SECTION 1
INTRODUCTION

1.1 Background

Alberta crop and livestock producers face challenges everyday, with increasing input costs, market competition, and continued pressure to improve environmental stewardship. Producers are seeking proven management practices that will allow them to maintain efficient and viable operations while protecting the environment.

In recent years, the impact of agriculture on the environment has been focused on livestock production, and in particular the intensive livestock industry and manure management. Manure is recognized as a beneficial source of nutrients, and a soil conditioner that can be used to decrease input costs. However, if not managed properly, manure application can lead to excess accumulation of nutrients in the soil and can pose a risk to the environment. As the impacts of agriculture on the environment are being determined, numerous beneficial management practices (BMPs) have been developed and promoted to minimize the impacts on the environment and increase the sustainability of the agricultural industry. While several BMPs have been developed for managing manure from the livestock industry, and nutrient management in general, it is unlikely that one BMP will effectively utilize manure nutrients for crop growth and at the same time reduce all negative environmental impacts. It is more realistic that a combination of management practices will result in improved nutrient retention for crop growth and reduced environmental impacts (Bishop et al. 2005).

The effectiveness of BMPs under Alberta conditions is not well known. This is, in part, because many BMPs were developed in other parts of North America or at a research plot scale. Individual BMPs have rarely been evaluated under Alberta conditions (Wuite and Chanasyk 2003) and recent studies have

recommended further research, especially with respect to phosphorus management (Paterson et al. 2006). In addition, producers are requesting site-specific, risk-based analytical tools to assist them in deciding which management practices would yield the greatest impact for their financial investment. Science-based proof is needed that these practices reduce risks to producers, gain economic and environmental advantages, and provide options for producers to meet regulatory requirements in Alberta.

Two key components that are needed to provide producers with additional decision-making information in Alberta are economic analysis and nutrient utilization. Producers and policy makers require information on the least-cost alternatives for decreasing environmental impacts, and this requires an economic analysis of costs and benefits to the producer and the environment. In addition, without information on the impact of management practices on nutrient utilization, prediction tools cannot provide the degree of accuracy producers need to make management decisions.

Traditional BMPs that have been implemented over the years are soil and water conservation practices developed to control soil erosion and increase water retention in the soil. However, these traditional BMPs do not provide sufficient capability in the control of non-point source pollution (Walter et al. 1979). Beneficial management practices have also been developed for the protection of water quality by managing nutrient input at source and application method. Examples include nutrient management plans; timing of manure application to avoid saturated, snow-covered, and frozen soils; injection of liquid manure; incorporation of surface applied manure; the maintenance of healthy riparian and pasture areas; and livestock management. Nutrient management fulfills crop nutrient requirements and minimize the potential of nutrients from becoming diffuse sources of pollutants (Oenema and Pietrzak 2002). Hairston et al. (2001) listed several types of agricultural BMPs with a summary as to the effectiveness of each type for surface water and groundwater protection. Hooda et al. (2000) have reviewed different successful measures that control nutrients and pathogens in livestock waste in surface runoff.

Although BMPs are promoted and supported through programs such as the Alberta Stewardship Network (ASN), Alberta Environmental Farm Plans (AEFP), Alberta Environmentally Sustainable Agriculture Program (AESA), and the Canada-Alberta Farm Stewardship Program (CAFSP), there is limited research to show their cumulative effects on the environment and specifically the health of watersheds.

At the farm scale, and particularly at the watershed scale, research becomes more difficult, fewer factors can be controlled, replication is less feasible, and large-scale studies are more expensive. In spite of the challenges involved with this type of research, several individual studies and large research projects have studied the effectives of BMPs at field and watershed scales, and in some cases carried out economic analysis. Examples of two major research projects are the Watershed Evaluation of Beneficial Management Practices (WEBs) Project in Canada (AAFC 2007) and the Conservation Effects Assessment Project (CEAP) in the United States (USDA 2008). Even though there is one research watershed under the WEBs Project in Alberta, additional sites are needed because of the diverse agro-climatic regions in the province.

1.2 Nutrients and Surface Water Quality

Eutrophication is the over-enrichment of receiving waters with dissolved mineral nutrients either naturally or by pollution. Eutrophication results in excessive production of algae and other aquatic vegetation (National Academy of Sciences 1993; Daniel et al. 1994; Correll 1998). This excessive production is accompanied by high respiration rates, leading to hypoxia or anoxia in lakes and streams, especially during warm conditions, and the release of many materials normally bound to bottom sediments including various forms of phosphorus (Kim et al. 2003; Ajmone-Marsan et al. 2006). The consequences are fish kills; loss of biodiversity; loss of aquatic plant beds and coral reefs; overall degradation of aquatic ecosystems; and impairment of water quality for drinking water, recreation, irrigation, and other purposes (Carpenter et al. 1998). The contribution of agriculture to the environmental problem of accelerated eutrophication of surface waters (Bennett 2001; Sims et al. 2000; Smil 2000) is very well recognized, especially in the United States (Sharpley et al. 1987, 1999; Carpenter et al. 1998) and Europe (Isermann 1990; Smith et al. 2001a, 2001b). The combination of increased levels of dissolved inorganic nitrogen (DIN) and phosphorus (DIP), their ratio (DIN:DIP) and the influence of climatic factors have been associated with the eutrophication of surface waters (Isermann 1990).

Chlorophyll yield in water bodies is a measure of algal biomass, and from a study of 228 north latitude lakes, chlorophyll was found to be dependent on the P concentration and on the ratio of total nitrogen to total phosphorus (TN:TP) (Smith 1982). In freshwaters, P is the main and N the secondary limiting nutrient, while in coastal waters it is the reverse (Schindler 1977; Cullen and Forsberg 1988; Isermann 1990; Blomqvist et al. 2004). Thus, most studies focus on P, and its control is paramount in minimizing the accelerated eutrophication of freshwaters (Schindler 1974; Sharpley et al. 1987).

Inputs of N and P into soil in the form of inorganic fertilizers or livestock manure are essential for profitable crop and livestock production. However, excessive application of nutrients beyond crop utilization and removal can lead to nutrient accumulation in the soil. Nutrients accumulated on the soil surface are susceptible to loss in surface runoff. Runoff from agricultural land is one of the major sources of non-point source pollutants, particular bioavailable P, which can impair water quality in lakes and streams (Sharpley 1993; Daniel et al. 1994). In many areas of the world, long-term trends in soil-test P (STP) values, which is an estimate of plant available P, have shown that soil P is now excessive, relative to crop requirements (Sims et al. 2000). In areas of intensive crop and livestock production in Europe (Barberis et al. 1995; Hooda et al. 1997), United States (Daniel et al. 1993; Sharpley et al. 1996; McDowell et al. 2002) and Canada (Campbell et al. 1986; Simard et al. 1995), P has accumulated in soils to levels that are a long-term eutrophication rather than an agronomic concern (Sharpley and Withers 1994; Sharpley 1995; Carpenter et al. 1998; Hooda et al. 2001; Sharpley et al. 2001). Intensive livestock production and concentrated animal feeding operations in many parts of the world have led to large problems with the disposal of manures and wastewaters and there is a need to improve nutrient management to avoid environmental problems associated with surplus nutrients entering the environment (Hooda, et al. 2000; Sims et al. 2000).

1.3 Pathogens and Surface Water Quality

Livestock wastes, particularly untreated slurry and faeces of grazing animals, can carry a variety of bacterial, protozoan, and viral pathogens from diseased and carrier animals (Mawdsley et al. 1995; Hooda et al. 2000). Pathogen contamination of water supplies may occur as a consequence of leakage from wastes in buildings or storage facilities, application of waste to land, and faeces deposited on pasture by grazing animals. Mawdsley et al. (1995) listed 11 bacteria, 3 viruses, and 4 protozoa (parasites) from livestock waste that may cause human diseases. Wildlife may also play a role in pathogen contamination of waters (Niemi and Niemi 1991). Since pathogens can survive for long periods in the environment, it is a matter of concern not only for livestock health but also for human health, which can be affected through contact with contaminated water.

Surface runoff may also carry pathogens (Tyrrel and Quinton 2003) in addition to nutrients and a host of other contaminants. Pathogen contaminated runoff has been reported from manure-applied fields (Patni et al. 1985; Thornley and Bos 1985), grazed pastures (Doran and Linn 1979; Doran et al. 1981; Howell et al. 1995), barnyard and manure piles (Thornley and Bos 1985) and feedlots (Young et al. 1980). Assessment of runoff bacterial contamination is generally achieved through the use of indicators such as total coliforms (TC), faecal coliforms (FC), faecal streptococci (FS) or enterococci. *Escherichia coli* (*E. coli*) count is also used as an indicator organism for detecting environmental faecal pollution (Mawdsley et al. 1995). High FC in runoff persisted for more than 1 yr after cattle were removed from a grazed area (Jawson et al. 1982). Bacteria persisted in the soil for at least 2 yr after application of dairy manure slurry on a grassland was stopped (Bittman et al. 2005), for 143 d for *Salmonella* after application of liquid pig manure (Gessel et al. 2004), and for 60 d for *E. coli* after cattle were removed from a grassland (Oliver et al. 2005).

1.4 Nutrient Release in Surface Runoff

Climate, soils, field management and landform combine to predispose an area for surface runoff (Kleinman et al. 2006). Runoff is usually generated when rainfall intensity exceeds the infiltration capacity of the soil (Horton 1933, 1940) and when the water table rises to the soil surface so that the water storage capacity of the soil is exceeded, resulting in a saturated soil condition (Hursh 1944; Dunne 1970). The latter can be promoted by subsurface features that cause a temporarily perched water table such as a fragipan, argillic horizon (Blanco-Canqui et al. 2002; Gburek et al. 2006), or a frozen ground layer during snowmelt (Hayashi et al. 2003). High surface moisture in areas near the stream contributed more to surface runoff over a short time than areas distant from the stream channel (Henninger et al. 1976) and thus, these areas could become major sources of P export to surface waters (Weld et al. 2001). Infiltration rates vary depending on the total soil moisture (ice and water) conditions near the ground surface (Kane and Stein 1983). High rate of cattle slurry application may result in surface capping of some soils that may decrease their surface infiltration capacity and consequently exacerbate pollutant export through runoff when slurry application is followed by a heavy rainfall (Smith et al. 2001a).

Nutrients (TP and TN) can be divided into dissolved and particulate categories based on separation using a 0.45 µm pore size filter, and each category can be subdivided into inorganic and organic fractions (Gburek et al. 2005). Dissolved reactive P (DRP) is that fraction of P that reacts with molybdate during the Murphy-Riley analytical procedure (Murphy and Riley 1962), and this fraction consists of orthophosphate ($H_2PO_4^-$ or HPO_4^{2-}) and other inorganic P forms and some organic P (Gburek et al. 2005). The principal forms of N exported through runoff are gaseous ammonia (NH_3), ammonium ion (NH_4^+), and nitrate (NO_3^-) (Marston 1989). Although NH_4^+ is easily transformed to NO_3^-, P and NH_4^+ are relatively immobile in the soil, while NO_3^- is mobile and can leach easily into groundwater (Chang and Entz 1996).

The loss of P in runoff is affected by several factors, which include runoff volume, sediment loss, forms and concentrations of soil P (Cassell et al. 1998), depth of interaction of the soil and water (Sharpley and Withers 1994), precipitation, and surface characteristics (Gburek et al. 2002). Sediment loss is dependent on intensity of rainfall, physical and chemical attachment between various solid components, and the amounts and energy of runoff waters (Guy 1970). Flooded manured fields may reach reduced conditions (oxygen-deficient) and can release bioavailable forms of P for a certain period (Young and Ross 2001; Ajmone-Marsan et al. 2006). Phosphorus losses occur in particulate forms with eroded surface soil and in soluble forms in runoff and, in some cases, in water leaching through soil (Haygarth and Jarvis 1996; Hansen et al. 2002).

Bioavailable P in agricultural runoff consists of soluble P and a variable portion of particulate P that are potentially available for algal uptake (Sharpley et al. 1992). According to Boström et al. (1988), bioavailable P is the sum of immediately available P and the P that can be transformed into an available form by naturally occurring processes. A study of agricultural catchments in the United Kingdom by Heathwaite and Johnes (1998) found that most of the P that was transported in runoff was in the unreactive (particulate and organic) form. In a simulated rainfall study on a grassland, Heathwaite et al. (1998) found that N and P exports in surface runoff from soils that received inorganic fertilizer were much greater than soils that received solid or liquid (slurry) cattle manure. Smith et al. (2001b) found that the addition of solid or slurry cattle manure increased particulate and soluble P loss in runoff, and increased rate of application of slurry increased all forms of P in runoff. In another simulated rainfall study, Kleinman et al. (2002) found that DRP in runoff was highly correlated with water soluble P concentration of the applied manure. Sharpley et al. (1992) found that bioavailability is determined by a combination of soil and fertilizer management, and physico-chemical processes that control erosion, particle-size enrichment, P desorption-dissolution reactions, and plant residue breakdown.

Whenever water is in contact with the soil profile, there is a possibility of P sorption, desorption, or dissolution reactions (Ryden et al. 1973). Transport of P either into deeper soil layers or in the surface runoff water is dependent on the availability of soluble P in the soil surface at the time of rainfall event. Soils have a finite sorption capacity (Tisdale et al. 1993) and this may be quantified as degree of phosphorus saturation (DPS) threshold. Soils that exceed such thresholds or are closer to P saturation levels have a higher potential of releasing P in runoff (Haygarth and Jarvis 1996). Casson et al. (2006) determined DPS thresholds for Alberta soils as 44 and 71 mg kg^{-1} for water- and calcium chloride-extractable P, respectively. In a laboratory study by Dou et al. (2000) to characterize dairy and poultry manure, they found that 70% of the total P in dairy manure was extractable by water, and this suggested weak binding energy of P and hence a high susceptibility for loss to waters when conditions favour runoff.

Eventually, the effect of nutrient transport on water quality is dependent on the ability of wetlands and streams to retain P transported by runoff. Mechanisms of P retention are a combination of physical, chemical, and biological processes that include uptake and release by vegetation, periphyton, and microorganisms; sorption and exchange reactions with soils and sediments; chemical precipitation in the water column; and sedimentation and entrainment (Reddy et al. 1999). The form of P from its release at the edge-of-field is generally changed to less available forms during its transport to a body of surface water (Sharpley and Menzel 1987). In watersheds with ephemeral streams, flow transmission losses may deposit nutrient-laden sediments in-stream (Renard and Laursen 1975) and that P may become soluble and mobilized depending on P concentrations and redox conditions (Patrick and Khalid 1974; Young and Ross 2001).

1.5 Agricultural Nutrients and Water Quality in Alberta

In general, most of the STP values in Alberta are lower (≤ 25 mg kg^{-1}) (Manunta et al. 2000) than the agronomic threshold of 60 mg kg^{-1} (Paterson et al. 2006). The percentage of farmers applying manure is lower in the prairie provinces (Alberta, 64%; Saskatchewan, 43%; Manitoba, 65%) compared to the provinces of Ontario (75%) and Quebec (78%) (George Morris Centre 2007). Yet , >40% of farms in Alberta have beef cattle as the predominant type of production, and beef cattle in Alberta represent about 49% of all the cattle raised in Canada. In Alberta, manure is applied on only 22% of the land of producers who use manure. Only 34% of the producers that apply manure in Alberta use a formal manure management plan.

An initial water quality survey was conducted in Alberta in 1995 and 1996 on 27 streams and 25 lakes in runoff prone agricultural areas (CAESA 1998). The associated watersheds were classifies as low, moderate, or high agricultural intensity based on livestock numbers, pesticides sales, and fertilizer sales. The study found that 99% of the high, 88% of the moderate, and 89% of the low intensity agricultural streams exceeded the Surface Water Quality Guidelines for use in Alberta (Alberta Environment 1999) for TP of 0.05 mg L^{-1}. The corresponding values for TN were 87%, 65%, and 32%, respectively, did not comply with the guidelines for TN (1.0 mg L^{-1}). Similarly, for lakes, 96% in high intensity and 38% in low intensity areas did not comply with the TP guideline. Fecal coliform levels in nearly all streams (90 to 100%) exceeded the guidelines for drinking water supply (prior to treatment) (1000 organisms per 100 mL). Fewer streams exceeded guidelines for irrigation and recreation uses (1000 organisms per 100 mL), but moderate intensity farming had greater non-compliance (68% for irrigation and 44% for recreation guidelines).

Following the CAESA study, the AESA long-term study continued monitoring 23 small agricultural watersheds in Alberta (Depoe 2006). On the sixth year of monitoring, a general pattern of elevated N and P concentrations, especially their dissolved forms, was found in streams in watersheds with high intensity farming. High agricultural intensity watersheds had the lowest compliance with Alberta's TP and TN guidelines. Although compliance in low and moderate intensity agricultural watersheds were than high intensity agricultural watersheds, overall compliance was low. Fecal coliforms were highest in streams with moderate agricultural intensity and irrigated farming.

A 3-yr study of eight different locations in Alberta by Little et al. (2007) reported that in some areas STP values could be much higher (200 to 500 mg kg^{-1}) than the agronomic threshold value of 60 mg kg^{-1} reported by (Howard 2006). They found a direct linear relationship between soil and runoff phosphorus. They also found that dissolved reactive phosphorus, TP, and degree of soil phosphorus saturation were greater in manured cultivated fields than in non-manured cultivated fields and a ungrazed grassland site.

Studies in the Central Parkland of Alberta have shown that the total yearly runoff from small agricultural watersheds is dominated by snowmelt (Gill et al. 1998; Wuite and Chanasyk 2003; Ontkean et al. 2005). A study of five cultivated microwatersheds in Alberta demonstrated that spring (mostly snowmelt) or summer runoff (rainfall) varied geographically within the natural regions of Alberta (Little et al. 2006). At the Lower Little Bow site (Mixedgrass Subregion), the average of 2 yr showed 84% of the total runoff volume was from summer irrigation runoff. Similarly, a single year data from the Grande Prairie site (Peace River Parkland), was 74% summer runoff. In contrast, at three sites (Renwick Creek, Three Hills Creek, and Ponoka) in the Central Parkland region of Alberta, total runoff volume average was 82% spring snowmelt runoff.

1.6 Project Objectives

Sustainable agriculture combines optimum agricultural productivity and profitability without damaging the environment, especially soil and water resources. Beneficial management practices are practical control measures (including technological, economic, and institutional considerations) that have been demonstrated to effectively minimize environmental impact (Ice 2003). For a number of years, BMPs have been promoted to and have been implemented by producers. However, these have not been evaluated under Alberta conditions for their effectiveness and economic benefit to agricultural producers. Numerous BMPs have been suggested and promoted to improve all aspects of farm operations. This study will examine nutrient management, with a focus on livestock production systems. This project will evaluate three BMP categories: manure management by land application (nutrient management), wintering site management, and riparian management. The specific project objectives are:

- Evaluate the effectiveness of individual nutrient BMPs in reducing agricultural impacts on the environment at the farm scale.
- Assess the impacts of selected BMPs on the water quality in specific reaches of the stream in the watershed.
- Predict the cumulative impacts of selected BMPs on the overall quality of the watershed stream using models.
- Evaluate nutrient management BMPs for effective use of manure in crop production.
- Assess economic costs and benefits associated with individual BMPs implemented in this study.
- Investigate the ability to determine the source of nutrient loss to the environment, i.e, manure or fertilizer.

1.7 Experimental Approach

There are several experimental and statistical approaches used to evaluate BMPs at field and watershed scales. Overviews of these approaches are in the literature, such as Spooner et al. (1985), Hirsch et al. (1991), and Walker (1994).

In our study, we have adopted the before and after approach. The main focus will be on water quality, but other indicators, such as rangeland and riparian health will be assessed as well, where applicable. The strength of the study will be to examine the effectiveness of individual BMPs within watersheds. In addition, watershed-wide assessments of water quality, land use, and economics, as well as the information obtained from individual BMP sites, will be used in a modeling exercise to predict BMP influence on agricultural watersheds in Alberta.

Once BMP sites are selected and instrumented, the sites will be monitored for 2 yr under existing management practices. This will provide the current status of various indicator parameters (e.g., water quality, riparian health) under current management practices. This is referred to as the pre-BMP phase. Then the BMPs will be applied and the sites monitored for another 2 to 3 yr. This will be the post-BMP phase. Regarding water quality parameters, the monitoring method at BMP sites will either be upstream and downstream monitoring, or edge-of-field monitoring, or a combination of the two monitoring methods. For some BMP sites, a control site will be used to make paired comparisons.

Two main watersheds in two different natural subregions were selected for the study as well as a single field sites in two other watersheds. The watersheds are the Indianfarm Creek near Pincher Creek and the Whelp Creek Sub-watershed near Lacombe. The other two watersheds with a single field each are the Battersea Drain and the Lower Little Bow River watersheds, both north-east of Lethbridge. Detailed information about the study sites, as well as detailed experimental methods, are presented in Sections 2, 3, 4, and 5. The Indianfarm Creek, Battersea Drain, and the Lower Little Bow River sites were selected in 2006, and the Whelp Creek site was selected in 2007. The experimental timeline for the latter watershed is a year behind the other three watersheds (Figure 1.1).

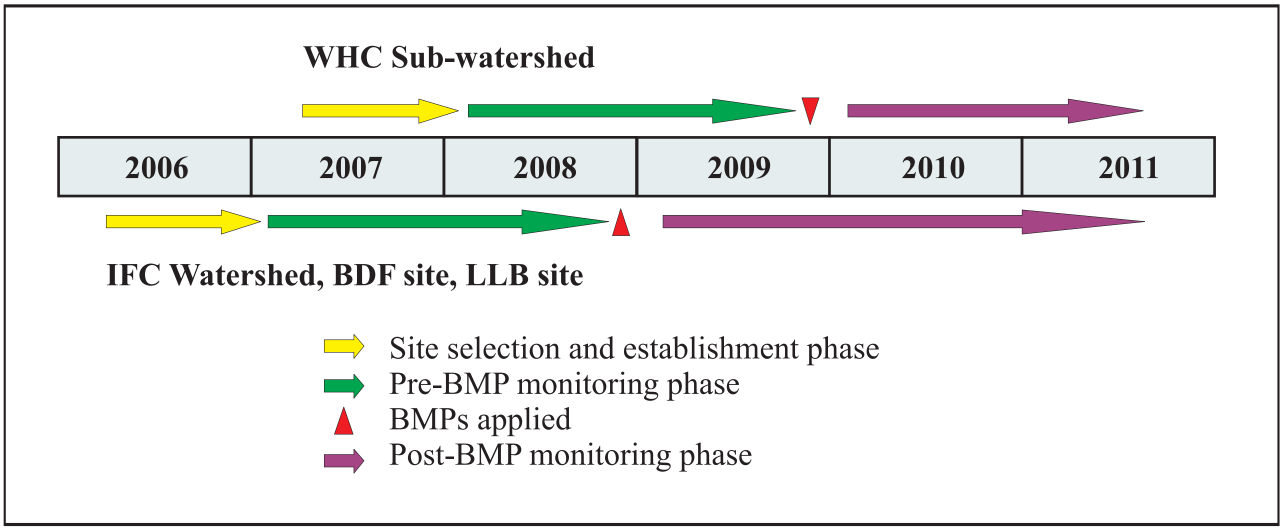

Figure 1.1. Project timeline and major phases for the Indianfarm Creek (IFC) Watershed, Battersea Drain Field (BDF) site, Lower Little Bow Field (LLB) site, and the Whelp Creek Sub-watershed.