow	0.21 (1.59)	0.00	12.00
Taraxacum officinale Weber	dandelion	0.14 (0.77)	0.00	5.00
Tragopogon dubius Scop.	goat beard	0.01 (0.07)	0.00	0.50
Unknown forb		0.47 (1.09)	0.00	4.00

Standard deviations are in brackets.

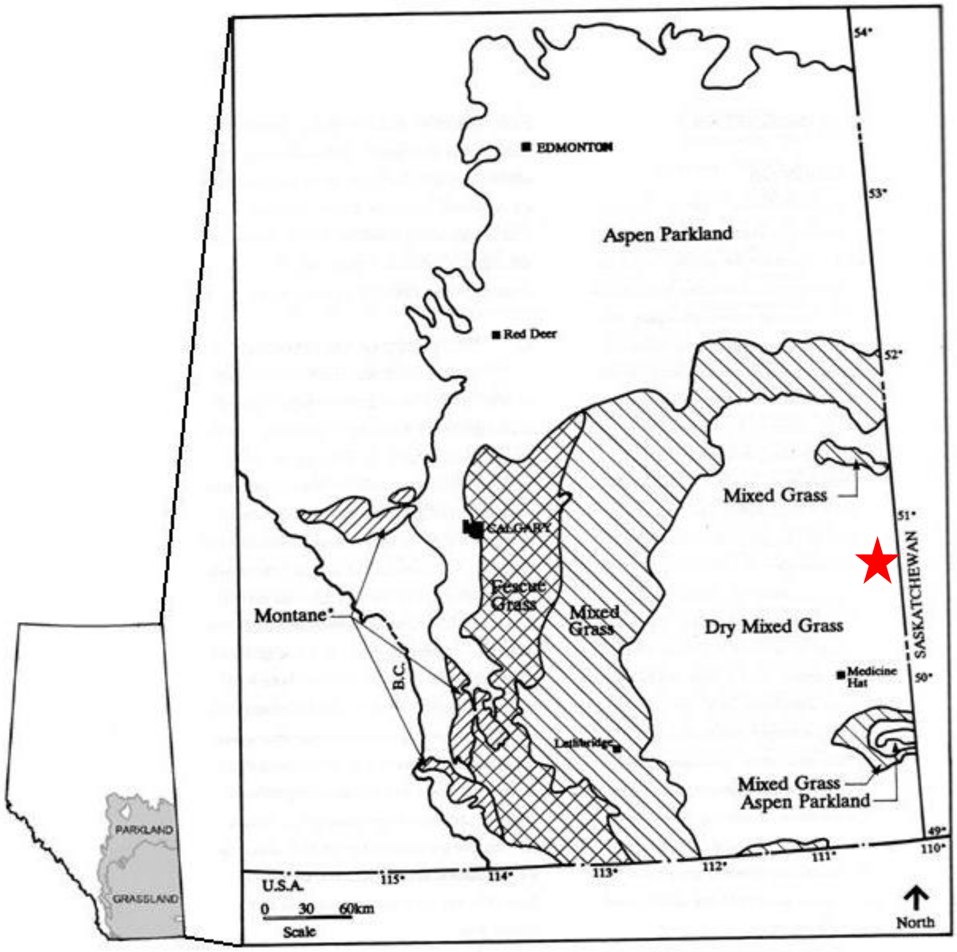

Figure 3.1. Map of Alberta showing grassland ecoregions and study location. Adapted from Kerr et al. 1993.

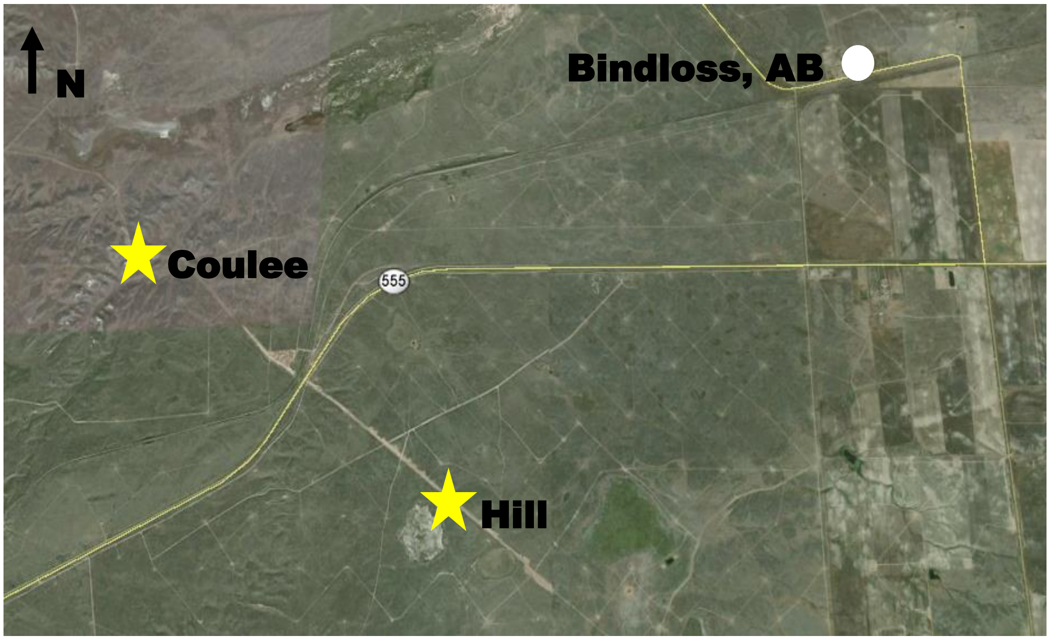

Figure 3.2. Location of Hill and Coulee research sites along the TransCanada Keystone pipeline. (Google Earth 2013)

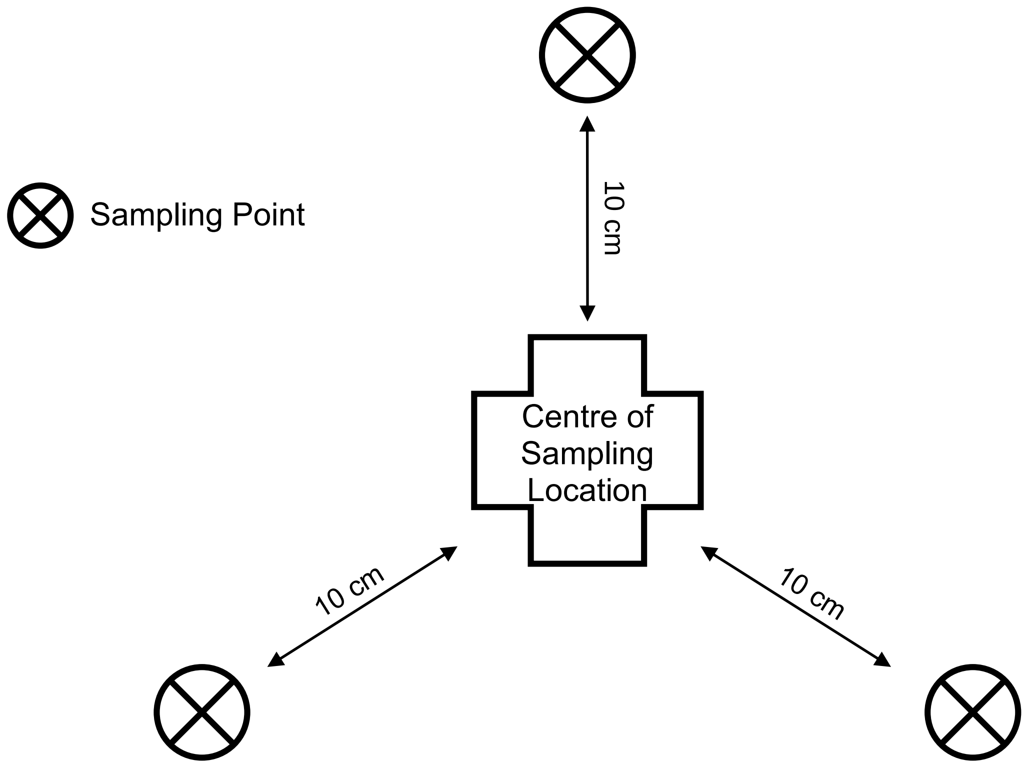

Figure 3.3. Sampling strategy for soil sample and soil penetration resistance.

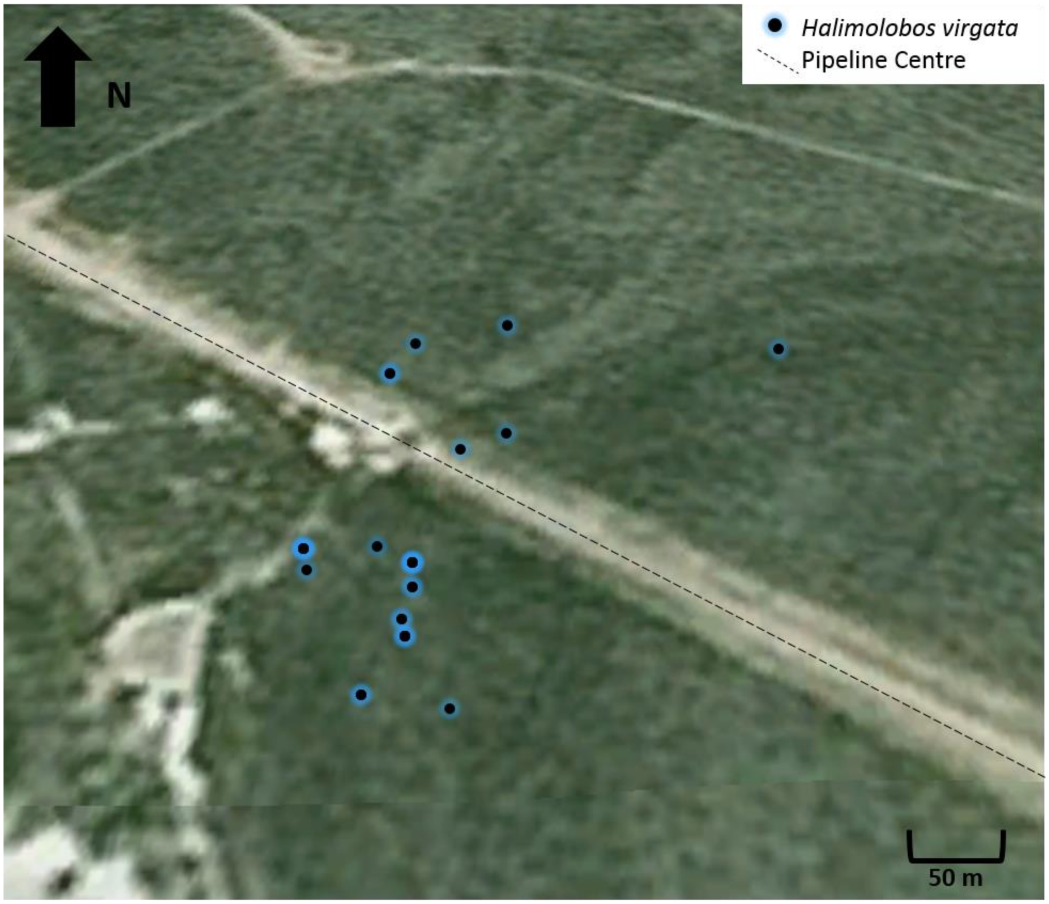

Figure 3.4. Distribution of *Halimolobos virgata* plants at Hill site in 2012. Intensity of colour surrounding an individual point is representative of density at that location; not all points are individual plants.

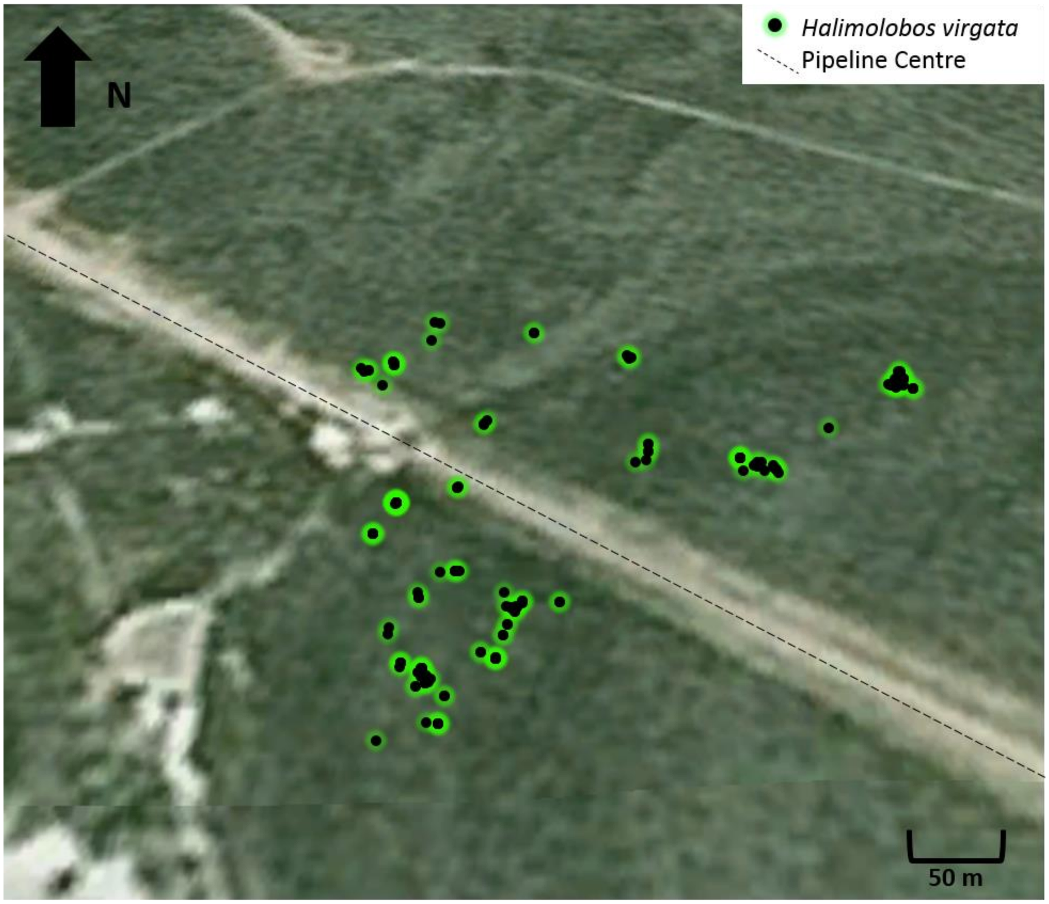

Figure 3.5. Distribution of *Halimolobos virgata* plants at Hill site in 2013. Intensity of colour surrounding an individual point is representative of density at that location; not all points are individual plants.

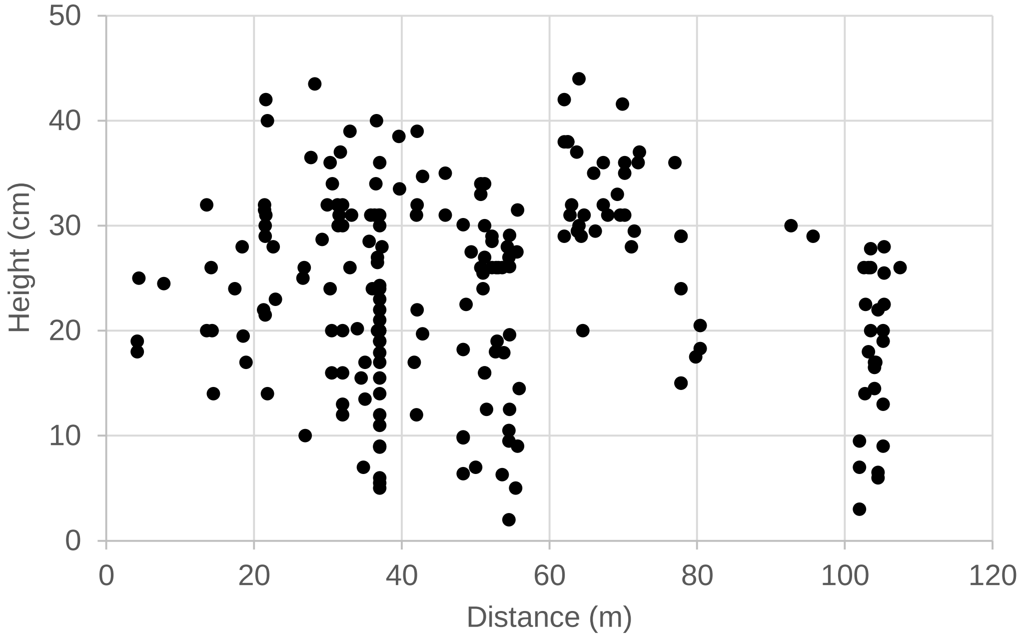

Figure 3.6. Relationship between height of individual *Halimolobos virgata* plants and distance from pipeline centre (N=211, ρ=-0.054, p=0.4315).

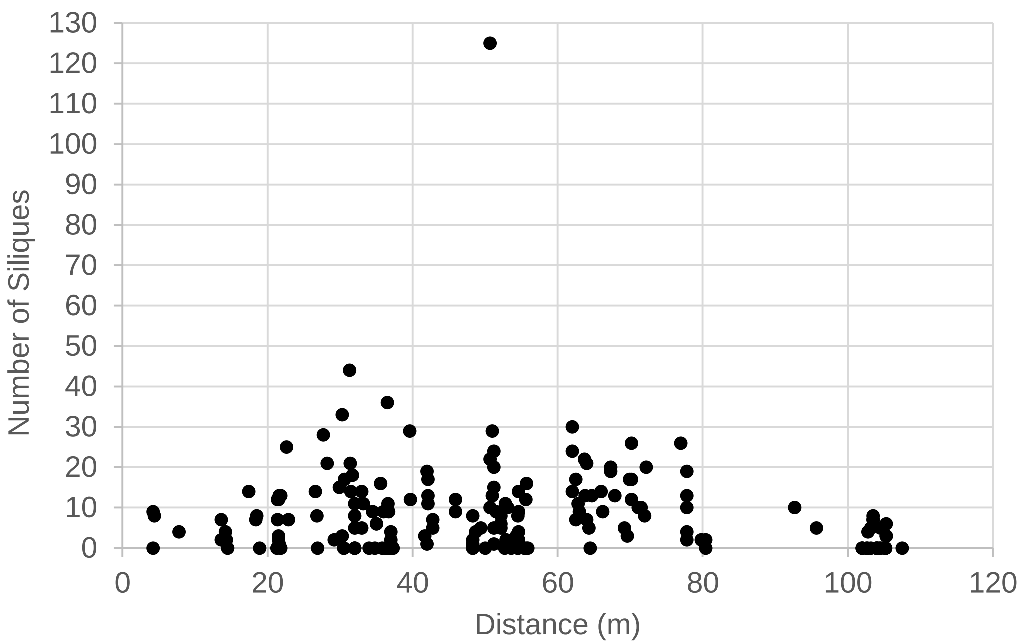

Figure 3.7. Relationship between number of siliques per individual *Halimolobos virgata* plants and distance from pipeline centre (N=211, ρ=-0.020, p=0.778).

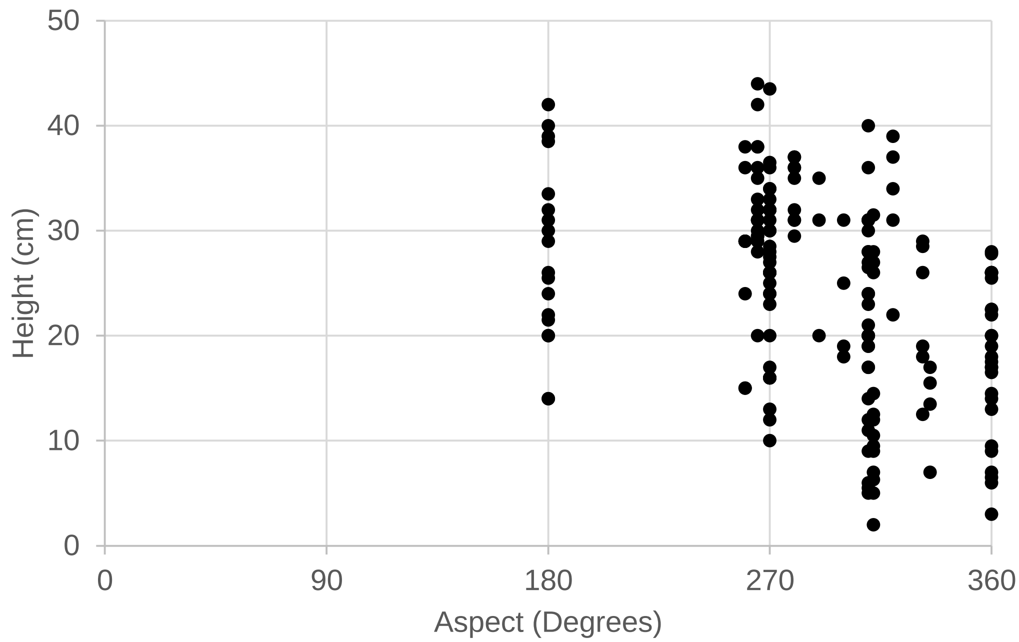

Figure 3.8. Relationship between height of individual *Halimolobos virgata* plants and aspect (N=182, ρ=-0.219, $p<0.001$).

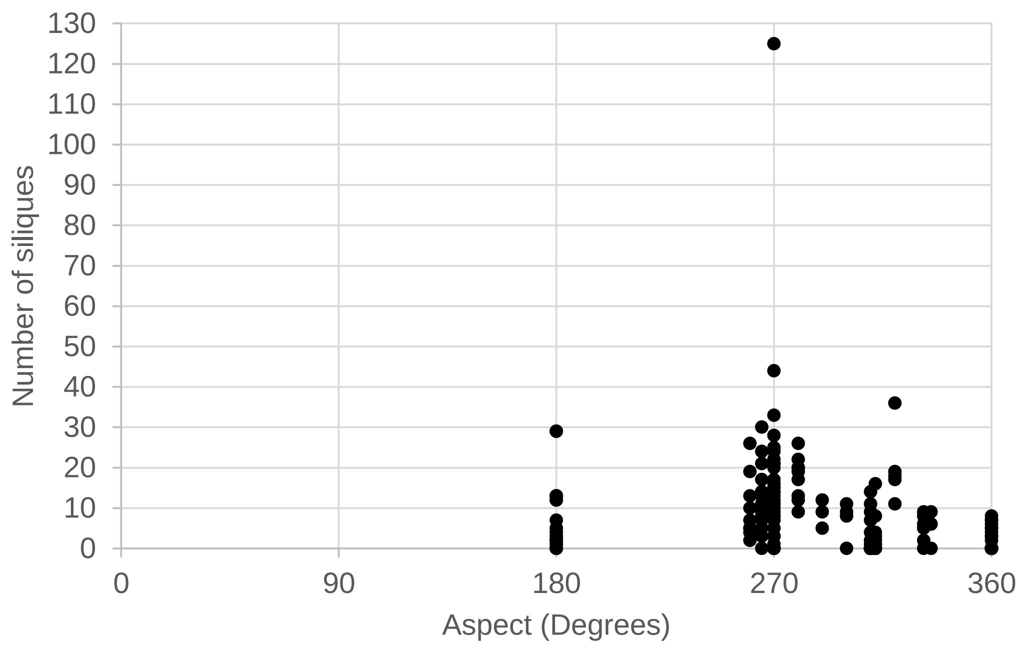

Figure 3.9. Relationship between number of siliques per individual *Halimolobos virgata* plants and aspect (N=182, ρ=-0.283, $p<0.001$).

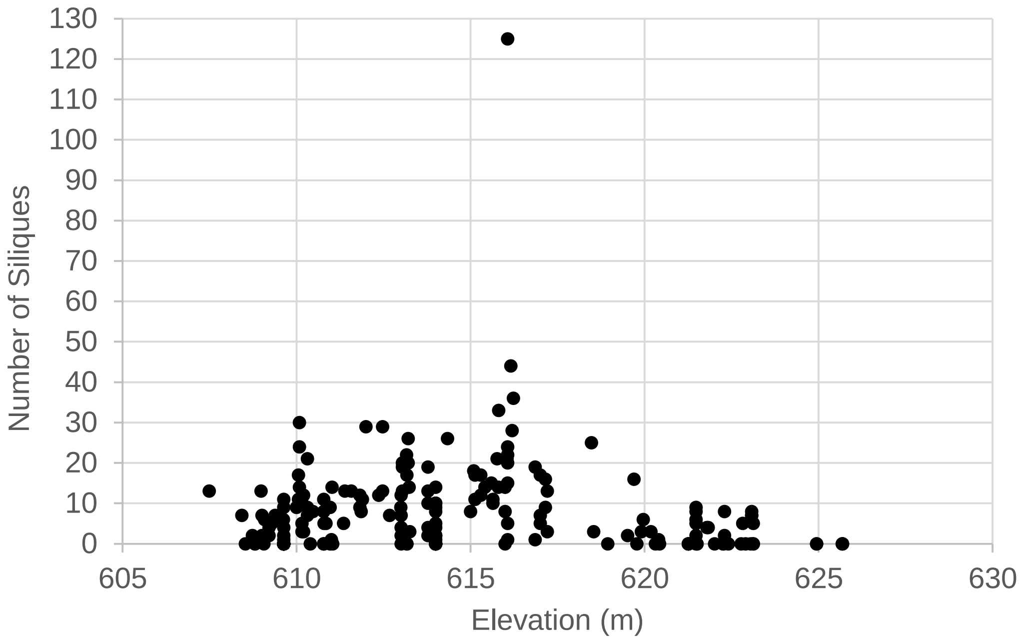

Figure 3.10. Relationship between number of siliques per individual *Halimolobos virgata* plants and elevation (N=211, ρ=0.032, p=0.644).

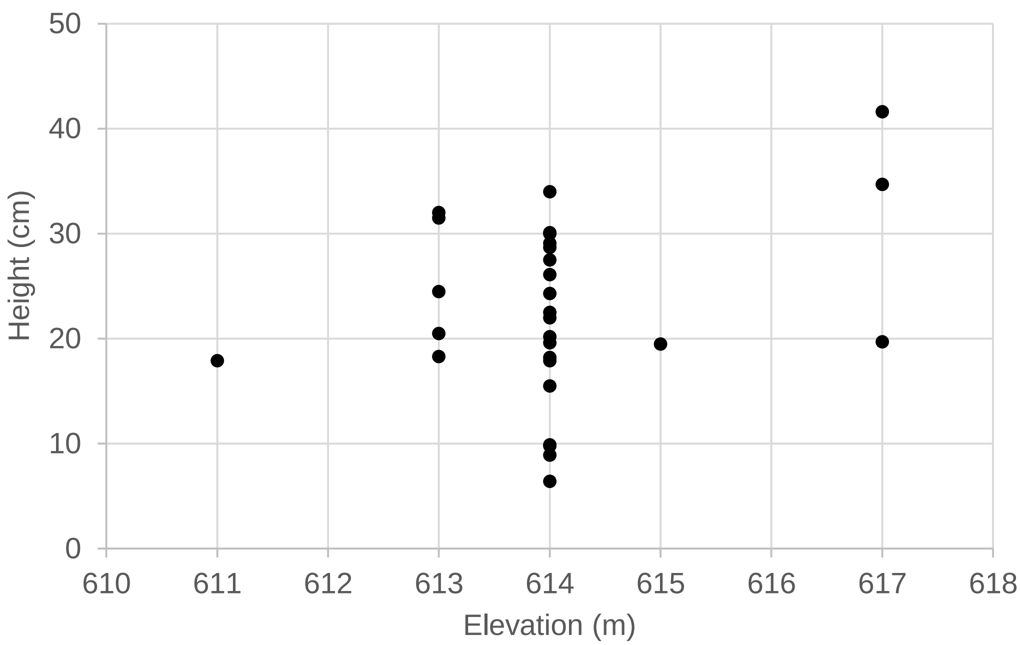

Figure 3.11. Relationship between height of individual *Halimolobos virgata* plants and elevation in 2012 (N=182, ρ=0.094, p=0.627).

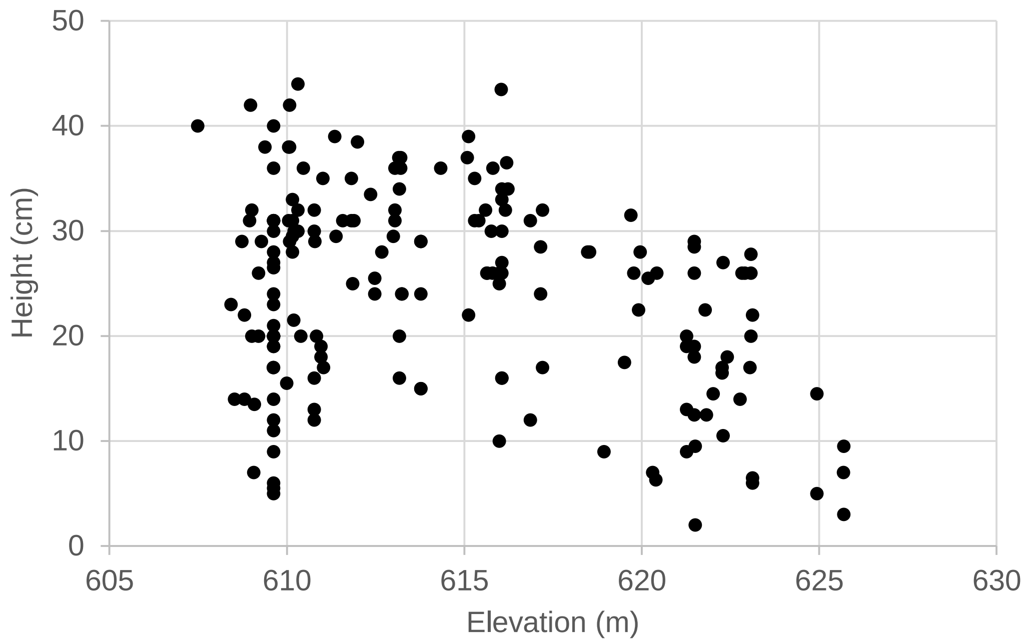

Figure 3.12. Relationship between height of individual *Halimolobos virgata* plants and elevation in 2013 (N=182, ρ=-0.220, p=0.003).

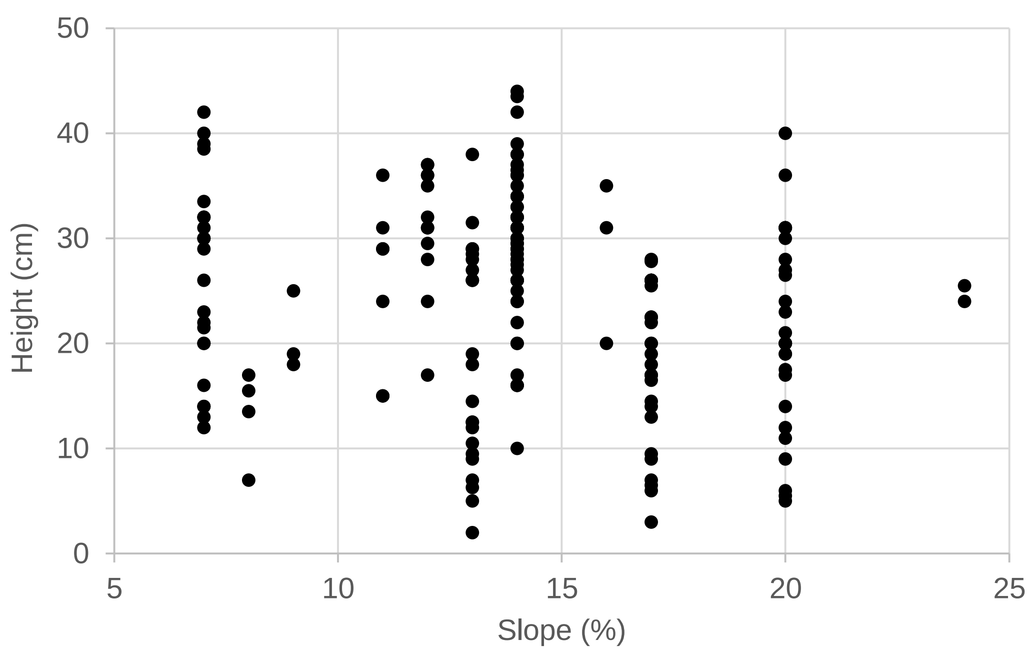

Figure 3.13. Relationship between height of individual *Halimolobos virgata* plants and slope (N=182, ρ=-0.149, p=0.044).

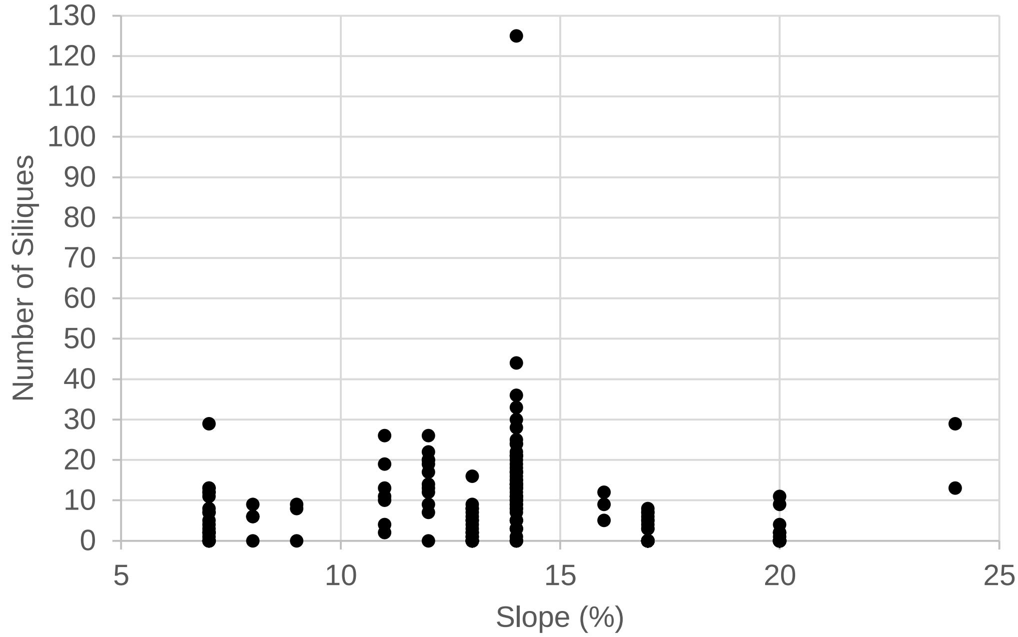

Figure 3.14. Relationship between number of siliques per individual *Halimolobos virgata* plant and slope (N=182, ρ=-0.283, p<0.001).

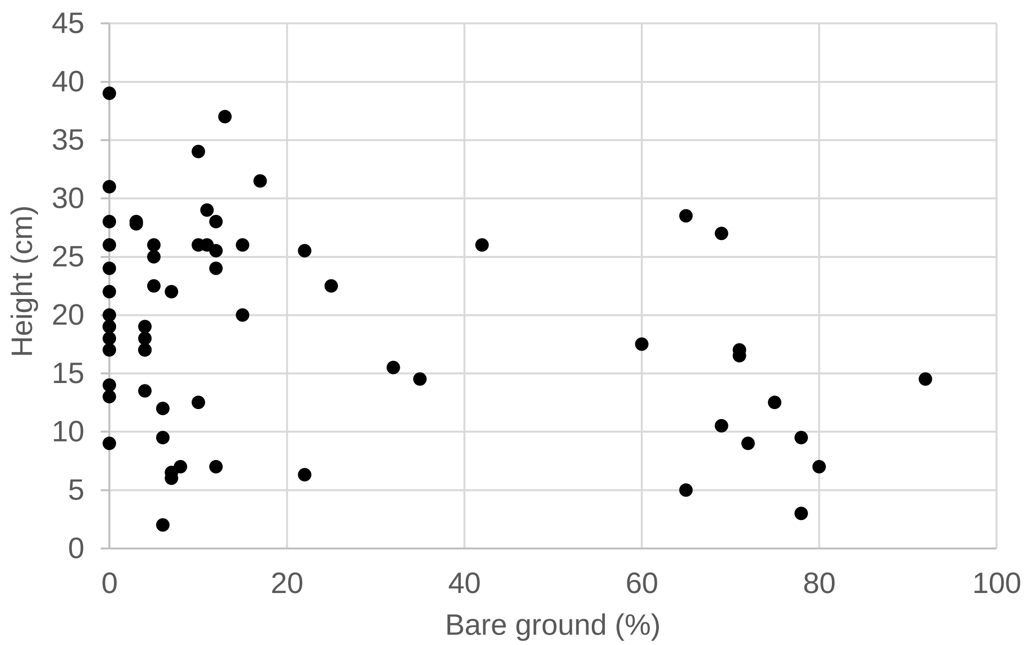

Figure 3.15. Relationship between height of individual *Halimolobos virgata* plants and bare ground (N=63, ρ=-0.219, p=0.084).

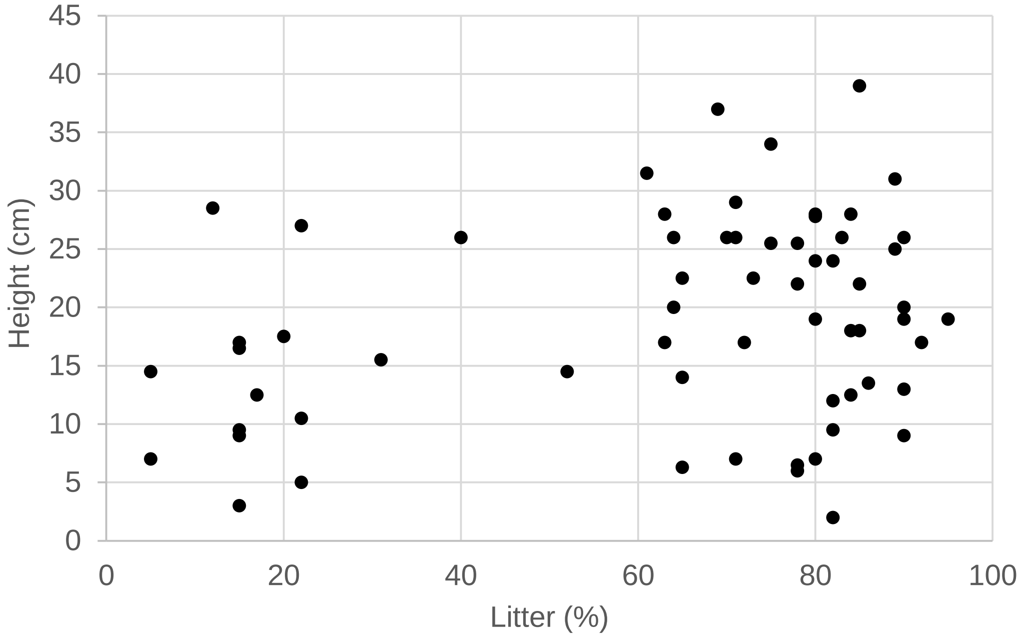

Figure 3.16. Relationship between height of individual *Halimolobos virgata* plants and litter (N=63, ρ=0.158, p=0.218).

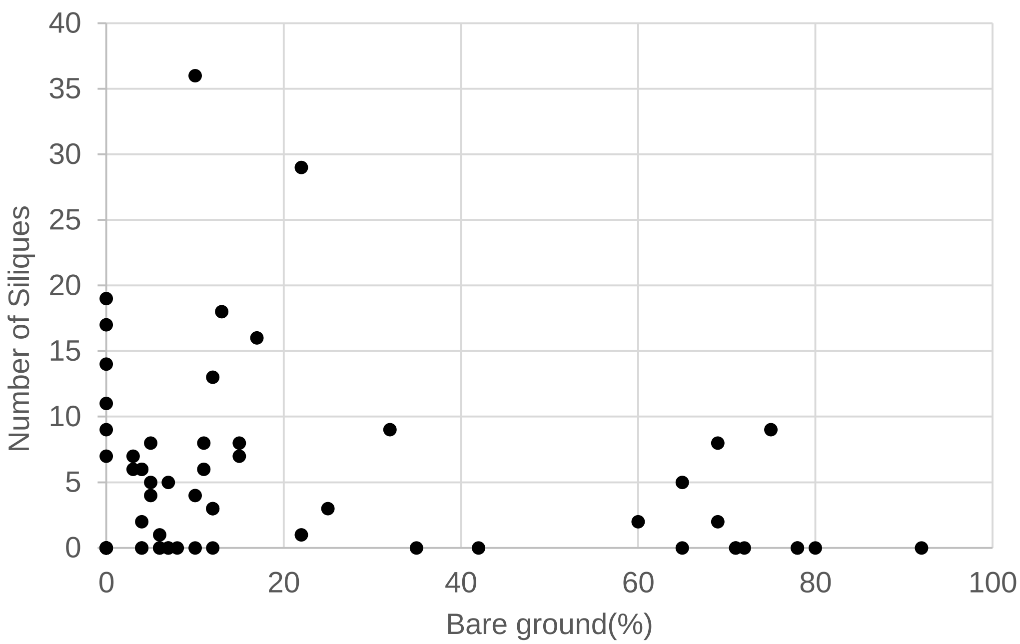

Figure 3.17. Relationship between number of siliques per individual *Halimolobos virgata* plants and bare ground (N=63, ρ=-0.081 p=0.529).

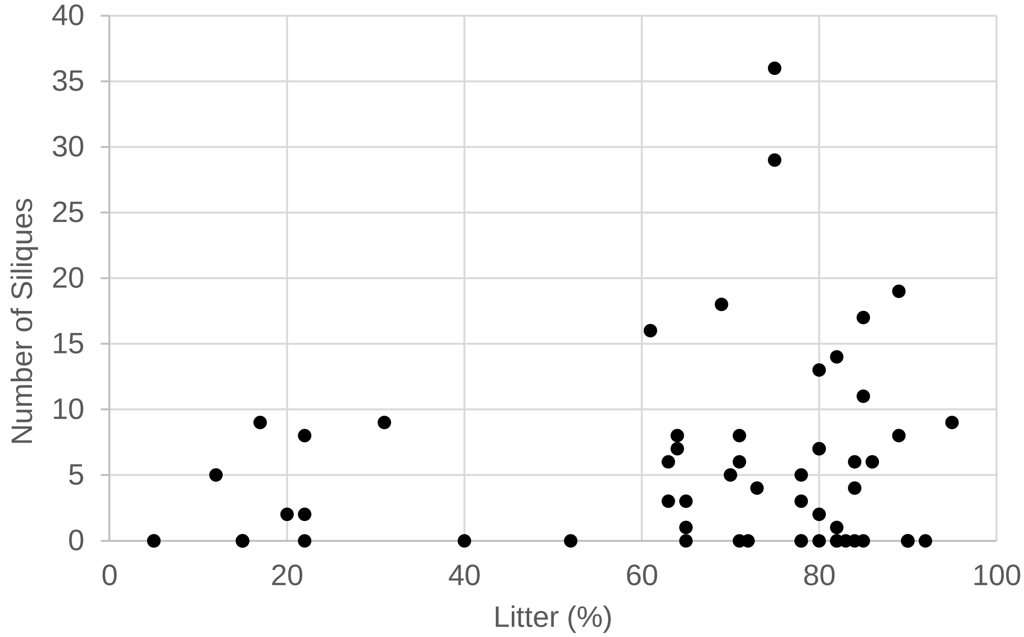

Figure 3.18. Relationship between number of siliques per individual *Halimolobos virgata* plants and litter (N=63, ρ=0.091, p=0.480).

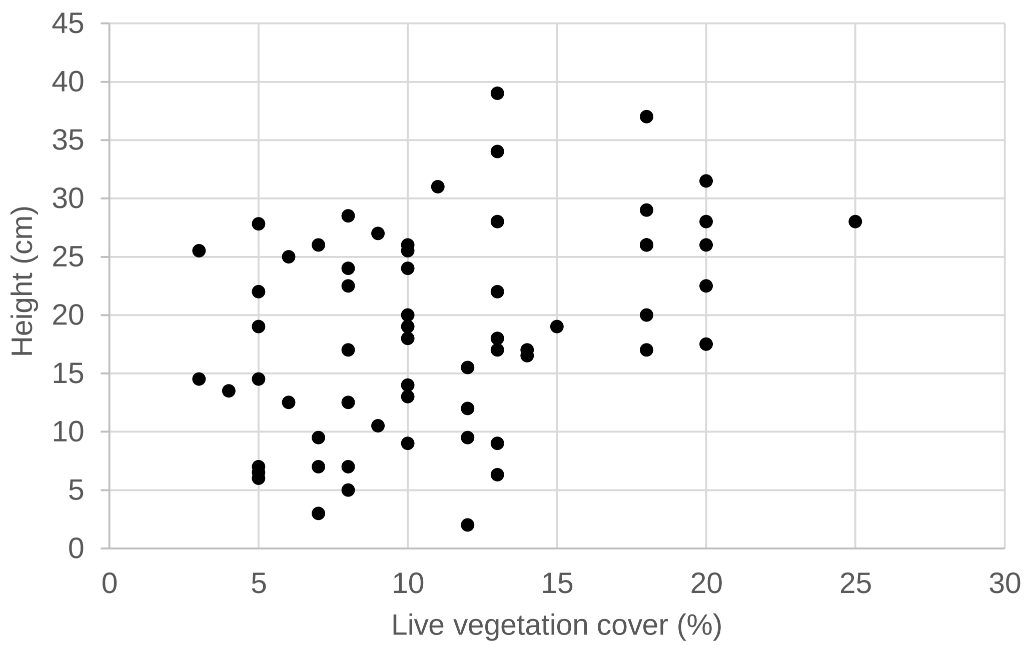

Figure 3.19. Relationship between height of individual *Halimolobos virgata* plants and live vegetation cover (N=63, ρ=0.384, p=0.002).

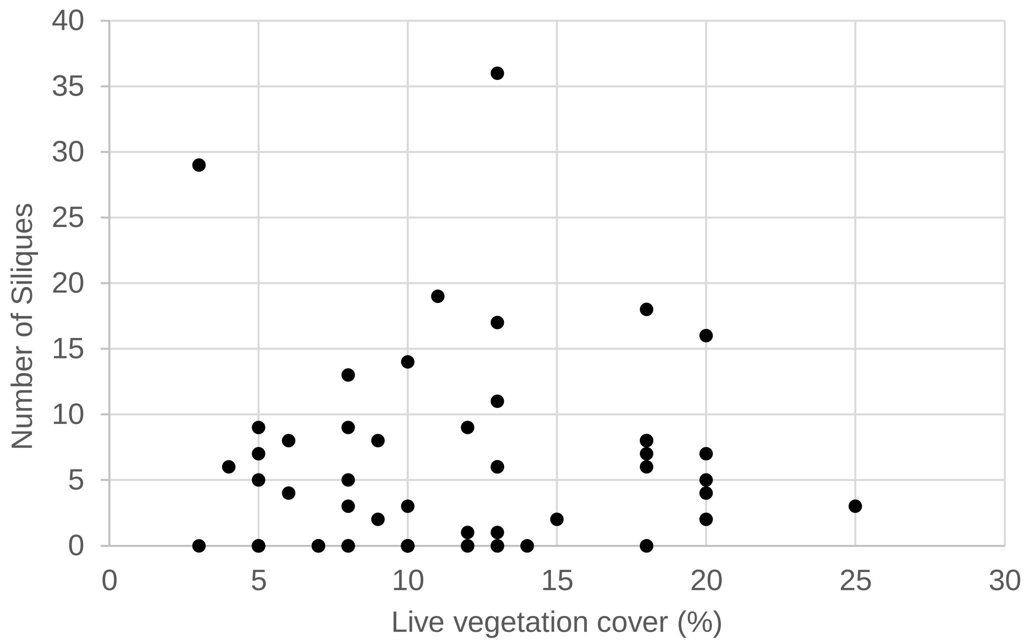

Figure 3.20. Relationship between number of siliques per individual *Halimolobos virgata* plants and live vegetation cover (N=63, ρ=0.172, p=0.179).

CHAPTER IV. SUMMARY AND FUTURE RESEARCH

1. SUMMARY

The objectives of this research were to investigate the impacts of pipeline disturbance on native dry mixed grass prairie, *Halimolobos virgata* (Nutt.) O.E. Schulz (slender mouse ear cress) and *Halimolobos virgata* habitat. Environment Canada recommends a non species specific set back of 300 m from species at risk for pipeline disturbances of any size on federal land; this research addressed the suitability of the 300 m set back by studying effects of distance to pipelines on *Halimolobos virgata*. Impacts to soil, vegetation and ground cover were studied on a right of way (ROW) between the different work areas and with distance from the pipeline centre up to 350 m away. Pipeline disturbance was studied at six sites along the Keystone Pipeline to account for differences in natural topography, pipeline construction techniques and management.

Impacts to chemical and physical soil properties, ground cover and vegetation from pipeline disturbance four and five growing seasons after construction were confined to the ROW when steep terrain and extensive grading were not factors. Top soil on the trench had lower organic matter, total inorganic carbon and percent saturation relative to other ROW areas. Impacts to organic carbon and saturation may cause some severe soil limitations on ROW according to soil quality criteria for reclamation. Impacts on electrical conductivity, pH and soluble salts varied with location from different construction conditions and underlying parent material. Five growing seasons after construction soil compaction on the ROW is still a concern. Penetration resistance before distance of effect (on ROW) was on average approximately 1 MPa greater than penetration resistance after distance of effect (off ROW). Ground cover and plant species composition were significantly impacted by pipeline disturbance and management; lack of grazing on the ROW caused a dissimilarity in ground cover and species composition. Ground cover showed signs of recovery on the ROW at some sites after five growing seasons. Whereas native plant species composition recovery appeared to be slower, key prairie species; *Artemisia cana*, *Opuntia polycantha* and *Selaginella densa,* were still absent from parts of the ROW.

Halimolobos virgata appears to favour areas with light disturbance and a micro habitat with soil properties different from the surrounding habitat. Soil texture, strength and water content are likely the most important components defining the micro habitat of *Halimolobos virgata.* No set back distance is likely needed between *Halimolobos virgata* and pipeline disturbance; pipeline disturbance did not have a significant impact on *Halimolobos virgata* and its habitat off ROW with typical construction methods. The ROW of pipeline disturbance may negatively impact *Halimolobos virgata* habitat up to five growing seasons after construction through soil compaction, introduction of competitive non native species and the alteration of habitat properties that influence soil water content.

2. MANAGEMENT IMPLICATIONS

No set back distance is required between *Halimolobos virgata* and pipeline disturbances, however pipeline routes should be carefully planned as the ROW and trench may negatively impact *Halimolobos virgata* habitat. Mitigation and appropriate management could reduce potential pipeline disturbance impacts on *Halimolobos virgata* habitat*.* Construction should be timed to not interfere with the growth and reproduction of plants and to reduce compaction; construction during winter months when the ground is frozen and/or dry would be beneficial. Weed cleaning stations during construction and management of invasive and weedy species after construction could help decrease the establishment of non native plant species and therefore the probability of *Halimolobos virgata* being outcompeted. Construction of one pipeline can lead to the creation of a transportation corridor with more pipeline disturbances in future. This is a concern as additional pipelines will increase the area impacted by the ROW. Long term effects of pipeline trenches and ROW on *Halimolobos virgata* habitat is unknown, therefore the impacts of additional pipelines to a corridor over time in *Halimolobos virgata* habitat may have the potential to impact populations. With increasing number of pipelines there is a greater chance of pipeline leaks which could potentially have detrimental effects on the habitat.

The location and surrounding terrain of the *Halimolobos virgata* population must be taken into account when planning pipeline routes. Pipeline disturbance crossing steep terrain results in more intensive construction methods and have greater impacts, some of which occur past the edge of the ROW. This is a potential issue for other species of concern or species sensitive to disturbance.

3. RESEARCH LIMITATIONS

Only one population of *Halimolobos* virgata was found along the pipeline disturbance during this study. Therefore conclusions concerning important micro habitat properties of *Halimolobos virgata* are based on one population. Additional populations with different surrounding habitat properties could provide for the detection of other important micro habitat properties.

Due to the unexpectedly high number of *Halimolobos virgata* plants and the time constraints in 2013, vegetation and ground cover assessments were not conducted for all plants found. More vegetation and ground cover assessments would have provided greater statistical power.

With limited soil samples from *Halimolobos virgata* plant locations, some trends concerning soil chemical properties may not have been detected.

This study was short over two summers with different precipitation and growing conditions which may have caused vegetation differences between years.

The short term of the study did not allow for trends in *Halimolobos virgata* populations to be studied as the plant can behave as an annual, a biennial or short lived perennial.

Surveys were conducted both summers for *Cryptantha minima* Rydb. (tiny cryptanthe) at Coulee and Highway. However no plants were located.

The different terrain and management of the six research sites resulted in sites being statistically analyzed individually. Statistical power could have been increased by reducing sites and increasing sampling.

4. FUTURE RESEARCH

This research addressed the effects of pipeline disturbance on native dry mixed grass prairie and one population of *Halimolobos virgata* and its habitat, four and five growing seasons after construction. Further research is needed to assess long term effects of pipeline disturbance. Long term studies would provide information on how different management practices impact the recovery time of native prairie, which would aid in creating best management practices.

Within five growing seasons, fencing of the ROW to protect it from cattle grazing significantly altered ground cover and plant community. Thus further research is needed on the long term effects of no grazing on recovery of disturbed sites and whether reintroduction of grazing will reverse the effects.

Studies on the recovery of native species is needed. Several important prairie species such as *Artemisia cana*, *Opuntia polycantha* and *Selaginella densa* were missing from the trench and parts of the ROW.

A study assessing potential habitat properties of *Halimolobos virgata* from several populations would aid in better defining important habitat properties over a range of landscapes and aid in habitat protection. Previous work in the research program by Candace Nemirsky along with this study has demonstrated that *Halimolobos virgata* inhabits a micro habitat or rim niche. Studying more populations would help determine if this is always the case or population specific.

Continual monitoring of *Halimolobos virgata* at the Hill research site is recommended to determine if *Halimolobos virgata* re establishes on the trench and whether it begins to have normal densities on the pipeline ROW. A study could be conducted on seed banks based on areas of the pipeline ROW and off ROW to determine whether there is a viable seed source on the ROW.

Longer studies are needed to determine if disturbances impact whether *Halimolobos virgata* favours an annual, biennial or short lived perennial life cycle.

Continued monitoring at Coulee is also recommended. Coulee had the greatest disturbance as a result of terrain, therefore, it would be valuable to monitor this site to determine whether the greater disturbance or natural fluctuations in *Halimolobos virgata* resulted in no plants being found during this study.

The number of *Halimolobos virgata* plants varied each summer since pipeline construction. Precipitation varied from below normal to well above normal, but no noticeable correlations between total precipitation and *Halimolobos virgata* were apparent. A study with a weather station located on site would help understand the connection between amount of precipitation and *Halimolobos virgata* density and timing of precipitation events which may be more important for germination and establishment of *Halimolobos virgata*. If combined with soil water monitoring at *Halimolobos virgata* plant locations, it could be determined whether potential habitat properties are important because they impact soil water or provide other habitat essentials.

Soil strength and soil water content appeared to be important habitat properties for *Halimolobos virgata*. A greenhouse study could help determine ranges of these properties tolerated by *Halimolobos virgata*. Understanding soil strength limits will be important to future disturbances in *Halimolobos virgata* habitat.

Continued monitoring for *Cryptantha minima* is recommended, along with habitat and populations studies away from pipeline disturbances to better understand the impacts of pipeline disturbance on *Cryptantha minima* and its habitat.

APPENDIX. SUPPLEMENTARY DATA

Table A1. P-values of 0 to 5 cm soil chemical properties between areas of the pipeline right of way and site.

	Ammonium (mg/kg)	Cation exchange capacity (meq/100g)	Carbon to nitrogen ratio	Total nitrogen (%)	Organic matter (%)	Total carbon (%)	Total organic carbon (%)	Reaction (pH)	Electrical conductivity (dS/m)	Saturation (%)	Soluble calcium (mg/kg)	Soluble magnesium (mg/kg)	Soluble sodium (mg/kg)	Soluble potassium (mg/kg)
Area	0.408	0.432	0.070	0.906	0.005	0.375	0.005	0.002	0.139	0.003	0.119	0.369	0.387	0.210
Site	<0.001	<0.001	0.038	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.068	0.000
Area:Site	0.687	0.686	0.703	0.594	0.603	0.409	0.605	0.016	0.054	0.214	0.001	0.006	0.899	0.017
Area														
Trench:Storage	-	-	-	-	0.045	-	0.045	-	-	0.003	-	-	-	-
Work:Storage	-	-	-	-	0.656	-	0.657	-	-	0.702	-	-	-	-
Work:Trench	-	-	-	-	0.005	-	0.005	-	-	0.023	-	-	-	-
Area:Site														
McNeil:Trench - McNeil:Storage	-	-	-	-	-	-	-	-	-	-	-	-	-	0.392
McNeil:Work-McNeil:Storage	-	-	-	-	-	-	-	-	-	-	-	-	-	0.067
McNeil:Work-McNeil:Trench	-	-	-	-	-	-	-	-	-	-	-	-	-	0.013
Remount Lowland:Trench-Remount Lowland:Storage	-	-	-	-	-	-	-	0.837	-	-	0.837	0.025	-	-
Remount Lowland:Work-Remount Lowland:Storage	-	-	-	-	-	-	-	0.001	-	-	0.001	0.003	-	-
Remount Lowland:Work-Remount Lowland:Trench	-	-	-	-	-	-	-	0.001	-	-	0.001	0.181	-	-

Table A2. P-values of 5 to 15 cm soil chemical properties between areas of the pipeline right of way and site.

	Ammonium (mg/kg)	Cation exchange capacity (meq/100g)	Carbon to nitrogen ratio	Total nitrogen (%)	Organic matter (%)	Total carbon (%)	Total organic carbon (%)	Reaction (pH)	Electrical conductivity (dS/m)	Saturation (%)	Soluble calcium (mg/kg)	Soluble magnesium (mg/kg)	Soluble sodium (mg/kg)	Soluble potassium (mg/kg)
Area	0.909	0.919	0.840	0.732	0.785	0.871	0.793	0.043	0.031	0.965	0.105	0.056	0.146	0.002
Site	<0.001	<0.001	0.145	0.310	<0.001	<0.001	<0.001	0.718	0.075	<0.001	0.018	0.086	0.024	<0.001
Area:Site	0.881	0.872	0.525	0.316	0.280	0.561	0.282	0.017	0.196	0.781	0.016	0.104	0.567	0.001
Area														
Trench:Storage	-	-	-	-	-	-	-	-	0.031	-	-	-	-	-
Work:Storage	-	-	-	-	-	-	-	-	0.808	-	-	-	-	-
Work:Trench	-	-	-	-	-	-	-	-	0.121	-	-	-	-	-
Area:Site														
Coulee Upland:Trench -Coulee Upland:Storage	-	-	-	-	-	-	-	0.043	-	-	0.000	-	-	0.002
Coulee Upland:Work-Coulee Upland:Storage	-	-	-	-	-	-	-	0.718	-	-	0.863	-	-	0.222
Coulee Upland:Work-Coulee Upland:Trench	-	-	-	-	-	-	-	0.017	-	-	0.000	-	-	0.015
McNeil:Trench - McNeil:Storage	-	-	-	-	-	-	-	0.040	-	-	0.017	-	-	-
McNeil:Work-McNeil:Storage	-	-	-	-	-	-	-	0.104	-	-	0.163	-	-	-
McNeil:Work-McNeil:Trench	-	-	-	-	-	-	-	0.736	-	-	0.226	-	-	-
Remount Lowland:Trench-Remount Lowland:Storage	-	-	-	-	-	-	-	0.035	-	-	0.791	-	-	-
Remount Lowland:Work-Remount Lowland:Storage	-	-	-	-	-	-	-	0.002	-	-	0.024	-	-	-
Remount Lowland:Work-Remount Lowland:Trench	-	-	-	-	-	-	-	<0.001	-	-	0.052	-	-	-

Table A3. P-values for distance of effect of soil chemical properties for 0 to 5 cm.

Property	Site	Distance of Effect (m)	P-value	Mean (Before)	Mean (After)
Ammonium (mg/kg)	Overall	35	0.0347	2402	2647
Cation Exchange Capacity (meg/100g)	Overall	35	0.0348	17.14	18.89
Carbon to Nitrogen Ratio	Remount Lowland	24	0.0074	8.08	10.72
Organic Matter (%)	Overall	29	0.0096	3.75	4.60
	Hill	9	0.0014	2.20	3.28
	Remount Lowland	28	0.0304	4.24	5.75
Total Inorganic Carbon (%)	Overall	32	0.0170	0.20	0.12
	Remount Lowland	16	0.0091	0.14	0.05
Total Organic Carbon (%)	Overall	29	0.0097	1.88	2.30
	Hill	11	0.0015	1.10	1.64
	Remount Lowland	28	0.0302	2.12	2.88
Reaction (pH)	Overall	27	0.0002	7.18	6.79
	Coulee	35	0.0440	7.63	7.20
	Coulee Upland	28	0.0104	6.53	6.03
	Hill	15	0.0015	7.78	7.31
	Remount Lowland	21	0.0003	7.21	6.37
Electrical Conductivity (dS/m)	Overall	20	0.0123	0.48	0.40
	Remount Lowland	21	0.0197	0.54	0.35
Saturation (%)	Overall	28	0.0078	59.14	64.38
	Coulee	34	0.0431	46.25	54.00
	McNeil	18	0.0050	54.56	61.33
Magnesium (mg/kg)	Remount Lowland	19	0.0399	13.26	8.23
Sodium (mg/kg)	Remount Lowland	7	0.0430	4.00	2.17

Table A4. Regression results for linear models for ammonium (mg/kg) 0 to 5 cm.

Site	Intercept	Slope	P-value
Coulee	1925.12	1.11	0.254
Coulee Upland	3081.74	-1.32	0.044
Hill	1821.01	7.31	<0.001
Highway	2712.09	-0.53	0.599
McNeil	2390.55	0.16	0.655
Remount Lowland	2797.25	0.16	0.835

Table A5. Regression results for linear models for cation exchange capacity (meq/100g) 0 to 5 cm.

Site	Intercept	Slope	P-value
Coulee	13.75	0.01	0.260
Coulee Upland	21.99	-0.01	0.046
Hill	13.01	0.05	<0.001
Highway	19.35	0.00	0.599
McNeil	17.06	0.00	0.652
Remount Lowland	19.97	0.00	0.844

Table A6. Regression results for linear models for calcium (mg/kg) 0 to 5 cm.

Site	Intercept	Slope	P-value
Overall	32.37	-0.03	0.070
Coulee	30.55	-0.03	0.212
Coulee Upland	31.88	-0.05	0.264
Hill	29.53	0.03	0.320
Highway	51.04	-0.05	0.078
McNeil	17.17	0.00	0.866
Remount Lowland	34.07	-0.06	0.136

Table A7. Regression results for linear models for potassium (mg/kg) 0 to 5 cm.

Site	Intercept	Slope	P-value
Overall	4.12	-0.01	0.424
Coulee	1.45	0.00	0.255
Coulee Upland	1.64	0.00	0.424
Hill	14.84	-0.02	0.575
Highway	2.34	0.00	0.392
McNeil	1.46	0.00	0.552

Table A8. Regression results for linear models for carbon to nitrogen ration 0 to 5 cm.

Site	Intercept	Slope	P-value
Coulee	10.62	0.00	0.978
Coulee Upland	11.21	-0.01	0.199
Hill	10.20	0.00	0.917
Highway	9.63	0.00	0.719
McNeil	10.12	-0.01	0.330

Table A9. Regression results for linear models for organic matter (%) 0 to 5 cm.

Site	Intercept	Slope	P-value
Coulee	3.02	0.00	0.623
Coulee Upland	7.20	-0.01	0.009
Highway	3.96	0.00	0.589
McNeil	3.30	0.00	0.987

Table A10. Regression results for linear models for total inorganic carbon (%) 0 to 5 cm.

Site	Intercept	Slope	P-value
Coulee	0.28	0.00	0.132
Coulee Upland	0.06	0.00	0.221
Hill	0.20	0.00	0.495
Highway	0.46	0.00	0.095
McNeil	0.03	0.00	0.646

Table A11. Regression results for linear models for total organic carbon (%) 0 to 5 cm.

Site	Intercept	Slope	P-value
Coulee	1.51	0.00	0.617
Coulee Upland	3.60	0.00	0.009
Highway	1.98	0.00	0.591
McNeil	1.65	0.00	0.977

Table A12. Regression results for linear models for reaction (pH) 0 to 5 cm.

Site	Intercept	Slope	P-value
Highway	7.54	0.00	0.133
McNeil	6.79	0.00	0.004

Table A13. Regression results for linear models for electrical conductivity (dS/m) 0 to 5 cm.

Site	Intercept	Slope	P-value
Coulee	0.48	0.00	0.037
Coulee Upland	0.39	0.00	0.126
Hill	0.52	0.00	0.810
Highway	0.56	0.00	0.451
McNeil	0.28	0.00	0.456

Table A14. Regression results for linear models for saturation (%) 0 to 5 cm.

Site	Intercept	Slope	P-value
Coulee Upland	75.14	-0.05	0.015
Hill	53.51	0.07	<0.001
Highway	65.96	0.00	0.913
Remount Lowland	65.01	0.01	0.716

Table A15. Regression results for linear models for magnesium (mg/kg) 0 to 5 cm.

Site	Intercept	Slope	P-value
Overall	9.41	0.00	0.610
Coulee	8.32	-0.01	0.478
Coulee Upland	9.46	-0.01	0.465
Hill	8.87	0.02	0.033
Highway	13.35	0.00	0.728
McNeil	5.13	0.00	0.912

Table A16. Regression results for linear models for sodium (mg/kg) 0 to 5 cm.

Site	Intercept	Slope	P-value
Overall	4.12	-0.01	0.424
Coulee	1.45	0.00	0.255
Coulee Upland	1.64	0.00	0.424
Hill	14.84	-0.02	0.575
Highway	2.34	0.00	0.392
McNeil	1.46	0.00	0.552

Table A17. P-values for distance of effect of soil chemical properties for 5 to 15 cm.

Property	Site	Distance of Effect (m)	P-value	Mean (Before)	Mean (After)
Carbon to Nitrogen Ratio	Coulee Upland	50	0.037	11.61	7.25
Total Inorganic Carbon (%)	Remount Lowland	6	0.031	0.48	0.03
Reaction (pH)	Overall	19	<0.001	7.44	7.07
	Coulee Upland	9	0.030	6.90	6.41
	McNeil	17	0.005	7.17	6.77
	Remount Lowland	14	<0.001	7.63	6.78
Electrical Conductivity (dS/m)	Overall	13	0.001	0.51	0.37
	Coulee Upland	6	<0.001	0.58	0.27
	McNeil	10	0.010	0.48	0.26
	Remount Lowland	15	<0.001	0.45	0.28
Saturation (%)	Coulee Upland	6	0.035	64.00	55.72
Soluble Calcium (mg/kg)	Overall	17	0.022	26.84	21.73
	Coulee Upland	6	<0.001	46.33	14.81
	McNeil	11	0.009	29.98	15.52
	Remount Lowland	16	0.001	24.60	15.23
Soluble Magnesium (mg/kg)	Overall	17	0.032	8.77	7.17
	Coulee Upland	6	<0.001	12.10	4.56
	McNeil	12	0.007	10.35	4.40
	Remount Lowland	14	0.001	9.72	6.02
Soluble Sodium (mg/kg)	Coulee Upland	9	0.042	2.67	1.33
	McNeil	19	0.011	3.22	1.20

Table A18. Regression results for linear models for ammonium (mg/kg) 5 to 15 cm.

Site	Intercept	Slope	P-value
Overall	2197.85	1.32	0.001
Coulee	1705.50	1.13	0.174
Coulee Upland	2581.00	0.02	0.971
Hill	1612.67	7.53	<0.001
Highway	2450.76	-1.21	0.079
McNeil	2239.81	-0.10	0.715
Remount Lowland	2597.00	0.55	0.384

Table A19. Regression results for linear models for cation exchange capacity (meq/100g) 5 to 15 cm.

Site	Intercept	Slope	P-value
Overall	2197.85	1.32	0.001
Coulee	1705.50	1.13	0.174
Coulee Upland	2581.00	0.02	0.971
Hill	1612.67	7.53	<0.001
Highway	2450.76	-1.21	0.079
McNeil	2239.81	-0.10	0.715
Remount Lowland	2597.00	0.55	0.384

Table A20. Regression results for linear models for total nitrogen (%) 5 to 15 cm.

Site	Intercept	Slope	P-value
Overall	0.17	0.00	0.716
Coulee	0.15	0.00	0.812
Coulee Upland	0.21	0.00	0.489
Hill	0.14	0.00	0.441
Highway	0.20	0.00	0.361
McNeil	0.18	0.00	0.206
Remount Lowland	0.18	0.00	0.822

Table A21. Regression results for linear models for organic matter (%) 5 to 15 cm.

Site	Intercept	Slope	P-value
Overall	2.63	0.00	0.303
Coulee	2.29	0.00	0.954
Coulee Upland	3.72	0.00	0.002
Hill	1.89	0.00	0.011
Highway	2.82	0.00	0.588
McNeil	2.56	0.00	0.008
Remount Lowland	2.51	0.00	0.260

Table A22. Regression results for linear models for total organic carbon (%) 5 to 15 cm.

Site	Intercept	Slope	P-value
Overall	1.31	0.00	0.306
Coulee	1.15	0.00	0.969
Coulee Upland	1.86	0.00	0.00173
Hill	0.94	0.00	0.012
Highway	1.41	0.00	0.597
McNeil	1.28	0.00	0.007
Remount Lowland	1.25	0.00	0.256

Table A23. Regression results for linear models for potassium (mg/kg) 5 to 15 cm.

Site	Intercept	Slope	P-value
Overall	7.63	0.00	0.321
Coulee	10.38	-0.02	0.140
Coulee Upland	14.96	-0.03	0.001
Hill	4.26	0.03	0.002
McNeil	5.42	0.00	0.330
Remount Lowland	4.67	0.00	0.826

Table A24. Regression results for linear models for carbon to nitrogen ration 5 to 15 cm.

Site	Intercept	Slope	P-value
Overall	9.27	0.00	0.409
Coulee	8.81	0.00	0.987
Hill	9.03	0.00	0.962
Highway	7.85	0.00	0.709
McNeil	11.44	-0.01	0.559
Remount Lowland	7.61	0.00	0.733

Table A25. Regression results for linear models for total inorganic carbon (%) 5 to 15 cm.

Site	Intercept	Slope	P-value
Overall	0.28	0.00	0.521
Coulee	0.33	0.00	0.814
Coulee Upland	0.04	0.00	0.036
Hill	0.35	0.00	0.830
Highway	0.81	0.00	0.249
McNeil	0.06	0.00	0.194

Table A26. Regression results for linear models for reaction (pH) 5 to 15 cm.

Site	Intercept	Slope	P-value
Coulee	7.63	0.00	0.051
Hill	7.70	0.00	0.993
Highway	7.65	0.00	0.358

Table A27. Regression results for linear models for electrical conductivity (dS/m) 5 to 15 cm.

Site	Intercept	Slope	P-value
Coulee	0.52	0.00	0.190
Hill	0.53	0.00	0.934
Highway	0.53	0.00	0.934

Table A28. Regression results for linear models for saturation (%) 5 to 15 cm.

Site	Intercept	Slope	P-value
Overall	52.32	0.02	0.001
Coulee	43.43	0.02	0.134
Hill	47.01	0.11	<0.001
Highway	59.53	0.00	0.888
McNeil	51.82	0.00	0.539
Remount Lowland	54.05	0.02	0.183

Table A29. Regression results for linear models for calcium (mg/kg) 5 to 15 cm.

Site	Intercept	Slope	P-value
Coulee	28.12	-0.02	0.494
Hill	19.86	0.06	0.005
Highway	36.60	0.00	0.876

Table A30. Regression results for linear models for magnesium (mg/kg) 5 to 15 cm.

Site	Intercept	Slope	P-value
Coulee	8.92	-0.01	0.554
Hill	6.54	0.03	0.001
Highway	11.35	0.00	0.793

Table A31. Regression results for linear models for sodium (mg/kg) 5 to 15 cm.

Site	Intercept	Slope	P-value
Overall	6.42	0.00	0.717
Coulee	3.42	-0.01	0.554
Hill	23.58	0.00	0.985
Remount Lowland	4.45	-0.01	0.228

Table A32. P-values for 0 to 5 cm and 5 to 15 cm soil physical properties between areas of the pipeline right of way.

	0 to 5 cm			5 to 15 cm		
	Sand	Silt	Clay	Sand	Silt	Clay
Area	0.502	0.045	0.006	0.331	0.520	0.073
Site	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Area:Site	0.356	0.317	0.205	0.848	0.706	0.934
Area						
Trench:Storage	-	0.044	0.018	-	-	-
Work:Storage	-	0.803	0.978	-	-	-
Work:Trench	-	0.161	0.011	-	-	-

Table A33. P-values for distance of effect of soil physical properties for 0 to 5 cm.

Particle Size	Site	Distance of Effect (m)	P-value	Mean (Before)	Mean (After)
Sand	Coulee Upland	50	0.0111	34.6	38.4
Silt	Coulee Upland	56	0.0126	50.3	45.8
	Remount Lowland	6	0.0340	36.6	47.5
Clay	McNeil	25	0.0163	13.6	12.1

Table A34. Regression results for linear models for sand 0 to 5 cm.

Site	Intercept	Slope	P-value
Overall	45.36	-0.01	0.064
Coulee	59.09	-0.04	0.084
Hill	51.29	-0.08	<0.001
Highway	38.44	0.01	0.218
McNeil	51.43	0.00	0.940
Remount Lowland	36.95	-0.01	0.596

Table A35. Regression results for linear models for silt 0 to 5 cm.

Site	Intercept	Slope	P-value
Overall	40.95	0.00	0.587
Coulee	29.55	0.03	0.117
Hill	39.76	0.01	0.171
Highway	44.85	-0.01	0.573
McNeil	35.66	0.00	0.466

Table A36. Regression results for linear models for clay 0 to 5 cm.

Site	Intercept	Slope	P-value
Overall	13.69	0.01	<0.001
Coulee	11.36	0.01	0.064
Coulee Upland	14.47	0.01	0.175
Hill	8.96	0.07	0.000
Highway	16.71	-0.01	0.065
Remount Lowland	17.73	0.00	0.411

Table A37. P-values for distance of effect of soil physical properties for 5 to 15 cm.

Particle Size	Site	Distance of Effect (m)	P-value	Mean (Before)	Mean (After)
Sand	Coulee Upland	22	0.016	33.6	36.6
	Remount Lowland	57	0.022	38.7	33.1
Silt	Coulee Upland	25	0.004	49.4	45.1
	Remount Lowland	25	0.002	38.4	43.5
Clay	Hill	25	0.046	10.8	18.5

Table A38. Regression results for linear models for sand 5 to 15 cm.

Site	Intercept	Slope	P-value
Overall	46.60	-0.02	0.054
Coulee	62.60	-0.04	0.100
Hill	52.71	-0.08	<0.001
Highway	38.38	0.02	0.180
McNeil	52.72	-0.01	0.345

Table A39. Regression results for linear models for silt 5 to 15 cm.

Site	Intercept	Slope	P-value
Overall	38.41	0.00	0.849
Coulee	26.22	0.02	0.185
Hill	38.21	0.00	0.810
Highway	42.26	-0.01	0.574
McNeil	34.69	0.00	0.643

Table A40. Regression results for linear models for clay 5 to 15 cm.

Site	Intercept	Slope	P-value
Overall	14.99	0.02	<0.001
Coulee	11.17	0.02	0.028
Coulee Upland	17.14	0.01	0.024
Highway	19.36	-0.01	0.029
McNeil	12.60	0.00	0.093
Remount Lowland	20.58	0.01	0.392

Table A41. P-values for 5 and 10 cm penetration resistance (MPa) and maximum penetration depth (cm) between different areas of the pipeline right of way.

	Penetration Resistance		Maximum
	5 cm	10 cm	Depth
Area	0.001	0.893	<0.001
Site	0.454	0.052	0.040
Area:Site	0.017	0.022	0.016
Area			
Trench:Storage	-	-	-
Work:Storage	-	-	-
Work:Trench	-	-	-
Area:Site			
Coulee:Trench-Coulee:Storage	-	-	-
Coulee:Work-Coulee:Storage	-	-	-
Coulee:Work-Coulee:Trench	-	-	-
Coulee Upland:Trench-Coulee Upland:Storage	0.012	0.001	0.005
Coulee Upland:Work-Coulee Upland:Storage	0.815	0.672	0.513
Coulee Upland:Work-Coulee Upland:Trench	0.023	0.001	0.016
Highway:Trench-Highway:Storage	-	-	-
Highway:Work-Highway:Storage	-	-	-
Highway:Work-Highway:Trench	-	-	-
Hill:Trench-Hill:Storage	-	-	0.933
Hill:Work-Hill:Storage	-	-	0.067
Hill:Work-Hill:Trench	-	-	0.043
McNeil:Trench-McNeil:Storage	0.003	0.004	<0.001
McNeil:Work-McNeil:Storage	0.025	0.032	0.002
McNeil:Work-McNeil:Trench	0.180	0.234	0.057
Remount Lowland:Trench-Remount Lowland:Storage	-	-	0.135
Remount Lowland:Work-Remount Lowland:Storage	-	-	0.153
Remount Lowland:Work-Remount Lowland:Trench	-	-	0.010

Table A42. P-values for distance of effect of 5 and 10 cm penetration resistance and maximum depth of penetration.

	Site	Distance of Effect (m)	P-value	Mean (Before)	Mean (After)
5 cm (MPa)	Overall	22	<0.001	3.1	2.2
	Coulee	35	<0.001	3.3	2.5
	Coulee Upland	6	<0.001	3.5	2.6
	Hill	19	<0.001	3.2	1.8
	Highway	24	<0.001	2.9	2.0
	McNeil	23	<0.001	3.3	1.8
	Remount Lowland	16	<0.001	3.4	2.5
10 cm (MPa)	Overall	21	<0.001	3.8	3.1
	Coulee	35	0.007	4.1	3.5
	Coulee Upland	6	<0.001	4.4	3.4
	Hill	19	<0.001	3.3	2.6
	Highway	24	<0.001	4.1	3.2
	McNeil	24	<0.001	3.1	2.0
	Remount Lowland	16	<0.001	4.8	3.6
Max Depth (cm)	All	18	<0.001	15	20
	Coulee	35	<0.001	14	20
	Coulee Upland	7	<0.001	14	19
	Hill	5	<0.001	12	20
	Highway	30	<0.001	15	20
	McNeil	22	<0.001	15	20
	Remount Lowland	9	<0.001	13	20

Table A43. P-values for ground cover (%) between areas of the pipeline right of way.

	2012			2013		
	Bare Ground	Litter	Live	Bare Ground	Litter	Live
Area	<0.001	<0.001	<0.001	0.001	0.041	<0.001
Site	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
Area:Site	<0.001	<0.001	<0.001	0.197	0.180	0.102
Area						
Trench:Storage	-	-	-	0.001	0.039	<0.001
Work:Storage	-	-	-	0.869	0.773	0.991
Work:Trench	-	-	-	0.004	0.158	<0.001
Area:Site						
Coulee:Trench-Coulee:Storage	<0.001	<0.001	-	-	-	-
Coulee:Work-Coulee:Storage	0.026	0.016	-	-	-	-
Coulee:Work-Coulee:Trench	0.023	0.031	-	-	-	-
Coulee Upland:Trench-Coulee Upland:Storage	0.073	0.047	0.006	-	-	-
Coulee Upland:Work-Coulee Upland:Storage	0.989	0.799	0.126	-	-	-
Coulee Upland:Work-Coulee Upland:Trench	0.061	0.022	0.082	-	-	-
Hill:Trench-Hill:Storage	-	-	0.809	-	-	-
Hill:Work-Hill:Storage	-	-	0.047	-	-	-
Hill:Work-Hill:Trench	-	-	0.022	-	-	-
McNeil:Trench-McNeil:Storage	-	-	<0.001	-	-	-
McNeil:Work-McNeil:Storage	-	-	0.001	-	-	-
McNeil:Work-McNeil:Trench	-	-	0.014	-	-	-
Remount Lowland:Trench-Remount Lowland:Storage	<0.001	0.004	0.018	-	-	-
Remount Lowland:Work-Remount Lowland:Storage	0.431	0.138	0.092	-	-	-
Remount Lowland:Work-Remount Lowland:Trench	0.001	0.051	0.002	-	-	-

Table A44. P-values for difference in ground cover (%) from 2012 to 2013 on pipeline right of way.

			Live			Litter			Bare Ground	
Site	Area	P-value	2012	2013	P-value	2012	2013	P-value	2012	2013
Coulee	Storage	0.888	15 (5)	14 (6)	0.451	74 (12)	63 (18)	0.532	11 (12)	21 (23)
	Trench	0.751	7 (6)	8 (1)	0.179	13 (11)	46 (29)	0.158	80 (16)	46 (28)
	Work	0.535	13 (2)	12 (3)	0.407	41 (3)	50 (14)	0.418	45 (3)	36 (16)
Coulee Upland	Storage	0.958	19 (4)	19 (3)	0.823	79 (4)	80 (5)	0.565	2 (2)	1 (2)
	Trench	0.150	9 (1)	12 (3)	0.235	91 (2)	87 (4)	0.640	0 (1)	1 (2)
	Work	0.078	14 (2)	17 (2)	0.745	77 (7)	78 (5)	0.444	9 (8)	4 (6)
Hill	Storage	0.399	15 (4)	12 (2)	0.234	62 (10)	72 (3)	0.189	23 (7)	14 (5)
	Trench	0.799	13 (4)	12 (1)	0.935	32 (18)	34 (26)	0.964	55 (22)	54 (26)
	Work	0.229	24 (3)	18 (6)	0.431	53 (4)	63 (17)	0.626	21 (8)	17 (12)
Highway	Storage	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Trench	0.400	12 (2)	15 (5)	0.377	26 (19)	40 (16)	0.266	62 (19)	45 (13)
	Work	0.786	22 (7)	24 (6)	0.902	49 (8)	48 (9)	0.992	27 (12)	27 (13)
McNeil	Storage	0.060	24 (1)	21 (2)	0.210	55 (20)	75 (4)	0.271	21 (21)	3 (3)
	Trench	0.362	10 (1)	9 (1)	0.058	47 (1)	74 (12)	0.055	43 (2)	17 (12)
	Work	0.740	15 (2)	15 (1)	0.047	71 (4)	80 (3)	0.064	14 (5)	4 (3)
Remount Lowland	Storage	0.642	20 (1)	22 (7)	0.190	66 (5)	61 (3)	0.561	13 (5)	15 (4)
	Trench	0.380	10 (4)	13 (2)	0.212	38 (10)	48 (3)	0.056	48 (6)	37 (2)
	Work	0.909	27 (4)	26 (8)	0.122	54 (3)	64 (7)	0.030	19 (4)	8 (3)

Numbers are means with standard deviations in brackets.

Table A45. P-values for distance of effect of ground cover (%) in 2012.

	Site	Distance of Effect (m)	P-value	Mean (Before)	Mean (After)
Live	Overall	4	<0.001	12.5	20.1
		30	0.004	20.1	22.8
	Coulee	4	0.009	9.9	15.9
		30	0.015	15.9	21.6
	Coulee Upland	6	<0.001	12.6	19.1
	Hill	3	0.016	15.1	20.8
	Highway	8	<0.001	15.1	20.8
	McNeil	20	<0.001	13.3	25.1
	Remount Lowland	4	<0.001	13.3	25.1
Litter	Overall	4	<0.001	52.4	65.3
	Coulee	10	<0.001	34.0	60.2
	Coulee Upland	5	<0.001	86.1	74.7
	Hill	4	<0.001	39.5	67.1
	Highway	3	0.001	22.4	55.5
	Remount Lowland	3	0.032	45.8	63.9
Bare Ground	Overall	3	<0.001	40.3	16.7
		22	<0.001	16.7	6.4
	Coulee	11	<0.001	54.1	15.2
	Hill	4	<0.001	44.2	10.1
	Highway	5	0.001	48.2	15.9
	McNeil	4	0.009	48.2	15.9
	Remount Lowland	3	0.001	41.9	9.1

Table A46. P-values for distance of effect of ground cover (%) in 2013.

	Site	Distance of Effect (m)	P-value	Mean (Before)	Mean (After)
Live	Overall	68	<0.001	18.5	24.9
	Coulee	26	<0.001	11.9	18.8
	Coulee Upland	50	0.005	17.7	22.8
	Hill	4	0.006	12.9	17.5
	Highway	3	<0.001	14.3	23.6
	McNeil	81	0.001	19.8	35.3
Litter	Overall	5	0.016	62.3	68.1
	Coulee	100	0.007	54.9	68.1
	Coulee Upland	4	<0.001	85.0	74.9
	Hill	3	0.001	40.3	71.5
	Highway	22	0.001	46.5	64.6
	McNeil	99	0.001	74.6	57.7
	Remount Lowland	11	<0.001	58.1	71.8
Bare Ground	Overall	4	<0.001	24.2	7.9
	Coulee	9	0.001	38.7	17.3
	Hill	4	<0.001	39.5	8.1
	Highway	18	<0.001	32.1	9.4
	Remount Lowland	4	<0.001	29.9	3.1

Table A47. Regression results for individual linear models for ground cover.

Ground Cover	Site	Intercept	Slope	P-value
Litter 2012	McNeil	64.7	0.0	0.158
Bare ground 2012	Coulee Upland	4.2	0.01	0.329
Live 2013	Remount Lowland	23.3	0.00	0.990
Bare ground 2013	Coulee Upland	1.9	0.01	0.071
	McNeil	4.8	-0.01	0.614

Table A48. P-values for native and non native species cover (%) between different areas of the pipeline right of way.

	2012		2013	
	Native	Non Native	Native	Non Native
Area	<0.001	0.373	<0.001	0.776
Site	0.012	0.758	<0.001	0.064
Area:Site	0.001	0.207	0.102	0.994
Area				
Trench:Storage	-	-	<0.001	-
Work:Storage	-	-	0.983	-
Work:Trench	-	-	0.000	-
Area:Site				
Coulee Upland:Trench-Coulee Upland:Storage	0.008	-	-	-
Coulee Upland:Work-Coulee Upland:Storage	0.163	-	-	-
Coulee Upland:Work-Coulee Upland:Trench	0.088	-	-	-
McNeil:Trench-McNeil:Storage	<0.001	-	-	-
McNeil:Work-McNeil:Storage	0.006	-	-	-
McNeil:Work-McNeil:Trench	0.015	-	-	-
Remount Lowland:Trench-Remount Lowland:Storage	0.070	-	-	-
Remount Lowland:Work-Remount Lowland:Storage	0.032	-	-	-
Remount Lowland:Work-Remount Lowland:Trench	0.002	-	-	-

Table A49. P-values for difference in native and non native (%) from 2012 to 2013 on pipeline right of way.

		Native			Non Native		
		p-value	2012 mean	2013 mean	P-value	2012 mean	2013 mean
Coulee	Storage	0.230	32 (18)	14 (5)	0.423	0.0 (0.0)	7.3 (12.7)
	Trench	0.950	7 (6)	7 (4)	0.446	1.1 (0.7)	7.4 (11.7)
	Work	0.683	15 (3)	16 (2)	0.338	0.3 (0.4)	1.4 (1.6)
Coulee Upland	Storage	0.888	23 (5)	22 (5)	0.357	0.9 (0.3)	2.4 (2.3)
	Trench	0.222	12 (2)	15 (3)	0.072	0.2 (0.3)	0.7 (0.3)
	Work	0.061	18 (1)	20 (1)	0.368	0.5 (0.5)	1.6 (1.6)
Hill	Storage	0.635	20 (7)	22 (3)	0.543	0.2 (0.3)	0.5 (0.8)
	Trench	0.748	24 (9)	22 (6)	0.309	0.4 (0.3)	0.1 (0.2)
	Work	0.148	32 (4)	24 (6)	0.460	0.2 (0.3)	0.0 (0.0)
Highway	Storage	-	-	-	-	-	-
	Trench	0.422	13 (5)	16 (3)	0.926	2.8 (4.8)	3.2 (5.5)
	Work	0.992	28 (9)	28 (7)	0.796	0.1 (0.1)	0.1 (0.2)
McNeil	Storage	0.206	27 (1)	29 (2)	0.800	1.1 (1.9)	0.8 (0.7)
	Trench	0.295	13 (2)	15 (2)	0.269	0.0 (0.0)	0.7 (0.8)
	Work	0.028	19 (2)	24 (1)	0.167	0.0 (0.0)	0.3 (0.2)
Remount Lowland	Storage	0.447	25 (5)	31 (9)	0.507	0.7 (1.1)	0.2 (0.3)
	Trench	0.174	13 (4)	18 (4)	0.423	0.0 (0.0)	0.0 (0.0)
	Work	0.393	40 (6)	35 (5)	0.192	0.0 (0.0)	0.1 (0.1)

Numbers are means with standard deviations in brackets.

Table A50. P-values for distance of effect of ground cover (%) in 2013.

Species Cover	Site	Distance of Effect (m)	P-value	Mean (Before)	Mean (After)
2012					
Native	Overall	4	<0.001	16.9	26.9
		68	0.023	26.9	29.6
	Coulee	21	<0.001	17.3	28.1
	Coulee Upland	35	<0.001	19.6	25.9
	Highway	8	<0.001	20.7	32.0
	McNeil	25	<0.001	20.9	29.8
	Remount Lowland	4	<0.001	18.8	34.7
Non Native	McNeil	15	0.044	0.2	1.0
2013					
Native	Overall	4	<0.001	17.6	28.6
	Coulee	29	<0.001	15.9	24.5
	Coulee Upland	40	<0.001	20.9	28.8
	Highway	3	<0.001	17.0	27.0
	McNeil	89	0.001	27.8	46.1
	Remount Lowland	4	<0.001	19.7	33.8
Non Native	Coulee Upland	86	<0.001	2.0	0.1

Table A51. Regression results for linear models for native and non native species cover.

Cover	Site	Intercept	Slope	P-value
2012				
Native	Hill	25.9	0.00	0.835
Non Native	Overall	0.7	0.00	0.110
	Coulee	0.3	0.00	0.077
	Coulee Upland	0.8	0.00	0.109
	Hill	0.7	0.00	0.543
	Highway	0.8	0.00	0.369
	Remount Lowland	0.7	0.00	0.533
2013				
Native	Hill	22.2	0.03	0.007
Non Native	Overall	0.8	0.00	0.031
	Coulee	1.0	0.00	0.279
	Hill	0.4	0.00	0.726
	Highway	0.7	0.00	0.560
	McNeil	0.5	0.00	0.816
	Remount Lowland	0.4	0.00	0.956

Table A52. Matched native forb and shrub species between 2012 and 2013 at distances from pipeline centre (0 to 350 m).

Distance (m)	2012 Achi mil	2013 Achi mil	2012 Amar alb	2013 Amar alb	2012 Andr sep	2013 Andr sep	2012 Annt spp	2013 Annt spp	2012 Ante par	2013 Ante par	2012 Arte can	2013 Arte can
0				3.0								
1				5.0								
2	3.0	2.0		2.0	0.0							
3												
4					0.5						1.0	12.0
5					0.8 (0.4)							3.0 (4.2)
7									0.5	1.0	4.0 (2.6)	17.0 (18.4)
9											4.0 (0.0)	1.0
11	29.0				0.5 (0.0)						80.0	11.0
13											5.0	
15												31.0
20							1.0			0.5	1.0	
30					0.0							
40				0.0	0.8 (1.1)	2.0			0.5		7.3 (6.7)	15.5 (20.5)
50		5.0 (1.4)			2.0 (2.2)	1.3 (0.4)						
100											11.0	2.3 (2.5)
150					11.0	3.0						9.0 (9.9)
200					0.5						3.5 (4.9)	10.0 (5.7)
250					0.0						6.5 (7.8)	13.0 (12.7)
300										1.5		
350					0.5							2.0

Numbers are means with standard deviations in brackets.

Achi mil = *Achillea millefolium*, Amar alb = *Amaranthus albus*, Andr sep = *Androsace septentrionalis*, Annt spp = *Antennaria* species, Ante par = *Antennaria parvifolia*, Arte can = *Artemisia cana*

Table A53. Matched native forb and shrub species between 2012 and 2013 at distances from pipeline centre (0 to 350 m).

Distance (m)	2012 Arte fri	2013 Arte fri	2012 Aste spp	2013 Aste spp	2012 Astr das	2013 Astr das	2012 Astr pec	2013 Astr pec	2012 Astr spp	2013 Astr spp	2012 Cast min	2013 Cast min
0	0.5	2.0										
1	5.8 (8.0)	1.8 (1.7)			7.0	0.0						
2	6.1 (4.2)	4.2 (3.7)										
3	5.6 (6.0)	2.9 (2.1)			3.0	0.0						
4	6.1 (4.9)	3.6 (4.0)			1.5							
5	3.3 (3.5)	13.1 (14.6)			0.5	1.5						
7	4.3 (6.2)	9.4 (9.7)			1.5	1.5						
9	9.2 (11.4)	8.3 (10.0)			1.5	10.0						
11	3.0 (3.6)	7.1 (6.4)			1.3 (0.4)	3.0 (2.6)	6.0	4.0				
13	9.7 (13.6)	7.4 (9.0)			7.2 (7.3)	0.2 (0.3)			1.0			
15	5.1 (6.0)	5.6 (7.3)			3.5	2.3 (1.1)	55.0	27.0				5.0
20	5.9 (5.4)	3.0 (1.7)			8.0 (4.2)	1.5 (2.1)			1.0			1.0
30	5.4 (5.1)	4.8 (2.1)			35.0	5.8 (3.9)			5.0 (2.8)			
40	1.3 (0.6)	2.5 (3.8)			1.0	2.5 (1.5)	0.0		0.0			
50	4.9 (3.1)	3.7 (4.4)			1.2 (0.6)	3.8 (3.2)			1.2 (1.6)			
100	4.4 (1.8)	6.5 (3.9)	0.5		2.3 (0.4)	2.3 (2.1)						
150	6.1 (1.7)	2.9 (5.0)			1.0							0.5
200	3.5 (3.5)	6.3 (5.8)							0.0			
250	1.0	1.0										
300	17.0 (17.5)	8.0 (7.9)					1.0					
350	4.4 (5.5)	3.9 (2.8)				8.0	0.0					

Numbers are means with standard deviations in brackets.

Arte fri = *Artemisia frigida*, Aste spp = *Aste*r species, Astr das = *Astragalus dasyglottis*, Astr pec = *Astragalus pectinatus*, Astr spp = *Astragalus* species, Cast min = *Castilleja miniata*

Table A54. Matched native forb and shrub species between 2012 and 2013 at distances from pipeline centre (0 to 350 m).

Distance (m)	2012 Chen lep	2013 Chen lep	2012 Chen sal	2013 Chen sal	2012 Cirs flo	2013 Cirs flo	2012 Cirs und	2013 Cirs und	2012 Cory viv	2013 Cory viv	2012 Cryp kel	2013 Cryp kel
0	0.3 (0.3)	0.2 (0.4)	8.0				60.0	32.0				
1	0.0	0.2 (0.4)										
2	0.0 (0.0)	0.3 (0.5)		3.0	9.0							
3	0.0	0.0 (0.0)		2.5								
4		0.1 (0.2)	0.0							2.0 (0.7)		
5	0.0	0.1 (0.2)										
7	0.0 (0.0)	0.4 (0.5)										
9	0.0	0.0 (0.0)										
11	0.3 (0.3)	0.5 (0.4)										
13		0.5										
15	0.0 (0.0)	0.0 (0.0)						3.0				
20	0.0 (0.0)	0.6 (0.6)					14.0	20.0			0.5	
30	0.0 (0.0)	0.2 (0.4)								3.0		
40	0.8 (1.4)	0.3 (0.4)	1.0									
50	0.0	0.4 (0.5)								3.5 (0.7)		
100	0.0	0.2 (0.4)								1.5 (0.7)		
150	0.0 (0.0)	0.2 (0.4)							4.5 (5.6)	8.0		
200	0.3 (0.3)	0.5 (0.7)	0.0									
250	0.0 (0.0)	0.6 (0.8)										
300	0.0 (0.0)	1.5 (0.7)			2.0							
350	0.3 (0.3)	0.2 (0.4)										

Numbers are means with standard deviations in brackets.

Chen lep = *Chenopodium leptophyllum*, Chen sal = *Chenopodium salinum*, Cirs flo = *Cirsium flodmanii*, Cirs und = *Cirsium undulatum*, Cory viv = *Coryphantha vivipara*, Cryp kel = *Cryptantha kelseyana*

Table A55. Matched native forb and shrub species between 2012 and 2013 at distances from pipeline centre (0 to 350 m).

Distance (m)	2012 Erig can	2013 Erig can	2012 Euph gly	2013 Euph gly	2012 Euro lan	2013 Euro lan	2012 Gaur coc	2013 Gaur coc	2012 Hapl spi	2013 Hapl spi	2012 Hede his	2013 Hede his
0		0.0	0.0 (0.0)	0.4 (0.7)	6.0							0.0
1	0.5		0.0	0.2 (0.2)			0.5	12.0			0.0	0.0
2			1.0	0.2 (0.4)							0.5	0.3 (0.3)
3	1.0	0.5		0.6 (1.1)								0.0
4	1.0	0.0 (0.0)	0.2 (0.3)	0.4 (1.2)	2.0 (2.8)						0.0 (0.0)	0.2 (0.3)
5	0.3 (0.3)	0.0 (0.0)	0.0	0.0 (0.0)		10.0	25.0	33.0			0.3 (0.6)	0.0
7	0.2 (0.3)	0.1 (0.2)	0.5	0.7 (0.6)							0.1 (0.2)	0.0 (0.0)
9	0.0 (0.0)	0.0	0.0	0.0 (0.0)	3.0	3.5					0.1 (0.2)	0.0 (0.0)
11	0.0	0.0 (0.0)		0.0	1.5	1.0	12.0	3.5			0.0 (0.0)	0.3 (0.3)
13	0.0	0.0 (0.0)		0.0	9.0	3.0		2.5			0.5 (0.7)	0.0
15	0.0	0.1 (0.2)		0.0 (0.0)			2.0 (0.0)	5.5			0.5 (0.7)	
20	0.8 (0.3)	0.4 (0.5)	0.0 (0.0)	0.0 (0.0)							1.6 (2.6)	0.0 (0.0)
30		2.8 (3.2)	0.0 (0.0)	0.0 (0.0)							3.0 (4.2)	0.5 (0.7)
40		0.2 (0.3)		0.0							0.4 (0.6)	0.0
50		1.4 (1.5)		0.0 (0.0)							0.0 (0.0)	0.4 (0.4)
100	5.0	0.2 (0.3)		0.0	2.0	4.0					0.7 (1.0)	0.6 (0.6)
150		0.0 (0.0)		0.3 (0.6)	8.0	10.0					0.0 (0.0)	0.0 (0.0)
200		0.3 (0.3)	2.0	0.0 (0.0)	6.0	6.0					0.0	0.5 (0.7)
250		0.0		0.0	0.5						0.3 (0.4)	0.3 (0.6)
300		0.0 (0.0)		0.0 (0.0)	3.3 (3.9)	9.0					0.8 (1.1)	0.0 (0.0)
350				0.0			3.0	6.0			0.2 (0.3)	0.5 (0.9)

Numbers are means with standard deviations in brackets.

Erig can = *Erigeron canadensis*, Euph gly = *Euphorbia glyptosperma,* Euro lan = *Eurotia lanata,* Gaur coc = *Gaura coccinea,* Hapl spi = *Haplopappus spinulosus,* Hede his = *Hedeoma hispidum*

Table A56. Matched native forb and shrub species between 2012 and 2013 at distances from pipeline centre (0 to 350 m).

Distance (m)	2012 Hete vil	2013 Hete vil	2012 Hier umb	2013 Hier umb	2012 Juni hor	2013 Juni hor	2012 Lact tat	2013 Lact tat	2012 Lepi den	2013 Lepi den	2012 Lith inc	2013 Lith inc
0									0.0 (0.0)	5.7 (4.9)		3.5
1										1.3 (0.6)		
2									0.0	8.0		
3				1.5					0.0	1.8 (2.5)		
4		1.0								0.0 (0.0)		1.0
5									0.0	0.0		
7									0.0	0.0		
9										0.0		2.0
11	2.0	8.5 (2.1)							0.0			0.5
13		1.5								0.3 (0.6)		0.0
15	3.7 (5.5)									0.0 (0.0)		
20	0.0	6.5 (6.4)							1.0 (1.4)	0.1 (0.2)		
30	0.5								1.0 (1.4)	1.7 (2.1)		
40	2.5	2.0 (2.8)								0.5		
50		0.0						0.0	0.0 (0.0)	0.6 (0.7)		1.0
100										0.2 (0.3)		
150										0.3 (0.6)		1.0
200										2.3 (4.0)		
250									0.5	0.2 (0.4)		
300					21.0	68.0				0.6 (0.9)		0.3 (0.3)
350										0.1 (0.2)		

Numbers are means with standard deviations in brackets.

Hete vil = *Heterotheca villosa*, Hier umb = *Hieracium umbellatum*, Juni hor = *Juniperus horizontalis*, Lact tat = *Lactuca tatarica*, Lepi den = *Lepidium densiflorum*, Lith inc = *Lithospermum incisum*

Table 57. Matched native forb and shrub species between 2012 and 2013 at distances from pipeline centre (0 to 350 m).

Distance (m)	2012 Lygo jun	2013 Lygo jun	2012 Moss	2013 Moss	2012 Opun pol	2013 Opun pol	2012 Orob fas	2013 Orob fas	2012 Orob lud	2013 Orob lud	2012 Orth lut	2013 Orth lut
0												
1						0.0 (0.0)						
2	0.5	1.8 (0.4)			0.2 (0.3)	0.8 (0.4)						
3	1.0	2.5			0.1 (0.2)	0.7 (1.0)	0.5					
4	3.6 (1.5)	1.3 (0.6)			0.0 (0.0)	0.0 (0.0)		0.5				
5	3.8 (3.6)	1.9 (1.3)				1.0 (1.0)						
7	2.6 (2.3)	2.3 (3.8)			1.5							
9	2.7 (2.0)	2.3 (1.8)	2.0		0.0	0.0						
11	2.9 (2.2)	2.0		0.0	0.0	0.5 (0.7)						
13	3.1 (0.9)	1.6 (1.1)			0.0	0.7 (1.1)						
15	2.0	2.0 (1.4)			3.0	3.0		0.5				
20	0.8 (0.4)				6.0	5.5 (7.8)						
30	1.3 (0.4)	1.2 (1.6)			1.5 (1.6)	1.8 (1.5)			0.5			
40	4.5 (5.6)	0.6 (0.5)			10.5 (10.5)	5.6 (6.8)						
50	5.2 (5.3)	1.6 (1.5)			3.3 (2.5)	3.7 (4.7)					1.0	
100		0.5			12.8 (8.8)	8.5 (4.9)						
150	6.3 (4.9)	1.1 (0.6)			4.3 (5.3)	1.5 (1.4)						
200		1.0 (1.4)			5.2 (3.9)	3.8 (3.9)						
250	0.0				9.3 (11.8)	6.6 (6.5)						
300	3.0	1.8 (0.8)		0.5	3.0 (4.2)	1.8 (2.8)						
350					2.8 (3.2)	5.0						

Numbers are means with standard deviations in brackets.

Lygo jun = *Lygodesmia juncea*, Opun pol = *Opuntia polycantha*, Orob fas = *Orobanche fasciculate*, Orob lud = *Orobanche ludoviciana*, Orth lut = *Orthocarpus luteus*

Table A58. Matched native forb and shrub species between 2012 and 2013 at distances from pipeline centre (0 to 350 m).

Distance (m)	2012 Oxyt ser	2013 Oxyt ser	2012 Pens alb	2013 Pens alb	2012 Peta pur	2013 Peta pur	2012 Phlo hoo	2013 Phlo hoo	2012 Plan pat	2013 Plan pat	2012 Poly ere	2013 Poly ere
0												11.0
1												1.5
2												
3							0.8 (0.4)	0.0				
4								4.0		0.0		
5	4.0						0.0					
7							2.5 (0.7)	1.8 (0.4)				
9							1.0	1.0	2.0 (1.4)	1.3 (1.4)		
11							1.5 (1.3)	1.5 (0.9)	0.0			
13	6.0						2.8 (2.3)	1.8 (1.8)	0.0	1.0 (1.3)		
15							1.0	0.5 (0.0)		2.0		
20								1.3 (1.1)	3.0	1.3 (2.3)		
30							2.0	0.5	1.0 (0.5)	2.8 (0.4)		
40				1.5				0.0	1.5 (0.5)	0.7 (1.1)		
50	14.0					7.0	7.0		7.0	0.7 (0.8)		
100									0.5	2.5		
150												
200							6.0	4.0				
250							4.0	6.3 (8.1)				
300							5.4 (5.4)	4.0 (4.0)				
350							5.5	2.5 (3.5)				

Numbers are means with standard deviations in brackets.

Oxyt ser = *Oxytropis sericea*, Pens alb = *Penstemon albidus*, Peta pur = *Petalostemon purpureum*, Phlo hoo = *Phlox hoodii*, Plan pat = *Plantago patagonica*, Poly ere = *Polygonum erectum*

Table A59. Matched native forb and shrub species between 2012 and 2013 at distances from pipeline centre (0 to 350 m).

Distance (m)	2012 Poly ram	2013 Poly ram	2012 Pote pen	2013 Pote pen	2012 Psor arg	2013 Psor arg	2012 Rosa woo	2013 Rosa woo	2012 Sela den	2013 Sela den	2012 Sile dru	2013 Sile dru
0	1.5											
1						4.0						
2						0.0			0.0			
3					0.0	2.0				0.0		
4					5.0	6.0			0.0	0.5 (0.7)		
5					5.8 (3.2)	11.0 (7.8)			1.3 (1.5)	2.0 (1.4)		
7					7.3 (4.2)	9.2 (7.7)			6.0	1.5		
9					13.5 (14.8)	14.0 (1.4)			0.0			
11					7.7 (5.0)	13.5 (9.2)			2.0	3.5 (3.5)		
13						6.0			1.3 (1.1)	1.5		
15					1.0 (0.0)	2.0			2.8 (0.4)	5.1 (4.2)		
20					20.5 (27.6)	2.3 (2.5)	6.0	5.0	4.9 (2.8)	6.2 (4.5)		
30					2.7 (1.2)	7.7 (4.9)			19.0 (14.0)	29.4 (17.4)		
40					3.3 (2.5)	1.5 (0.0)			12.3 (9.1)	21.9 (25.9)		
50			2.0		9.0 (7.1)	1.0 (0.7)			16.3 (13.4)	10.6 (11.0)	1.5	
100					10.5 (13.4)	5.0 (4.2)			21.3 (9.3)	34.6 (27.1)		
150					3.5 (1.8)	6.0 (1.4)			20.2 (17.4)	21.6 (15.4)		
200					9.0	0.5			14.1 (12.8)	16.8 (2.8)		
250					18.5 (4.9)	13.5 (14.8)			2.4 (1.6)	14.0 (7.2)		
300									12.2 (11.6)	14.0 (18.2)		
350						3.0			9.4 (8.4)	11.3 (10.0)		

Numbers are means with standard deviations in brackets.

Poly ram = *Polygonum ramosissimum*, Pote pen = *Potentilla pensylvanica*, Psor arg = *Psoralea argophylla*, Sela den = *Selaginella densa*, Sile dru = *Silene drummondii*

Table A60. Matched native forb and shrub species between 2012 and 2013 at distances from pipeline centre (0 to 350 m).

Distance (m)	2012 Sola tri	2013 Sola tri	2012 Soli spp	2013 Soli spp	2012 Spha coc	2013 Spha coc	2012 Vici ame	2013 Vici ame
0	1.5							
1	0.0							
2					1.8 (0.8)	2.1 (1.7)		
3					1.3 (1.1)	1.4 (0.9)		
4					0.9 (0.8)	2.0 (2.2)		5.0
5			2.5		2.6 (2.2)	2.4 (2.3)		
7					1.8 (1.6)	1.4 (1.5)	0.5	
9			4.0	0.5	4.1 (4.3)	4.6 (4.9)		2.5
11					1.8 (1.2)	3.6 (5.9)		
13					2.9 (1.7)	2.2 (2.3)	3.0	
15					1.5 (0.7)	2.9 (1.2)		
20					2.5 (0.9)	3.1 (3.1)		
30					4.1 (6.6)	3.6 (5.3)	3.0	3.0 (3.5)
40				0.0	2.5 (2.1)	1.9 (1.4)		10.0
50					1.5 (1.4)	2.2 (0.6)		2.0
100					2.0 (2.0)	1.6 (1.0)	1.5	5.8 (1.8)
150					2.7 (2.2)	2.5 (1.5)		0.0
200					2.1 (2.3)	1.9 (1.3)		
250					1.5 (1.1)	1.9 (1.3)	0.5	
300					2.0 (1.0)	2.3 (1.9)	2.0	
350					3.0 (2.8)	3.7 (3.3)	1.0	1.0

Numbers are means with standard deviations in brackets.

Sola tri = *Solanum triflorum*, Soli spp = *Solidago* species, Spha coc = *Sphaeralcea coccinea*, Vici ame = *Vicia americana*

Table A61. Matched native forb and shrub species between 2012 and 2013 at distances from pipeline centre (0 to 350 m).

Distance (m)	2012 Viol adu	2013 Viol adu	2012 Viol nut	2013 Viol nut
0				
1				
2				
3				
4				
5				
7				
9				
11				
13				
15				
20				
30				
40				
50				
100				
150				
200	2.5			4.0
250				
300				
350				

Numbers are means with standard deviations in brackets.

Viol adu = *Viola adunca*, Viol nut = *Viola nuttallii*

Table A62. Matched native grass species between 2012 and 2013 at distances from pipeline centre (0 to 350 m).

Distance (m)	2012 Agro alb	2013 Agro alb	2012 Agro das	2013 Agro das	2012 Agro smi	2013 Agro smi	2012 Agro spp	2013 Agro spp	2012 Agro tra	2013 Agro tra	2012 Agro tra*	2013 Agro tra*
0			0.3 (0.3)	3.8 (1.9)	4.4 (4.1)	8.7 (7.9)			4.5 (2.8)	7.7 (4.8)	7.3 (2.6)	1.5
1			5.3 (5.6)	4.2 (3.2)	5.8 (4.3)	6.9 (4.5)	0.5		5.4 (4.5)	10.7 (8.0)	5.4 (4.8)	4.0
2	2.0		2.4 (2.9)	3.1 (2.3)	5.1 (4.3)	6.4 (4.2)			6.7 (3.9)	13.9 (11.2)	6.2 (3.0)	
3			3.0 (2.7)	2.3 (2.4)	4.5 (3.1)	6.9 (7.0)			6.0 (5.3)	11.4 (11.7)	6.8 (7.0)	
4	2.0 (2.8)		2.8 (2.0)	2.6 (2.2)	5.9 (6.9)	6.7 (4.3)			6.9 (4.8)	8.0 (5.3)	2.0	
5			3.1 (3.0)	3.0 (2.7)	4.8 (2.0)	4.6 (2.9)			11.5 (3.5)	7.4 (4.8)	4.0 (1.4)	1.5
7			3.6 (3.4)	5.1 (5.9)	5.4 (3.9)	5.1 (3.3)			4.1 (2.9)	4.2 (2.9)	5.0 (1.4)	
9			4.6 (3.5)	2.3 (1.2)	5.8 (6.4)	5.1 (3.7)			6.1 (4.5)	8.7 (3.1)	3.0	1.0
11			4.1 (4.3)	3.8 (4.1)	4.7 (2.8)	5.5 (3.9)	5.0		5.2 (2.8)	8.0 (6.8)	1.0	1.0
13			6.1 (4.4)	1.8 (2.4)	4.0 (2.6)	4.3 (3.1)			5.0	0.8 (1.0)		
15			3.2 (0.8)	1.6 (1.4)	4.9 (3.7)	5.6 (3.1)			2.5 (0.7)	7.0		
20			0.8 (0.4)	2.5 (2.1)	5.5 (6.7)	3.9 (3.3)			4.3 (4.9)			
30			13.2 (9.6)	4.7 (3.5)	3.7 (3.1)	3.7 (3.2)			4.0			
40			7.6 (7.3)	4.5 (3.1)	2.8 (2.3)	3.1 (2.4)			0.0			
50			1.5 (0.9)	3.8 (2.3)	2.4 (1.7)	3.9 (2.2)			2.0 (1.4)			
100			2.8 (1.3)	0.5	4.1 (3.0)	3.7 (2.2)						
150			3.7 (2.3)	1.0 (0.0)	4.0 (3.6)	4.1 (2.6)						
200			5.5 (6.0)	2.0 (0.0)	5.1 (7.0)	4.7 (2.3)						
250			0.5 (0.7)	0.8 (0.4)	6.4 (5.3)	3.5 (2.5)						
300			2.0	0.3 (0.3)	4.1 (4.8)	3.8 (4.6)			6.0 (4.2)			
350			5.0 (3.6)	1.0	3.6 (2.1)	4.5 (3.6)			2.0 (0.0)			

Numbers are means with standard deviations in brackets.

Agro alb = *Agropyron albicans* var. albicans, Agro das = *Agropyron dasystachyum*, Agro smi = *Agropyron smithii*, Agro tra = *Agropyron trachycaulum*, Agro tra* = *Agropyron trachycaulum* var. unilaterale

Table A63. Matched native grass and grass like species between 2012 and 2013 at distances from pipeline centre (0 to 350 m).

Distance (m)	2012 Bout gra	2013 Bout gra	2012 Cala lon	2013 Cala lon	2012 Cala mon	2013 Cala mon	2012 Care spp	2013 Care spp	2012 Dant cal	2013 Dant cal	2012 Dist str	2013 Dist str
0	2.1 (1.6)	2.4 (0.9)		7.5 (7.8)				0.0			14.0	33.0
1	4.1 (3.8)	6.2 (5.8)	1.0	1.1 (0.6)			0.8 (1.1)	2.3 (1.3)			4.0	5.0
2	3.3 (1.7)	5.4 (3.8)	3.2 (2.4)	2.5 (1.8)		1.0	0.0	1.1 (0.8)			20.0 (14.1)	6.7 (6.4)
3	14.4 (13.4)	10.0 (11.4)	3.8 (2.3)	3.8 (2.4)			2.4 (2.5)	3.5 (2.4)	6.0		23.0 (1.4)	4.0 (0.0)
4	15.0 (16.8)	17.1 (14.4)	2.7 (2.0)	2.8 (1.2)			2.8 (4.0)	5.3 (4.0)			10.0 (2.8)	4.0 (2.8)
5	11.2 (11.3)	12.9 (10.5)	1.3 (0.3)	3.4 (2.3)			4.2 (4.5)	4.2 (2.5)			18.5 (13.4)	4.0 (2.8)
7	14.1 (13.6)	15.3 (14.3)	3.3 (1.1)	3.6 (2.9)		1.5 (2.1)	3.5 (3.6)	4.7 (4.0)			7.3 (3.9)	5.0 (5.7)
9	11.3 (10.6)	11.1 (10.8)	1.0 (1.4)	2.5 (2.1)		3.0	2.3 (2.2)	4.3 (3.2)			16.0	5.0 (2.9)
11	12.1 (9.7)	10.9 (7.6)	4.0 (5.6)	2.4 (2.1)		1.1 (1.0)	5.4 (7.5)	4.7 (3.3)	0.5		19.5 (3.5)	3.3 (2.5)
13	13.0 (10.0)	10.3 (9.6)	1.0 (1.4)	2.3 (1.5)	0.5	1.0 (0.7)	4.7 (7.4)	4.0 (3.2)	3.0		10.5 (0.7)	7.5 (7.5)
15	12.1 (12.4)	11.6 (11.7)	2.5 (2.1)	2.0 (2.0)	2.3 (3.2)	1.0	1.7 (1.7)	5.2 (4.0)			8.0 (5.7)	2.5 (0.7)
20	14.0 (12.1)	11.3 (9.9)	6.5 (0.7)	2.0		1.0	3.5 (4.0)	4.8 (3.7)			9.5 (0.7)	5.3 (1.1)
30	9.3 (7.4)	9.3 (7.4)		1.0		3.0	7.9 (12.4)	6.2 (6.9)			11.0 (5.7)	7.5 (5.2)
40	14.4 (9.6)	11.2 (8.3)				1.5 (0.7)	3.4 (3.9)	6.2 (5.0)			8.5 (0.7)	5.5 (0.7)
50	11.3 (9.9)	9.4 (6.2)	5.5 (2.1)	1.3 (0.4)	1.0	0.0	2.8 (3.4)	3.5 (3.4)			19.5 (21.9)	2.8 (2.0)
100	15.7 (11.3)	13.3 (10.4)	17.0	7.0			3.9 (8.5)	5.4 (5.2)	2.0		1.5	0.5
150	12.6 (11.2)	12.2 (10.5)	13.0	7.0 (1.4)			2.3 (2.1)	3.6 (2.4)			16.0	8.0
200	11.5 (8.1)	11.5 (6.2)			0.5		4.2 (5.4)	4.9 (4.7)				
250	11.6 (11.0)	13.0 (8.7)	10.0	4.0			2.4 (2.3)	3.5 (3.0)			5.0	
300	17.1 (15.0)	12.6 (8.3)					3.0 (3.2)	4.0 (2.8)				
350	11.8 (8.9)	11.8 (7.7)					3.2 (2.4)	5.9 (7.3)				

Numbers are means with standard deviations in brackets.

Bout gra = *Bouteloua gracilis*, Cala lon = *Calamovilfa longifolia*, Cala mon = *Calamagrostis montanensis*, Care spp = *Carex* species, Dant cal = *Danthonia californica*, Dist str = *Distichlis stricta*

Table A64. Matched native grass species between 2012 and 2013 at distances from pipeline centre (0 to 350 m).

Distance (m)	2012 Elym can	2013 Elym can	2012 Fest spp	2013 Fest spp	2012 Koel mac	2013 Koel mac	2012 Muhl cus	2013 Muhl cus	2012 Oryz hym	2013 Oryz hym	2012 Poa pal	2013 Poa pal
0		7.0 (1.4)							7.0	3.0	4.2 (1.8)	3.0
1	3.0	4.6 (3.4)			2.0				3.0		3.0 (2.2)	2.8 (2.5)
2		3.0 (2.8)							3.7 (2.8)	2.0	3.3 (1.9)	2.3 (0.6)
3		2.2 (2.4)			7.0				2.0		2.5 (1.8)	2.8 (1.0)
4		2.0			2.5	20.0 (14.1)		0.0	0.5	3.0	1.4 (0.8)	0.0
5		3.0 (2.8)			2.5 (2.1)	6.0 (0.0)		1.0		0.8 (0.4)	2.0 (0.0)	
7		1.0	0.5		6.0				2.0	3.0	7.5 (2.1)	
9		2.0			2.0	4.0 (0.0)					3.5 (0.7)	2.5
11		3.5 (2.1)			2.5 (0.7)	4.3 (1.1)			0.5		6.0	
13		1.7 (0.8)								1.0	6.5 (7.8)	
15		5.5 (6.4)			2.3 (3.2)	4.0					15.5 (20.5)	6.0
20		1.4 (1.1)			2.0							
30		0.0			3.8 (1.9)							
40		0.0				3.0						
50					1.5	3.3 (3.9)						
100		0.0										
150					2.0	5.5 (2.1)						
200					0.5							
250					4.0	7.0 (9.5)						
300					3.0 (1.0)	2.0 (2.0)						
350					1.5	6.3 (6.7)						

Numbers are means with standard deviations in brackets.

Elym can = *Elymus canadensis*, Fest spp = *Festuca* species, Koel mac = *Koeleria macrantha*, Muhl cus = *Muhlenbergia cuspidata*, Oryz hym = *Oryzopsis hymenoides,* Poa pal = *Poa palustris*

Table A65. Matched native grass species between 2012 and 2013 at distances from pipeline centre (0 to 350 m).

Distance (m)	2012 Poa san	2013 Poa san	2012 Stip com	2013 Stip com	2012 Stip vir	2013 Stip vir
0		1.8 (0.8)	1.8 (1.3)	3.0	2.8 (0.4)	4.6 (2.2)
1		1.8 (0.6)	3.3 (2.1)	4.0 (3.6)	5.4 (3.3)	2.9 (2.4)
2		1.5 (1.3)	2.4 (1.1)	1.8 (1.2)	4.6 (3.8)	7.0 (7.5)
3		4.0	3.0 (1.7)	3.4 (2.7)	12.0 (15.6)	2.1 (1.1)
4			5.4 (4.9)	7.6 (8.0)	0.5	3.0
5	3.0	5.0 (4.2)	6.8 (6.5)	3.8 (2.6)	2.0 (1.8)	3.5 (1.3)
7		4.0	7.0 (4.8)	8.0 (10.4)	2.0 (1.4)	1.0 (0.0)
9	2.5 (0.7)	3.4 (3.4)	5.2 (3.5)	5.6 (4.9)	2.0 (1.0)	3.0
11	2.0	2.5 (0.7)	8.0 (6.6)	5.6 (4.8)	9.5 (9.4)	6.6 (8.7)
13	2.5	2.3 (0.6)	6.4 (4.9)	5.5 (4.3)	17.0 (6.1)	15.5 (17.8)
15		1.0 (0.7)	7.9 (8.9)	5.9 (5.5)	6.0 (3.3)	6.6 (5.8)
20	1.0	5.0 (3.6)	6.1 (3.4)	5.0 (2.9)	2.3 (1.1)	2.7 (2.1)
30		0.0	9.7 (9.7)	7.4 (5.0)	9.5 (9.2)	2.3 (1.1)
40		1.5 (2.1)	8.1 (7.8)	6.9 (5.4)	22.0	8.3 (8.1)
50		1.5	9.5 (9.8)	7.5 (10.5)	2.0	
100		1.0	5.7 (3.5)	8.6 (8.7)	4.0	2.0
150			10.8 (8.1)	7.9 (6.2)		1.8 (0.4)
200		1.0	9.2 (6.4)	9.3 (8.4)	5.0	2.8 (1.0)
250			8.3 (6.7)	8.2 (6.7)		1.5
300	1.5 (0.7)	3.3 (2.8)	6.5 (5.0)	7.9 (4.4)	2.0	6.3 (6.7)
350	3.0	1.5	8.7 (9.0)	7.6 (5.8)	5.5 (3.5)	6.0 (1.7)

Numbers are means with standard deviations in brackets.

Poa san = *Poa sandbergii*, Stip com = *Stipa comata*, Stip vir = *Stipa viridula*

Table A66. Matched non native forb species between 2012 and 2013 at distances from pipeline centre (0 to 350 m).

Distance (m)	2012 Amar bli	2013 Amar bli	2012 Amar ret	2013 Amar ret	2012 Arte abs	2013 Arte abs	2012 Arte lud	2013 Arte lud	2012 Cent mac	2013 Cent mac	2012 Chen alb	2013 Chen alb
0												7.0
1		0.5									1.3 (1.8)	6.0
2												10.7 (12.2)
3											7.0	
4				1.5								
5										4.0		
7												
9												
11												
13							1.5	3.0				
15						4.0	11.5 (2.1)	3.5 (2.1)				
20								1.0				
30							18.0	4.0 (3.5)				
40												
50												
100												
150								5.0				
200												
250												
300												
350						0.0						

Numbers are means with standard deviations in brackets.

Amar bli = *Amaranthus blitoides*, Amar ret = *Amaranthus retroflexus,* Arte abs = *Artemisia absinthium*, Arte lud = *Artemisia ludoviciana,* Cent mac = *Centaurea maculosa*, Chen alb = *Chenopodium album*

Table A67. Matched non native forb species between 2012 and 2013 at distances from pipeline centre (0 to 350 m).

Distance (m)	2012 Cirs arv	2013 Cirs arv	2012 Crep tec	2013 Crep tec	2012 Desc sop	2013 Desc sop	2012 Eruc gal	2013 Eruc gal	2012 Koch sco	2013 Koch sco	2012 Medi lup	2013 Medi lup
0				0.0	3.5	1.3 (1.5)			3.0	16.5		
1					0.5					0.5		
2				0.0								2.0
3										2.0		0.0
4												
5					0.0							
7												
9												
11						0.5						
13						0.0						
15												
20						1.5						
30						0.0						
40	1.0	1.0			0.5			1.0				
50						2.3 (1.1)						
100												
150			5.0			1.2 (0.3)						
200						1.0						
250						2.5						
300						0.5						
350						0.5						

Numbers are means with standard deviations in brackets.

Cirs arv = *Cirsium arvense*, Crep tec = *Crepis tectorum*, Desc sop = *Descurainia sophia*, Eruc gal = *Erucastrum gallicum*, Koch sco = *Kochia scoparia*, Medi lup = *Medicago lupulina*

Table A68. Matched non native forb species between 2012 and 2013 at distances from pipeline centre (0 to 350 m).

Distance (m)	2012 Nesl pan	2013 Nesl pan	2012 Poly avi	2013 Poly avi	2012 Poly con	2013 Poly con	2012 Pote arg	2013 Pote arg	2012 Sals kal	2013 Sals kal	2012 Sisy alt	2013 Sisy alt
0			4.0	10.0					1.5	0.5 (0.7)		
1			2.0	16.3 (19.4)					0.5 (0.7)	6.0		
2				14.5 (10.6)		0.5 (0.7)			1.0	10.0		
3				18.0		0.0				0.5 (0.7)		5.0
4												
5									1.3 (0.4)			
7												
9						4.0						
11												
13												
15												
20												
30							1.5					
40								3.0				
50												
100							1.0					
150		0.0										
200									0.0			
250										0.5		
300												
350												

Numbers are means with standard deviations in brackets.

Nesl pan = *Neslia paniculata*, Poly avi = *Polygonum aviculare*, Poly con = *Polygonum convolvulus*, Pote arg = *Potentilla argentea,* Sals kal = *Salsola kali*, Sisy alt = *Sisymbrium altissimum*

Table A69. Matched non native forb species between 2012 and 2013 at distances from pipeline centre (0 to 350 m).

Distance (m)	2012 Sonc arv	2013 Sonc arv	2012 Tara off	2013 Tara off	2012 Trag dub	2013 Trag dub
0				2.0		1.7 (0.6)
1		2.0		0.5 (0.9)	1.0	
2		0.0	1.0	1.8 (2.0)		1.8 (1.0)
3			2.0	1.5 (1.7)	3.0	1.3 (1.1)
4			0.3 (0.3)	1.8 (1.9)	0.0	2.5 (2.0)
5			2.5 (0.7)	1.4 (2.1)	1.0	5.0
7				0.5 (0.7)	0.5	1.3 (1.8)
9			1.5	2.6 (2.9)		1.3 (1.0)
11			1.5	2.0 (1.3)	7.0 (4.2)	1.5 (1.8)
13			2.3 (2.5)	6.5 (4.9)	5.0 (5.7)	1.8 (1.0)
15			8.0	7.7 (8.5)	3.0 (1.4)	1.0 (0.6)
20			2.8 (1.8)	10.7 (10.3)	9.8 (10.3)	0.7 (0.3)
30			1.0	3.5		2.5 (1.4)
40				0.8 (1.0)	1.5 (1.7)	0.8 (0.3)
50			0.5	1.8 (1.3)	1.0 (0.7)	1.5
100				2.0 (1.0)	1.6 (0.8)	0.3 (0.3)
150			0.5	1.0	1.0	1.2 (0.8)
200				0.8 (0.4)	5.2 (6.8)	2.0 (2.0)
250						1.2 (0.6)
300			8.0	3.8 (4.6)	4.0	2.0
350				5.0	0.8 (0.4)	2.5 (0.7)

Numbers are means with standard deviations in brackets.

Sonc arv = *Sonchus arvensis*, Tara off = *Taraxacum officinale,* Trag dub = *Tragopogon dubius*

Table A70. Matched non native grass species between 2012 and 2013 at distances from pipeline centre (0 to 350 m).

Distance (m)	2012 Agro pec	2013 Agro pec	2012 Brom ine	2013 Brom ine	2012 Hord jub	2013 Hord jub
0			0.0		3.0	
1			2.3 (2.4)	1.6 (1.2)	1.3 (1.1)	
2			2.5	2.2 (1.8)	0.5	
3			6.0	6.0		
4						
5			2.0	5.0		
7						
9	5.5 (5.7)	3.0				
11	8.4 (4.9)	12.0 (14.1)	1.0			
13	0.0	1.5				
15	10.0	4.0 (2.8)	2.0			
20	29.5 (6.4)	7.3 (5.0)				
30						
40						
50						
100						
150			2.0			
200						
250						
300						
350						

Numbers are means with standard deviations in brackets.

Agro pec = *Agropyron pectiniforme,* Brom ine = *Bromus inermis*, Hord jub = *Hordeum jubatum*

Table A71. P-values for distance of effect of grass and forb species cover (%) in 2012 and 2013.

	Site	Distance of Effect (m)	P-value	Mean (Before)	Mean (After)
Grass Cover 2012	Overall	4	<0.001	14.9	21.8
	Coulee	17	<0.001	13.1	22.0
	Coulee Upland	33	0.019	18.1	21.5
	Hill	4	0.008	16.2	22.4
	Highway	4	0.005	17.0	27.1
	Remount Lowland	4	0.001	18.3	27.7
Forb Cover 2012	Overall	24	<0.001	4.4	7.5
	Coulee Upland	13	0.004	1.5	4.3
	McNeil	26	<0.001	6.1	15.0
	Remount	11	<0.001	2.5	7.8
Grass Cover 2013	Overall	4	<0.001	16.0	21.9
	Coulee	28	<0.001	12.8	19.2
	Coulee Upland	40	0.043	19.3	22.9
	Highway	3	0.001	14.0	23.2
	McNeil	87	0.003	19.0	25.8
	Remount	4	<0.001	18.9	27.4
Forb Cover 2013	Overall	33	<0.001	5.0	8.5
	McNeil	88	0.012	9.2	21.0
	Remount Lowland	46	0.039	4.8	8.0

Table A72. Regression results for linear models for grass and forb species cover.

Species Cover	Site	Intercept	Slope	P-value
2012				
Grass	McNeil	15.6	0.00	0.730
Forb	Coulee	4.6	0.00	0.733
	Hill	5.9	-0.01	0.355
	Highway	4.0	0.00	0.734
2013				
Grass	Hill	17.9	0.04	<0.001
Forb	Coulee	4.8	0.00	0.890
	Coulee Upland	3.7	0.01	0.068
	Hill	4.7	-0.01	0.362
	Highway	4.2	0.00	0.870

Table A73. Regression results for linear models for grass and forb species cover.

Month	2009	2010	2011	2012	2013
January	7	0	52	3	2
February	12.5	0	5.5	12.5	3.5
March	0	20	12	11.9	16
April	0	19.4	4.1	12	17.6
May	7.9	101	28.4	52.4	26.7
June	42.2	102.6	98.3	66.6	105.4
July	54.4	80.6	52.6	51	35.4
August	71.7	65.9	61	17.6	53.3
September	11.5	29.3	14.1	13.4	19.3
October	25	3.9	8.3	5	6.7
November	2	8.5	13.5	24	n/a
December	26	7	2.5	44	n/a
TOTAL	260.2	438.2	352.3	313.4	285.9

Note: Monthly data was not available from the Oyen Cara, Alberta station for November and December 2013 (Government of Canada 2014)