Environmental Effects Assessment of Oil and Gas Development on a Grassland Ecosystem

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By

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ABSTRACT

The northern Great Plains of Saskatchewan is one of the most significantly modified landscapes in Canada. While the majority of anthropogenic disturbance to Saskatchewan's grasslands is the result of agricultural practices, oil and gas activity are of increasing concern to grassland conservation efforts. Although such developments require formal regulatory approval (Environmental Impact Assessment), follow-up and monitoring of the effects of oil and gas development on grasslands is not common practice. In the absence of empirical based follow-up and monitoring, the actual environmental effects of petroleum and natural gas (PNG) development on grassland ecology and the spatial extent of development are largely unknown.

This thesis examines the spatial and temporal extent of PNG development and its effects on grassland ecology within a PFRA (Prairie Farm Rehabilitation Administration) pasture in southwest Saskatchewan. The extent of the changes to infrastructure and the actual impacts from development within the study area were documented from 1955 to 2006. The actual impacts of oil and gas activity on grassland ecology were determined by analyzing ground cover characteristics, soil properties, and community composition at lease sites and compared to reference pasture sites. Associated with construction practices, lease sites had low herbaceous, Lycopodiaceae, litter, organic horizon (Ah) thickness, and soil compaction values. Lease sites were also found to have low desirable species diversity, range health values, and greater undesirable species presence. Impacts from development were amplified at active, highly productive lease sites. The impacts associated with PNG development were also found to persist for more than 50 years, and extend 20m – 25m beyond the physical footprint of infrastructure. This research will contribute to monitoring and mitigation measures for oil and gas development within Saskatchewan and Canadian grasslands.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

AAFC: Agriculture and Agri-Foods Canada
ABG: Abandoned Gas Well
ABO: Abandoned Oil Well
ACT: Canadian Environmental Assessment Act
AG: Active Gas Well
AO: Active Oil Well
AP3: Antelope
Bbl: Barrels of Oil
CEAA: Canadian Environmental Assessment Agency
CEA: Cumulative Effects Assessment
D&A: Drilled and Abandoned Well
EA: Environmental Assessment
EIA: Environmental Impact Assessment
EMP: Environmental Management Plan
EMPA: Environmental Management and Protection Act
EMS: Environmental Management Systems
EPP: Environmental Protection Plan
GSHRES: Great Sand Hills Regional Environmental Study
HT1/2: Hatton
HTHR4: Hatton-Haverhill
IV: Indicator Value
mcf: Thousands of Cubic Feet
MRPP: Multi-Response Permutation Procedure
MAH: Municipal Affairs and Housing
NMDS: Non-Metric Multidimensional Scaling
NTS: National Topographical System
PFRA: Prairie Farm Rehabilitation Administration
PNG: Petroleum and Natural Gas
PTG: Potential Gas Well
RM: Rural Municipalities
ROW: Right of Way
SAF: Saskatchewan Agriculture and Food
SE: Saskatchewan Environment
SEM: Saskatchewan Energy and Mines
SG: Suspended Gas Well
SO: Suspended Oil Well
WHPA: Wildlife Habitat Protection Act
VEC: Valued Ecosystem Component

CHAPTER 1
INTRODUCTION

The majority of the Canadian northern Great Plains is located in Saskatchewan, covering over 235,000 km^2 or approximately 25% of the province's total land area (CPRC 1998). In Saskatchewan, this prairie ecozone is divided into two grassland ecoregions: the mixed grassland and the moist mixed grassland. The mixed grassland ecoregion is the most predominant and accounts for 86,444 km^2 or 64.5% of the total prairie (Coupland 1961, CPRC 1998).

The mixed grasslands of Saskatchewan once supported a rich and highly specialized flora and fauna. Today, however, the mixed grasslands is considered endangered habitat (Adams et al. 2004). Since 1995, for example, 37 species of birds, mammals and plants that once thrived in the prairies have been placed on the List of Species at Risk by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (CPRC 1998). Pressures from agriculture, and more recently oil and gas development have resulted in the region now being one of the most significantly modified landscapes in Canada.

Increased surface disturbance via conventional and non-conventional (coal bed methane) oil and gas activity have the potential to cause both long term and wide spread effects on mixed grassland ecosystems. Oil and gas surface lease sites, on average, disturb an area of 1.6 ha (Berquist et al. 2007). For conventional oil and gas activity, lease sites contain a single well and supporting infrastructure, including a pump jack or screw pump, separator, and solution tank. For non-conventional activity, the 1.6 ha area includes up to five wellheads, water disposal and injection facilities, and multiple access roads (Berquist et al. 2007). Associated with lease site activities is surface disturbance, the potential loss of native species, and risk of significant alteration of flora composition due to both fragmentation and the direct elimination of native habitat (Wilson 1995; Adams et al. 1996; Sinton 2001; Adams et al. 2004).

There are more than 20,000 operating oil wells and approximately 10,000 gas wells (sweet and sour) located in the prairie ecozone, of which 10,465 (35%) are located in Saskatchewan (CAPP 2007). In 2006, 2,250 and 1,350 new oil and gas wells were drilled in Saskatchewan (CAPP 2007), the majority of which were drilled in the southwest mixed grassland region (CCEI 2006). The future of oil and gas activity in the province is likely to include not only increased conventional energy sources, but also unconventional operations (CCEI 2006). It is estimated that 80% of oil and gas production over the next 10 years will come from currently untapped sources, which are primarily of unconventional sources (CCEI 2006). Further, by 2025, unconventional gas, namely coal bed methane, tight gas, and shale gas, is projected to account for over 50% of the total gas produced in Canada (CCEI 2006). This is of particular concern in Saskatchewan, given that nearly all of the province's unconventional gas deposits are located in grassland ecosystems.

The management and regulation of the impacts associated with oil and gas activities occurs largely through the Environmental Impact Assessment (EIA) process. At the federal level, this includes the *Canadian Environmental Assessment Act*, and in Saskatchewan *The Saskatchewan Environmental Assessment Act*. Environmental impact assessment is broadly defined as a formal process designed to systematically identify, evaluate, predict, mitigate, and monitor the effects of development activities on the environment (Bailey 1997; Gibson 2002; Cashmore 2004). In practice however, the majority of attention in the EIA process is on the pre-decision stages of project approval, with limited attention to the post-development stages to determine the actual environmental effects of project development and whether mitigation measures were actually implemented and are effective (Arts et al. 2001; Marshall 2005). This, in turn, prevents the Valued Ecosystem Components (VECs) identified in EIA (see Beanlands and Duinker 1983) from being included in future policy and practice, and limits the empirical focus of follow-up programs.

In the context of this study, the most significant limitation to current follow-up practice in EIA is the lack of integration of ecosystem components, and thus limited conservation of ecological integrity through post-decision monitoring and mitigation programs (Tinker et al. 2005; Legg et al. 2006). To date, "…few detailed empirical based studies that explore the utility of follow-up techniques…" have been done (Morrison-Saunders et al. 2003). Legg et al. (2006), for example, argue that monitoring programs that address the conservation of ecological components need to be revisited, so as to ensure that predicted effects can be verified and effectively mitigated. In the absence of ecological-based follow-up, we know little about the actual outcomes of project development (Morrison-Saunders et al. 2003). This is problematic given that EIA is the primary means for identifying and mitigating the effects of oil and gas activity on grassland ecosystems, and oil and gas development is expected to increase in the province in the near future.

This thesis examines ecological-based follow-up programs for oil and gas activity in grassland ecosystems, particularly within the context of Prairie Farm Rehabilitation Administration (PFRA) lands, Agriculture and Agri-Food Canada (AAFC). Established in 1935, the PFRA's primary goals are the protection of grasslands productivity and biodiversity within the prairie provinces of Canada (PFRA 2005). Despite this mandate, the requirements outlined for project assessment and approval on PFRA lands lack the implementation of follow-up or monitoring programs (PFRA 2005a).

This research examines the current state of development of oil and gas activity on PFRA lands, and the integration of ecological components in mitigation and monitoring practices. Ecological-based follow-up refers to the monitoring and assessment of grassland range health, which includes measures of vascular plant community composition; percent cover, and soil properties; compaction, pH, electro-conductivity, texture and horizon thickness.

1.1 Purpose and Objectives

The overall purpose of this research is to advance the current understanding and practice of ecological-based EIA follow-up programs. More specifically, this thesis 'follows-up' on decades of oil and gas activity on PFRA lands in southwest Saskatchewan in order to assess the effects of oil and gas development on grassland ecosystems. This is accomplished through two research objectives.

The first objective was to characterize the spatial and temporal footprint of oil and gas development in the Swift Current-Webb Community Pasture. This consists of the following sub-objectives:

- to characterize the distribution of oil and gas infrastructure in the study area from 1955 to 2006; and
- to determine the total pasture occupied by oil and gas lease site development.

The second objective was to assess the effects of oil and gas lease sites on grassland ecology. This consists of the following sub-objectives:

- to assess how abiotic and biotic conditions differ between lease and off-lease sites;
- to determine how the impacts to abiotic and biotic conditions vary with lease site drill date and infrastructure lease class;

- to determine how the impacts to abiotic and biotic conditions vary based on lease site annual and cumulative production measures;
- to examine the relationship between abiotic and biotic conditions at increasing distance from the well sites; and
- to determine the spatial extent of the impacts from PNG development to abiotic and biotic conditions.

The main contributions of this research are threefold. First, this research helps to advance the current understanding and practice of ecological-based follow-up programs in EIA. This, in turn, will allow for more informed EIA decisions, including mitigation measures, to be made with regards to ecological considerations. Alongside improving the PFRA management programs, this will contribute to improved understanding of ecological-based follow-up programs. Second, the collection and analysis of ecological field data in the Swift Current-Webb Community pasture provides for a better understanding of the effects of oil and gas activity on grassland communities. The results contribute to improved scientific understanding of how grassland communities respond to oil and gas lease site activity, and the effectiveness of the EIA process in managing those effects. Third, this research provides a methodology for conducting ecological-based EIA follow-up programs and site assessments to mitigate the impacts of oil and gas activity on grasslands. This methodology addresses concerns raised by the Canadian Environmental Assessment Agency (2000) regarding the lack of ecological-based follow-up methods and applications in Canadian EIA.

1.2 Thesis Organization

This thesis consists of five chapters, including the introductory chapter. Chapter 2 reviews the current literature on grassland ecosystems within the context of the potential effects of oil and gas development, and examines the state-of-practice of post-decision EIA follow-up. The research methods and study area are described in Chapter 3, followed by presentation of the research results in Chapter 4. Chapter 5 consolidates and discusses the overall thesis findings and situates these findings within the broader context of EIA follow-up programs, and identifies directions for future research.

CHAPTER 2

OIL AND GAS DEVELOPMENT IN SASKATCHEWAN AND POST-DECISION EFFECTS ASSESSMENT

2.1 Introduction

This chapter reviews the current state of grasslands in Saskatchewan and the effects of anthropogenic disturbance, including oil and gas development, on prairie ecosystems. The regulatory processes and environmental assessment framework associated with oil and gas development in the province are also introduced, and the current limitations of project level EIA in assessing the total effects of disturbance caused by oil and gas development on grasslands is addressed. Specific attention is given to the status of post-decision follow-up programs and the inability of current EIA follow-up practices to understand the actual effects of oil and gas development on grassland ecosystems.

2.2 The Great Plains of Saskatchewan, Canada

The northern Great Plains of Saskatchewan is one of the most significantly modified landscapes in Canada (Gauthier et al. 2003). Historically, natural disturbances such as fire, grazing and drought were the primary factors determining vegetation succession in this grassland ecosystem (Holechek et al. 1995). The introduction of anthropogenic disturbance, however, specifically large scale crop cultivation, livestock rearing, and grazing, alongside the suppression of fire, have dramatically altered grassland composition, structure and function (Forman 1995; Holechek et al. 1995).

Approximately 85% of all Canadian prairies have been transformed by anthropogenic disturbance (Adams et al. 2004). In the northern Great Plains, more than 80% of mixed grasslands have been transformed (PCAP 1995). The native grasslands that once characterized the Canadian Great Plains supported rich and highly specialized communities of flora and fauna, endemic only to the ecoregion. Today the prairie ecozone is home to a growing number of exotic, threatened, and endangered species (Adams et al. 2004). Over the last century, agricultural practices in the northern Great Plains have had the greatest impact on the prairie ecosystem. However, in recent years, increased pressures from large-scale commercial oil and gas development have significantly altered the remaining native prairie landscape (Sinton 2001; Berquist et al. 2007). All ecosystem properties are sensitive to natural and anthropogenic disturbance. When these disturbances are dispersed over large temporal and spatial scales, the impacts are minimized. However, oil and gas lease sites often include multiple wells located in close proximity to other petroleum and natural gas (PNG) infrastructure.

The construction of oil and gas lease sites, have the potential to reduce grassland productivity due to transformation of natural soil components, removal of native plant communities, and the introduction of exotic species (Wilson 1995; Adams et al. 1996; Sinton 2001; Adams et al. 2004). The effects of surface disturbances associated with oil and gas activity relate predominantly to the disruption of nutrient and water exchange (Jentsch 2002). The medium for this exchange is soil, with chemical and physical components that are sensitive to alteration (Willms et al. 2005). While natural disturbances rarely alter soil properties, anthropogenic disturbances caused by industrial development have the potential to dramatically affect soil structure (Zink et al. 1995). For example, a study conducted by Rowell et al. (1993) in south and central Alberta on the rehabilitation of soils following oil well drilling and pipeline construction in a grassland ecosystem, revealed that the impacts of industrial activity on soils affect a variety of chemical, physical and biological components. As a result of physical alteration (e.g. soil compaction, loss of bulk density, redistribution of clay particles, and horizon admixing) from pipeline construction, disturbed sites were found to have high electrical conductivity, and sulfate concentrations, and low pH, organic matter, cation exchange capacity, and moisture content in comparison to adjacent sites undisturbed by pipeline construction (Rowell et al. 1993; Cummings et al. 2005).

Soil disturbances in grassland ecosystems have a direct effect on vegetation community composition. Berquist et al.'s (2007) work on grassland species composition near coal bed methane development sites supports this claim. Their research found that non-native species richness increased with increasing proximity to well heads and, at the same time, low native species richness was observed surrounding disturbed well sites but increased with increasing distance from the well head. Associated with species composition differences between disturbed and undisturbed sites were differences in chemical and physical soil properties. Non-native species at well sites were correlated most significantly with high percentages of nitrogen in soils, low pH, and low percentages of native plant species (Berquist et al. 2007). Alteration in environmental gradients and competition regimes surrounding coal bed methane lease sites was found to promote non-native species establishment.

Altered environments are, however, still subject to species succession and environmental cycles (MacDougall et al. 2006). This is supported by Wilson et al. (1995), who studied the natural revegetation of disturbed mixed grasslands in Saskatchewan, dominated by non-native, exotic and/or fugitive plant species. Their findings indicate that natural succession of disturbed sites occurred from exotic species to a more native community composition (*Stipa comata*, *Bouteloua gracilis*). Further, a study of 45-year old mined land in Dakota by Wali (1999) reveals how vegetation succession occurs in mixed grasslands following disturbance. Prior to disturbance, the Dakota site was comprised of *Stipa comata*, *Bouteloua gracilis*, *Agropyron smithii*, *Carex filifolia* and *Koelaria cristata*. Following disturbance, the site experienced an influx of exotics such as *Descurainia sophia*, *Hordeum jubatum* and *Kochia scoparia*. Over the 45-year period, invasive species were replaced by *Stipa viridula*, *Achillea millefolium* and *Schizachyrium scoparium*. While the relationship between biodiversity and ecosystem function is complex, this study suggests that following disturbance natural succession over time can restore ecosystem biodiversity (Tilman 2004; Fridley et al. 2007).

The conservation of biodiversity is imperative for the preservation of ecological properties and processes, and is the focus of a great deal of applied ecological research (see Tilman 1997; Hobson et al. 2002; Schneider et al. 2003; Balvanera et al. 2006). The alteration of biophysical components associated with anthropogenic disturbances results in the alteration of ecological properties, which in turn, often results in a loss of biodiversity and a decline in ecosystem function and native plant species richness (Hooper et al. 2005). This stresses the importance of incorporating measures of ecological integrity into environmental management and EIA practices for industrial development sites in grassland environments.

This thesis adopts an applied ecological-based approach to the assessment of grassland productivity in EIA follow-up that includes examining net primary production, physical and chemical soil properties, soil hydrologic function (permeability and erosion), cycling of nutrients and energy from litter, and plant species diversity. This ecological-based approach is termed ‘range health assessment’, and is specifically developed for assessing the ecological integrity of grassland ecosystems (Adams et al. 2005). Range health assessments are methodological tools that build upon the more traditional 'range conditions approach' for site assessment, placing special consideration on plant community type in relation to site potential (Adams et al. 2004). In this thesis the examination of grassland ecological integrity incorporates a refined range health assessment methodology to determine the impacts of oil and gas activity.

2.3 Oil and Gas Development in Saskatchewan

Early oil and gas discoveries in Saskatchewan were the result of intensive exploration activities of large multinational corporations exploring reserves near Lloydminster (CPRC 2006). Of the first wells drilled in the province, the most significant was a gas well drilled by the Lloydminster Gas Company, in the rural municipality of Vermillion River (Roy 1998). The extraction of shallow gas in the province was followed by the discovery of heavy oil, both in the Lloydminster area and in southwest Saskatchewan (Roy 1988). Within the province, the commercial development of oil began in the late 1940s (Knight 1956; CPRC 2006). Current production is largely driven by non-integrated Canadian and American energy companies (CPRC 2006; GSER 2009a), while the majority of the province's oil is exported to the United States (Minnesota and mid-west) and Ontario, via the Enbridge Pipeline (CPRC 2006; GSIR 2008). Much of the natural gas produced in Saskatchewan is retained in the province, and supports larger energy-intensive mining operations (CPRC 2006).

The majority of oil and gas reserves in the province are under the jurisdiction of Crown dispositions. The three major dispositions in the province are petroleum, natural gas, and oil shale and oil sands (GSER 2009a). Oil reserves are located predominantly in the west, southwest and south central parts of the province, whereas gas reserves are situated primarily in the west-southwest, south central, and southeast parts of the province (GSER 2009a). Petroleum and natural gas reserves are extracted from five main Cretaceous formations, namely Bearpaw, Battle, Belly River, and Milk River (GSER 2009). Recent oil shale and oil sands development in the province is primarily in the southeast and northwest, and northwest regions of the province, respectively (GSER 2009a). As of 2009, 78% of total PNG rights in Saskatchewan were held by the Provincial Crown (GSER 2009a). Freehold land claims (18.5%), Indian reserves (2%), and Federal jurisdiction (1.5%) comprise the remaining PNG land holdings in the province (GSER2009a). The province's 78% of PNG dispositions accounts for approximately 24 million hectares of Crown land. Of this, approximately 7 million hectares (29%) has been leased to national and international oil and gas companies (GSIR 2008).

The majority of Crown dispositions leased by the provincial government are for the exploration of PNG reserves (GSER 2009). The remaining lease sites issued are for the exploration of oil shale (38 leases: 777692.5 ha) and oil sand deposits (5 leases: 45355.4 ha) (GSER 2009). In 2008, revenues from royalties, taxes and sales of petroleum leases totaled $1.12 billion, or approximately 15% of provincial government revenues (GSIR 2008). The greatest financial contribution to provincial revenue stems from over 3,200 lease sites in the southwest region of the province, including Weyburn-Estevan (1,398 wells), Kindersley (1,006 wells), and Swift Current (776 wells) (GSER 2009b).

Over the last twenty years, PNG production in Saskatchewan has doubled (CAPP 2007). This increase has been most significant in the southwest region of the province (Maple Creek, Swift Current area) (CAPP 2007). In 2006, 2,250 new oil wells and 1,350 new gas wells were drilled in the province (CAPP 2007), the majority in the southwest region (CCEI 2006). Most of the province's future sources of unconventional gas reserves, namely coal bed methane, tight gas, and shale gas, are also situated in this prairie ecozone.

2.4 Oil and Gas Regulatory Process and Environmental Impact Assessment

Saskatchewan's PNG reserves are managed under *The Department of Energy and Mines Act* and *The Oil and Gas Conservation Act* (DJC 2007). The acts outline and administer the exploration, development, management and conservation provisions and requirements for non-renewable resources in the province (GSIR 2001; DJC 2007). Given that the majority of PNG reserves are located on Crown land, a number of government bodies are involved in PNG regulation and approval processes (GSHRES 2007). Four governing bodies oversee provincial regulations for PNG drilling and exploration: Saskatchewan Energy and Mines (SEM), Saskatchewan Environment (SE), Municipal Affairs and Housing (MAH), and Saskatchewan Agriculture and Food (SAF) (GSIR 2001). Under certain circumstances, such as PNG development on PFRA community pastures, the purchase or lease of surface and mineral rights also involves the jurisdiction of the federal government.

Prior to obtaining approval for oil and gas exploration and development, companies must be registered in Saskatchewan under the Corporations Branch of Saskatchewan Justice (BSIB 2001). Exploration approval is followed by the purchase or lease of the subsurface PNG rights, from either individual freehold mineral holders or the Crown (GSIR 2001). In Saskatchewan, over 75% of mineral rights are held by the province, while 1.5% is held by the federal government (GSIR 2001). Mineral rights purchased from the Crown are done so through the Mineral Rights Branch of SEM, and are subject to public offerings (GSIR 2001). It is the role of SEM to determine if the land in question has any surface restrictions (Table 2.1). If SEM decides to post the PNG rights for sale, a public offering is held. Once the successful bidder obtains the PNG lease, the proponent submits to SEM an application to drill, operate and produce (GSIR 2001). SEM then issues a license to drill, operate and produce based on the information contained in the application and in compliance with regulatory conditions (GSIR 2001). It is during this time that the proponent obtains surface lease access from the surface owner (GSIR 2001). For developments on PFRA lands, regulatory approval is granted by the federal government for the Right-of-Entry to Survey, and a Right-of-Entry to Construct (GSIR 2001).

Table 2.1 Provincial regulatory requirements for the disposition of oil and gas lease sites (modified from GSIR 2001).

Department	Acts/Regulations	Administration
Saskatchewan Energy and Mines **(SEM)**	*The Crown Minerals Act*	Grants access to Crown mineral and Crown mineral lands in Saskatchewan
	The Mineral Resources Act, 1985	Involves the exploration, development, conservation and management of mineral resources
	The Seismic Exploration Regulations, 1999	Regulations for safety to the public for seismic operations
	The Oil and Gas Conservation Act	Grants well and facilities license once project has been approved by SEM, SE, MAH and RM's
	The Oil and Gas Conservation Regulations, 1985	Publishes Land Sale Notices in a public hearing setting (bidding process)
Saskatchewan Environment **(SE)**	*The Environmental Assessment Act*	Assessing the impacts from new "developments'
	The Wildlife Habitat Protection Act (WHPA)	The management of Crown agriculture lands for wildlife
	The Wildlife Habitat Lands Disposition and Alterations Regulations	Applies only to Saskatchewan Crown agricultural (grazing) lands administered by SAF
	The Environmental Management and Protection Act (EMPA)	The management and protection of the environment*
	The Provincial Lands Act	Administers provincial lands in the province
	The Fisheries Act	Both provincial and federal management of fisheries habitat
	The Forest Resource Management Act	
	The Wildlife Act	
	Wild Species at Risk Regulations	
Saskatchewan Agriculture and Food **(SAF)**	*The Provincial Lands Act*	The administration of provincial lands
	The Provincial Lands Regulations	

* 'Specific environmental protection requirements addressed under *The Oil and Gas Conservation Act* are exempt from the EMPA' (GSIR 2001)

Before site preparation and development can commence, all necessary approvals must be obtained from SE, SAF, MAH and/or the respective Rural Municipalities (RM's) (GSIR 2001). Regardless of private or Crown surface rights, the proponent must obtain environmental clearance from SE (GSIR 2001). In those cases where surface rights fall on Crown agricultural land (i.e., PFRA land holdings), the proponent must also contact SAF to secure surface lease rights from the lessee (GSIR 2001) before development can begin. Under SAF jurisdiction, the proponent is required to submit a site restoration plan as part of the development proposal (GSIR 2001). For development on PFRA lands, the proponent contacts SAF to determine if any restrictions exist. If the lessee grants approval, the proponent prepares a survey plan, project proposal and restoration plan for SAF and SE. For development within environmentally sensitive areas, such as native prairie, SE requires the proponent to submit both project proposals and environmental protection plans (GSIR 2001). Once SAF has conducted its environmental review of the proposed project, a surface lease agreement is prepared and approval for drilling is granted (GSIR 2001). At this stage, it is possible for SE to determine the project a 'development' under section 2(d) of *The Saskatchewan Environmental Assessment Act*, which initiates the EIA process and a formal review of the development plan or environmental protection plan by the Environmental Assessment Branch (EAB) (GSIR 2001).

2.5 Post-decision Effects Assessment of Oil and Gas Development

The first environmental assessment process in Canada was introduced in 1973, by way of the federal Environmental Assessment and Review Process (EARP), later to be implemented as law in 1995 under the *Canadian Environmental Assessment Act* (Gibson 2002). In Saskatchewan, EIA was adopted in 1975, and formally implemented as law under *The Saskatchewan Environmental Assessment Act* in 1980. Broadly defined as a decision making tool employed to identify and evaluate the potential environmental effects of particular actions (Cashmore 2004; Hanna 2005), EIA ensures "an evaluation of the effects likely to arise from a major project or action which significantly affects the environment" (Jay et al. 2007).

From a practical standpoint, the main goal or purpose of EIA is to constitute the generation of information (focused reports) related to the decision making process through the provision of accurate impact forecasts (Bailey 1997; Cashmore 2004). The process of conducting an EIA, which fulfills this purpose, involves a series of sequential steps from proposal development to post-approval follow-up (Table 2.2). The follow-up stage of EIA, which focuses on the actual ecological implications of development actions, is arguably the most important part of EIA in ensuring that the process meets its sustainability mandate. The problem, however, is that follow-up in EIA is rarely done or rarely done well (Hanna 2005; Marshall et al. 2005; Jay et al. 2007).

2.5.1 Follow-up practice

It is widely recognized and accepted that the EIA process is made more accountable through the integration of follow-up programs (Figure 2.1) (Table 2.3) (Bailey 1997; Arts et al. 2001; Marshall et al. 2005; Jay et al. 2007; Morrison-Saunders et al. 2007). In Canada, follow-up programs are a legislated requirement under the *Canadian Environmental Assessment Act* (CEAA 2000) for comprehensive and review panel assessments, and at the discretion of the regulatory authority for screening-level EIAs. Under *The Saskatchewan Environmental Assessment Act* there is no formal requirement for follow-up, but the Minister of Environmental has the authority to require that follow-up be conducted and monitoring programs implemented as a condition of project approval. Despite this, follow-up programs are yet to be effectively included in the EIA process, provincially, federally, or internationally, with any consistent degree of success (Marshall 2004). Jay et al. (2007) suggest that this is because EIA itself is simply not being conducted with enough due-diligence. Frost (1997) similarity criticizes research and practice concerning EIA follow-up, stating that “[i]t is almost as if those involved with EIA would rather concentrate on the procedures than dare look at the end results.”

Table 2.2 Basic steps involved in Canadian EIA.

Stage	**Purpose**	**Components**	**Importance**
Proposal	Description of the proposed action, including details sufficient for an assessment.	Screening	Ensures that a more responsive and acceptable proposal will be tendered.
Screening	Determination of whether the action is subject to an EIA and the level and type of assessment.		Ensure the proposal is subject to the assessment scrutiny required.
Scoping	Delineation of key issues and the boundaries to be considered in the assessment.	Baseline assessment	Terms of reference are established and potential issues impacts and baseline trends are identified.
Assessment of Proposal	Prediction of environmental impacts, impact significance and mitigation strategies.	Information identification, collection, analysis of data	Impacts are predicted, along with mitigation measures, and a future monitoring program described.
Assessment Review	Technical and public review of the assessments findings and subsequent recommendations. Decision on whether or not the proposed action should proceed and under what conditions.	Presentation of findings and public review	Ensures information collected and analyzed is brought together and placed in the EIA report. The findings of the assessment are presented.
Decision Made	Decision whether project should proceed.	Review and decision	Recommendations are made to approving or rejecting the project, approve the project, or approve with conditions.
Follow-up	Collection of monitoring data and evaluation for compliance and effects management.	Post-project monitoring and evaluation	Determines the effectiveness of mitigation strategies and examined actual environmental outcomes.

Source: Modified from Hanna 2005 and Noble 2006.

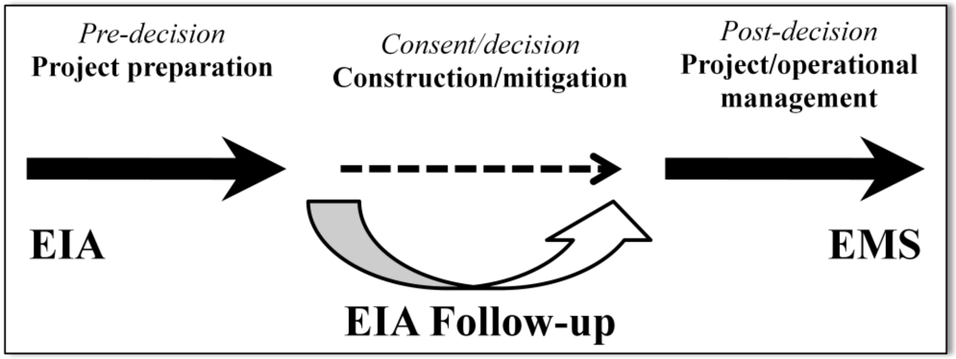


Figure 2.1. EIA follow-up bridging the implementation gap, (Source: modified from Marshall 2004)

Table 2.3 Components of the follow-up process

Elements	**IAIA 00' Actions Outlined**	**Functions or Objectives of Follow-Up**
Monitoring	The collection of data and comparison with standards, predictions or expectations	Provide information about the consequences of an activity
Evaluation	The appraisal of the conformance with standards, predictions or expectations as well as the environmental performance of the activity	Enhance scientific knowledge about environmental systems
Management	Making decisions and taking the appropriate action in response to issues arising from monitoring and evaluation activities	Improve public awareness about the actual effects of development projects
Communication	Informing the stakeholders as well as the general public about the results of the EIA follow-up	Maintain some decision-making flexibility

Source: Compiled based on Arts et al. 2001; Marshall 2005

Addressing these concerns is imperative to advancing follow-up in EIA and thus determining the actual outcomes of development and the effectiveness of mitigation measures. Incorporating feedback into the EIA process in the form of follow-up promotes learning from experience, and prevents EIA from becoming a *pro forma* exercise (Marshall 2005). Morrison-Saunders et al. (2005) and Morrison-Saunders and Marshall (2007), for example, argue that follow-up programs can be implemented to control compliance, verify predictions, reduce uncertainty, and improve pre-decision making within an EIA framework. The overall benefit of follow-up in EIA, is an improved understanding of impact uncertainties associated with an activity through project planning and decision-making, and the opportunity to mitigate potentially unforeseen adverse environmental outcomes (Arts et al. 2001).

Much international attention has focused on identifying the results of follow-up through case study analysis (Morris et al. 1995), and the culmination of core has been the focus of several annual general meetings of the International Association of Impact Assessment (IAIA) (see Morrison-Saunders et al. 2003). Storey and Noble (2002), for example, using examples drawn primarily from Canada illustrate the limitations of current follow-up approaches and suggest "that greater value from the process could be achieved by focusing on whether the objectives of the project in question were achieved" rather than retaining the current focus of EIA follow-up on verifying the predictive accuracy of the project's environmental impact statement. Their investigation of follow-up was an empirical focus on methodologies, which is a rare but beneficial approach to follow-up analysis. The advantage of studying methodologies is that such research reveals the underlying structure and systematic approach associated with conducting follow-up, identifying gaps in knowledge and potential flaws in the process (Morris et al. 1995).

Lessons learnt from methodological reviews of follow-up (see Storey and Noble 2002) reveal that the effectiveness of the impact assessment process itself is secondary to the monitoring and post-approval assessment of actual environmental outcomes. In other words, predictive accuracy and promised mitigation is of secondary importance to verifying the effectiveness of impact management measures and determining whether unanticipated environmental effects are occurring. At a time when follow-up was perceived as important, but rarely done, the approach taken by Storey and Noble (2002) was innovative, focusing on methodological efficiency in terms of mitigating real impacts. As a result, advancements in follow-up research need to focus on the efficacy of follow-up, and in particular follow-up methodology, in order to shift current practice from a simple 'damage control' function towards a more proactive approach to environmental management through the EIA process. The challenge, however, is that although the benefits associated with conducting more effects-based follow-up programs are well documented, knowledge of how follow-up programs can be advanced through empirical research is relatively unknown.

The Canadian Environmental Assessment Agency has addressed this concern, in part, through research priorities developed to improve follow-up effectiveness associated with EIA science, which include the development of effective approaches for determining follow-up requirements that are of a consistent design; methods for assessing and reporting on the accuracy of predictions and the effectiveness of mitigation measures; the development of consistent approaches or 'best practices' in conducting follow-up; assessment of the contributions of follow-up programs to better understand cumulative effects assessment (CEA) and proposed directions for integrating CEA and follow-up design; and identifying, integrating and applying broad and case-specific sustainability decision criteria and indicators (CEAA 2000).

2.6 Conclusion

It is well documented that the construction of oil and gas infrastructure (pipelines, access roads, lease sites) can dramatically reduce grassland biodiversity. This is of significant concern in Saskatchewan, given that oil and gas development in the mixed grasslands region is likely to increase in the foreseeable future. The problem is amplified by the inability of the current environmental management framework, EIA, to properly identify, predict, mitigate and monitor the effects of development on the environment. The literature indicates that, in practice, the most important component of the EIA process, follow-up, is rarely done or rarely done well. As a result, the EIA process, and hence development management and mitigation, is focused primarily on predicted outcomes. Such an approach fails to address the actual environmental effects associated with oil and gas development on grassland ecosystems (see Tinker et al. 2005; Legg et al. 2006).

There have been few detailed, empirically based studies that explore the utility of follow-up, particularly within the context of grassland ecosystems (see Morrison-Saunders et al. 2003). A recent review of the requirements for project approval on PFRA lands, for example reveals that no attention is given to monitoring and mitigation programs (PFRA 2005a). This lack of follow-up prevents knowing the actual effects of oil and gas development, and whether the mitigation measures implemented are working. As such, follow-up programs that address the conservation of ecological components needs to be revisited, and a more scientifically robust approach developed such that attention can be directed towards identifying and managing actual project outcomes on ecological systems (see Legg et al. 2006). This research will help determine the actual effects of oil and gas development on grassland ecology, and provide guidance for future follow-up program design and implementation on PFRA lands in southwest Saskatchewan.

CHAPTER 3

RESEARCH METHODS AND ANALYTICAL TOOLS

3.1 Introduction

This research uses a combination of methods and analytical tools including aerial photo analysis, secondary-source data, and the collection and analysis of ecological field data. Both methods were used to determine the spatial extent of oil and gas development and the impacts to grassland ecosystems. The goal of the first phase of this research was to determine the spatial and temporal distribution and associated physical footprint of oil and gas infrastructure in the study area. To accomplish this, satellite and air photo imagery were used, and direct loss of PFRA pasture from PNG infrastructure was calculated.

The second phase of the research, the assessment of environmental effects of oil and gas development on grasslands, involved the collection and analysis of field data from the Swift Current-Webb PFRA community pasture. To gain a representative sample, thirty-one lease sites were surveyed, stratified into three groups. The data collected included ground cover, physical and chemical soil properties, and plant community data. The goal was to assess the effects of oil and gas development on grassland plant communities and soil properties. To realize this objective, differences between oil and gas lease sites and reference pastures were examined based on plant community and soil variables. Lease site drill year, infrastructure, operational status, and production data were examined to gain a greater understanding of the factors that may influence development impacts, and to determine the ecological footprint surrounding oil and gas lease sites, beyond the direct footprint of the infrastructure.

3.2 Study Area: Swift Current-Webb Community Pasture

Swift Current-Webb Community Pasture was established in 1938 by the PFRA, Agriculture and Agri-Foods Canada. While the provincial government of Saskatchewan holds the land rights, the pasture falls under the jurisdiction of the federal government. The pasture covers a total area of approximately 98.8 km^2 (9,882 ha), and is situated within the RMs of Webb (No. 138) and Swift Current (No. 137). The pasture is further defined by the legal land locations of Twn15/Rge16, Twn16/Rge15 and Twn15/Rge15 W3M (Figure 3.1).

Swift Current-Webb has a cold, semi-arid steppe climate. The average annual temperature is approximately 3 ^{o}C, with mean monthly temperatures ranging from -10 ^{o}C (January) to 16.0^{o}C (July) (Environment Canada Meteorological Service of Canada 2007). On average, the area receives approximately 350mm of precipitation: 280mm of rain and 70mm of snow water equivalent (Environment Canada Meteorological Service of Canada 2007). Prevailing winds are from the west-northwest, where the average annual wind speed is approximately 20km/h (GSHRES 2007).

Landscape features in the region are a direct result of both the advance and retreat of the Late Wisconsinan Laurentide ice sheet during the last glaciation period (late Pleistocene and early Holocene) (GSHRES 2007). Topographic relief is low, and is reflective of the low energy fluvial environment present approximately 11,000 year ago (Klassen 2002). The aspect of the study area is generally to the NW, with an average slope of 0.64^{o}. Remnants of the glaciation event are reflected by gently irregular glaciolacustrine plains, consisting of glaciofluvial complexes, fine grained glaciolacustrine silts and sands, and aeolian deposits (Klassen 2002). The fine-grained sediments were further transported by wind activity (aeolian) which resulted in the soil textures and dune complexes currently observed.

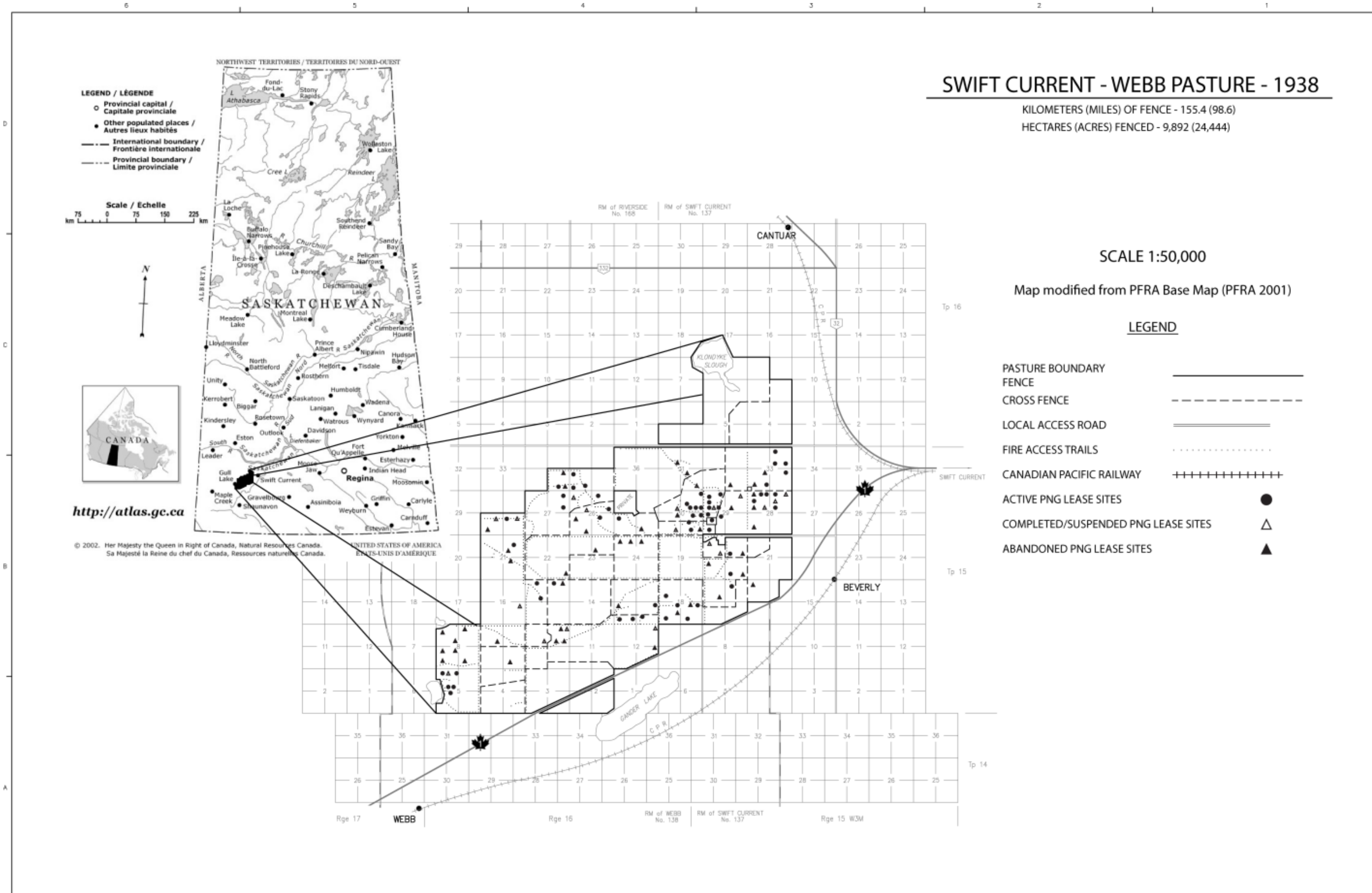


Figure 3.1 Swift Current-Webb Community Pasture
Source: Provincial Maps of Canada, (http://atlas.gc.ca) and Prairie Farm Rehabilitation Administration Archives

Sand dunes are located within the NW section of the pasture, and are part of the same dune complex that comprises the Great Sand Hills.

Glacial and post-glacial deposits have resulted in the formation of a predominantly fine grained, well sorted sandy environment. Three dune sand and sandy loam soil classes, all of which fall under the brown classification, dominate Swift Current-Webb pasture. The three main soil taxonomic groups are the humic regosol Antelope (AP3), and orthic brown Hatton-Haverhill (HTHR4) and Hatton (HT1/2). The fine-grained nature of the parent material along with increased wind alteration has resulted in all soils displaying poor development (Saskatchewan Institute of Pedology 1998). Soil textures increase the pasture's susceptibility to wind erosion, particularly when surface vegetation is removed. The sensitivity of the area to disturbance has resulted in the land being used historically for grazing rather than cereal crop production (Saskatchewan Institute of Pedology 1998).

Despite the pasture's isolation from agricultural cultivation and urban development, industrial development and cattle grazing activity have significantly altered the vegetation. Swift Current-Webb pasture is a remnant patch of semi-intact native prairie surrounded by cultivated lands. Fire has been suppressed within the pasture since it was established, thus drought and grazing pressures have been the predominant factors influencing species and community composition. An ecological assessment circa 2005 (PFRA 2005b) indicates that the native grassland communities make up 49.40 km^2 (approximately 50%) of the pasture, while the remaining 50% consists of re-seeded vegetation (PFRA 2005b). The portions of the pasture re-seeded were done so with *Agropyron pectiniforme* (crested wheat grass), in an attempt to stabilize the highly eroded landscape. The remainder of the pasture consists of a mix of both tall and short annual grass species: *Stipa comata* (needle-thread grass), *Calamovilfa longifolia* (sand reed grass), *Agropyron smithii* (western wheat grass), and *Koelaria cristata* (June grass). *Bouteloua gracilis* (blue grama) is also present, but is not dominant (Table A.1). Stands of shrubs are present, particularly in the sand dunes, and include *Artemisia cana* (sagebrush), *Elaeagnus commutata* (wolf willow), *Juniperus horizontalis*, (creeping juniper), and *Symphoricarpus occidentalis* (western snowberry). The most common perennial forbs are *Rosa acicularis* (prickly rose), *Heterotheca villosa*, (hairy golden aster), *Psorelea lanceolata* (lanced leaved psorelea), *Artemisia frigida* (pasture sage), *Salvia argentea* (silver sage) and *Grindelia squarrosa* (gumweed).

Petroleum and natural gas resources have been exploited in the region since the 1950's and, next to agriculture, the exploration and acquisition of oil and gas reserves is the largest economic contributor to the region's economy (GSHRES 2007). While sweet and sour gas is the dominant product outside of PFRA pasture boundaries, the majority of dispositions within the pasture are associated with oil production (GSHRES 2007). As of 2006, 387 wells have been drilled within the area, with 170 of those wells located within Swift Current-Webb community pasture. Oil reserves within the pasture are extracted from five oil pools. Combined, the five oil pools underlie 4353.8ha or, approximately 43% of the total pasture.

The single gas pool in the study area is located in the northwest corner of the pasture, and underlies approximately 16% (1556.6ha area) of the total pasture. There are only three pipelines within the pasture boundaries. Few lease sites in the pasture are tied into pipelines. Instead, the majority of the lease sites in the study area retain produced materials in on-site storage tanks. Since 1999, the government of Saskatchewan has realized on average $35.7 million/yr from wells in the area (GSHRES 2007).

3.2.1 PFRA objectives and land management

Established in 1935, the PFRA's original mandate, under the *Prairie Farm Rehabilitation Act*, was to manage soil erosion and water resources in Manitoba, Saskatchewan, and Alberta (AAFC 2007a; DJC 2009). As prairie drought and distress were regarded a short-term problem, the initial total appropriation was just under five million dollars, and the PFRA was to cover a period of four to five years (AAFC 2007b). The primary objectives of the PFRA during the 1930s were the development of irritation projects, which included dugouts, and dams, and the development of methods for controlling soil erosion (AAFC 2007a). In 1937, the *PFRA Act* was amended to add land utilization and management programs (AAFC 2007b). It was during this time that the Community Pasture Program began in Saskatchewan (AAFC 2007b). Following the most severe drought in the history of the west in the summer of 1939, the PFRA's mandate was extended, removing the originally imposed five-year limit (AAFC 2007b).

Currently, PFRA lands encompass over 80% of Canada's native prairie agricultural land base in the prairie provinces (AAFC 2007a). In Saskatchewan, the Community Pasture Program includes sixty-two pastures, covering a total area of over 700,000 hectares (AAFC 2007a). Although the Community Pasture Program was primarily established for summer grazing and cattle breeding, conservation has become a principal objective of land management:

> "…keeping these lands under permanent cover, a great deal of the prairies' diverse plant, insect, bird, reptile and mammal life is maintained. In Saskatchewan, forty-nine of the pastures—some of the last uncultivated land on the prairies—provide a home for "species at risk" as defined by the Committee on the Status of Endangered Wildlife in Canada" (AAFC 2001).

PFRA land management also addresses the “Biodiversity Strategy” outlined by AAFC through the conservation of natural lands within agro-ecosystems (AAFC 2007a). This is accomplished through the use of conservation range management principles and practices to maintain biodiversity on rangelands (AAFC 2007a). Given that both the mixed and short grass prairies of North America have been reduced to approximately 30% of their former extent (Gauthier et al. 2003; AAFC 2009), the role of prairie ecosystem conservation is of significant importance within the province of Saskatchewan. However, despite conservation initiatives, pressures from development are posing limitations on ecosystem based land management strategies.

It should be expected that PFRA management plans for oil and gas reflect the goals of its mandate, but this is not necessarily the case. A review of the requirements for oil and gas project approval on PFRA lands reveals that limited to no attention is given to following-up on development actions through monitoring programs (PFRA 2005a). As a result, there is limited knowledge of the effects of oil and gas development on the grassland ecosystem. This is concerning given that as a federal department, the PFRA (AAFC) has a legislated responsibility under the *Canadian Environmental Assessment Act* to ensure that the effects of development are assessed and appropriately managed.

3.3 Data Collection and Analysis

Two types of data were collected to realize the objectives of this thesis: aerial photo and secondary-source data for oil and gas wells in the study area, and primary field data. To realize the first objective, aerial photo and secondary-source data of oil and gas well production and distribution were collected to characterize the spatial and temporal footprint of oil and gas infrastructure development in the study area. The second objective, to assess the effects of oil and gas lease sites on grassland ecology, was realized through primary field data collection and analysis. For multivariate statistical analyses, multiple methods were used to ensure that the trends were not biased by the method chosen.

3.3.1 Aerial photo and secondary source data

Well ticket (GeoScout^{TM}) information was used to classify all lease sites within the study area into one of five time periods (pre-1970, 1970-1979, 1980-1989, 1990-1999, and 2000-2006). Oil and gas lease sites were then further stratified based on infrastructure type (oil, or gas) and well activity (active, completed/suspended, or abandoned).

The amount of the study area occupied by oil and gas infrastructure was determined by air photo and satellite imagery analysis. Air photos (A25143–1979, A27728-1997) were obtained from the National Air Photo Library, Natural Resources Canada, and cover a township area (1:50,000). Prior to analysis, air photos were orthorectified using ArcGIS 9.3^{TM}. Satellite images (2005 - SPOT 5 Imagery) were used to document recent oil and gas activity in the study area. The high resolution (2.5m) black and white SPOT 5 images used are part of the Saskatchewan Geospatial Imagery Collaborative Project, and were obtained from the Information Technologies Office website of the Government of Saskatchewan. To cover the study area, three 1:50,000 satellite images (NTS – 72K08, 72K01, 72J05) were required.

For each of the three years where imagery are available (1979, 1997, and 2005), the footprint of oil and gas infrastructure was calculated by overlaying polygons onto surface features. Area and perimeter were calculated for PFRA roads, trails, lease sites and lease access roads using HAWTH TOOLS^{TM}. Fragmentation metrics calculated for each patch class included patch density (#/100ha), and edge density (edge:area ratio) (Linke et al. 2008). The percentage of pasture area occupied by PFRA roads, trails, lease sites and lease access roads was determined over the entire twenty-six year time period. PFRA trails represent cattle trails with light vehicle traffic, PFRA roads are ROWs present prior to PNG development. PNG infrastructure includes lease sites and lease site access roads. Maps were generated to display land use change occurring from 1979-1991 and 1991-2005. Because no air photos or satellite images of the study area exist for the 1980s, the timeframe of the analysis differs from the distribution maps.

3.3.2 Field data collection and analysis

Primary field data were collected in the Swift Current-Webb Community pasture and analyzed to determine:

- how abiotic and biotic conditions differ between lease and off-lease sites;
- how the impacts to abiotic and biotic conditions vary with lease sites drill date and infrastructure class;
- how the impacts to abiotic and biotic conditions vary based on lease site annual and cumulative production measures;
- the relationship between abiotic and biotic conditions at increasing distance from the well site; and
- the spatial extent of the impacts from PNG development to abiotic and biotic conditions.

3.3.2.1 Sampling site selection

The sample size consisted of thirty one oil and gas lease sites located within Swift Current-Webb Community Pasture. The thirty one lease sites selected for analysis were derived from the screening of the 170 lease sites present in the study area. Prior to sampling, lease sites were stratified based on land class, soil taxonomic unit, and decadal drill year based on well ticket information. Sixteen of the lease sites sampled were located within the dune upland land class, while fifteen were located within mixed grassland. Due to the spatial distribution of the lease sites, it was not possible to sample an equal representation of lease sites stratified by the three soil taxonomic units Antelope (AP3), Hatton-Haverhill (HTHR4), and Hatton (HT1/2) (Table A.2). The lease sites encompassed final drill years from 1955 to 2005. With the exception of the pre-1970s decade class, eight lease sites per decade (1970, 1980, 1990 and 2000) were sampled.

3.3.2.2 Field sampling design

Field data were collected during the summer (May 28th to July 19th) of 2008. Due to the spatial extent of the disturbance on the landscape, a gradient to background approach was adopted for assessing the impacts from development. Estimation of a species area curve from pre-existing range health data (PFRA 2005b), indicated that four transects provided sufficient sample area to adequately characterize plant community composition at a lease site. Since the extent of lease site disturbance from the wellhead was initially unknown, pilot sites were used to determine the appropriate transect length. The 6 pilot sites included oil and gas wells drilled in the 1980s, 1990s, and 2000s from the two landscape classes. A transect length of 40m was determined from the pilot sites to adequately capture the spatial extent of disturbance from the wellhead, which was then applied to the remainder of the lease sites sampled (Figure 3.2). To prevent overlap of the transects, azimuth orientations were separated by a minimum of 10 degrees. In cases where a transect ran parallel to or intersected with a roadway, the transect azimuth was re-determined. Following the sampling design for the Great Sand Hills Regional Environmental Study (GSHRES 2007), all transects were not allowed to be within 20m of a roadway buffer generated from a species response curve. This was a precautionary measure to prevent bias from the disturbance effects of roadways.

Transects were used to position the plots at even intervals away from the lease, where a $0.50m^2$ litter estimation frame and a .20m x .50m Daubenmire frame were used to collect environmental and biotic data. For each 40m transect, the distance between each of the subplots was 5m. The sampling design was based on previous research done in Alberta and Saskatchewan grasslands (GSHRES 2007). When enclosures located within the lease site ROW ran perpendicular to the transect line, their distance (m) from the wellhead was recorded.

For every lease site surveyed, a reference sample (pasture land) located 100m from the lease site ROW boundary was established. The reference sites were located within a similar land class as the associated lease site, and upwards of 200m from dugouts, and areas of heavy grazing activity. Each reference site was comprised of eight subplots divided into four transect lines oriented N-S and E-W. Each of the four transect lines contained two subplots where biophysical information was collected using both a $0.50m^2$ litter estimation frame and a .20m x .50m Daubenmire frame. Reference site soil data were collected from a single soil sample from the center of the ‘x’ sampling pattern. The reference sites were also located at least 20m from adjacent and surrounding roadways.

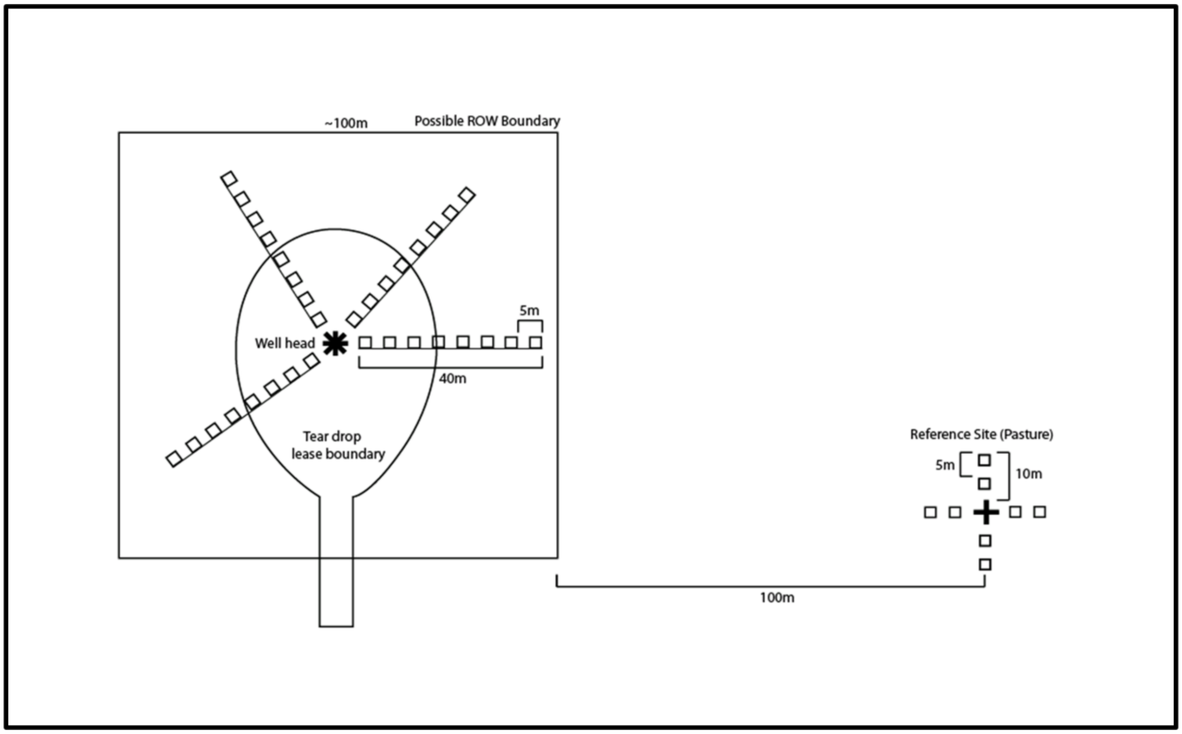


Figure 3.2 Schematic diagram showing the sampling design for well sites and reference pasture

3.3.2.3 Field data collection

Data were collected at the quadrat level from the thirty one lease sites and associated reference sites. The environmental variables examined included: slope, aspect, % herbaceous, % bare ground, % litter, soil compaction, % aggregates, % clubmoss (Lycopodiaceae), % oil spill/contaminated. For each transect, the environmental variables mentioned were sampled at the subplot level. Eight samples were collected per transect and reference site, for a total of 32 samples per lease site. Lease site slope (^{o}) is expressed as an average value per transect, measured from quadrats one, four, five and eight using a Brunton Compass. For the reference sites, a single slope value was recorded for each of the four transects. Canopy cover values were used to determine visual estimates of herbaceous, bare ground, aggregate, clubmoss, and oil spill/contaminated ground cover values. Cover values, which summed to 100%, were visually estimated to the nearest 1%. Soil compaction was measured by penetration resistance (kg/cm^2)

using a calibrated ring penetrometer with a 12mm cone diameter at 2cm depth. Litter cover values were determined by hand raking the 0.50m^2 quadrats, as outlined by Adams et al. (2003).

Data collected from soil samples included: pH, electro-conductivity, % silt, % sand, % clay. For both the lease and reference sites, soil samples were taken to a depth of 15cm with a 10cm diameter soil corer. Given that the landscape (blowout dune complex) displays poorly developed soils, a 15cm coring depth was considered deep enough to document soil conditions in the rooting zone and organic soil horizon depths. At the lease sites, samples were taken from two randomly selected transects. The soil samples used to determine pH and electro-conductivity were taken from quadrats one, four, five and eight for one transect, and quadrats one and eight for the other transect. Of the two transects selected for pH and electro-conductivity soil samples, soil texture (% silt, % sand, % clay) was determined from the first, middle, and last quadrat of one transect. For each reference site, a single soil sample was taken. Soil pH and electro-conductivity were measured using a Fisher Scientific AP62™ portable soil pH/mV meter. Soil texture was measured using a Horiba LA-950™ laser particle size analyzer. Particle size distribution was determined for sand, silt and clay.

Biotic data collected from both lease and reference pasture sites consisted of plant species, visually estimated to the nearest 1% cover. Percent cover data was collected for all observed grasses and herbaceous or woody forb species, considered desirable or undesirable to the study area. For each species the average % cover for the transect line was calculated. Vegetation trampling and trailing from livestock were also documented.

Production data from oil and gas lease sites included: final drill year and month; year suspended; production time; and production type (gas, oil, water). Oil and gas data were collected from GeoScout™ well tickets. Lease type was also obtained from well tickets, and classed accordingly (oil, suspended oil, abandoned oil, gas, suspended gas, abandoned gas, potential gas, and drilled and abandoned). Drilled and abandoned lease sites represent test wells. If a test well was later producing, it was reclassified as a producing oil or gas lease site. Production time was measured in years of oil and gas lease site production. Production data was recorded as a measure of cumulative production during the operation cycle of a well, and lease site production per year was determined.

3.3.2.4 Pre-analysis data screening and transformations

Prior to the analysis of lease and reference pasture sites data, all matrices were screened, transformed, and separated into environmental and biotic data matrices. Biotic matrices for both the lease and reference sites received similar treatment prior to analysis. For the biotic data matrices, a large number of quadrats had zero cover - no vascular plant cover. These quadrats contained important information and were included in statistical analyses.

All species within lease and reference pasture biotic matrices were separated into desirable and undesirable (invasive/exotic) classes, based on *Weeds of the Prairies* (Alberta Agriculture and Food 2000) and *The Flora of Alberta* (Moss 1983). For the two classes (desirable species, undesirable species) linearity was interpreted using bivariate scatter-plots. From this it was found that few of the variables displayed linear relationships. A logarithmic transformation (log{x}) was selected for multivariate analyses, as it led to more linear relationships within the data (Legendre et al. 2001; McCune et al. 2002). Given that the data contained zero values, and that the nearest nonzero value was close to one, a constant (lowest value in the dataset) was added to the calculation; b=log{x+1} (McCune et al. 2002). For each of the b=log{x+1} biotic matrices, three measures of alpha diversity (species richness, Shannon's Diversity Index, and

Simpson's Diversity Index) were calculated using PCORD v.5(MjM Software Design 2002^{TM}). With the exception of soil electro-conductivity, none of the environmental variables were transformed. Soil electro-conductivity was log{b+(lowest #)+1} transformed prior to running all ordination analyses to achieve a more interpretable output and to adjust for negative values, to accommodate the distance measure.

From the complete biotic matrix, range health values were calculated at the quadrat, transect and well site levels. Range health was determined using the *Rangeland Health Assessment for Native Grassland and Forest* (Adams et al. 2003). Range health was assessed using four indicators of grassland integrity as outlined by Adams et al. (2003). Plant species composition data was collected to determine biodiversity and species richness. Litter estimates collected were used as indicators of soil moisture and nutrient cycling (Adams et al. 2003). Ground cover class (herbaceous vs. bareground) indicated site stability and soil erosion. Finally, undesirable weed distribution and cover, as outlined by *Weeds of the Prairies* (Alberta Agriculture and Food 2000) and *The Flora of Alberta* (Moss 1983), were collected as an indicator of ecological integrity. Given that short grasses dominate the landscape, community structure data were not collected. Based on Adams et al. (2003), Abouguendia (1990), and following the lead of the GSHRES (2007), range health scores were placed into one of three categories: healthy site (> 70); healthy but with problems (35-69); and unhealthy (< 35). Range health values were first calculated at the quadrat level. From quadrat level range health measures, median values for range health at transect and lease site levels were determined. Species richness was a measure of the number of species in a 20cm x 50cm area (McCune et al. 2002). The Shannon (Shannon-Weiner) diversity index is a measure of the number of species with an equal abundance. Simpson's diversity index represents the chance that two randomly selected plants will be of the same species (McCune et al. 2002).

Prior to running all statistical analyses, data matrices were screened for multivariate outliers using the most appropriate distance measure. All samples found to have a distance greater than 2.0 standard deviations from the overall mean were removed. A Euclidean distance measure was used for all analyses involving environmental variables, while a Bray-Curtis (Sørenson) distance measure was used for the biotic data (McCune et al. 2002).

3.3.2.5 Multi-Response Permutation Procedure (MRPP)

All MRPP analyses were run using PCORD v.5(MjM Software Design 2002™). Distance measures were selected on the basis of maintaining consistency with associated analyses (outlier analysis, ordination) and attaining the most logical/interpretable output. MRPP analyses were selected for group comparison given that they are not confined by the assumptions of linearity (McCune et al. 2002). This non-parametric randomization procedure calculates the average within-group distance for each group, and the probability of difference by randomly reassignment of sample units to groups. The output of this procedure is a test statistic (*A-value*, *Delta*, and *t-statistic*) that represents a measure of difference between groups. An *A-value* equal to zero indicates within group heterogeneity expected by change, while a value greater than zero indicates greater heterogeneity occurring within groups by chance. Assumptions are based on the calculated *p*-value, where a value <0.05 indicates significant group differences (McCune et al. 2002). For all MRPP analyses, plots were used as replicates.

MRPP analysis was used to test for statistical differences between the lease and reference sites. The two sites were compared based on ground cover variables: % herbaceous ground cover, % bare ground cover, % club moss cover; environmental variables: litter (lb/ac), Ah soil horizon depth (mm), soil compaction (kg/cm^2); soil properties: pH, and electro-conductivity; and biotic variables: range health (median values per transect), and desirable and undesirable species alpha diversity. For each group of variables, a separate MRPP test was run.

Statistical differences in response values between lease site final drill year and infrastructure type were tested using MRPP analysis. Response variables included the ground cover and environmental variables identified above as well as biotic variables of range health (median values per transect), and desirable/undesirable species alpha diversity. The soil sampling design prevented the comparison of final drill year, and infrastructure type based on soil pH, electro-conductivity, and texture.

3.3.2.6 Non-Metric Multidimensional Scaling (NMDS)

To determine the basis for which *a priori* defined groups differed, an NMDS (McCune et al. 2002) method of ordination was used. NMDS is considered an exploratory ordination technique, and in this case was used as an investigative tool (McGarigal et al. 2000; Beals 2006; Hirst et al. 2007). Variables were input to NMDS where ordinal scale environmental and biotic data were used to generate vector overlay plots to compare *a priori* groups (McCune et al. 2002). For the analysis of ground cover, soil and biotic data, plots were used as replicates. NMDS was selected as the ordination method because despite log transformation, the data remained non linear, which is accommodated by NMDS (McCune et al. 2002). Although NMDS does not require linear data, monotonic transformations reduce stress and improve stability of the final solution as they alter the distances calculated between observations within the ordination data without changing their ranks (Legendre et al. 2001; McCune et al. 2002). Further, environmental and biotic variables contained a significant number of zero values, which would have resulted in poor performances with other ordination techniques. For each ordination analysis, the distance measure was selected to maintain consistency with other analytical tools. All NMDS ordinations were run with PCORD v.5(MjM Software Design 2002™). The *a priori* defined group variables (drill year, infrastructure class, and distance from well head) were overlaid in the ordination with symbols to display classes. Environmental and biotic variables were used to generate vector overlay plots (McCune et al. 2002). For each analysis, the number of samples, variables, runs, dimensionality, stress, instability, Monte Carlo test *p*-value, axis scores (r^2) values, and distance measure were recorded. Scree plots were generated for each NMDS analysis to determine the number of axes (dimensionality) in the final solution which captured the most variation in the data, with the lowest stress. The number of axes selected was based on the "elbow" in the scree plot (McCune et al. 2002).

The analysis of lease site final drill year and infrastructure type was based on the same data used for the MRPP analysis. The median values provided a more interpretable and accurate ordination output. An NMDS ordination analysis was used to determine how lease site production influenced ground cover, environmental, and soil variables, as well as the biotic variables range health (median values per well), and desirable/undesirable species alpha diversity. The analysis used production data (production time (yrs), gas (mcf), oil (Bbl), and water (Bbl)) from each of the thirty one leases sites. From the NMDS, a correlation analysis was used to determine how distance from the well head influenced ground cover, physical and chemical soil, and biotic variables. Distance measures from the well head were assigned to classes 0m – 40m at a 5m intervals: 0m, 5m, 10m, 15m, 20m, 25m, 30m, 35m, 40m. The analysis included all ground cover, soil, and range health values, measured as a median values across transects. Biotic variables include the % cover and alpha diversity measures of desirable and undesirable species. To correct for the presence of zero range health values close to the well, the lowest observed value (2) was added to all sample units.

3.3.2.7 Indicator species analysis

Using PCORD v.5(MjM Software Design 2002^{TM}), Dufrene and Legendre's (1997) method for calculating species indicators (McCune et al. 2002) were run to determine how a priori groups differed based on desirable and undesirable species presence. Indicator analyses were run for both the desirable and undesirable species classes to determine which species most significantly differed between lease sites based on drill year and lease type. For all indicator analyses, a Monte Carlo test of significance was set to 4,999 permutations and a random seed was selected. Indicator Values (IV %) were selected as the strongest indicators of difference between the groups. From all analyses, all species had a relative abundance value greater than 5%, and were not considered rare to the environment. For the comparison of lease and reference sites the desirable plant species dataset contained 1183 plots and 46 variables (species) while the undesirable plant species dataset contained 1176 plots and 40 variables. For this analysis, an IV was used to determine how species differed between the four classes: desirable by year, desirable by lease, undesirable by year and undesirable by lease.

3.3.2.8 Calculating the spatial extent of ecological effects

Graphical representations were used to determine how variables differed with distance from the well head. Geographic extents of effects in meters were calculated for ground cover characteristics, soil properties and biotic data. Ground cover and soil variables % herbaceous and % bareground, % aggregate and soil compaction, and soil pH and electro-conductivity were plotted against each other due to strong correlation scores. The representation of biotic data included undesirable species richness and range health values.

The spatial extent of the impacts from development (i.e., distance from the well head) was calculated for each of the following date classes: 1950 – 1979, 1980s, 1990s, and 2000s. These 'impact zones' were generated for trails, PFRA and lease access roads, and lease sites. Impact zones were calculated in ArcGIS 9.3^{TM} using BUFFER WIZARD^{TM} and HAWTH TOOLS^{TM}. Fragmentation metrics were calculated for each patch class included patch density (#/100ha), and edge density (Linke et al. 2008).

For the three years (1979, 1997, and 2005), the spatial extent of the ecological effects were generated for trails, PFRA and lease access roads, and lease sites. The spatial extents were calculated in ArcGIS 9.3^{TM} using BUFFER WIZARD^{TM} and HAWTH TOOLS^{TM}, and overlain onto the previously generated polygons for each of the three maps (1979, 1997, and 2005). From the impact assessments of the Great Sand Hills (GSHRES 2007), a 20m impact zone was adopted for trails, and roads. Based on the results from the graphical representations a 25m impact extent was assigned to all lease sites.

CHAPTER 4

RESULTS

4.1 Introduction

This chapter presents the results for each of the two main objectives outlined in Chapter 1. The results include findings from the analysis of the spatial and temporal development and distribution of oil and gas lease sites and associated infrastructure in Swift Current-Webb PFRA pasture and surrounding area, and the effects of oil and gas lease site activity on grassland plant communities and soil properties.

4.2 Spatial and Temporal Development of Oil and Gas in the Swift Current-Webb Community Pasture

The majority of oil and gas development in the study area and surrounding region occurred during the mid to late 1990s (Table 4.1) (Figures 4.1, 4.2). Over 60% of PNG development in the area occurred during this time period, with four times as many wells drilled in this decade than in the previous decades combined. The magnitude of development that occurred during the latter part of the 1990s is reflected by the calculated patch density metric of wells per hectare for oil and gas lease sites, which increased from 0.4 wells/ha in 1997 to 1.10 wells/ha by 2005. The comparison of study area lease site drill dates to provincial data reveals that production trends in the study area reflect the development of oil pools throughout southwest region of Saskatchewan in general (GSIR 2009).

Development in the study area and surrounding region is focused primarily on oil extracted from six oil pools that encompass an area approximately of 43.6 km^2. As of 2006, there were 81 actively producing oil wells within the pasture, or which approximately 75% were drilled during the latter part of the1990s. During the fifty-year period of development in the area, natural gas production accounted for only 4% of total well development. The dominance of oil production in the study area is not reflective of production in the region. Southwest Saskatchewan (Wymark, Gull Lake, and Maple Creek) is dominated by natural gas production (GSIR 2009). The majority of oil production occurs in the southeast (Weyburn, Estevan) region of the province (GSIR 2009).

4.2.1 Physical footprint of oil and gas infrastructure

Between 1979 and 2005, the physical footprint of oil and gas infrastructure increased from 0.20% to 1.00% of the landscape in the study area. Most of this increase occurred between 1997 and 2005, when oil and gas infrastructure and the total direct loss of grassland habitat more than doubled (Figures 4.3 – 4.5). The direct loss of grassland habitat to trails and PFRA roads decreased between 1979 and 2005. During the same time, however, lease access roads increased from occupying 0.13% to 0.42% of the landscape. The trend was also observed in patch density values, where patch density per 100ha increased from 0.11 patches in 1979 to 0.12 patches in 1997 and 0.42 patches in 2005 (see Tables 4.2 – 4.4). This increase is due in part to the change in use and reclassification of roads and trails as lease access roads. The observed trend coincides with findings from the GSHRES (2007), where new road segments were 150 times more likely to be associated with new lease development than elsewhere on the landscape.

Edge density values associated with development were greatest for existing PFRA and lease site access roads (Tables 4.2 - 4.4). In 2006 the total percent loss from infrastructure within the pasture was 1.26% (Table 4.4). Of this 1.26%, PFRA and lease site access ROWs accounted for 6% and 33% of the study area, respectively, with an edge density value for ROWs of 3,299m/ha.

Lease sites, which contributed to 49% of the total 1.26% loss, had a combined edge density value of only 595m/ha. This indicates that the edge density values from ROWs are nearly six times greater than those associated with oil and gas lease sites. One of the most significant findings from the fragmentation metric is the change in edge density from 3,676.7 for 11 access roads in 1979, to 1954.0 for 41 access roads in 2005. This indicates that management practices involving the construction of ROWs have decreased edge habitat. A similar trend was observed for oil and gas lease sites. Although lease sites on average had much lower area to edge values, the change from 419.7 for 14 wells in 1979 to 595.0 for 108 wells in 2005 indicates some improvements in management practice. At the landscape level, these are desired trends given that increased edge density increases the edge effect and landscape fragmentation. Edge habitats are often associated with undesirable plant species, and reductions in desirable plant biodiversity.

TABLE 4.1 Oil and gas infrastructure in the Swift Current-Webb Community Pasture, 1955 – 2005.

Lease Site Classification	pre-1970s	1970s	1980s	1990s	2000s
Active Oil	1	1	9	61	9
Completed/Suspended Oil	0	0	5	17	1
Abandoned Oil	11	3	11	26	2
Active Gas	2	1	0	0	0
Completed/Suspended Gas	2	1	0	3	1
Abandoned Gas	0	1	1	0	0
Total Number of Leases	***16***	***7***	***26***	***107***	***13***

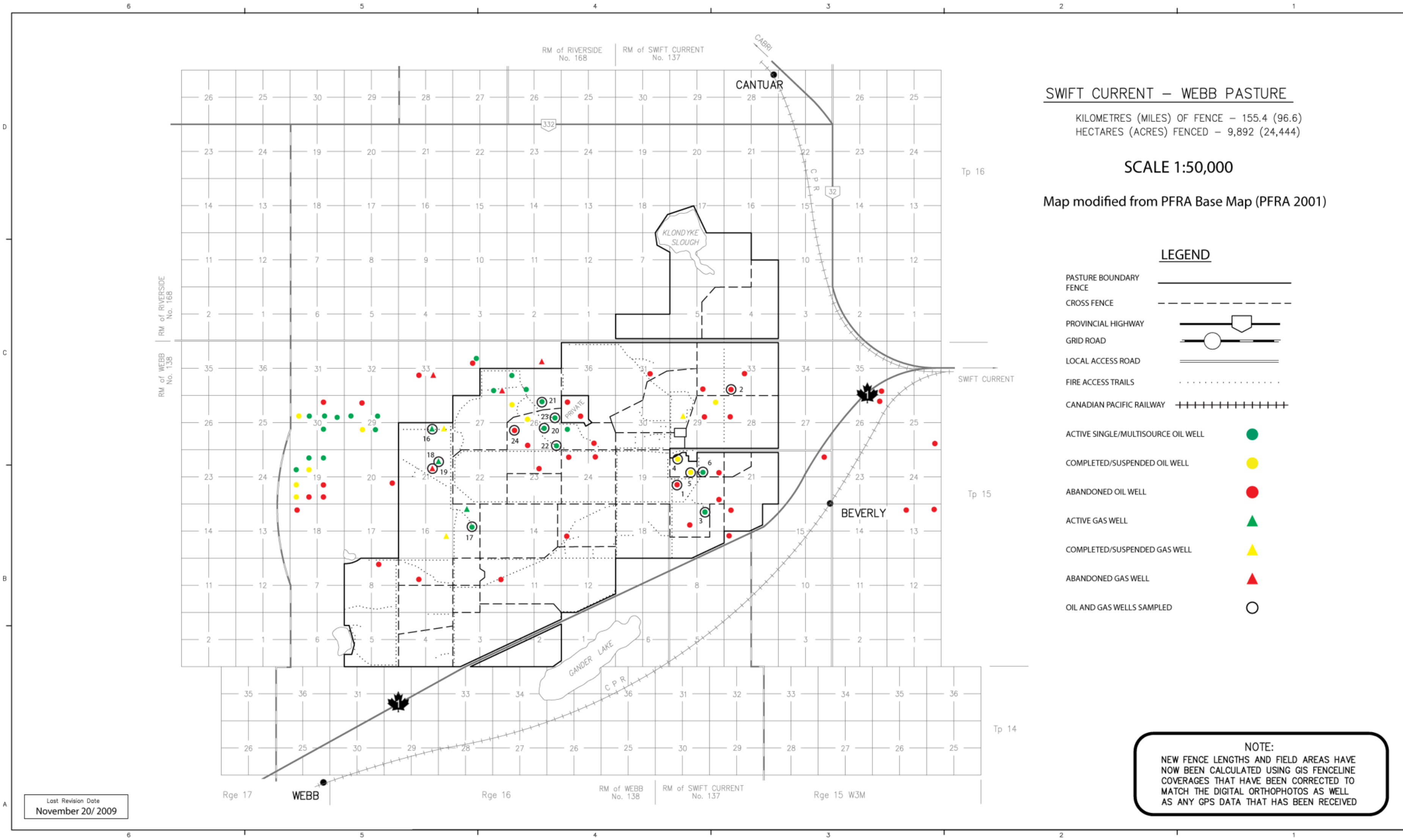


Figure 4.1 Distribution of oil and gas lease sites within Swift Current-Webb Community Pasture from 1955 to 1989. Circles and triangles represent oil and gas lease sites, respectively. Green indicates active single or multisource producting oil and gas wells as of 09/21/06. Yellow indicates completed or suspended lease sites which have been drilled but are not producing. Red indicates oil and gas wells that have been been abandoned. Wells labelled 1-15 and 16-31 represent sites sampled from the mixed grassland and sand dune land classes, respectively.

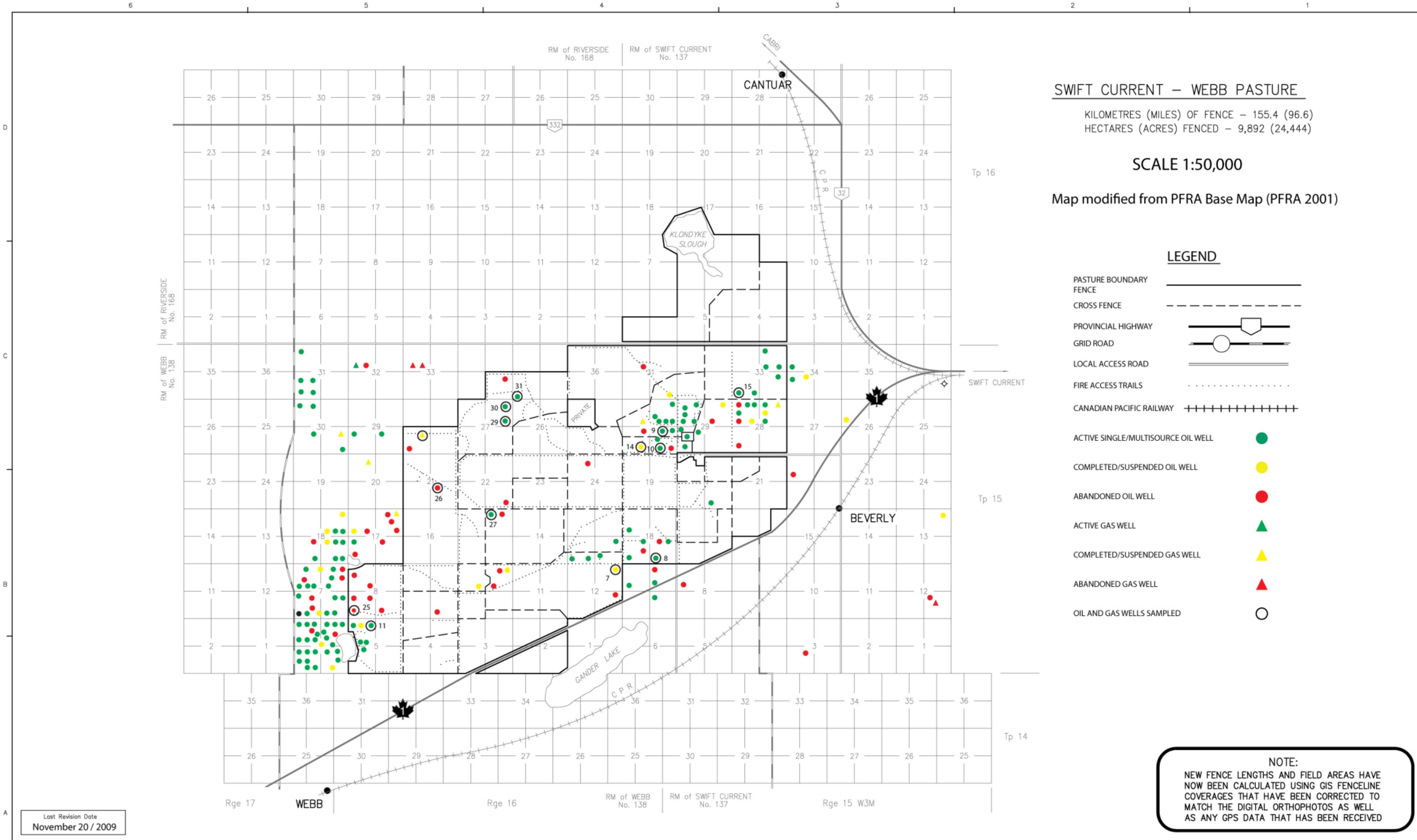


Figure 4.2 Distribution of oil and gas lease sites within Swift Current-Webb Community Pasture from 1990 to 2006. Circles and triangles represent oil and gas lease sites, respectively. Green indicates active single or multisource producting oil and gas wells as of 09/21/06. Yellow indicates completed or suspended lease sites which have been drilled but are not producing. Red indicates oil and gas wells that have been been abandoned. Wells labelled 1-15 and 16-31 represent sites sampled from the mixed grassland and sand dune land class, respectively.

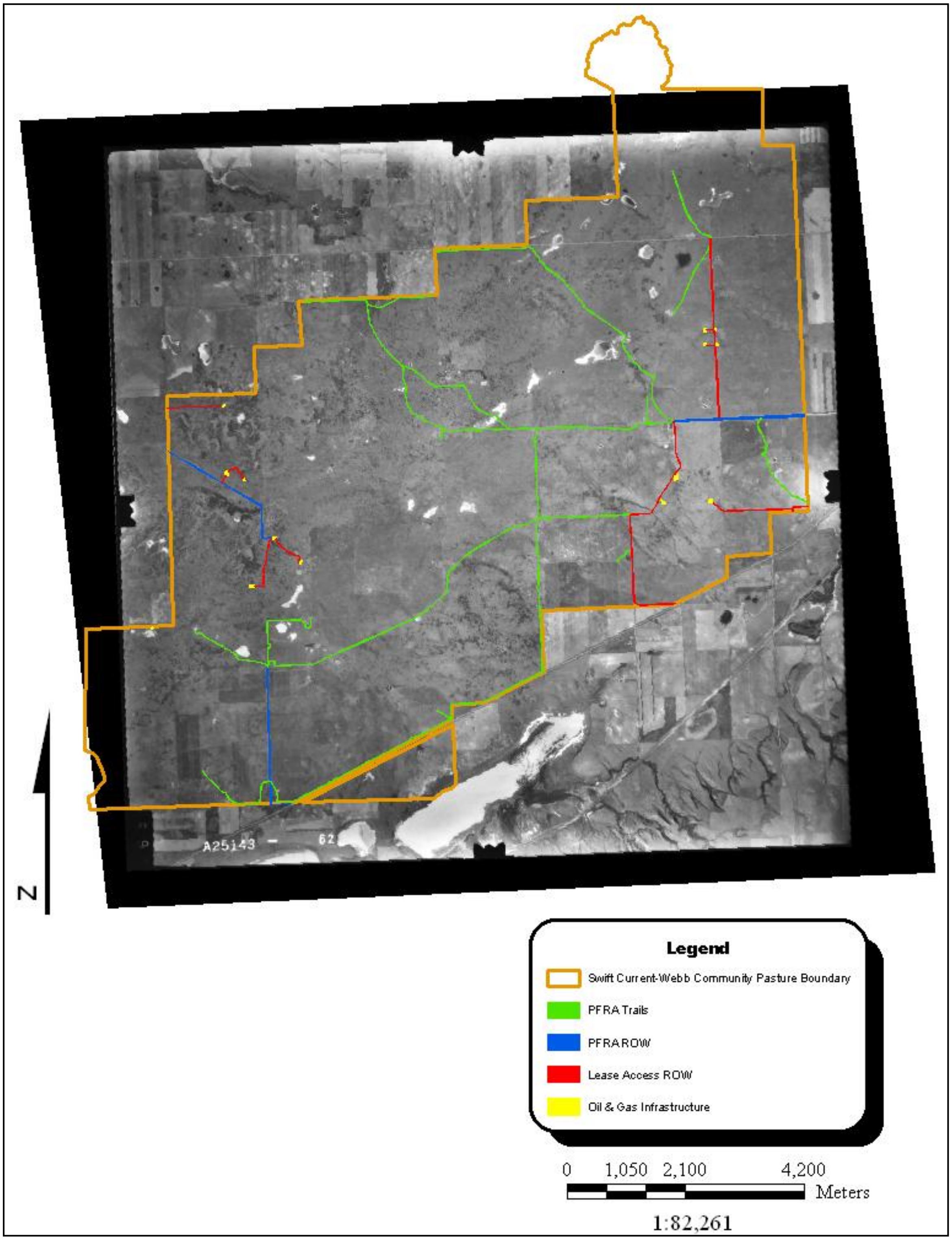


Figure 4.3 Distribution of oil and gas lease sites within Swift Current-Webb Community Pasture (AAFC-PFRA) in 1979.

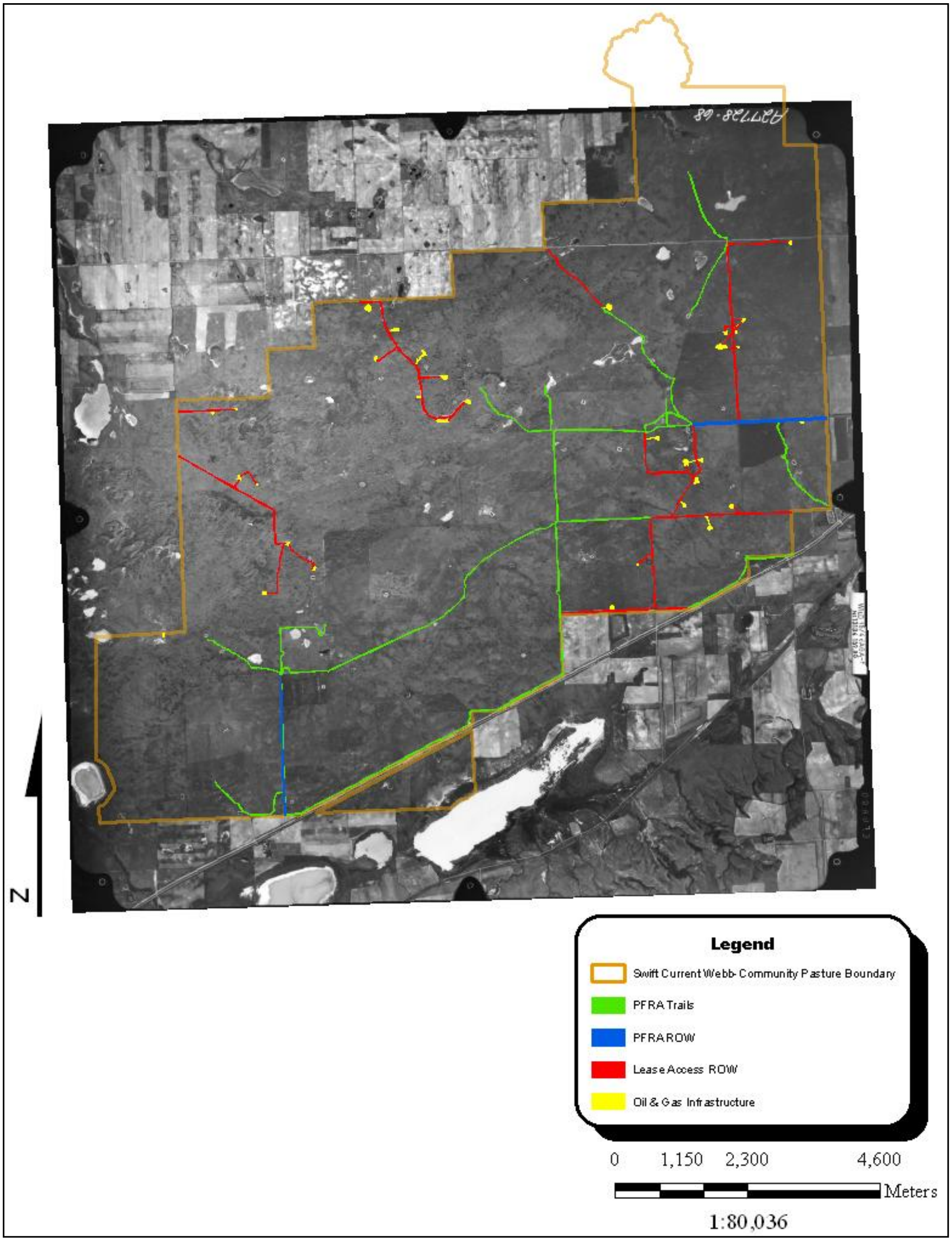


Figure 4.4 Distribution of oil and gas lease sites within Swift Current-Webb Community Pasture (AAFC-PFRA) in 1997.

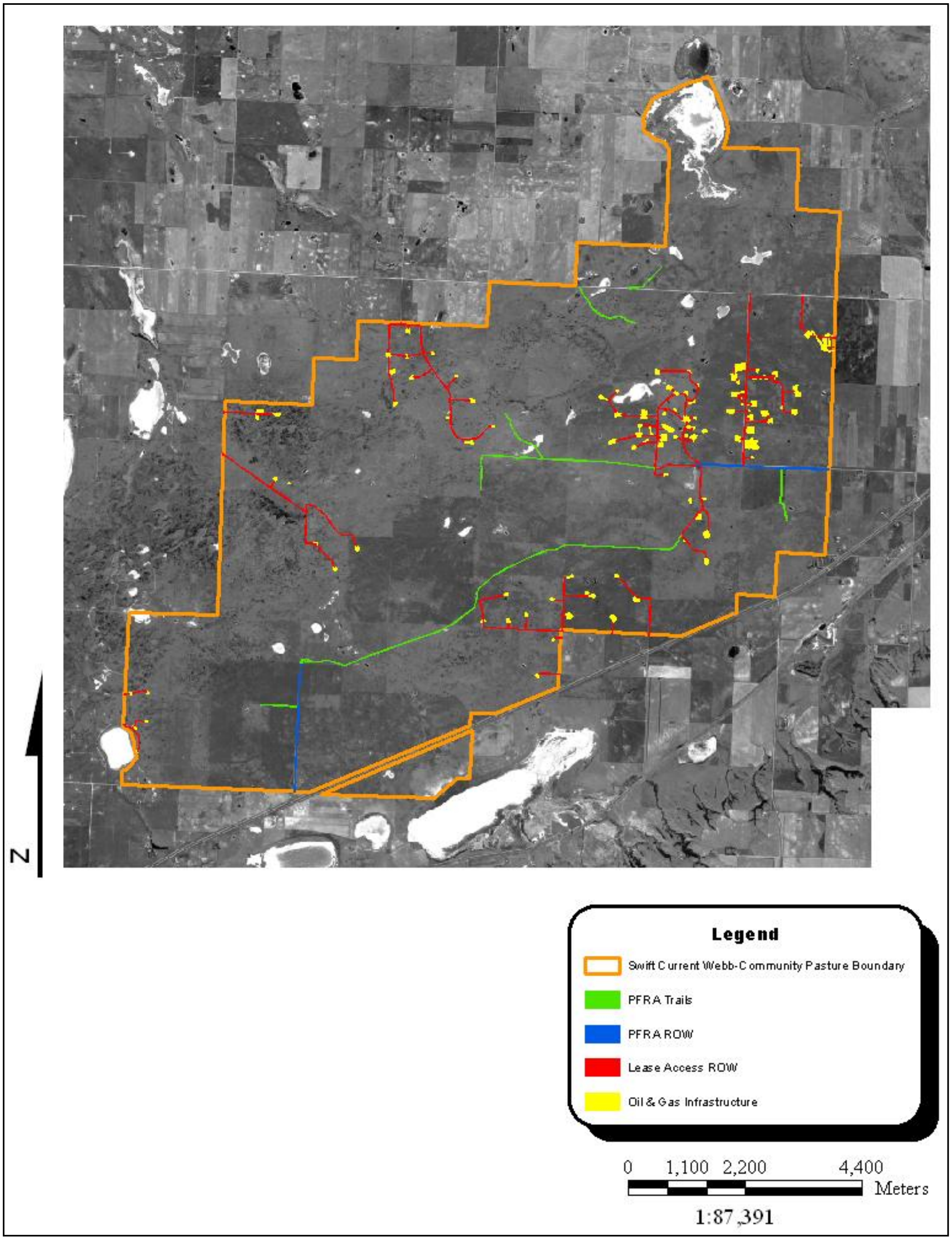


Figure 4.5 Distribution of oil and gas lease sites within Swift Current-Webb Community Pasture (AAFC-PFRA) in 1997.

TABLE 4.2 Pasture area occupied by oil and gas infrastructure (PFRA roads, trails, lease sites, lease access roads) in 1979

1979 Air Photo						
Patch Count	**Patch Class**	**Area (ha)**	**Perimeter (m)**	**Patch Density (#/100ha)**	**Edge Density (m/ha)**	**%Area Loss**
2	PFRA Pasture	9,736.21	58,837.18	N/A	N/A	N/A
3	PFRA Roads	14.66	15,700.88	0.03	1,071.30	0.15
13	Trails	42.70	93,495.01	0.13	2,189.60	0.44
14	Lease Sites	6.77	2,841.23	0.14	419.70	0.07
11	Lease Access Roads	12.66	46,547.26	0.11	3,676.70	0.13
TOTAL						
43	**N/A**	***9,813.00***	***21,7421.56***	***N/A***	***N/A***	***0.79***

TABLE 4.3 Pasture area occupied by oil and gas infrastructure (PFRA roads, trails, lease sites, lease access roads) in 1997

1997 Air Photo						
Patch Count	**Patch Class**	**Area (ha)**	**Perimeter (m)**	**Patch Density (#/100ha)**	**Edge Density (m/ha)**	**% Area Loss**
2	PFRA Pasture	9,702.20	59,046.50	N/A	N/A	N/A
2	PFRA Roads	10.72	9,641.50	0.02	899.10	0.11
13	Trails	46.98	82,642.63	0.13	1,759.00	0.48
34	Lease Sites	12.45	10,454.15	0.4	839.60	0.13
12	Lease Access Roads	33.71	52,193.80	0.12	1,548.30	0.35
TOTAL						
63	**N/A**	***9,806.07***	***21,3978.52***	***N/A***	***N/A***	***1.07***

TABLE 4.4 Pasture area occupied by oil and gas infrastructure (PFRA roads, trails, lease sites, lease access roads) in 2005

2005 Air Photo						
Patch Count	**Patch Class**	**Area (ha)**	**Perimeter (m)**	**Patch Density (#/100ha)**	**Edge Density (m/ha)**	**% Area Loss**
2	PFRA Pasture	9,815.39	59,050.93	N/A	N/A	N/A
2	PFRA Roads	7.33	9,851.90	0.02	1,345.00	0.08
6	Trails	17.48	33,210.46	0.06	1,900.50	0.18
108	Lease Sites	57.47	34,191.74	1.10	595.00	0.59
41	Lease Access Roads	41.38	80,861.10	0.42	1,954.00	0.42
TOTAL						
159	**N/A**	***9,939.03***	***217,166.129***	***N/A***	***N/A***	***1.26***

4.3 The Effects of Oil and Gas Lease Sites on Grassland Ecology

Understanding the spatial and temporal development of the oil and gas industry, and the direct physical footprint of associated oil and gas infrastructure, is necessary, but not sufficient, to understand the actual effects of development activities on the landscape. Arguably, the effects of oil and gas development extend well beyond the direct disturbance of the infrastructure. The broader impacts of oil and gas development on grassland ecosystems may be assessed by evaluating the influences of the timing of lease site drill activities, infrastructure type, PNG production on grassland communities, and the distance to which the effects from development progress outwards from the well head.

4.3.1 Comparing lease sites to off-lease sites

Oil and gas lease sites in the study area differed most significantly from the reference pasture based on ground cover composition variables and species composition. MRPP analysis from the thirty-one surveyed sites and reference pastures revealed that the PNG lease sites differed from the reference pasture based on undesirable species diversity, and ground cover composition variables (Table 4.5).

TABLE 4.5 MRPP analysis comparing oil and gas lease sites to the reference pasture

	Multi-response Permutation Procedure (MRPP)					
Test	*n*-lease	*n*-Reference pasture	*A-value*	*Observed Delta*	*Expected Delta*	*t-stat*
Ground cover composition	29	118	0.13	0.23	0.26	-34.40**
Undesirable species % cover	31	115	0.09	0.26	0.29	-18.03**
Undesirable alpha species	25	120	0.36	0.15	0.23	-71.04**

*****Superscript ** indicates values at a 0.01 significance level.

When compared to reference pasture sites, lease sites were observed to have lower % herbaceous cover, % clubmoss cover, % litter values, and greater % bareground values (Table 4.6). On average, the percentage of bare ground (34%) observed within 20m of oil and gas lease sites was 3.5 times greater than that at the reference pasture sites. At the same time, the percent of lease site herbaceous ground cover (65%) was significantly lower than the reference pasture sites (93%). Lease site litter values were 3 times lower than those at the reference pastures (Table 4.6).

Soil Ah horizon thickness was found to significantly differ between the lease and reference pasture sites. When compared to lease sites, on average, the Ah thickness values at reference sites (7cm) were almost 3 times thicker. Similarly, when compared to the lease sites, the upper 20cm of the soil column at the reference sites had lower pH, % clay, and higher electro-conductivity values (Table 4.6). Lease and reference sites showed no difference based on soil compaction.

TABLE 4.6 Median values ± standard deviation and *t-tests* scores for ground cover, and physical and chemical soil variables at lease sites and reference pastures.*

	Lease sites ± std.	Reference pasture ± std.	*t*
% Herbaceous	65.38 ± 7.46	93.13 ± 11.49	18.33**
% Bare ground	34.44 ± 7.34	6.88 ± 11.35	-20.62**
% Club moss	5.56 ± 10.72	10 ± 4.03	7.03**
% Litter	33.75 ± 40.11	75 ± 23.41	6.66**
Ah thickness	0.5 ± 3.45	7 ± 2.58	14.76**
Soil Compaction	1.8 ± 1.17	1.8 ± 1.13	0.57
% Sand	88.01 ± 3.69	88.15 ± 4.16	2.17*
% Clay	0.69 ± 0.74	0.38 ± 0.96	-3.24**
% Silt	11.23 ± 3.24	11.07 ± 3.47	-1.39
pH	7.43 ± 0.62	6.76 ± 0.49	-12.38**
Log (Electro-conductivity)	2.86 ± 0.12	3.06 ± 0.17	12.55**

***** Superscript ** indicates a 0.01 significance level, while superscript * indicates a 0.05 significance level.

The analysis of % cover of undesirable species indicated that lease and reference pasture sites form well-separated, homogenous clusters (*A* = 0.089, *t* = -18.03) (Table 4.5). More specifically, lease and reference sites were found to differ based on alpha measures of undesirable species diversity. This indicated that while lease and reference sites may have similar desirable species compositions, collectively lease sites have a greater abundance of undesirable species. The indicator species analysis of undesirable species suggested significant differences between lease and reference sites based on the increased abundance of several undesirable species at the lease sites (Table 4.7). Lease sites were likely to have a greater abundance of alkali grass (*Puccinellia nuttalliana*), wood whitlow-grass (*Draba nemorosa*), flixweed (*Descurainia sophia*), ball mustard (*Neslia paniculata*), bluebur (*Lappula squarrosa*), foxtail barley (*Hordeum jubatum*), kochia (*Kochia scoparia*), and Russian thistle (*Salsola pestifer*). The analysis revealed that lease sites were more likely to be dominated by undesirable perennial forbs than the desirable graminoid species that were present in the reference pasture (see Table 4.7).

The desirable species found to differ between the lease and reference sites were blue grama grass (*Bouteloua gracilis*), Indian rice grass (*Oryzopsis hymenoides)*, Canada blue grass (*Poa compressa*), muhly spp. (*Muhlenbergia spp.)*, aster species (*aster spp.*), pale comandra (*Comandra palliada)*, silver-leaved psoralea (*Psoralea argophylla*), and thread-leaved sedge (*Carex filifolia*) (Table A.3).

The impacts from PNG lease site construction to ground cover and biotic variables were similar across landscape types (dune and mixed grassland) and soil taxa. This suggests that impacts associated with lease activity are independent of changes to soil texture.

TABLE 4.7 Results of indicator analysis of undesirable species comparing lease sites to reference pasture sites.*

Undesirable species	Oil and gas lease sites (IV%)	Reference pasture sites (IV%)
No Species Present	25.0**	0.0
Alkali grass (*Puccinellia spp.*)	33.7**	0.0
Kentucky blue grass (*Poa pratensis*)	18.5*	0.0
Pygmy-flower (*Androsace septentrionalis*)	0.0	20.0*
Fringe sage (*Atremisia frigid*)	55.7**	0.0
Wood whitlow grass (*Draba nemorosa*)	20.6**	0.0
Flixweed (*Descurainia sophia*)	31.5*	0.0
Ball mustard (*Neslia paniculata*)	24.2*	0.0
Skeleton weed (*Lygodesmia rostrata)*	0.0	12.2*
Bluebur (*Lappula squarrosa*)	28.3*	0.0
Foxtail barley (*Hordeum jubatum*)	20.8*	0.0
Kochia (*Kochia scoparia*)	18.3*	0.0
Russian thistle (*Salsola pestifer*)	21.7*	0.0

*****Shaded cells indicate species that were significant indicators for each of the lease classes. Superscript ** indicates values at a 0.01 significance level, while superscript * indicates a 0.05 significance level.

4.3.2 Relationship between well drill year and lease class, and the impacts to grassland ecology

Although slight differences in species composition were observed between oil and gas wells, no significant differences were observed between lease infrastructure types based on species composition (Figure 4.6). Instead, lease sites were found to differ based on operational status, specifically based on ground cover and plant species conditions. From the ordination analyses (with lease operational status categories) and joint plot overlay of environmental and range health values, it was found that ‘active’ lease sites had greater % bare ground values, and lower % litter, % herbaceous, and range health values (Figure 4.6, Table 4.8). Amongst all 8 lease type classes, ‘active’ oil and gas lease sites displayed, on average, the greatest % bare ground values (25% bare ground) and the lowest values for % herbaceous and % litter at 75% and 20% respectively. All operational status classes were found to have low % clubmoss (0-2%) and low

Ah horizon thickness. At the same time, the analysis revealed no significant differences between lease sites based on final drill year.

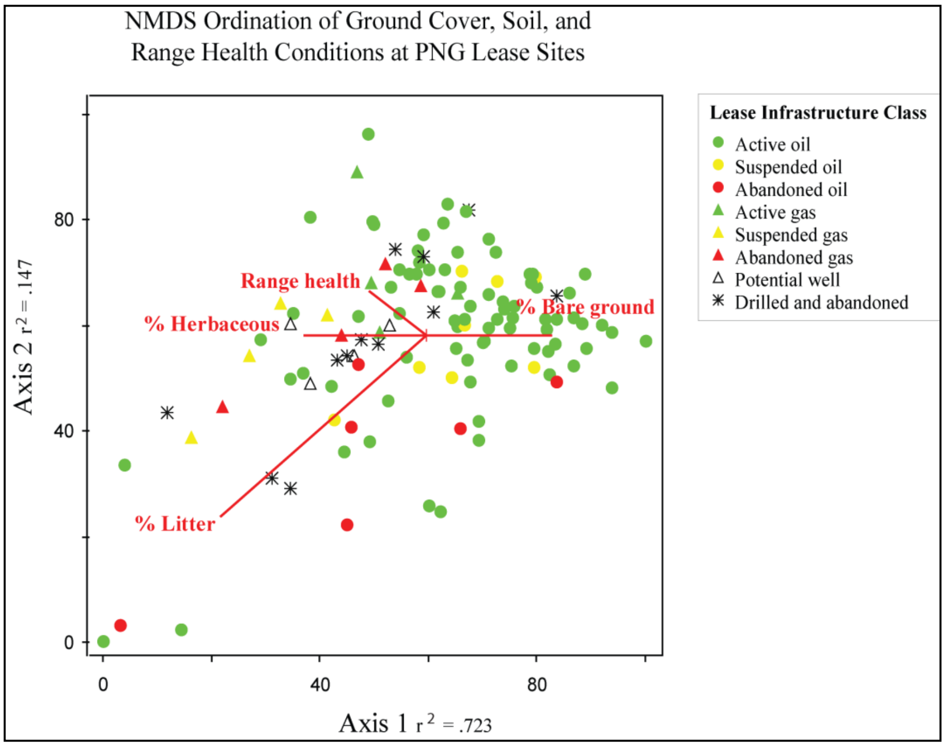


Figure 4.6 Ordination scatterplot of the 121 transects plotted in environmental variables and range health space with lease class group overlay. *

*****Raw data were ground cover variables and range health. The ordination analysis was run with a Euclieanl distance measure, with 50 real and random runs. A three dimensional solution was select as additional dimensions provided only small reductions in NMDS stress. The final stress of the best solution was 2.69, achieved after 97/250 iterations. From the Monte Carlo test the randomized stress value was 7.61, where the probability of the observed pattern arising from random chance is p=0.02. The quadrats are plotted against axis 1 and axis 2 as they explained the most variation in the distance matrix. The variance captured by axes 3 was r^2= .137, while the total variance captured by the three axes was 96.2%. The ordination biplot was not rotated.

Conversely, the ordination analysis indicated that 'potential' and 'drilled and abandoned' lease sites have greater % litter and % herbaceous values than the other operational status classes (see Figure 4.6, Table 4.8). For both 'potential' and 'drilled and abandoned' classes, % herbaceous values were above 90%. On average, Ah horizon thickness (1-5mm) and % litter values (40%) were similar to those of the reference pasture. For almost all lease sites, soil compaction ranged from 1.65 to 2.20 kg/cm^2. The only exceptions were 'potential' and 'suspended' gas lease sites drilled in highly active sand dune blowouts, where compaction values were 0.50 kg/cm^2. Lease sites located within the sand dune environment were also found to have low % herbaceous, % litter, and range health values.

Based on operational status, the MRPP analysis suggested that oil and gas lease sites differ from the reference sites more significantly based on desirable species diversity than undesirable diversity measures (Table 4.9). When compared to reference pasture all lease classes were found to have significantly greater undesirable species richness, and diversity values (Table 4.10). All five lease classes displayed similar desirable species richness and diversity values (Table 4.10). Compared to the reference pasture, 'active' oil and gas lease sites were found to have higher undesirable species richness, and diversity values. The undesirable species richness, and diversity values recorded at 'active' oil and gas lease sites were, on average, 3.5 times greater than those associated with the reference sites (Table 4.10).

TABLE 4.8 Axis correlation scores for axis 1 and axis 2 for the NMDS ordination analysis of 121 transects plotted in environmental variables and range health space with lease class group overlay.

	Axis 1 (r^2 = .723)	**Axis 2** (r^2 = .147)
	r value	*r value*
% Herbaceous	-0.649	0.097
% Bare ground	0.658	0.097
% Clubmoss	0.008	-0.022
% Litter	-0.903	-0.72
Ah soil horizon thickness (mm)	-0.109	-0.052
Soil compaction (kg/cm)	0.011	-0.06
Range health	-0.414	0.485

TABLE 4.9 MRPP analyses examining how PNG lease operational statuses differ based on measures of desirable and undesirable species alpha diversity*

	Multi-Response Permutation Procedure (MRPP)			
Test	*A-value*	*Observed Delta*	*Expected Delta*	*T-stat*
Comparison of PNG operational status by desirable species alpha diversity	0.15	0.17	0.20	-8.19**
Comparison of PNG operational status by undesirable species alpha diversity	0.11	0.12	0.13	-6.40**

*Superscript ** indicates values at a 0.01 significance level.

TABLE 4.10 Measures of desirable and undesirable species diversity, richness, and range health for each of the five lease infrastructure classes and reference pasture sites.*

Undesirable species	**Species richness**	**Shannon's diversity index**	**Simpson's Diversity index**	
Active PNG	5.25	1.34	0.69	
Suspended PNG	4.0	1.12	0.61	
Abandoned PNG	5.0	1.30	0.67	
Potential PNG	5.0	1.43	0.73	
Drilled and abandoned	6.0	1.56	0.76	
Reference pasture*	1.5	0.29	0.18	
Desirable species	**Species richness**	**Shannon's diversity index**	**Simpson's diversity index**	**Range health**
Active PNG*	3.5	0.99	0.58	34.06
Suspended PNG*	3.0	0.75	0.47	32.58
Abandoned PNG*	3.0	0.97	0.57	19.88
Potential PNG	3.5	1.08	0.64	42.50
Drilled and abandoned	4.0	1.28	0.68	29.63
Reference pasture	5.0	1.25	0.43	40.00

* Based on an MRPP analysis, sites with superscript * are those classes that differ significantly (*p-value* = 0.05) from the other PNG classes.

'Active', and 'suspended' oil and gas lease sites were dominated by undesirable species including: Canadian wild-rye (*Elymus canadensis*), alkali grass (*Puccinellia spp.*), kentucky blue grass (*Poa pratensis*), crested wheat grass (*Agropyron pectiniforme*), foxtail barley (*Hordeum jubatum*), fringe Sage (*Atremisia frigida*), flixweed (*Descurainia sophia*), blue-bur (*Lappula echinata*), kochia (*Kochia scoparia*) and prostrated knapweed (*Centaurea maculosa*) (see Table

A.4). The abundance of undesirable species at the 'active' and 'suspended' sites supports the low range health values calculated. Average range health values for 'active' (34.0), and 'suspended' (32.5) sites were considerably lower than average range health values for reference pasture sites (40.0) (see Table 4.10), which had more desirable tufted and rhizomatous grasses than PNG lease sites (Table 4.11).

TABLE 4.11 Results of indicator analysis of desirable species at the reference pasture sites.*

Desirable species	Reference pasture sites (IV%)
Northern wheat grass (*Agropyron dasystachyum*)	59.5*
June grass (*Koeleria cristata*)	65.7**
Needle and thread grass (*Stipa comata*)	53.7*
Thread-leaved sedge (*Carex elecocharis*)	68.8**

***Superscript ** indicates values at a 0.01 significance level, while superscript * indicates a 0.05 significance level.

Of the five infrastructure classes, 'drilled and abandoned' and 'potential' lease sites had the greatest desirable species richness, and diversity values (see Table 4.10). Although average desirable species richness values for 'drilled and abandoned' and 'potential' oil and gas lease sites were greater than all other lease site operational classes, they were still lower than the average reference pasture value. When compared to the other lease classes, 'drilled and abandoned' sites displayed the greatest undesirable species richness, and diversity. 'Drilled and abandoned' sites were dominated by foxtail barley (*Hordeum jubatum*), and perennial forbs; yellow sweet clover (*Melilotus officinalis*), skeleton weed (*Lygodesmia rostrata*), and kochia (*Kochia scoparia*) (see Table A.4). The presence of undesirable species surrounding 'drilled and abandoned' sites speaks to the lack of reclamation activity within the study area. This is supported by the low range health values (20.0) and desirable species richness and diversity at 'abandoned' lease sites (see Table 4.10).

Slight differences were observed between lease infrastructure types (oil well vs. gas well) based on species presence. Oil lease sites were dominated by undesirable rhizomatous and tufted grass species such as alkali grass (*Puccinellia spp.*), crested wheat grass (*Agropyron pectiniforme*), and foxtail barely (*Hordeum jubatum*), as well as fringe sage (*Artemisia frigida*), and prostrate knotweed (*Centaurea maculosa*) (see Table A.4). Gas wells were found to have lower undesirable species diversity and presence than oil wells. 'Active', 'suspended', and 'abandoned' gas wells were dominated by crested wheat grass (*Agropyron pectiniforme*), and perennial forbs; fringe sage (*Artemisia frigida*), flixweed (*Descurainia sophia*), and blue-bur (*Lappula echinata*) which were rare at gas lease sites (see Table A.4). 'Drilled and abandoned' sites displayed low undesirable species diversity measures compared to the other lease classes. 'Drilled and abandoned' sites were dominated by foxtail barley (*Hordeum jubatum*), and perennial forbs; yellow sweet clover (*Melilotus officinalis*), skeleton weed (*Lygodesmia rostrata*), and kochia (*Kochia scoparia*) (see Table A.4).

The analysis of drill year, and month suggested that compared to the reference pasture, lease site classes drilled at any time of the year have low % litter, % herbaceous, and range health values. This suggested that the impacts associated with lease site activity persist for over 50 years. Lease sites were dominated by bare ground, crested wheat grass (*Agropyron pectiniforme*), downy brome (*Bromus tectorum*), foxtail barley (*Hordeum jubatum*), flixweed (*Descurainia Sophia*) and prickly rose (*Rosa acicularis*). At the same time, lease sites failed to form significant clusters based on drill month. An exception to the above is that the oil sites drilled from 2004 to 2005 were dominated by northern wheat grass (*Agropyron dasystachyum*), blue grama (*Bouteloua gracilis*), Indian rice grass (*Achnatherum hymenoides*), false solomon's-seal (*Smilacina trifolia*), goldenrod (*Solidago spp.*), and western snowberry (*Symphoricarpos* *occidentalis*) (see Table A.5). This finding implies that lease sites drilled more recently may benefit from improved management practices and reseeding techniques.

4.3.3 Well production and abiotic and biotic conditions

Prior to comparing well site production information with the environmental and biotic variables, a NMDS ordination was run on the production data for each of the thirty-one lease sites. To determine how different oil and gas lease sites (classed by operational status) grouped based on production time (yrs), gas (mcf), oil (Bbl), and water (Bbl). As expected, the 'active' oil lease sites were found to have the greatest production of oil (Bbl) and water (Bbl). It was important to make this distinction so that comparisons between annual and cumulative lease site production data, and oil and gas lease site operational status could be made.

The analysis indicated that increased cumulative well site production at lease sites was related to increased alteration of ground cover, soil pH/electro-conductivity, and plant species composition variables (Table 4.12). Of the ground cover variables examined, % litter showed the greatest alteration from increased oil production (Table 4.13). Irrespective of drill date, the analysis of lease site cumulative production data revealed that increased production resulted in lower % litter values. Lease sites with increased oil production levels also displayed lower % herbaceous, and greater % bare ground values (Table 4.13). As expected, the analysis of annual production levels revealed similar finding.

TABLE 4.12 MRPP run for the six tests which examines how ground cover, soil, and biotic variables differ with cumulative well site oil, gas, and water production.*

	Multi-Response Permutation Procedure (MRPP)				
Test	# Entries	*A-value*	*Observed Delta*	*Expected Delta*	*t-stat*
Ground cover	496	0.19	66.73	82.7	-49.66**
Silt, sand, clay	120	0.02	8.60	8.62	-0.12
pH and electro-conductivity	181	0.06	0.75	0.80	-5.27**
Desirable species richness	853	0.08	0.33	0.36	-23.85**
Undesirable species richness	900	0.01	0.37	0.38	-3.38**
Range health	997	0.06	0.44	0.46	-28.50**

*Superscript ** indicates values at a 0.01 significance level.

As with the comparison of lease and reference sites, Ah horizon thickness was found to be significantly affected by increased lease site production (Table 4.14). Lease sites with increased production levels were found to have shallower Ah thickness. Given that litter and Ah thickness are highly correlated, the variables are expected to show a similar response to increased lease site activity. When compared against cumulative lease site production data, soil electro-conductivity was found to decrease with increased oil production (Figure 4.14). Low correlations were observed between lease site oil production and soil compaction, and % sand (Table 4.14). Results from the NMDS indicate that lease sites with increased oil production have lower soil compaction and more moving sand. From a separate MRPP analysis, the impacts from increased production were found to be independent of soil taxonomic unit. The NMDS ordination of range health data suggested that range health declines with increased cumulative production (Figure 4.7, Table 4.15). When compared to the reference pasture sites, range health values associated with highly productive oil sites were considerably lower, and considered unhealthy.

TABLE 4.13 Axis correlation scores for axis 1 and axis 3 for the NMDS ordination analysis ground cover properties from 121 transects plotted lease site production data (gas, oil, water, production time) space.*

	Axis 1 (r^2 = .379)	**Axis 3** (r^2 = .305)
	r value	*r value*
% Herbaceous	.177	-.305
% Bare ground	-.219	.092
% Clubmoss	-.015	.141
% Litter	.217	-.305
Gas production levels (Mcf)	-.077	.084
Oil production levels (Bbl)	-.326	.554
Wrt production levels (Bbl)	-.167	.731

*The ordination analysis was run with a Euclidean distance measure, with 50 real and random runs. A three dimensions solution was select as additional dimensions provided only small reductions in NMDS stress. The variance captured by axes 2 was r^2= .108, while the total variance captured by the three axes was 79.3%. The final stress of the best solution was 4.28, achieved after 130/250 iterations. From the Monte Carlo test the randomized stress value was 11.03, where the probability of random chance is p=0.02.

TABLE 4.14 Axis correlation scores for axis 1 and axis 2 from the NMDS ordination analysis of ground cover and soil properties for the thirty one oil and gas lease sites plotted in lease site production data (gas, oil, water, production time) space with lease class groups overlay.*

	Axis 1 (r^2 = .896)	**Axis 2**(r^2 = .092)
	r value	*r value*
% Sand	-.097	.172
Soil electro-conductivity	.188	.186
%Litter	.154	.101
Ah soil horizon depth(mm)	.131	.125
Soil compaction (kg/cm^2)	.094	.074
Oil (Bbl)	-.152	-.044

*The ordination analysis was run with a Euclidean distance measure, with 50 real and random runs. A three dimensions solution was select as additional dimensions provided only small reductions in NMDS stress. The variance captured by axes 2 was r^2= .108, while the total variance captured by the three axes was 79.3%. The final stress of the best solution was 4.42, achieved after 50/250 iterations. From the Monte Carlo test the randomized stress value was 10.28, where the probability of random chance is p=0.02.

The analysis of plant community data against lease site annual production data revealed that as oil and gas production increased, desirable species richness, declined (Table 4.16). Overall, increased annual production of both oil and gas also resulted in a decline of desirable species biodiversity. Conversely, undesirable species diversity measures were not influenced by cumulative oil and gas production.

The ordination analysis of desirable species richness, and diversity with production data supports the trends observed with range health measures (Table 4.16). However, the low r^2 values for both axes, as well as the low axis scores and instability of the final solution suggested that the high undesirable species richness values associated with PNG activity are more strongly associated with lease site construction than operational status and PNG production.

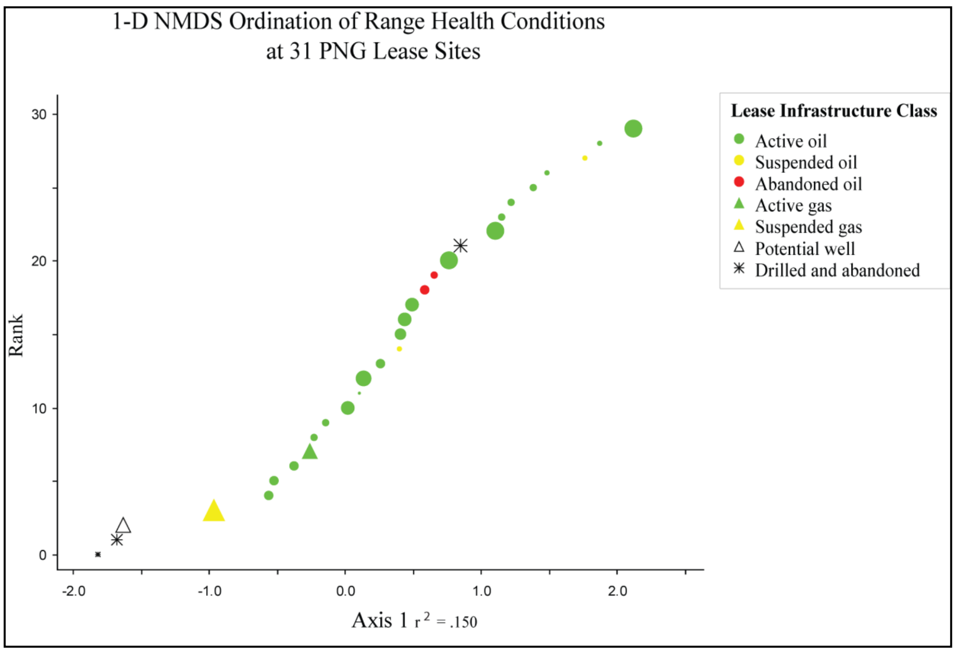


Figure 4.7 Ordination scatterplot of range health for the thirty one oil and gas lease sites plotted in production data (gas, oil, water, production time) space with lease class groups overlay.*

* Lease sites are weighted based on their correlation with median range health. Overlay with size of symbols proportional to the cumulative production data where larger symbols, indicate greater cumulative production. The analysis was run with a Bray Curtis distance measure, with 50 real and random runs. The analysis was done using a one dimensional solution. The number of dimensions selected was done so to minimize the amount stress. For the one dimensional solution of range health per well, the final stress was 2.11, achieved after 158/250 iterations. The Monte Carlo test revealed a randomized stress value of 9.68, where the probability of random chance is $p=0.02$. The ordination plot was rotated. The lease class abandoned gas was considered an outlier and was not included in the analysis.

TABLE 4.15 Axis correlation scores from the NMDS ordination analysis of range health for the thirty one oil and gas lease sites plotted in production data (gas, oil, water, production time) space with lease class groups overlay (Figure 4.7).

	Axis 1 (r^2 = .150)
	r value
Range Health (Median)	-.159
Oil (Bbl)	.555
Gas (Mcf)	.205

TABLE 4.16 Axis correlation scores from the NMDS ordination analysis of desirable species richness, diversity, and production data (oil, gas) for the thirty one oil and gas lease sites plotted in production data (gas, oil, water, production time) space with lease class groups overlay.*

	Axis 1 (r^2 = .645)	**Axis 2**(r^2 = -.021)
	r value	*r value*
Shannon's Diversity Index	.346	.301
Simpson's Diversity Index	.396	.304
Oil production levels(Bbl)	-.453	.305
Gas production levels (Mcf)	-.342	-.339

*The analysis was run with a Bray Curtis distance measure, with 50 real and random runs. A three dimensional solution was selected to minimize stress. The final stress was 8.89, achieved after 250/250 iterations. The Monte Carlo test revealed a randomized stress value of 9.29, where the probability of random chance is *p=0.02*. Lease sites are plotted against axis 1 (r^2 = .645) and axis 2 (r^2 = -.021) as they explained the most variation in the distance matrix. The variation captured by the NMDS ordination was 62.3%.

4.3.4 Abiotic and biotic conditions at increasing distance from the well head

Ground cover, soil conditions, and plant communities differed significantly with increasing distance from the well head. Of all of the impacts associated with lease sites, % litter, Ah thickness, % herbaceous cover, desirable species diversity and range health were found to increase with distance from the well head. Soil compaction, electro-conductivity, and % bare ground cover were found to decrease with increasing distance from the well head. With the exception of % litter and soil compaction, the observed impacts were found to be irrespective of infrastructure type, well operational status, and/or the number of years of production (see Table A.6).

The MRPP analysis of distance groups (0m, 5m, 10m, 15m, 20m, 25m, 30m, 35m, 40m, 45m) based on ground cover variables indicated significant within group homogeneity (A = 0.193) and well separated clusters (t = -49.66). From the NMDS ordination analysis, the variables most strongly associated with axis 1 (r^2=0.125) were % litter (-0.931), % bare ground (0.762), and % herbaceous (-0.761). For axis 2 (r^2=0.875), % herbaceous (-0.942), and bare ground (0.935) were the most strongly correlated variables (Figure 4.8, Table 4.17). From the NMDS ordination joint plot overlay (Figure 4.8) of ground cover and soil variables, quadrats close to the well head were found to have greater % bare ground, and soil compaction values (see Table 4.17). On the other hand, the well head had lower % herbaceous, % litter, and Ah horizon thickness values. The graphical results indicated that ground cover variables (% herbaceous, % bare ground, and % litter) increase significantly with distance from the well. The results suggested that the effects of development extend at least 25m from the well head (Figures 4.9, 4.10, 4.11, 4.12, and 4.13).

The analysis of soil properties revealed that soil compaction and aggregate material (as a % of ground cover) increased with proximity to the well. Although soil compaction values at the lease site were greater than the reference pasture, the analysis indicated that the highest compaction were within 5m – 10m of the well head (Figure 4.11). Values for both variables were greater within 10m of the well head than those of the reference pasture sites. The observed spatial extent of the impacts is consistent with construction practices that involve the re-contouring and padding of the lease site.

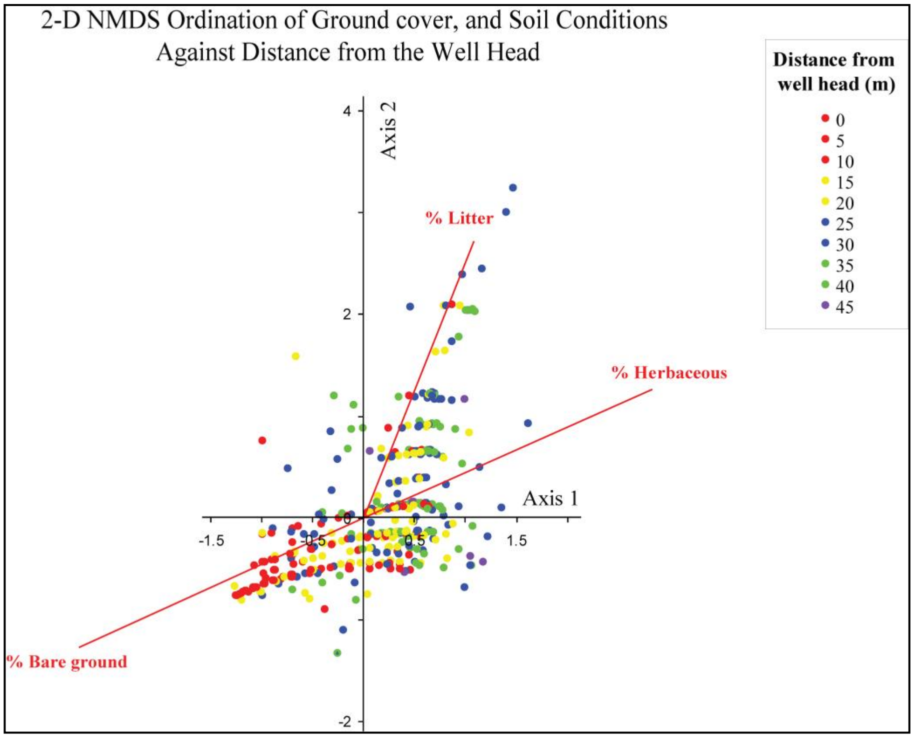


Figure 4.8 Ordination scatterplot of the 496 quadrats within two randomly selected transects from each of the thirty one oil and gas lease sites with a ground cover, and soil overlay.*

*The NMDS ordination analysis was run with a Euclidean distance measure, with 50 real and random runs. A three dimensional solution was selected as additional dimensions provided only small reductions in NMDS stress. The final stress of the best solution was 5.24, achieved after 121/250 iterations. From the Monte Carlo test the randomized stress value was 8.67, where the probability of the observed pattern arising from random chance is p=0.03. The Quadrats are plotted against axis 1 and axis 2 as they explained the most variation in the distance matrix. The variance captured by axes 1 and 2 are (r^2= 0.125) and axis 2 (r^2= 0.875), respectively. A ground cover, and soil joint plot was added to interpret how the variables related to the *a priori* defined group formations. The ordination biplot was rotated 27 degrees to improve the interpretation. Two randomly selected transects were used for comparison given sufficient data and a large sample size.

TABLE 4.17 Axis correlation scores for axis 1 and axis 2 for the NMDS ordination analysis of 496 quadrats within two randomly selected transects from each of the thirty one oil and gas lease sites with a ground cover, and soil overlay

	Axis 1 (r^2 = .425)	**Axis 2** (r^2 = .969)
	r value	*r value*
% Herbaceous	0.946	0.586
% Bare ground	-0.947	-0.587
% Clubmoss	0.325	0.135
% Litter	0.561	0.947
Ah soil horizon thickness (mm)	0.326	0.252
Aggregate >2mm	-0.186	-0.152
Soil compaction (kg/cm)	-0.292	-0.173
% Erosion	-0.232	-0.185
% Spill	-0.06	-0.064

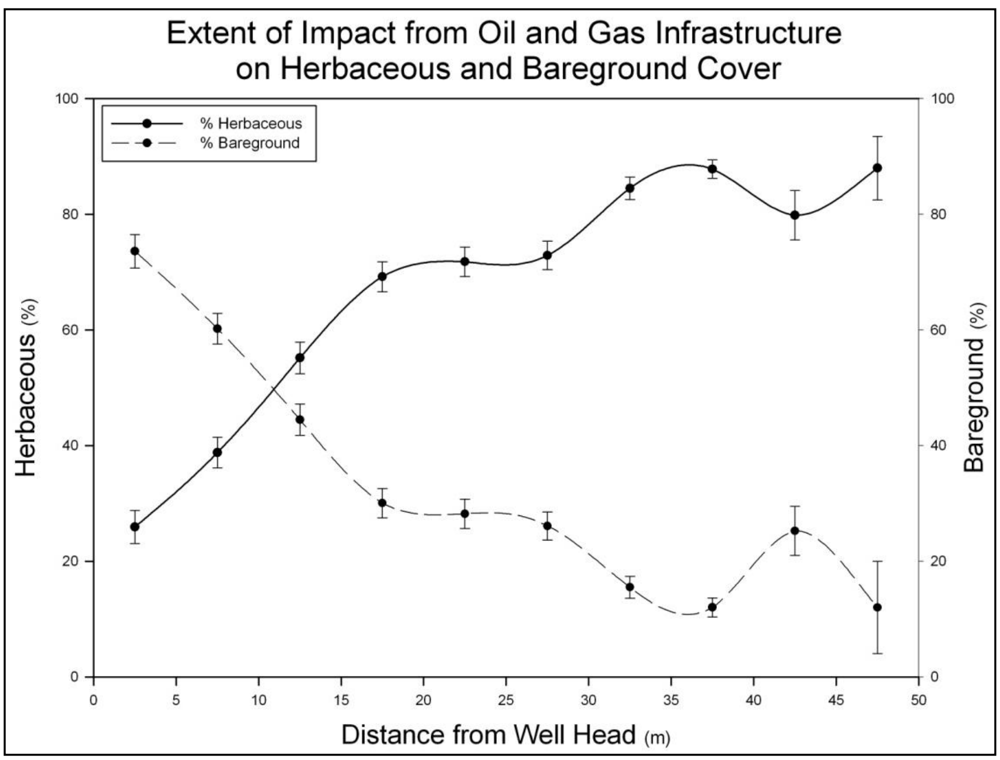


Figure 4.9 **Bareground and herbaceous ground cover values against distance from the center of the well head. Values are plotted as median values with +/- standard error.**

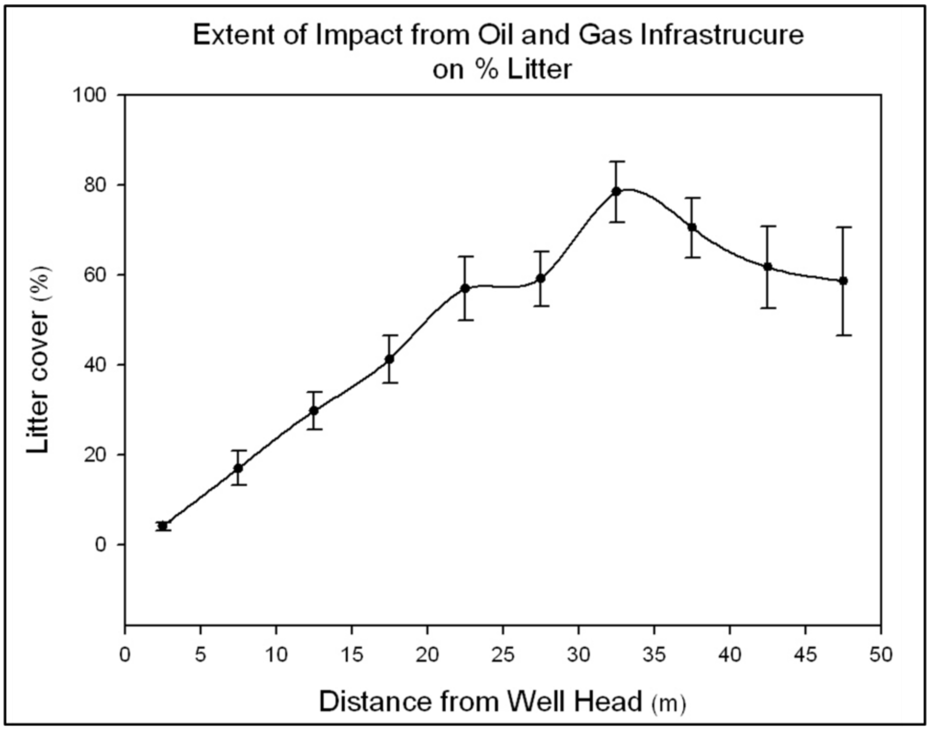


Figure 4.10 **Litter ground cover value against distance from the center of the well head. Values are plotted as median values with +/- standard error.**

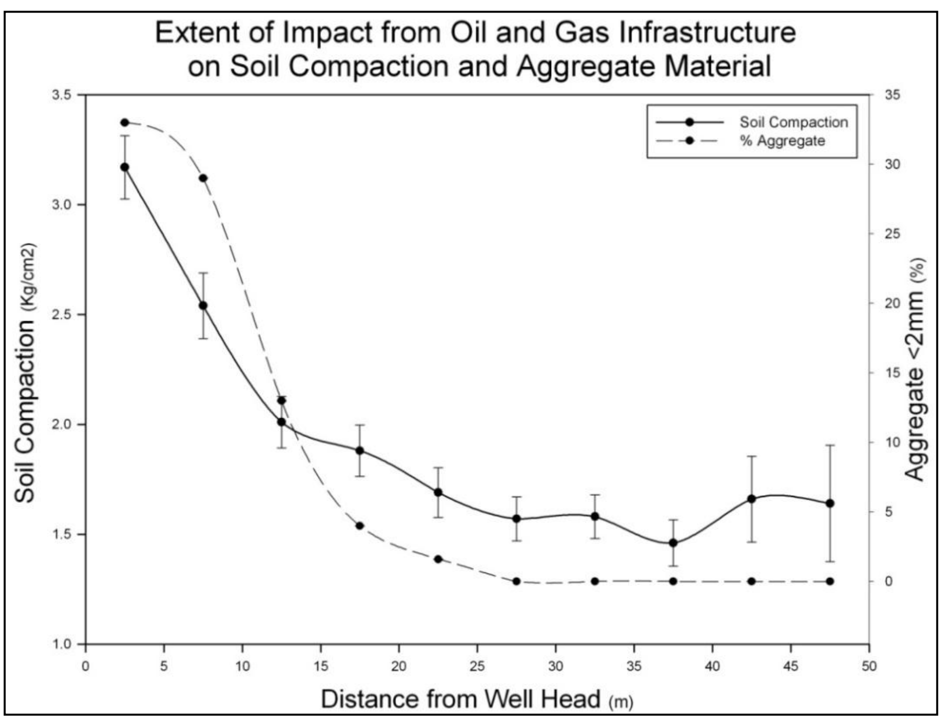


Figure 4.11 **Soil compaction and aggregate values against distance from the center of the well head. Values are plotted as median values with +/- standard error.**

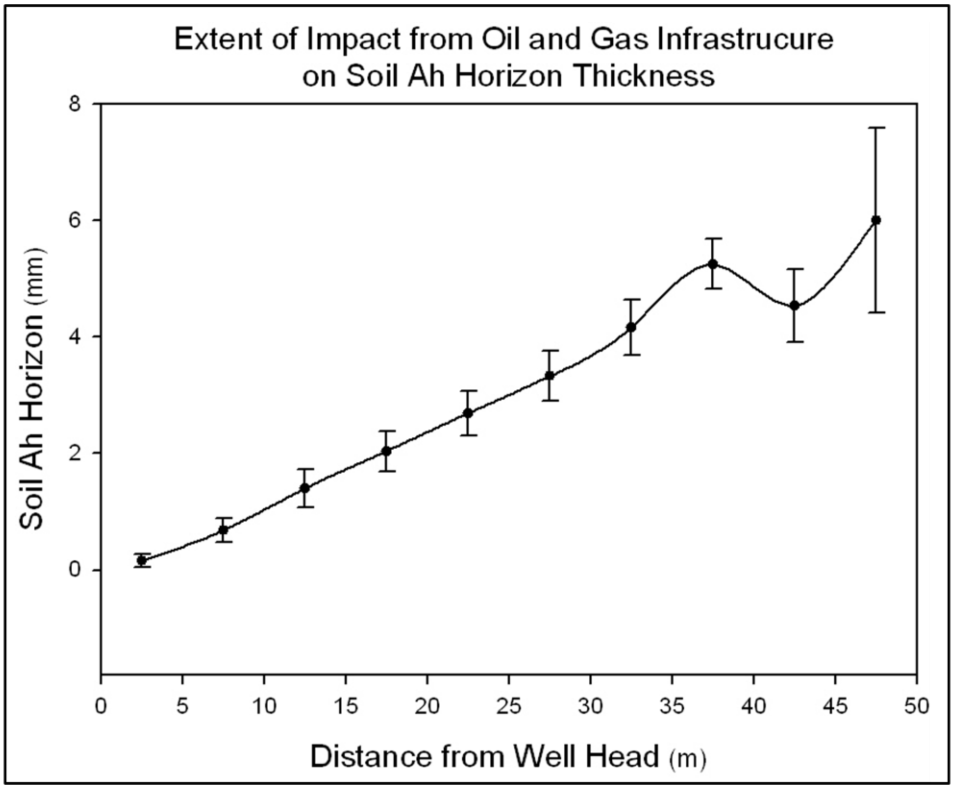


Figure 4.12 Soil Ah horizon thickness values against distance in meters from the center of the well head. Values are plotted as median values with +/- standard error.

Ah thickness was found to increase with increasing distance from the well head, with the greatest alterations occurring within 0m - 5m (Figure 4.12). Although the impacts to Ah thickness from lease site development were most severe at close proximity to the well head, values were lower than the reference pasture (Figure 4.12). Lease sites differed from the reference pasture sites within 0m – 5m of the well based on Ah soil horizon thickness.

No difference was observed between distance classes based on texture (sand, silt, clay). The sites surveyed were dominated by poorly developed sandy soils. Although the sites were dominated by sand, other studies suggest that the construction of access roads increased the presence of % silt, and % clay in the soil. The plots did suggest that the impacts to soil pH and electro-conductivity extend 35m from the well head. Further, both soil pH and electro-conductivity decrease with distance from the well head (Figure 4.13). Given that soil pH and electro-conductivity are highly correlated, it is expected that both variables vary in unison.

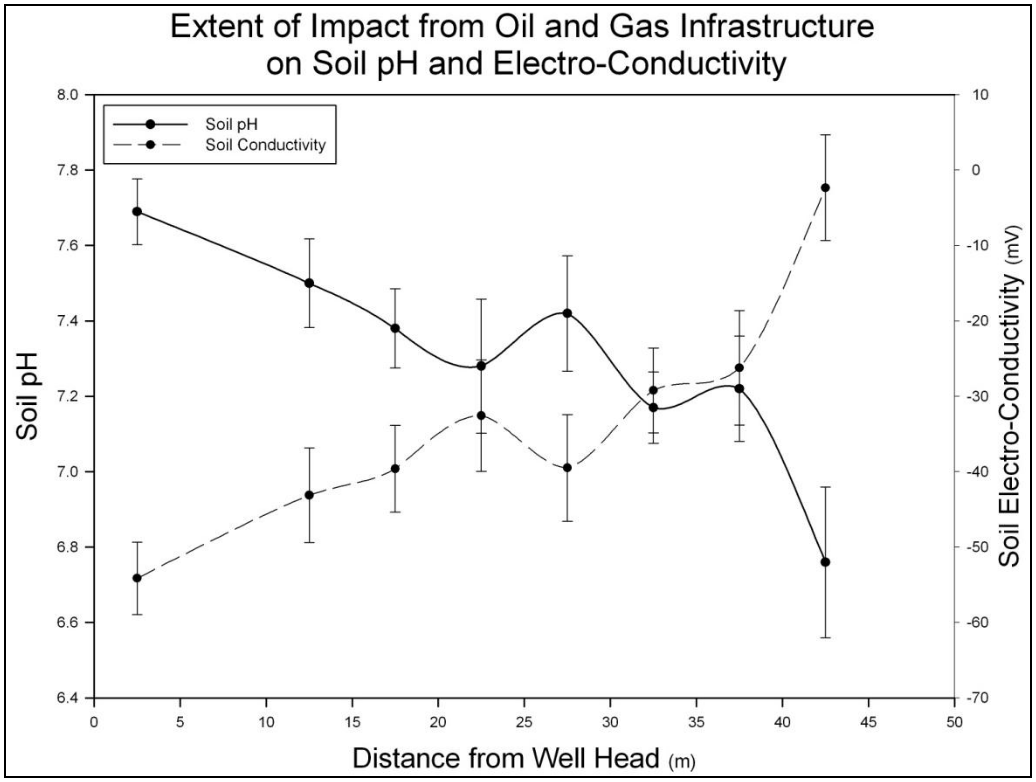


Figure 4.13 Soil pH and electro-conductivity values against distance from the center of the well head. Values are plotted as median values with +/- standard error.

The analysis of desirable and undesirable species presence indicated that desirable species presence increased with distance from the well head. The ordination of quadrats in desirable diversity space indicated increased desirable species diversity with increased distance from the well head. It can be concluded that desirable species vary more with distance from the well head than do undesirable species. This helps explain the trends observed when examining the relationship between range health and distance from the well head, and supports findings from section 4.3.1. From an MRPP analysis, distance groups were found to vary based on range health. The overall trend is an increase in range health values with increased distance from the well head (Figure 4.14).

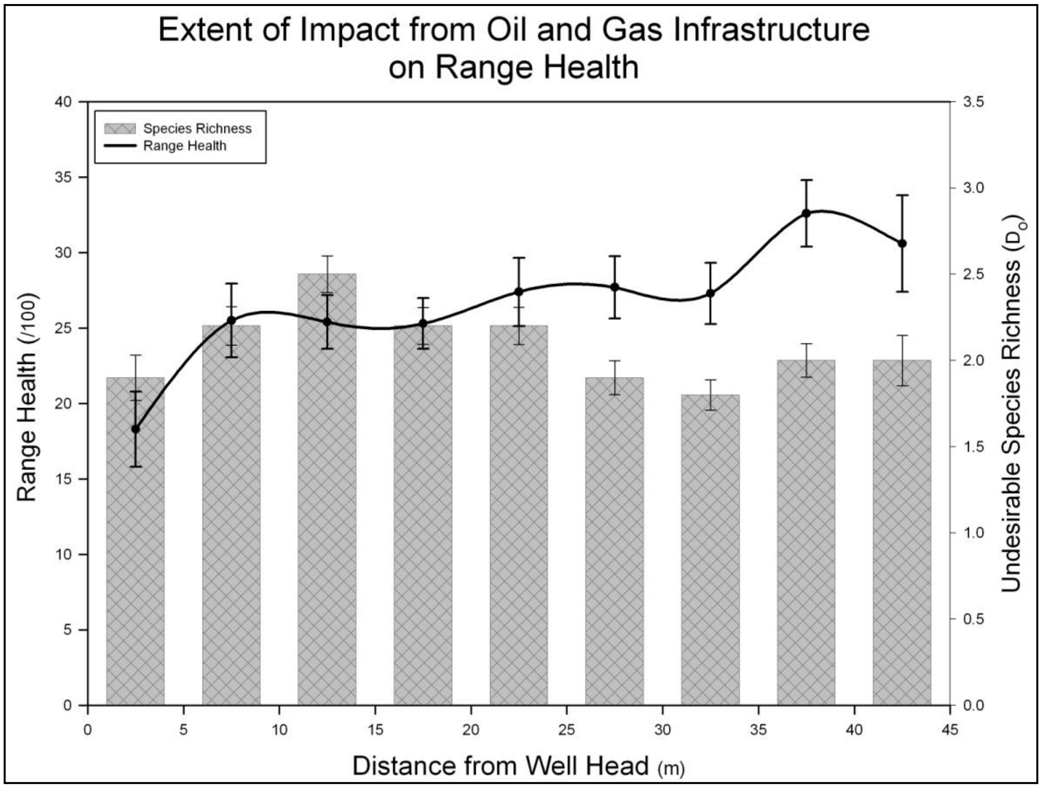


Figure 4.14 Range health values and undesirable species richness against distance from the center of the well head. Values are plotted as median values with +/- standard error..*

*Range health is a measure of ecosystem biodiversity and productivity, placing consideration on plant community composition in relation to the sites potential (Abouguendia 1990). Desirable species richness (*Do*) is in units of effective number of species (McCune et al. 2002).

When range health values were compared between the distance groups, the presence of a 5m and 25m zone of environmental impact was revealed (Figure 4.14). The sharp contrast of range health values within 5m of the lease site is due to the presence of the well pad and access road. From the clustering of the quadrats in the ordination biplot (see Table 4.17) and the graph (see Figure 4.14), it is concluded that a impacts to range health exists up to 25 meters from the center of the lease site. However, based on criteria established by Adams et al. (2004), and Abouguendia (1990), range health conditions can be considered poor within 45m of the well head. Within the lease site ROW, all range health values were considered unhealthy (< 35). When compared to the reference pasture median range health value of 40, it is evident that although range health conditions improve with distance from the well head, conditions are still poor.

4.3.5 Spatial extent of oil and gas well sites impacts on grassland ecology

The impacts of oil and gas development on grassland ecology extend up to 25 meters from the well head. To determine how, and if, changes to environmental management (EIA/EPP) over the 50 year development period have affected the spatial extent of lease site impacts, the lease sites were analyzed at a temporal scale. The spatial extent of impacts to ground cover and soil variables during each time period (1950-1979, 1980s, 1990s, 2000s) revealed slight differences between lease site drill dates (Figure A.1). The spatial extent of the impacts from lease sites drilled from 1950 to 1999 were observed to be greater than those drilled more recently (Figure 4.15).

For each date class, the spatial extents of the impacts were calculated by comparing lease distance values (0 to 40m) to the median values from the reference pasture. For lease sites drilled from 1950 to 1979, the spatial extent of impacts to ground cover (% herbaceous, % bare ground, and % litter), and soil variables were found to extend 15m from the well head (Figure A.1). This suggests that although lease sites have not been reclaimed, natural re-vegetation has, to an extent, reduced the footprint of oil and gas development; however, the impacts from development are long term.

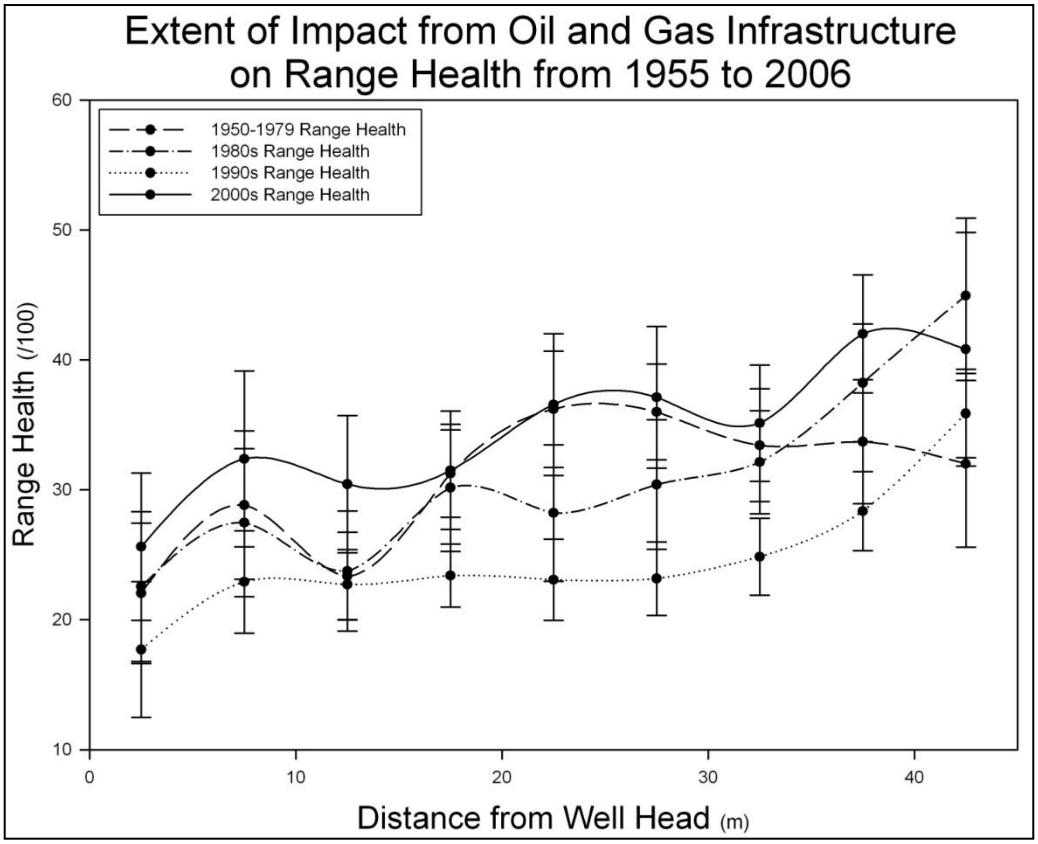


Figure 4.15 Range health values for lease sites from 1955 to 2006 against distance from the well head. Values are plotted as median values with +/- standard error.

The impacts to range health from those lease sites constructed from 1950 to 1979 were found to extend approximately 15m from the well head (Figure 4.15). Lease sites drilled from 2000 to 2006 had smaller ground cover and soil impacts than those drilled during the 1990s. The impacts associated with lease sites drilled from 2000 to 2006 were found to extend 10m to 15m from well head (Figure 4.15). The analysis of lease sites drilled during the 2000s revealed smaller impacts to range health than lease sites drilled earlier. Lease sites drilled during the 1990s exhibited the greatest spatial extent of impacts - the majority of development within the study area also occurred during this decade (Figure 4.15).

While on average, impacts were found to extend 25m from the well head, impacts to range health were found to extend beyond 40m from the well head (see Figure 4.14). When compared to reference pasture sites, range health at oil and gas lease sites is considerably lower, regardless of the year the site was drilled and/or abandoned. An unexpected finding is that oil and gas impact type and severity were irrespective of landscape type (dune or mixed grassland) and/or soil taxon. Further, the duration and severity of the impacts were found to be irrespective of infrastructure type, operational status, and/or the number of years of production. This suggests that regardless of environmental conditions, lease sites require significant time to recover and in most cases natural re-vegetation is not a sufficient management practice for grassland conservation and EIA.

CHAPTER 5

DISCUSSION AND CONCLUSIONS

5.1 Introduction

The purpose of the thesis was to examine follow-up implementation in current EIA practice, and to further the understanding of the effects of PNG development on grassland ecosystems. While the majority of anthropogenic disturbance to Saskatchewan grasslands has been the result of agricultural practices, over the last two and a half decades increased PNG activity has played a significant role in grassland disturbance. This is of significant concern in Saskatchewan, given that PNG development is expected to increase in the near future, and that the EIA process in place to manage the effects of such development focuses more on the pre-decision stage of impact prediction than it does following-up to verify and manage the actual effects of development.

This Chapter summarizes the key findings emerging from the thesis. The research results are discussed in the context of the broader literature on grassland effects assessment from PNG activity and the practice of EIA follow-up. PFRA's current approach to development impact assessment and management, and the lessons emerging for future practices are also discussed. The Chapter concludes by identifying limitations to the research, and outlines areas for future consideration.

5.2 Spatial and Temporal Development of PNG Activity in Southwest Saskatchewan

Over the last 50 years, PNG development in the study area and in southwest Saskatchewan in general has focused primarily on the production of crude oil. During this time, the majority of development occurred in the mid to late 1990s. The introduction of new technologies such as horizontal drilling has allowed for the retrieval of resources previously considered uneconomical. While this technology was first introduced and implemented in the province during the mid 1980s, its use and subsequent resource production did not peak until the 1990s (CPRC 2006).

Since 1979, the percentage of the landscape in the PFRA study area occupied by PNG infrastructure, including lease sites and access roads, has increased fivefold, the majority of which occurred between 1997 and 2005. Despite the significant increase in PNG activity in the study area over the last decade, there has been little EIA/EPP activity associated with this development. Of all the EIAs and EPPs conducted in the study area, for example, seven (29%) were for development proposals during the 1990s – five for single wells, one for monitoring activities, and one for a multi well project. Of the forty-nine oil and gas developments that occurred between 1955 and 1989, only three project proposals were submitted, all of which were submitted during the 1980s. From 2000 to 2006, 17 project proposals were submitted for oil and gas development in the study area, thirteen of which were EIAs/EPPs associated with the construction of individual or multi-well oil and gas lease sites.

In those cases where EIAs or EPPs have been completed in the study area, the focus has been primarily on the lease site, or on individual well activity, with little consideration for cumulative effects or for effects beyond the direct physical footprint of the lease site infrastructure itself. However, and consistent with previous research, this research affirms that the concentration of multiple lease site activities, including the construction of access roads as part of PNG development, has the potential to significantly alter grassland habitat (GSHRES 2007). For example, ROWs classified as PFRA roads in the study area are, on average, 16m in width. The construction of ROWs involves re-contouring and grading of the surface for the development of the coarse sand and gravel aggregate pad. Despite all the ROWs being crowned to facilitate drainage, few of the existing PFRA roads have underground culverts or ditches. Lease access roads in the study area range from 12m to 18m in width. In many cases, lease access roads do not involve the buildup of an aggregate pad. To minimize the environmental impacts, lease access roads within highly sensitive terrain (e.g. sand dune/blowout complex) employ a ‘drive on grass’ approach (Golder 2005). In some cases, tar (‘oiled roads’) has been used in attempt to stabilize highly eroded and moving sand sections. Despite best intentions, it appears that the ‘drive on grass’ approach fails as a mitigation measure. Many of the access roads in the sand dune complex are cut deeply into the landscape (Figure 5.1). From the survey of lease sites, the impacts from access roads are long term.

Figure 5.1 Representative photographs of ‘drive on grass’ lease site access roads. Access roads are located in a sand dune, blowout complex located in Twn15/Rge15 sections 35, 26, 23, 16, and 21.

The construction of roadways and increased truck traffic associated with a producing well results in the loss of vegetation, which in turn exposes large sections of moving sand (see also Patten et al. 2006; GSHRES 2007). Independent of re-seeding as a site mitigation practice, the impacts from PNG development are significant in that they are associated with a long-term loss of grassland biodiversity (Forman et al. 2003; Gelbard et al. 2003; Patten et al. 2006). Where possible, new access roads in the study area have made use of existing oil and gas and PFRA ROWs and trails to minimize impacts. However, despite the impacts associated with ROW construction in this highly sensitive environment, they are largely ignored in development planning and impact assessment (Van Lamoen et al. 2002). Rather, attention is focused on the regulatory requirements for site access, construction and operations.

5.3 Impacts of PNG Lease Sites on Mixed Grassland Ecosystems

Consistent with recent literature (see Hammermseister 2001; Osterman 2001; Desserud 2006; Elsinger 2009), the 31 PNG lease sites surveyed were found to differ significantly from the reference pasture based on ground cover conditions, physical and chemical soil properties, and undesirable plant diversity. Work by Neath (1987), Osterman (2001), Berquist et al. (2007), and Elsinger (2009), in a similar environment, suggests that the admixing and stripping of topsoil during the construction, operation and maintenance of sites significantly alters ground cover and soil properties. Findings from this research suggest that the admixing of soil horizons and the removal of surface vegetation associated with the re-contouring and leveling of PNG lease sites in the PFRA pasture results in a loss of herbaceous, litter and clubmoss ground cover.

In most cases, the pre-selected lease site is leveled to facilitate the construction of the well head, flare stack, pump jack, and storage tanks. The shallow Ah thickness values observed at the lease sites (2.5cm) is likely the direct result of soil admixing and construction practices, which involve the removal of topsoil (see Berquist et al. 2007; Elsinger 2009). Petherbridge (2000) found that the mixing of organic rich topsoil with the mineral subsoil elevates clay, electro-conductivity, and pH concentrations. The inability to separate horizons during the re-contouring process of lease site construction results in significant alteration of the organic soil horizon. This is exacerbated in the study area given the nature of the landscape and poor soil development (see Neath 1987).

Alteration of the upper O and A soil horizons results in the loss of desirable seed bank, which has been found to increase the susceptibility of a disturbed site to exotic and/or undesirable species invasion (Wilsey et al. 2003). Results from this research indicate that the alteration of soil properties (admixing) associated with PNG development results in the loss of grassland biodiversity, structure, and an influx of undesirable species. Neath (1990), Berquist (et al. 2007), and Elsinger (2009) suggest that the absence of desirable species associated with oil and gas development in grasslands results from: rapid colonization of undesirable following disturbance; the ability of undesirable species to cope with 'unfavorable' environmental conditions; the alteration of physical (compaction, bulk density) and chemistry (organic horizon) soil properties; and the competitive advantage of an established undesirable community. Once an undesirable 'hot-spot' becomes established, surrounding areas are prone to invasion (Maron et al. 2004). From a landscape management perspective, this is problematic given that lease sites facilitate the dispersal of undesirable species into the surrounding 'native' environment (Maron et al. 2004).

Vegetation cover at the lease site is controlled by the industry proponent (mowing program) in order to minimize the risk of grass fires within the lease sites. This removal of vegetation helps explain the low litter values observed at the lease sites, which, in turn, accelerates soil erosion and provides unfavorable growing conditions for germinating plants. The absence of litter prevents shading, thereby increasing surface temperature and removing soil moisture. From a physiological standpoint, the removal of organic material has been found to significantly affect desirable plant species diversity and seed banks due to the removal of growth promoting chemicals (gibberellins, auxins, and amino acids) derived from humus found in healthy grassland soils (Saviozzi et al. 2001).

Although considered undesirable for grazing, clubmoss (*Lycopodiacea*) is an integral component of grassland ecosystems as it provides soil stability, reducing the risk of erosion (Colberg and Romo 2003). The observation of little to no clubmoss at lease sites in the study area is consistent with other studies where physical alteration has resulted in a long-term (up to 75 years) loss of clubmoss (Neath 1987; Ostermann 2001). The loss of clubmoss at lease sites is well documented and is considered damaging to desirable grassland productivity, given that little is known regarding its re-establishment once removed (Colberg and Romo 2003; Romo and Bai 2004).

Surprisingly, no significant differences were observed between samples taken from fenced lease sites, versus those not fenced. Fences that enclose the PNG lease site ROW and/or infrastructure, are established by the proponent to prevent cattle contact with the well head. Consequently, lease fences act to limit ‘on-site’ grazing activity. Results from this research suggest that the effects of development are independent of grazing activity. Given that range health values are considered poor both outside and inside the fenced area, it can be inferred that the development of a lease site ROW has a greater impact to grassland ecosystems than grazing.

5.4 The Role of PNG Productivity, Infrastructure Type, and Year Drilled

The construction and maintenance of lease sites was found to result in the reduction of herbaceous ground cover, % litter, Ah soil horizon thickness, and % clubmoss, and an influx of undesirable species - independent of infrastructure type, and/or operational status. However, the impacts from development are accelerated on 'active' oil and gas lease sites due to the increased amount of traffic for well service, and tank truck vehicles associated with a producing site.

Most lease sites in the study area are oil lease sites, not connected via pipeline, and thus require vehicle traffic, specifically tank truck traffic, to empty storage batteries. The increased activity at operating (active), and/or previously operating (suspended) oil lease sites was found to result in a loss of vegetative ground cover (see, also, Berquist et al. 2007). To facilitate increased traffic at production sites, access roads are constructed around the lease site, involving the removal of vegetation and the buildup of an aggregate pad. The majority of 'active', and some 'abandoned', lease sites were found to have low (unhealthy) range health values. These findings suggest that operational, highly productive lease sites have the greatest impact to grassland ecology.

Interestingly, the impacts from development were not as severe for highly productive gas lease sites. This observation is likely because all of the gas wells in the pasture and surrounding area are tied into pipelines. Also, gas wells were drilled with a truck-mounted rig, and some incorporated a 'drive-on-grass' access road, which, to an extent, minimized disturbance. Low soil compaction levels associated with oil and gas well heads were unexpected, but speak to the nature of the terrain within the study area. Many of the surveyed oil lease sites in the study area are located in a sand dune complex.

Lease sites drilled in 1955 showed no significant difference in terms of ground cover, species diversity, and range health from those drilled more recently. These results suggest that the impacts from development are long term. The long-term nature of the impacts of PNG development is due to the fact that the majority of lease sites within the study area are left abandoned and/or suspended rather than decommissioned. This, in turn, prevents rehabilitation practices from taking place. Findings indicate that lease sites not decommissioned, but left abandoned and/or suspended for over 50 years, are not being re-vegetated through natural processes. The lack of abandoned and/or suspended PNG lease site decommissioning prevents the onset of reclamation efforts to facilitate the rehabilitation of degraded grasslands within the lease site.

As outlined in EIA/EPPs for the study area, lease sites are to be reseeded with an agronomic mix following construction. Under reclamation requirements, the mixture applied is certified under *The Canadian Seed Act* and consists of northern wheatgrass,(*Agropyron dasystachyum*) western wheatgrass(*Agropyron smithii*), blue grama grass(*Bouteloua gracilis*), prairie sand reed grass(*Calamovilfa longifolia*), green needle grass(*Stipa viridula*), Indian rice grass(*Achnatherum hymenoides*), and Canadian wild-rye (*Elymus canadensis*). Findings from this research, however, indicate that lease site reseeding methods are limited in their ability to reduce non-desirable species diversity. Although desirable species presence was found to increase after reseeding, undesirable forb and graminoid species were found to dominate PNG lease sites. This is true for all lease sites in the study area, regardless of the year drilled. Given the lack of reclamation within the study area, findings suggest that the impacts associated with development persist, even after a well is abandoned.

With regard to the time of year a lease site is drilled, no significant differences in impacts were observed between those sites drilled during the winter months and those drilled during other times of the year. Although most PNG development in the study area occurs in the winter months, the majority of disturbance is associated with the maintenance and service of the lease site, which occurs throughout the year. Contrary to 'best management practices', winter drilling programs in the study area appear to have the same long-term impact to grasslands as those drilled during the summer, spring, and fall seasons. However, lease sites drilled during the months of December to March appear to have a slight positive correlation with % litter and % herbaceous. Despite this observation, there is insufficient evidence to support the notion that drilling programs have lower impacts to grasslands during the winter months. Although winter drilling programs are less detrimental to grasslands in the short term, the long-term operation throughout the year is when the majority of the disturbance occurs.

It is important to note that the comments made regarding winter drilling as a mitigation measure for PNG activity are specific to this research, and study area. During the winter months, Swift Current-Webb Community Pasture receives very little snow (Golder 2005), which in turn prevents the degradation of sod and soil during PNG lease site construction. Other studies examining the impacts of lease site operations on grassland ecosystems emphasize the importance of winter drilling as an environmental management plan (EMP) (GSHRES 2007). By no means does this thesis suggest not incorporating winter drilling programs as an EMP for PNG activity in Saskatchewan. When applicable, winter drilling programs should be adopted as an EMP for PNG construction, given that the benefits outweigh the drawback.

5.5 Spatial Extent of the PNG Impacts to Grassland Ecosystems

In 1979, the percentage of the study area occupied by lease sites and lease access roads was 0.07% and 0.13%, respectively. However, when the ecological effects of lease site activities are considered, namely the effects of construction, operations, and maintenance, the total ecological footprint of lease sites and access roads increased to 0.31% and 0.67%, respectively. Combined, the total ecological footprint of PNG development pre-1979 accounted for 25% of the total disturbed area in the pasture. The other 75% of disturbance within the study area is accounted for by PFRA access roads and trails. In 1997, the percentage of the pasture occupied by both lease sites and access roads was 1.07%. In 2005, the percentage occupied by lease sites and access roads increased to 1.30%. When the ecological effects of lease sites and access roads were considered, the percent loss increased to 4.50% in 1997, and 5.10% in 2005. In 1997, the ecological footprint of PNG development accounted for 45% of the total disturbance in the study area while the other 55% of disturbance is accounted for by PFRA access roads and trails. In 2005, the ecological footprint of PNG development accounted for over 75% of the total disturbed area in the pasture. The remaining 25% of disturbance is accounted for by PFRA access roads and trails. Although management practices appear to be minimizing the spatial extent of the impacts associated with individual PNG lease sites, these results suggest that at the landscape level fragmentation and cumulative loss from PNG development is increasing.

Effects associated with the construction, maintenance, and operation of oil and gas lease sites extend beyond the direct physical footprint of the infrastructure. The average size of PNG lease sites in the study area, and surrounding region, is 10,000m^2 or 1ha. Given that the well head is at the center of the lease, the distance from the well head to the lease boundary is approximately 50m. Where required, construction occurs throughout the 10,000m^2 lease.

However, findings from this thesis suggest that the impacts from PNG development do not occupy the entire 10,000m^2 ROW.

Construction of the aggregate pad and lease road, which in some instances also involves re-contouring of the lease site, alters soil properties and results in the removal of herbaceous ground cover. The well head itself is treated with chemical herbicides to prevent fire hazards. This, in turn, significantly reduces the presence of both desirable and undesirable species within 0m – 10m of the well head. Low Ah values associated with oil and gas lease sites is the result of construction practices. It is not surprising that mineral soil horizons are so poorly developed within 0m – 10m of the well head, given the presence of the aggregate pad. In terms of range health surrounding the well head, conditions were considered poor within 40m of the well head.

Associated with the construction of an oil or gas lease site are an aggregate pad upon which the pump jack or screw pump is located, and the lease site road. It is important to note that the lease site road and the lease access road differ in size, construction techniques, and also impact. Lease site roads are often simply extensions of the aggregate pad upon which traffic travels. Findings from the analysis indicated that although the impacts from the aggregate pad and lease road are severe, they are confined to close proximity to the well head itself.

Low soil acidity and increased electro-conductivity values close to the well head reflect construction practices prior to the mid 1980s, which involved the handling of spills and solution water. Before regulations outlined in the EIA regarding the handling of spills and solution water were introduced, it was common practice for operations to spread solution water and spills throughout the lease, rather than removing them. This in turn increased the alkali concentration in soils and reduced soil acidity (Letey 2000). As previously discussed, increased bare ground accelerates soil moisture evaporation, which is likely contributing to soil salinity, and electro-conductivity.

In order to restore sections of the pasture that have been altered through oil and gas developed to native conditions, reclamation practices are required. Work by Hammermeister (2001), Desserud (2006), and Elsinger (2009) indicates that the restoration of once native grassland ecosystems following oil and gas development requires adaptive monitoring to control grazing pressures, and promote native grassland community establishment. However, given that the majority of abandoned oil and/or gas lease sites within the study area have not been decommissioned, reclamation practices have not been implemented. As a result the impacts associated with the infrastructure and the construction of the aggregate pad (within the ROW) persists for 50 years. This suggests that recent changes to lease site management and construction practices (EIA/EPP) are decreasing the associated impacts to grassland ecosystems. Although management has reduced the impacts of oil and gas lease site activity on grassland ecology, significant impacts exist within the study area.

5.6 Implications for EIA Follow-up Programs and Grassland Management

An effective follow-up program should contribute knowledge for the management of future development projects (Arts et al. 2001). Findings from this thesis, however, reveal a disconnect between impact assessment, planned mitigation, and understanding and managing the actual outcomes of development. A good follow-up program allows for more appropriate decisions concerning future developments, including choices about mitigation measures, to be made with consideration for ecological effects management. As emphasized in the literature (e.g. Treweek

1996; Cashmore 2004; Tinker et al. 2005; Legg et al. 2006), follow-up programs, supported by empirical science, allows for key VECs to be included in future policy and practice.

From conducting a 'follow-up' assessment of nearly fifty years of oil and gas activity within a grassland ecosystem it is recommended that construction practices strive to minimize surface disturbance. To minimize the loss of desirable/native species, vegetative diversity, and essential ground cover characteristics, it is suggested that:

1. PNG lease site construction practices should avoid recontouring and leveling the entire lease ROW when possible. In cases where recountouring is required, attempts should be made to avoid soil admixing by separating organic and mineral horizons.

2. To avoid soil contamination, spills and solution fluids should be trucked off site. The burial and/or spreading of solution water, drilling chips and/or fluids within the lease ROW should not be permissible.

3. Given the sensitivity of the study site, areas of moving sand should be avoided. Following lease site construction, exposed soil should be covered with Geotextile fabric and litter to help stabilize the soil, and promote revegetation. It is not recommended that crested wheat grass (*Agropyron pectiniforme*) be used to stabilize the landscape.

Regarding PNG development in the study area, current guidelines for project proposals are detailed in PFRA's 2005 'Environmental Assessment Plan Outline' (PFRA 2005a). This document encompasses key components that need to be addressed and included in project proposals and EIA/EPPs. Specifically, the review of project proposals (EIA/EPPs) reveals that sufficient pre-decision attention is directed towards the construction of a lease site. However, little to no attention is given to decommissioning and reclamation of the lease site, or to following-up on the cumulative or landscape impacts of multiple lease sites. In this regard, mitigation measures outlined in PFRA's 2005 'Environmental Assessment Plan Outline' require greater detail regarding the key VECs to be addressed in assessment and monitoring programs, as well as the implementation of specific post-construction measures to control surface disturbance.

Despite the intent of PFRA's reclamation guidelines and strategy, it is limited by the fact that few of the PNG lease sites within the study area are decommissioned. Rather, most lease sites are left abandoned. Under the current legislation, it is more financially viable for the proponent to continue renewing an abandoned lease site, rather than engage in de-construction and reclamation strategies. Findings from this research reveal that lease sites left abandoned are unable to recover to pre-development conditions via natural processes. In order to address the long term impacts form development, PNG lease sites need to be decommissioned.

5.7 Conclusions

A number of issues have emerged from this research that require further attention. First, while indirect, the study identified significant impacts to grasslands associated with the construction and maintenance of lease site access roads. Numerous studies, including the GSHRES (2007), identify access roads as a major contributor to the fragmentation and degradation of grassland landscapes. Although included in the project proposal screening stage, the construction of access roads requires little to no post-decision monitoring or follow-up. As a result, the total impacts of PNG development are unknown or largely ignored. Although it was beyond the scope of this thesis, preliminary findings in the study area and findings from research elsewhere, suggest that the impacts of access roads should not be overlooked in future scenarios.

Second, uncertainty remains regarding the construction of pipelines within the study area and the effects of pipeline development. While none of the oil lease sites within the study area and surrounding region are tied into pipelines, the majority of gas well are. Collectively, the total footprint of gas lease sites were observed to be lower than the those associated with oil wells, which may be due to lower truck traffic at gas sites due to the presence of the pipeline. However, insufficient evidence exists to suggest that all lease sites should be connected to pipelines rather than use storage tanks, as the effects of pipeline construction and fracturing in the study area were outside the scope of this thesis. While construction practices associated with the development of oil and gas pipelines in grassland ecosystems have significantly improved over the last fifteen years, it is unknown whether the impacts are lower than those associated with increased vehicle traffic.

Third, as with many environmental studies of this nature, the lack of appropriate temporal and spatial baseline information needs to be addressed. From a temporal standpoint, insufficient baseline information exists for the study area before the 1990s. As a result, lease sites drilled from 1955 to present can only be compared to baseline data collected in the summer of 2008. Spatially, to ensure that the baseline data collected were independent of PNG impacts, the reference pasture sites were located upwards of 100m from PNG lease site ROWs. Further, given that cattle grazing has been the primary focus of land use within the study area, it is important to make the distinction that baseline data collected in the study area represents lands, that have been subjected to over 30 years of disturbance due to conservation grazing activities. This baseline needs to be taken into consideration when making inferences regarding the impacts of PNG on ‘pristine’ native grasslands. In order to advance the understanding of the impacts of development within the study area, range health management plans conducted by the PFRA should attempt to focus on the collection of long term, collaborative baseline data.

Fourth, given the historical and ongoing nature of land use in the study area, to fully understand the impacts associated with PNG development there is a need to assess total or cumulative environmental effects. Conservation grazing remains the predominant focus of land use in the study area. Although not fully supported by this thesis, research by Neath (1990) and Elsinger (2009) suggest that the impacts and restoration efforts associated with PNG developments are negatively affected by increased grazing pressures. Given that lease site ROWs located in heavily grazed fields are often not fenced, grazing occurs in close proximity to lease site infrastructure. The areas surrounding lease sites are subject to interactive and synergistic cumulative effects form PNG lease site construction and grazing pressures. Interactive and synergistic pressures likely also persist surrounding lease access roads where grazing occurs. Future research in this area is required to address recent concerns presented by Environment Canada regarding the nature of cumulative effects in the province, which include PNG development within PFRA lands.

In conclusion, the impacts of PNG development to dune blowouts and mixed grasslands in the study area extend well beyond the direct, physical footprint of infrastructure itself and are long term. The research indicates that under current EIA/EPP practice, the actual effects of development are not sufficiently addressed or understood. While the role of the EIA process is to identify, evaluate, predict, mitigate, and monitor the effects of PNG development on the environment, the lack of follow-up monitoring programs prevents knowing the actual spatial and temporal extent of the impacts, and whether or not the implemented mitigation measures were successful. In order to better understand and manage the effects of PNG development on grasslands in Saskatchewan and Canada, the EIA process requires a more adaptive approach where scientific, ecological-based knowledge derived from follow-up programs is incorporated into pre-decision stages of development assessment and decision making.

LITERATURE CITED

Abouguendia Z. 1990. Range plan development. A practical guide to planning for management and improvements of Saskatchewan rangeland. New pasture and grazing technology project, Appendix E.

Adams B.W., W. Tedder, D. Downing, and A. Janz. 1996. Reclamation of mixed grass prairie disturbed by pipeline construction; reclamation research technical advisory committee, 50pp.

Adams, B.W., G., Ehlert, C., Stone, D., Lawrence, M., Alexander, M., Willoughby, D. Moisey, A., Burkinshaw, J. Carlson. 2004. Rangeland health assessment for grassland, forest and tame pasture. Alberta Sustainable Resource Development, Public Lands and Forests, p.12-19.

Agriculture and Agri-Food Canada; Historical Series (AAFC). 2001. [Online] http://epe.lac-bac.gc.ca/100/205/301/ic/cdc/agrican/pubweb/hs3_toc.asp Accessed Feb 2 2009.

Agriculture and Agri-Food Canada (AAFC). 2006. Re-establishment of a mixed native grassland in southwest Saskatchewan.

Agriculture and Agri-Food Canada; Environmental Assessment (AAFC). 2009. [Online] http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1187706462232&lang=eng Accessed Feb 2 2009.

Agriculture and Agri-Food Canada; Prairie Farm Rehabilitation Administration (AAFC)– Organizational Overview. 2007a. [Online] http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1187364281958⟨=e Last Accessed: Feb 2 2009.

Agriculture and Agri-Food Canada; PFRA History (AAFC). 2007b. [Online] http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1187374232064&lang=eng Last Accessed: Feb 2 2009.

Alberta Agriculture and Food. 2000. Weeds of the prairies. Alberta Agriculture and Food, Edmonton, Alberta. 266 pp.

Arts J., P. Caldwell, and A. Morrison-Saunders. 2001. Environmental impact assessment follow-up: good practice and future directions – findings from a workshop at the IAIA 2000 conference. *Impact Assessment and Project Appraisal* **19**: 175-185.

Bailey J. 1997. Environmental impact assessment and management: An anderexplored relationship. *Environmental Management* **21**:317-327.

Balvanera P., A.B. Pfisterer, N. Buchmann, J.S. He, T. Nakashizuka, D. Raffaelli, and B. Schmid. 2006. Quantifying the evidence for biodiversity effects on ecosystem functioning and services *Ecological Letters* **9**: 1146-1156.

Beals, M.J. 2006. Understanding community structure: A data-driven multivariate approach. *Oecologia*, **150**: 484-495.

Beanlands G. and P. Duinker. 1983. An ecological framework for environmental impact assessment. *Journal of Environmental Management*, **18**: 267-277.

Berquist E., P. Evangelista, and T.J. Stohlgren. 2007. Invasive species and coal bed methane development in the Powder River Basin, Wyoming. *Environmental Monitoring Assessment* **128**: 381-394.

Business Services Improvement Branch Economic and Co-operative Development; The Provincial regulatory approval process in Saskatchewan for petroleum and natural gas drilling and seismic exploration (BSIB). 2001. [Online] http://www.ir.gov.sk.ca/adx/aspx/adxGetMedia.aspx?DocID=2946,3384,5460,2936,Documents&MediaID=4721&Filename=drillingpaper.pdf Accessed Feb 21 2009.

Canadian Association of Petroleum Producers (CAPP). 2007. [Online]. http://www.capp.ca/default.asp?V_DOC_ID=677 Last Accessed: 26 February 2008.

Canadian Center for Energy Information (CCEI). 2006. Canada's unconventional natural gas resources.

Canadian Environmental Assessment Agency (CEAA). 2000. [Online]. http://www.ceaa.gc.ca/015/priorities_e.htm Last Accessed: 9 November 2007.

Canadian Plains Research Center (CPRC). 1998. Saskatchewan prairie biodiversity study, *eds.* Pepper G.W., and D.A. Gauthier, Canada/Saskatchewan Agricultural Green Plan Agreement.

Canadian Plains Research Center (CPRC), University of Regina: The encyclopedia of Saskatchewan. 2006. [Online] http://esask.uregina.ca/entry/oil_and_gas_industry.html Last Accessed: Jan 24 2009.

Cashmore M. 2004. The role of science in environmental impact assessment: process and procedure versus purpose in the development of theory. *Environmental Impact Assessment Review* **24**: 403-426.

Clarke K.R., P.J. Somerfield, and M.G. Chapman. 2006. On resemblance measures for ecological studies, including taxonomic dissimilarities and a zero-adjusted Bray-Curtis coefficient for denuded assemblages. Journal of Experimental Marine Biology & Ecology **330**: 55-80.

Colgerg T.J., J.T. Romo. 2003. Club moss effects on plant water status and standing crop. *Journal of Range Management* **56**: 489-495.

Coupland R.T. 1961. A reconsideration of grassland classification in the northern great plains of North America. *Journal of Grassland Ecology* **l8**: 135 – 167.

Cummings J., N. Reid, I. Davies, and C. Grants. 2005. Adaptive restoration of sand-mined areas for biological conservation. *Journal of Applied Ecology* **42**: 160-170.

Department of Justice Canada; The oil and gas conservation regulations, 1985 (DJC). 2007. [Online] http://www.qp.gov.sk.ca/documents/English/Regulations/Regulations/O2R1.pdf Accessed Feb 21 2009.

Department of Justice Canada; Prairie Farm Rehabilitation Act (AAFC). 2009. [Online] http://laws.justice.gc.ca/en/showdoc/cs/P-17///en?page=1 Last Accessed Feb 2 2009.

Desserud, P.A. 2006. Restoration of rough fescue grasslands on pipelines in southwest Alberta. M.Sc. Thesis. University of Calgary. Calgary, Alberta: pp.190.

Dufrene M., and P. Legendre. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecological Monographs* **67**: 345-366.

Elsinger, M.E. 2009. Reclamation status of rough fescue grasslands at Rumsey block in central Alberta, after oil and gas well sites and pipeline disturbances. M.Sc. Thesis. University of Alberta. Edmonton, Alberta: pp. 247.

Environment Canada - Meteorological Service of Canada. 2007. Annual temperature trends, extremes and current season ranking, 1948-2008 (61 Years). Online, accessed March 31st 2007. http://www.msc-smc.ec.gc.ca/ccrm/bulletin/rsummarytable_e.html?table=temperature&season=Winter&date=2008&nyears=61

Forman R.T.T. 1995. Land Mosaics: The ecology of landscapes and regions; Cambridge University Press, UK, p. 407.

Forman R.T.T., D. Sperling, J.A. Bissonette, A.P. Clevenger, C.D. Cutshall, V.H. Dale, L. Fahriq, R.L. France, C.R. Goldman, K. Heanue, J. Jones, F. Swanson, T.Turrentine, and T.C. Winter. 2003. Chapter 4, Roadsides and Vegetation, *in*, *Road Ecology; Science and Solutions*, Island Press, Washington D.C., pp. 75-113.

Fridley J.D., J.J. Stachowicz, S. Naeem, D.F. Sax, E.W. Seabloom, M.D. Smith, T.J. Stohlgren, D. Tilman, and B. Von Holle. 2007. The invasion paradox: reconciling pattern and process in species invasion. *Ecology* **88**: 3-17.

Frost R. 1997. EIA monitoring and audit, *in* Weston J., ed., Planning and environmental impact assessment in practice: Harlow, Addison Wesley, p. 141-164.

Gauthier D.L., Johnson, H.B., Mayeux, H.S. and Polley, H.W. 2003. *in* Grasslands towards a North American conservation strategy. Co-published by commission for environmental cooperation and Canadian plains research center, University of Regina 2003.

Gelbard J.L., and S. Harrison. 2003. Roadless habitats as refuges for native grasslands: Interactions with soil, aspect, and grazing. *Ecological Applications* **13**: 404-415.

Gibson R.B. 2002. From Wreck Cove to Voisey's Bay: the evolution of federal environmental assessment in Canada. *Impact Assessment and Project Appraisal* **20**: 151-159.

Golder Associates Ltd. 2005. Project proposal for the proposed Java South 2-20-15-15 W3M drilling project, prepared for Husky Energy Ltd, Swift Current, Saskatchewan.

Government of Saskatchewan Energy and Resources (GSER). 2009. [Online] http://www.infomaps.gov.sk.ca/website/SIR_Geological_Atlas/viewer.htm Last Accessed: February 1 1009.

Government of Saskatchewan Energy and Resources; Crown dispositions (GSER). 2009a. [Online] http://www.er.gov.sk.ca/Default.aspx?DN=3832,3402,3384,2936,Documents Accessed Feb 3 2009.

Government of Saskatchewan Energy and Resources; Great year for oil and gas well drilling (GSER). 2009b. [Online] http://www.gov.sk.ca/news?newsId=2f88c86a-6906-41f1-b472-eb8527dc9666 Accessed Feb 3 2009.

Government of Saskatchewan Industry and Resources; The Provincial regulatory approval process – petroleum and natural gas drilling (Detailed) (GSIR). 2001. [Online] http://www.ir.gov.sk.ca/adx/aspx/adxGetMedia.aspx?DocID=2946,3384,5460,2936,Documents&MediaID=4724&Filename=drilling.pdf Accessed Feb 21 2009.

Government of Saskatchewan Industry and Resources; Crude oil in Saskatchewan (GSIR). 2008. [Online]http://www.ir.gov.sk.ca/adx/aspx/adxGetMedia.aspx?DocID=5871,5775,2936,Documents&MediaID=18882&Filename=crude.pdf Last Accessed: Jan 24 2009.

Government of Saskatchewan Industry and Resources (GSER). 2009. [Online] http://www.infomaps.gov.sk.ca/website/SIR_Oil_And_Gas_Wells/viewer.htm Last Accessed: January 24 2009.

Great Sand Hills Regional Environmental Study (GSHRES). 2007. [Online]. http://www.environment.gov.sk.ca/Default.aspx?DN=32911ed7-b6a9-495c-8d47-66c593a5d92a Last Accessed: November 27th 2007.

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

Hanna K.S. 2005. A brief introduction to environmental impact assessment, *in* Hanna K. S., ed., Environmental Impact Assessment, Practice and Participation: New York, Oxford University Press, p. 3-15.

Hirst C.N., and D.A. Jackson. 2007. Reconstructing community relationships: the impacts of sampling error, ordination approach, and gradient length. *Diversity and Distributions* **13**: 361-371.

Hobson K.A., E.M. Bayne, and S.L. Van Wilgenburg. 2002. Large-scale conservation of forest to agriculture in the Boreal Plains of Saskatchewan. *Conservation Biology* **16**: 1530-1541.

Holeckek J.L., R.D. Pieper, C.H. Herbel. 1995. *Range Management Principles and Practices, Second Edition*. Prentice Hall, New Jersey, pp. 112-130, 208, 445-464.

Hooper D.U., F.S. Chapin, J.J. Ewel, A. Hector, P. Inchausti, S. Lavorel, J.H. Lawton, D.M. Lodge, M.Loreau, S. Naeem, B. Schmid, H. Setala, A.J. Symstad, J. Vandermeer, and D.A. Wardel. 2005. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. *Ecological Monographs* **75**: 3-35.

Jay S., C. Jones, P. Slinn, and C. Wood. 2007. Environmental impact assessment: retrospective and prospect. *Environmental Impact Assessment Review* **27**: 287-300.

Jentsch A. 2002. Impact of disturbance on biodiversity and resilience of ecosystems. Integrated Project (1.6.3 Global Change and Ecosystems): Disturbance. Center of Environmental Research Leipzig-Halle, Germany.

Klassen, R.W. 2002. Surficial geology of the Cypress Lake and Wood Mountains, Map areas, Southwestern Saskatchewan. *Geological Survey of Canada* **562**: 3-22.

Knight O. 1956. Oil – Canada's New Wealth *in* The Business History Review, The Presidents and Fellows of Harvard College, vol30, #3 pp. 297 – 328.

Legendre P., and E.D. Gallagher. 2001. Ecologically meaningful transformations for ordination of species data. *Oecologia* **129**: 271-280.

Legg C., and L. Nagy. 2006. Why most conservation monitoring is, but need not be, a waste of time. *Journal of Environmental Management* **78**: 194-199.

Letey P. 2000. Soil salinity poses challenges for sustainable agriculture and wildlife: *California Agriculture*, **54**: 43.

Linke J., G.J. McDermid, A.D. Pape, A.J. McLane, D.N. Laskin, M. Hall-Beyer, and S.E. Franklin. 2008. The influence of patch-delineation mismatches on multi-temporal landscape pattern analysis. *Landscape Ecology*, **24**: 157-170.

MacDougall A.S., J. Boucher, R. Turkington, and G.E. Bradfield. 2006. Patterns of plant invasion along an environmental stress gradient. *Journal of Vegetation Science* **17**: 47-56.

Maron L.J., Vila M. Bommarco, R. Elmendorf, and P. Beardsley. 2004. Rapid evolution of an invasive plant: *Ecological Monographs*, Ecological Society of America, pp. 261-280.

Marshall R. 2004. Can industry benefit from participation in EIA follow-up? The ScottishPower experience in Morrison-Saunders and Arts (2004a), pages 118-153.

Marshall R. 2005. Environmental impact assessment follow-up and its benefits for industry. *Impact Assessment and Project Appraisal* **23**: 191-196.

Marshall R., J. Arts, and A. Morrison-Saunders. 2005. International principles for best practice EIA follow-up. *Impact Assessment and Project Appraisal* **23**: 175-181.

McCune B., and J.B. Grace. 2002. Analysis of Ecological Communities, MjM Software Design, Glendale Beach, Oregon, p. 45-58, 75-77, 102-114, 112-124, 188-194.

McGarigal K., Cushman S., Stafford S. 2000. Chapter 4, Discriminant Analysis, *in Multivariate Statistics for Wildlife and Ecology Research,*Springer Science + business Media Inc, New York, pp.129-179.

Morris P., and R. Therivel. 1995. Introduction and Interactions Between Impacts, *in* Morris P., and R. Therivel, eds., Methods of Environmental Impact Assessment: Vancouver, UBC Press, p. 1-7, 297-305.

Morrison-Saunders A., J. Arts, and J. Baker. 2003. Lessons from practice: Towards successful follow-up. *Impact Assessment and Project Appraisal* **21**: 43-56.

Morrison-Saunders A., and J. Arts. 2005. Learning from experience: emerging trends in environmental impact assessment follow-up. *Impact Assessment and Project Appraisal* **23**: 170-174.

Morrison-Saunders A., and R. Marshall. 2007. EIA Follow-up, International Best Practice Principles. Special Publication Series No.6, Fargo, USA: International Association for Impact Assessment.

Moss E.H. 1983. Flora of Alberta. Second Edition, revised by J.G. Packer. University of Toronto Press, Toronto, Ontario. 687 pp.

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

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

Noble B.F. 2006. Introduction to Environmental Impact Assessment, A guide to principles and practice: New York, Oxford University Press, p. 10 – 24.

Noss R. 1990. Indicators for monitoring biodiversity: a hierarchical approach. *Conservation Biology* **4**: 355-363.

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

Patten M.A., E. Shochat, D.L. Reinking, D.H. Wolfe, and S.K. Sherrod. 2006. Habitat edge, land management, and rates of brood parasitism in tallgrass prairie. *Ecological Applications* **16**: 687-695.

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

Prairie Conservation Action Plan (PCAP). 1995. Alberta prairie conservation action plan; 1996-2000. Prairie Conservation Forum, 17pp.

Prairie Farm Rehabilitation Administration (PFRA). 2005. [Online] http://www.agr.gc.ca/pfra/pfhist_e.htm Last Accessed: November 17 2007.

Prairie Farm Rehabilitation Administration. 2005a. PFRA Environmental assessment plan outline. Prairie Farm Rehabilitation Administration (PFRA) – AAFC.

Prairie Farm Rehabilitation Administration (PFRA). 2005b. Range management plan for Swift Current-Webb PFRA Community Pasture.

Prairie Farm Rehabilitation Administration (PFRA). 2007. [Online] http://www.agr.gc.ca/pfra/biodiversity/intro_e.htm Last Accessed: November 17 2007.

Romo J.T., and Y. Bai. 2004. Seed bank and plant community composition, mixed prairie of Saskatchewan. *Journal of Range Management* **57**: 300-304.

Rowell M.J., and L.Z. Florence. 1993. Characteristics associated with difference between undisturbed and industrially-disturbed soils. *Soil Biology and Biochemistry* **25**: 1499-1511.

Roy, Schaeffer. 1988. In the public interest: The oil and gas industry of Saskatchewan 1905 – 1950. Masters Thesis, University of Saskatchewan.

Saskatchewan Institute of Pedology, 1998, *Preliminary Soil Map and Report*: Saskatchewan Soil Survey, University of Saskatchewan, p.30-36

Saviozzi A., R. Levi-Minzi, R. Cardelli, and R. Riffaldi. 2001. A comparison of soil quality in adjacent cultivated, forest and native grassland soils. *Plant and Soil* **233**: 251-259.

Scheider R.R., J.B. Stelfox, S. Boutin, and S. Wasel. 2003. Managing the cumulative impacts of land uses in the Western Canadian Sedimentary Basin: A modeling approach. *Conservation Biology* **7**: 1-8.

Sinton H. M. 2001. Prairie Oil and Gas – A Lighter Footprint: Edmonton, Alberta, Alberta Environment.

Storey K., and B. Noble. 2002. Increasing the utility of follow-up in Canadian environmental assessment: a review of requirements, concepts and experience. [Online]. http://www.ceaa-acee.gc.ca/015/001/030/index_e.htm Last Accessed: 11 November 2007

Tilman, D. 1997. Chapter 8, Mechanisms of plant competition, *in* Crawley, M.J., ed. *Plant Ecology*, Blackwell Science, United Kingdom, pp. 242-262.

Tilman, D. 2004. Nice tradeoffs, neutrality, and community structure: a stochastic theory of resource competition, invasion, and community assembly. *Proc. National Academy of Science* **101**: 10854-10861.

Tinker L., D. Cobb, A. Bond, and M. Cashmore. 2005. Impact mitigation in environmental assessment: paper promises or the basis of consent conditions? *Impact Assessment and Project Appraisal* **23**: 265-280.

Treweek J. 1996. Ecology and Environmental Impact Assessment. *Journal of Applied Ecology* **33**: 191-199.

Van Lamoen F., and J. Arts. 2002. EIA follow-up for road projects: What do we want and need to know? Paper presented at the International Association for Impact Assessment Annual Conference June 2002. The Hague, NL.

Wali K.W. 1999. Ecological succession and the rehabilitation of disturbed terrestrial ecosystems. *Plant and Soil* **213**: 195-220.

Willms W.D., and B.H. Ellert, H.H. Janzen, and H. Douwes. 2005. Evaluation of native and introduced grasses for reclamation and production. *Rangeland Ecology Management* **58**: 177-183.

Wilsey, J.B. and Polley, W.H., 2003, Effects of Seed Additions and Grazing History on Diversity and Productivity of Subhumid Grasslands. *Ecology, Ecological Society of America*, 930-931.

Wilson S.D., and A.K. Gerry. 1995. Strategies for mixed-grass prairie restoration: Herbicide, tilling and nitrogen manipulation. *Society of Ecological Restoration* **3**: 290-298.

Zink J.A., M.F. Allen, D. Heindl-Tenhunen, and E.B. Allen. 1995. The effect of a disturbed corridor on an ecological reserve. *Restoration Ecology* **3**: 304-310.

CHAPTER 6

APPENDIX

Table A.1 Desirable and undesirable grasses, grass-likes, forbs and woody forbs in Swift Current-Webb Pasture

List of grass and grass-like species, including common and Latin names[1]

Common Name	Latin Name	Undesirable Range Species (x)
Indian Rice Grass	*Achnatherum hymenoides*	
Northern Wheat Grass	*Agropyron dasystachyum*	
Crested Wheat Grass	*Agropyron pectiniforme*	x
Western Wheat Grass	*Agropyron smithii*	
Blue Grama Grass	*Bouteloua gracilis*	
Smooth Brome	*Bromus inermis*	x
Downy Brome	*Bromus tectorum*	x
Sand Grass	*Calamovilfa longifolia*	
Low Sedge	*Carex elecocharis*	
Thread-leaved sedge	*Carex filifolia*	
Canadian Wild-rye	*Elymus canadensis*	x
Quack Grass	*Elytrigia repens*	x
Foxtail Barley	*Hordeum jubatum*	x
Baltic Rush	*Juncus balticus*	
June Grass	*Koeleria cristata*	
Plains Muhly	*Muhlenbergia cuspidata*	
Mat Muhly	*Muhlenbergia richardsonis*	
Kentucky Blue Grass	*Poa pratensis*	x
Sandlebergs Blue Grass	*Poa sandbergii*	
Alkali Grass	*Puccinellia spp.*	x
Sand Dropseed	*Sporobolus cryptandrus*	
Needle and Thread Grass	*Stipa comata*	
Western Porcupine Grass	*Stipa curtiseta*	

[1]Latin names taken from USDA Plants Database (http://plants.usda.gov/) and Flora of Alberta (Moss 1983)

List of forb species, including common and Latin names[1]

Common Name	Latin Name	Undesirable Range Species (x)
Yarrow	*Achillea millefolium*	
Nodding Onion	*Allium cernuum*	
Pymgy Flower	*Androsace septentrionalis*	x
Pussytoes	*Antennaria spp.*	
Rock Crest	*Arabis spp.*	
Pasture Sage	*Artemisia frigida*	x
Buffalo Bean	*Astragalus crassicarpus*	
Milk-Vetch	*Austragalus spp.*	x
Blue Bell	*Campanula rotundifolia*	
Nodding Thistle	*Carduus nutans*	x
Prostrate Knapweed	*Centaurea maculosa*	x
Field Chickweed	*Cerastium arvense*	x
Goosefoot	*Chenopodium spp.*	x
Hairy Golden Aster	*Chrysopsis villosa*	
Canadian Thistle	*Cirsium arvense*	x
White Thistle	*Cirsium hookerianum*	x
Pale Comandra	*Comandra pallida*	
Flixweed	*Descurainia sophia*	x
Wood Whitlow Grass	*Draba nemorosa*	x
Horsetail Species	*Equisetum spp.*	x
Aven species	*Geum spp.*	
Gumweed	*Grindelia squarrosa*	x
Spiny Ironplant	*Haplopappus spinulosus*	x
Kochia	*Kochia scoparia*	x
Blue-Bur	*Lappula echinata*	x
Pepper Grass	*Lepidium densiflorum*	x
Skeletonweed	*Lygodesmia rostrata*	x
Yellow Sweet Clover	*Melilotus officinalis*	x
Alfalfa	*Medicago sativa*	x
Pin Cushion Cactus	*Navarretia minima*	
Ball Mustard	*Neslia paniculata*	x
Prickly Pear Cactus	*Opuntia spp.*	
Locoweed	*Oxytropis spp.*	x
White Beards Tongue	*Penstemon albidus*	x
Moss Phlox	*Phlox hoodii*	
Plantain	*Plantago spp.*	x
Prairie Cinquefoil	*Potentilla*	
Silverweed	*Potentila anserina*	x
Shrubby Cinquefoil	*Potentilla fruticosa*	

List of forb species, including common and Latin names continued

Common Name	Latin Name	Undesirable Range Species (x)
Silver-leaved psoralea	*Psoralea argophylla*	
Prairie Cone Flower	*Ratibida columnifera*	
Russian Thistle	*Salsola pestifer*	x
Solomon's Seal	*Smilacina trifolia*	x
Wild Tomato	*Solanum triflorum*	
Goldenrod	*Solidago spp.*	
Sow Thistle	*Sonchus spp.*	x
Scarlet Mallow	*Sphaeralcea coccinea*	
Dandelion	*Taraxacum officinale*	x
Golden Bean	*Thermopsis rhombifolia*	x
Yellow Goat's Beard	*Tragopogon dubius*	x
American Vetch	*Vicia americana*	

[1]Latin names taken from USDA Plants Database (http://plants.usda.gov/) and Flora of Alberta (Moss 1983)

List of woody forb species, including common and Latin names[1]

Common Name	Latin Name	Undesirable Range Species (x)
Western Snowberry	*Symphoricarpos occidentalis*	
Silver Sagebrush	*Artemisia cana*	
Wolf Willow	*Elaeagnus commutata*	
Wild Licorice	*Glycyrrhiza lepidota*	
Prickly Rose	*Rosa acicularis*	x
Wood Rose	*Rosa woodsii*	

[1]Latin names taken from USDA Plants Database (http://plants.usda.gov/) and Flora of Alberta (Moss 1983)

Table A.2 Oil and gas lease sites surveyed within Swift Current-Webb Community pasture based on date, topology, and soil taxonomy.

				Drill Decade							Topology		Soil Taxonomic Unit			
Sample #	Well Ticket Number	Proponent	Activity Type	Pre-1970	1970	1980	1990	2000	Drill Date	Legal Land Location (W3M)	Dune Upland	Mixed Grass	AP3	HTHR4	HT1/2	Specific Soil Taxon
1	311	Husky Oil	AG		x				2/22/1977	101/10-21-015-16	x		x			Antelope-Laton
2	312	Husky Oil	G		x				2/22/1977	101-10-21-015-16	x		x			Antelope-Laton
3	317	Exxonmobil Cda	D&A		x				10/27/1971	101/15-24-015-16	x		x			Antelope
4	132	Husky Oil	D&A			x			11/21/1986	111/07-31-015-15	x		x			Antelope
5	319	Avenir Operating	Oil			x			9/20/1985	121/05-25-015-16	x		x			Antelope
6	324	Avenir Operating	D&A			x			7/15/1985	131/05-26-015-16	x		x			Antelope
7	330	Avenir Operating	Oil			x			7/19/1985	141/15-26-015-16	x		x			Antelope
8	133	Husky Oil	D&A				x		6/22/1995	121/11-31-015-15	x		x			Antelope
9	310	Husky Oil	D&A				x		5/24/1996	141/07-21-015-16	x		x			Antelope-Laton
10	313	Husky Oil	D&A				x		10/18/1996	131/01-22-015-16	x		x			Antelope
11	333	Husky Oil	D&A				x		8/7/1996	131/04-28-015-16	x		x			Antelope
12	316	Apache Cda	D&A					x	3/30/2000	131/14-24-015-16	x		x			Antelope
13	331	Husky Oil	Oil					x	3/12/2003	121/09-27-015-16	x		x			Antelope
14	332	Husky Oil	Oil					x	10/19/2001	141/16-27-015-16	x		x			Haverville-Antelope
15	383	Avenir Operating	Oil					x	1/16/2004	121/04-35-015-16	x		x			Haverville-Antelope
16	18	Husky Oil	Oil		x				9/12/1969	101/15-17-015-15		x			x	Antelope
17	27	Husky Oil	D&A		x				6/30/1977	101/01-20-015-15		x			x	Hatton
18	34	Husky Oil	D&A		x				10/23/1969	101/09-20-015-15		x			x	Hatton
19	251	BP Cda Enrg Rs	D&A		x				7/6/1973	131/14-10-015-16		x		x		Hatton-Birsay
20	35	Husky Oil	Oil			x			10/24/1985	121/10-20-015-15		x			x	Hatton
21	38	Husky Oil	SO			x			7/10/1985	101/13-20-015-15		x			x	Hatton
22	110	Husky Oil	SO			x			4/7/1985	111/16-29-015-15		x		x		Hatton-Haverville
23	250	Anadarko Cda	D&A			x			9/2/1983	131/09-10-015-16		x		x		Hatton-Birsay
24	19	Husky Oil	Oil				x		10/21/1997	131/02-18-015-15		x			x	Hatton
25	26	Husky Oil	Oil				x		8/15/1997	131/12-18-015-15		x		x		Hatton-Haverville
26	118	Husky Oil	Oil				x		11/23/1998	191/07-30-015-15		x			x	Hatton
27	256	Husky Oil	Oil				x		12/11/1996	131/02-13-015-16		x		x		Hatton-Haverville
28	60	Husky Oil	Oil					x	10/4/1999	141/12-28-015-15		x		x		Hatton-Haverville
29	72	Husky Oil	Oil					x	9/28/1999	131/15-28-015-15		x			x	Hatton
30	115	Husky Oil	Oil					x	10/4/1999	191/02-30-015-15		x		x		Hatton-Haverville
31	139	Husky Oil	Oil					x	11/19/1999	111/04-33-015-15		x			x	Hatton

TABLE A.3 Results of indicator analysis of desirable species comparing lease sites to reference pasture sites.*

Desirable species	**Oil and gas lease sites (IV%)**	**Reference pasture sites (IV%)**
Blue grama grass (*Bouteloua gracilis)*	32.9^{**}	0.0
Indian rice grass *(Oryzopsis hymenoides)*	10.7^{*}	0.0
Canada blue grass *(Poa compressa)*	40.7^{*}	0.0
Muhly species *(Muhlenbergia spp.)*	15.2^{**}	0.0
Aster species *(aster spp.)*	9.7^{*}	0.0
Pale comandra *(Comandra palliada)*	18.4^{*}	0.0
Silver-leaved psoralea *(Psoralea argophylla)*	28.5^{*}	0.0
Three-leaved sedge *(Carex filifolia)*	31.7^{**}	0.0

*****Indicator species were selected based on a measure of Indicator Value (%) at a 0.05 significance level. Shaded cells indicate species that were significant indicators for each of the lease classes. All species have a relative abundance value greater than 5%, and are not considered rare to the environment.

Table A.4 Results of indicator analysis of undesirable species comparing lease sites by class. Indicators species were selected based on a measure of Indicator Value (%) at a 0.05 significance level. Yellow indicates species which are significant indicators for each of the lease classes. Red indicates species which were significant, but considered rare (below 5% Relative Abundance). Significant results are shown in bold.

Lease Class	**Active Oil**	**Active Gas**	**Suspended Oil**	**Suspended Gas**	**Abandoned Oil**	**Abandoned Gas**	**Potential Well**	**Drilled and Abandoned**	*p*-value
Elymus canadensis	0	0	39	0	0	0	5	0	**0.02**
Puccinellia spp.	6	5	38	0	7	0	1	0	**0.04**
Poa pratensis	6	0	0	0	3	0	47	0	**0.01**
Agropyron pectiniforme	17	28	2	2	14	21	2	0	**<0.01**
Hordeum jubatum	1	0	3	0	1	1	0	58	**<0.01**
Atremisia frigida	16	26	7	15	9	16	4	1	**0.01**
Melilotus officinalis	0	0	0	0	1	0	0	42	**0.02**
Lygodesmia rostrata	0	4	0	1	0	0	0	35	**0.04**
Descurainia sophia	4	0	7	56	0	5	5	0	**<0.01**
Solanum triflorum	0	50	0	0	0	0	0	0	**<0.01**
Lappula echinata	9	0	6	49	0	2	1	1	**<0.01**
Kochia scoparia	1	0	0	0	1	17	0	38	**0.03**
Centaurea maculosa	1	0	80	1	1	0	0	0	**<0.01**
Glycyrrhiza lepidota	0	0	0	0	23	0	58	0	**<0.01**
Cirsium hookerianum	1	0	0	0	9	0	63	0	**<0.01**

Table A.5 Results of indicator analysis of desirable species comparing lease sites by class. Indicators species were selected based on a measure of Indicator Value (%) at a 0.05 significance level. Yellow indicates species which are significant indicators for each of the lease classes. Red indicates species which were significant, but considered rare (below 5% Relative Abundance). Significant results are shown in bold.

Lease Class	**Active Oil**	**Active Gas**	**Suspended Oil**	**Suspended Gas**	**Abandoned Oil**	**Abandoned Gas**	**Potential Well**	**Drilled and Abandoned**	***p-value***
No species present	7	1	0	0	5	29	0	0	**0.04**
Agropyron smithii	12	**3**	7	17	5	8	0	45	**<0.01**
Agropyron dasystachyum	9	0	42	13	7	**3**	11	7	**<0.01**
Calamovilfa longifolia	7	1	0	43	11	4	**2**	0	**0.01**
Poa sandbergii	**1**	0	0	0	2	0	88	0	**<0.01**
Stipa curtiseta	0	0	10	9	0	1	3	36	**0.03**
Achnatherum hymenoides	0	0	45	2	0	0	0	0	**0.01**
Carex filifolia	7	3	0	4	17	8	44	3	**<0.01**
Smilacina trifolia	0	0	49	0	2	0	2	4	**<0.01**
Antennaria spp.	3	2	0	0	0	2	32	0	**0.05**
Symphoricarpos occidentalis	**1**	8	35	0	3	**2**	21	18	**0.03**

Table A.6 Kruskal-Wallis one way analysis of variance of the lease classes based on ground cover and soil properties.*

	% Herbaceous		**% Bare Ground**		**% Litter**		**Soil Compaction**	
Lease Class	*Std. Error*	*p-value*	*Std. Error*	*p-value*	*Std. Error*	*p-value*	*Std. Error*	*p-value*
PNG vs. Suspended	-	-	-	-	11.49	**0.01**	0.28	**<0.01**
PNG vs. Drilled & Abandoned	-	-	-	-	13.19	**0.01**	0.29	**<0.01**
Oil vs. Abandoned	6.05	**<0.01**	6.03	**<0.01**	7.8	**<0.01**	0.24	**<0.01**
Gas vs. Abandoned	-	-	-	-	12.01	**<0.01**	0.28	**<0.01**

**Null hypothesis: variables are equal between the a priori groups. Significant results are shown in bold.*

Figure A.1 Ecological extent of the impacts from oil and gas infrastructure to ground cover characteristics and soil properties which extend beyond the physical footprint of infrastructure from 1955 to 2006. Standard error of the mean was calculated by dividing the standard deviation by the square root of the sample size.

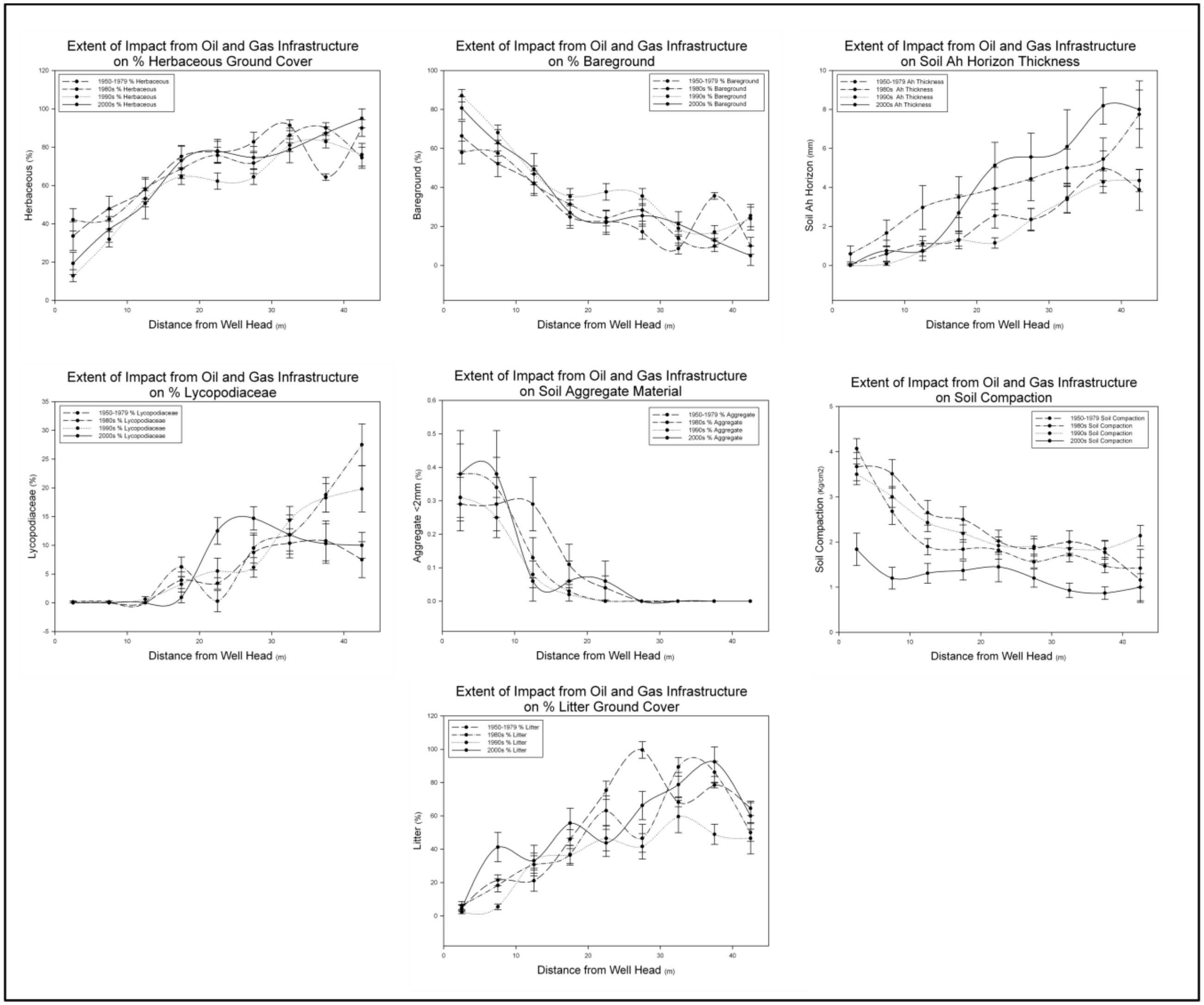


Table A.7 Pasture area occupied by the calculated oil and gas impact radii (PFRA roads, trails, lease sites, lease access roads) in 1979.

1979 Air Photo – Impact Extents						
Patch Count	**Patch Class**	**Area (ha)**	**Perimeter (m)**	**Patch Density (#/100ha)**	**Edge Density (m/ha)**	**%Area Loss**
2	PFRA Pasture	9736.214	58837.182	N/A	N/A	N/A
3	PFRA Roads	46.429	16070.670	0.03	349.3	0.477
5	Trails	229.476	93352.941	0.05	407.7	2.357
14	Lease Sites	30.600	5447.200	0.14	178.0	0.314
8	Lease Access Roads	65.530	26915.647	0.08	410.7	0.673
TOTAL						
32	**N/A**	***10108.249***	***200623.641***	***N/A***	***N/A***	***3.821***

Area and perimeter values were calculated in ArcGIS 9.3™ using Buffer Wizard and HAWTH TOOLS™. Analysis indicates that trails account for the greatest amount of altered pasture (area - 2.36%). From impact extents, the combined percent associated with lease sites and access roads accounts for an alteration area of 0.987% (Figure A.1).

Table A.8 Pasture area occupied by the calculated oil and gas impact radii (PFRA roads, trails, lease sites, lease access roads) in 1997.

1997 Air Photo – Impact Extents						
Patch Count	**Patch Class**	**Area (ha)**	**Perimeter (m)**	**Patch Density (#/100ha)**	**Edge Density (m/ha)**	**% Area Loss**
2	PFRA Pasture	9702.202	59046.490	N/A	N/A	N/A
2	PFRA Roads	30.259	9892.568	0.02	327.6	0.312
4	Trails	211.180	81842.814	0.04	387.7	2.177
33	Lease Sites	53.036	16365.466	0.33	308.6	0.547
8	Lease Access Roads	142.969	54375.914	0.08	380.5	1.474
TOTAL						
49	**N/A**	***10139.645***	***221523.252***	***N/A***	***N/A***	***4.509***

Area and perimeter values were calculated in ArcGIS 9.3™ using Buffer Wizard and HAWTH TOOLS™. Analysis indicates that trails still account for the greatest amount of altered pasture area (2.18%). From impact extents, the combined percent associated with lease sites and access roads accounts for an alteration area of 2.01% (Figure A.2). The percent of pasture altered by lease sites has nearly doubled since 1979.

Table A.9 Pasture area occupied by the calculated oil and gas impact radii (PFRA roads, trails, lease sites, lease access roads) in 2005.

2005 SPOT Satellite Image – Impact Extents						
Patch Count	**Patch Class**	**Area (ha)**	**Perimeter (m)**	**Patch Density (#/100ha)**	**Edge Density (m/ha)**	**% Area Loss**
2	PFRA Pasture	9815.385	59050.930	N/A	N/A	N/A
2	PFRA Roads	27.284	10103.105	0.02	371.4	0.278
6	Trails	87.989	35067.484	0.06	403.1	0.896
108	Lease Sites	183.622	48960.056	1.08	266.6	1.871
41	Lease Access Roads	205.610	83196.365	0.41	404.6	2.095
TOTAL						
159	**N/A**	***10319.890***	***236377.940***	***N/A***	***N/A***	***5.140***

Area and perimeter values were calculated in ArcGIS 9.3™ using Buffer Wizard and HAWTH TOOLS™. Lease sites account for the greatest amount of altered pasture area (3.97%). Access roads account for the greatest percent of perimeter alteration (46.92%). The percent altered from trails has decreased since 1997 due to their reclassification as lease side access roads (Figure A.3).

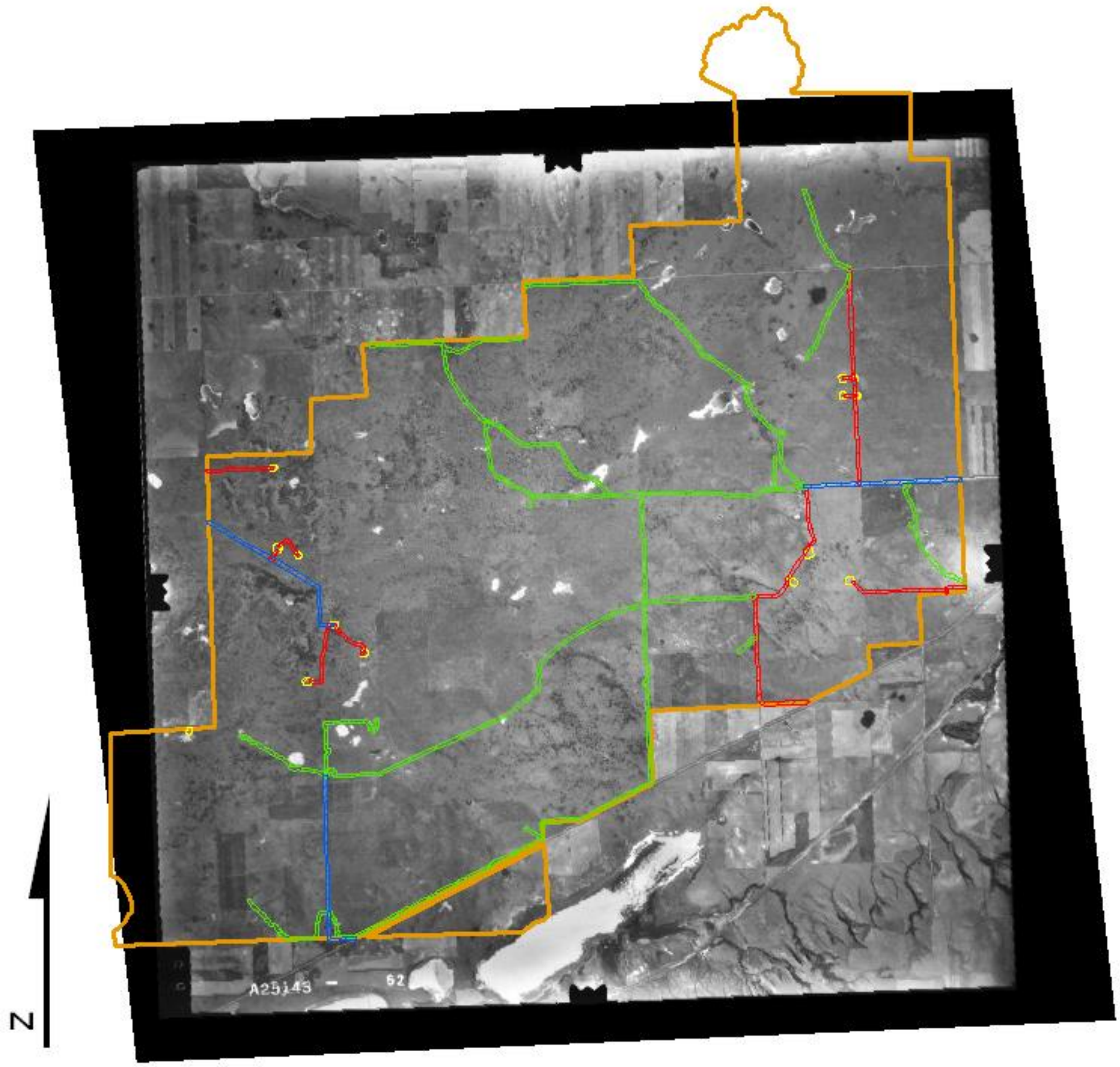
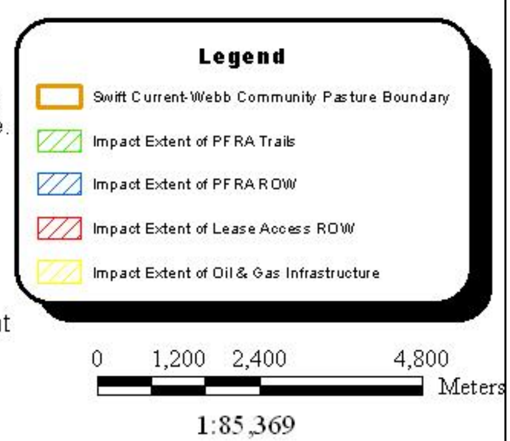


Figure A.2 Spatial extent of the impacts from oil and gas development which extend beyond the physical infrastructure in Swift Current-Webb Community Pasture (PFRA) in 1979.*

*Impact extents used to determine if the impacts from development are greater than simply the direct physical footprint of infrastructure. Shape files and map generated using ArcGIS 9.3. Template air photo A25143 - 1979 provided by the National Air Photo Library (NAPL). PFRA trails represent cattle trails with light vehicle traffic. PFRA ROW represent roads present prior to the development of oil and gas infrastructure. Oil and gasinfrastructure includes lease site infrastructure associated with operational and suspended oil and gas lease sites. From the GSHRES (2007) study, impact extent for PFRA, trails, and lease access roads is set to 20m. From the ordinationa and background to gradient analysis, oil and gas infrastructure impacts extents were set to 25m.



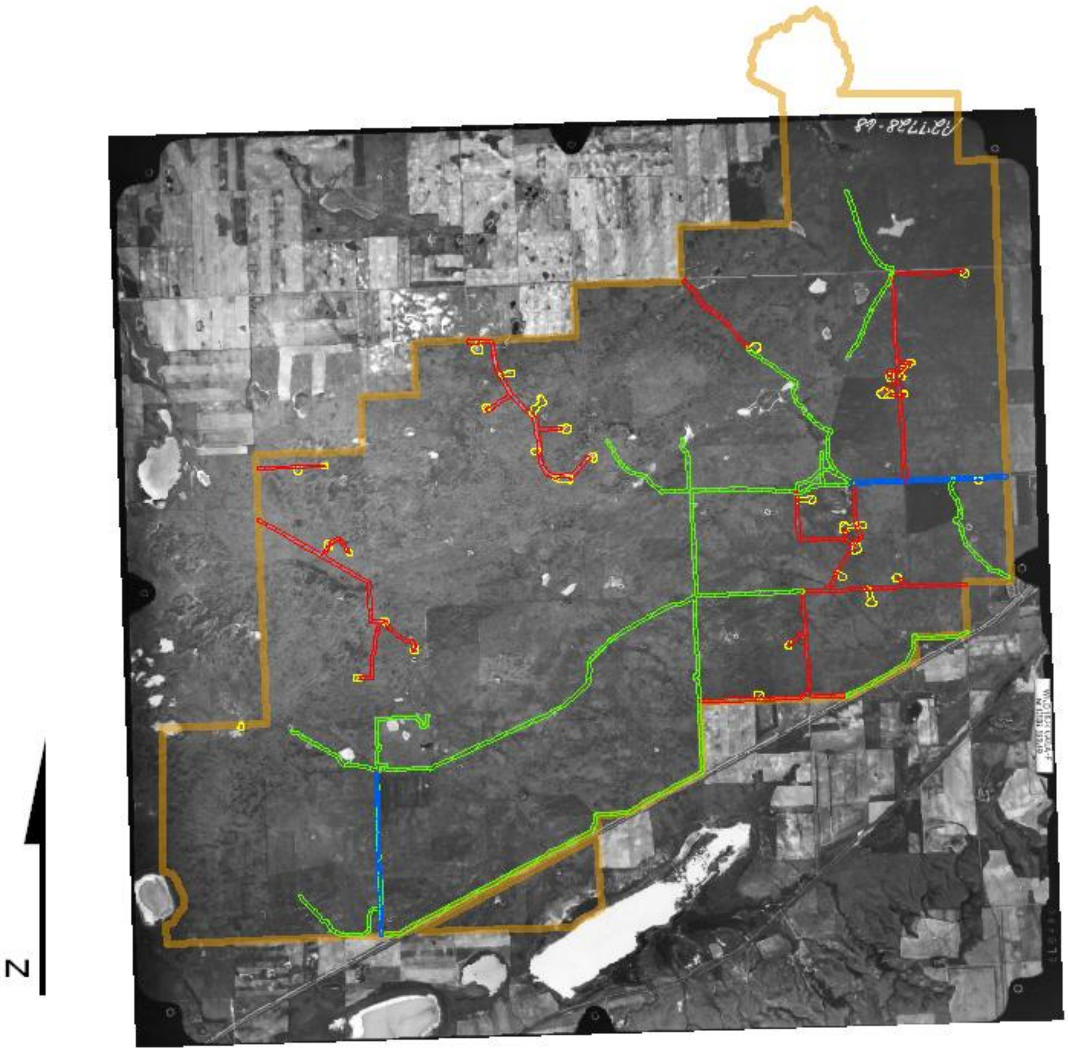
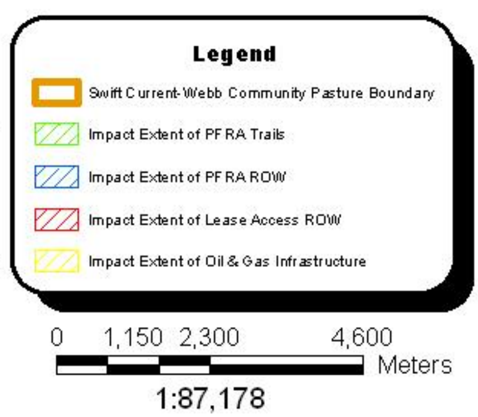


Figure A.3 Spatial extent of the impacts from oil and gas development which extend beyond the physical infrastructure in Swift Current-Webb Community Pasture (PFRA) in 1997.*

*Impact extents used to determine if the impacts from development are greater than simply the direct physical footprint of infrastructure. Shape files and map generated using ArcGIS 9.3. Template air photo A27728 - 1997 provided by the National Air Photo Library (NAPL). PFRA trails represent cattle trails with light vehicle traffic. PFRA ROW represent roads present prior to the development of oil and gas infrastructure. Oil and gas infrastructure includes lease site infrastructure associated with operational and suspended oil and gas lease sites. From theGSHRES (2007) study, impact extent for PFRA, trails, and leaseaccess roads is set to 20m. From the ordinationa and backgroundto gradient analysis, oil and gas infrastructure impacts extents were set to 25m.



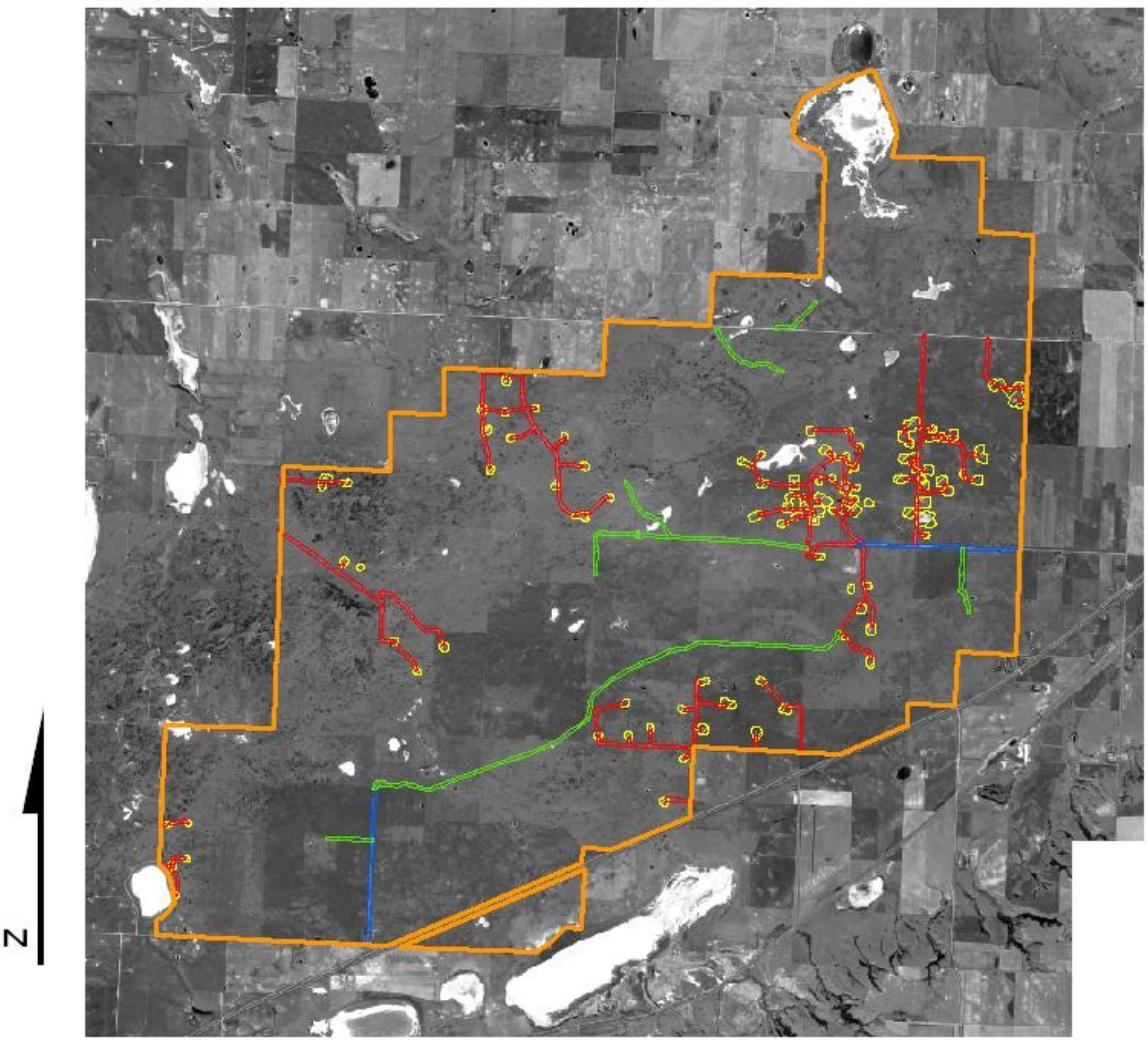


Figure A.4 Spatial extent of the impacts to oil and gas development which extend beyond the physical infrastructure in Swift Current-Webb Community Pasture (PFRA) in 2005.*

*Impact extents used to determine if the impacts from development are greater than simply the direct physical footprint of infrastructure. Shape files and map generated using ArcGIS 9.3. SPOT 5 satellite images 072J05, 072K01, 072K08 were provided by the Saskatchewan Geospatial Imagery Collaborative (SGIC) Project. PFRA trails represent cattle trails with light vehicle traffic. PFRA ROW represent roads present prior to the development of oil and gas infrastructure. Oil and gas infrastructure includes lease site infrastructure associated with operational and suspended oil and gas lease sites. From theGSHRES (2007) study, impact extent for PFRA, trails, and leaseaccess roads is set to 20m. From the ordinationa and background to gradient analysis, oil and gas infrastructure impacts extents were set to 25m.