Section 5
Relative Effects of Manure Spreading and Confined Feeding Operations on Groundwater Quality

5.1 Introduction

The third objective of the Livestock Manure Impacts on Groundwater Quality in Alberta Project is to compare relative impacts on groundwater quality from manure field application and manure storage facilities (Section 1). To answer this objective, four field sites with a history of beef manure application in the Battersea area were selected and instrumented to better understand the processes of potential groundwater contamination from manure spreading in southern Alberta (Section 3). Additionally, five confined feeding operations (CFOs) were selected to investigate the impacts of CFOs and earthen manure storages (EMSs) on groundwater quality: three in central Alberta, near Lacombe-Ponoka, and two in southern Alberta, near Picture Butte (Section 4). In addition to utilizing data collected from the field and CFOs, two methods will be used in this part of the study: (1) source assignment and (2) source contribution assessment. Source assignment attempts to determine the source (manure spreading, EMSs, or CFOs) of the contaminant (e.g., nitrate nitrogen and chloride) measured in a well or within a specific area of a study site, while source contribution assessment attempts to determine how much each manure source contributes to a receptor, such as a downgradient well, or to the study site as a whole. This section of the report discusses potential approaches and anticipated work to answer Objective 3.

5.1.1 Background

Generally, Alberta's geologic and semi-arid climatic conditions should protect groundwater resources in the province (Hendry *et al.* 2007, Rodvang and Ryan 2011). Much of the landscape in Alberta is covered in thick, clay till aquitards (fine-grained soils). However, areas overlain with coarse-grained soils, such as sands and gravels, shallow unconfined aquifers, or a thin layer of sediments overlying laterally extensive confined aquifers represent hydrogeologic conditions that are sensitive to contamination. Fractures, which commonly occur in weathered clay till and lacustrine sediments, can increase the rate of migration of contaminants as well as move them to greater depths. Increased vertical migration of contaminants through fractures and depression focused recharge may pose a greater risk to underlying aquifers (Hendry *et al.* 2007, Hendry Groundwater Sciences 2009), influencing the extent of contamination and remediation efforts.

Based on the depth to the aquifer, surficial geology, and groundwater recharge through precipitation, regions of the province with greater aquifer vulnerability exist between the Calgary-Edmonton corridor and extending south along the foothills, north of Edmonton, between Grande Prairie and Peace River, and in the east-central part of the province (Figure 5.1). Since most land applications of manure occur near CFOs, areas with concentrated CFOs in Alberta (i.e., near Lethbridge, between Calgary and Edmonton, and north of Edmonton; Figure 1.1) may be areas where groundwater is most vulnerable to impacts from manure application. Regionally, there is some overlap of areas with concentrated CFOs and areas with higher aquifer vulnerability.

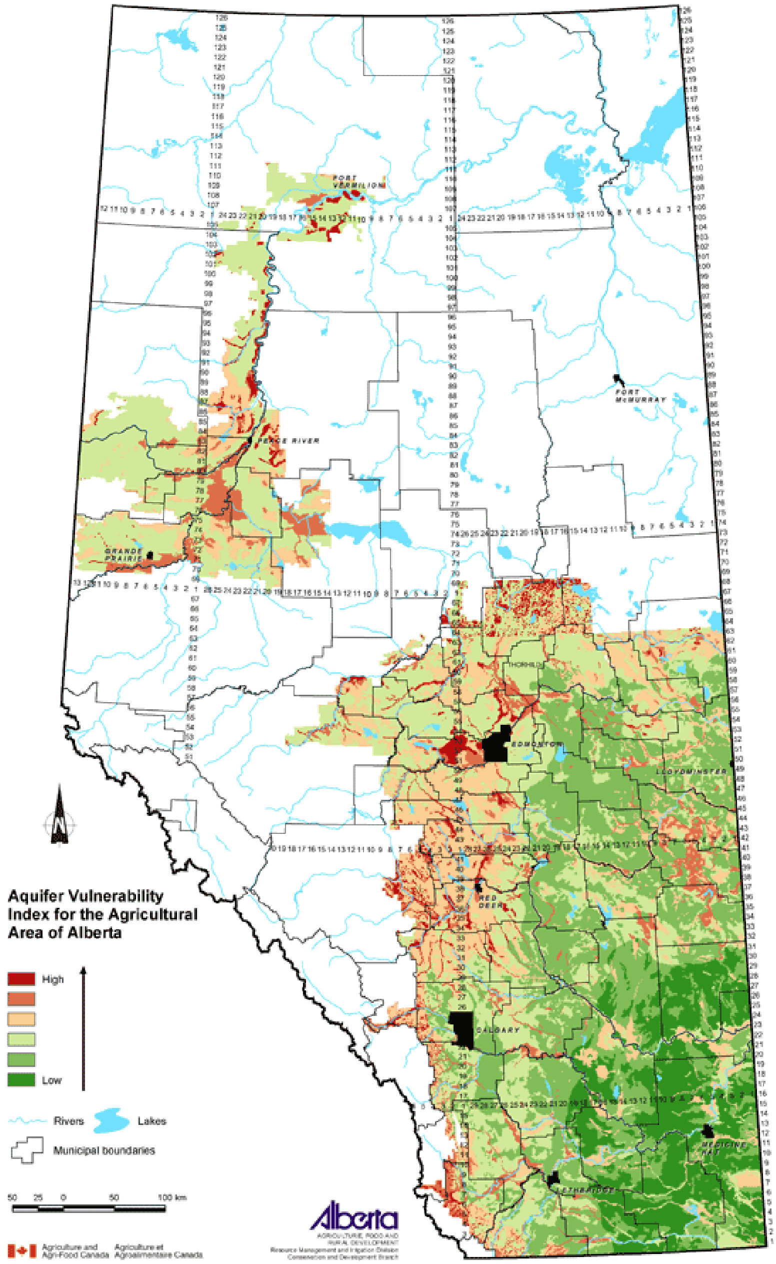

Figure 5.1. Aquifer vulnerability index for the agricultural area of Alberta (AFRD 2005).

Natural attenuation, the process by which the mass, toxicity, mobility, volume, or concentration or a contaminant is reduced (USEPA 1999), should decrease the risk of groundwater impact from manure constituents. Natural attenuation processes include biodegradation, sorption, dispersion, dilution from recharge, and volatilization (Rodvang and Ryan 2011). Chloride migrates in a relatively unattenuated manner in groundwater, moving at the same rate as the groundwater velocity and marking the leading edge of a contaminant plume. Other contaminants, such as ammonium nitrogen (NH_4-N) or potassium (K), may be attenuated through adsorption to organic matter and clay particles and move at velocities much slower than those of the groundwater. Of note, NH_4-N attenuation is limited in sandy or permeable environments. Nitrate in anaerobic conditions may be removed through denitrification when a suitable electron donor, such as pyrite, is available. Although manure constituents may enter the groundwater environment, natural attenuation processes may remove them further along the groundwater flow path, limiting the extent of impact.

5.1.2 Source Assignment

To answer Objective 3, an understanding of the impact from the individual manure sources (manure spreading, EMSs, and CFOs) is required before comparisons can be made. It can be difficult to assess individual sources when groundwater beneath a site may be impacted by two or more sources. For example, a CFO may have an EMS on the site and manure applied to fields adjacent to and/or surrounding the CFO.

Contaminants that are mobile in groundwater and unique to the EMS, CFO, and manured field are required to distinguish among these three sources as well as from other anthropogenic sources. The difficulty in finding a unique tracer to differentiate among the EMS, CFO, and manured field sites is that the initial source is the same (i.e., manure). Additionally, biogeochemical processes, such as denitrification, geochemical reactions, and mixing of groundwater with different chemical concentrations may alter the water quality of the contamination plume. Chloride (Cl^-) and nitrogen (N) can be useful indicators of manure impacts on groundwater quality; however, they cannot be used to distinguish among different manure sources.

Methane and carbon dioxide gases are produced in EMSs under anoxic conditions. When dissolved gas concentrations exceed the solubility limits of the liquid within the EMS, the dissolved gases are volatilized, during which time other gases, such as nitrogen (N_2), argon (Ar), neon (Ne), and helium (He), which all initially started out in equilibrium with the atmosphere, are also volatilized from the EMS. This process depletes the EMS of dissolved gases and should lead to low and fractionated dissolved gas concentrations in the EMS and in the EMS seepage (Brennwald *et al.* 2005, McNab *et al.* 2006, Zhou *et al.* 2006). The seepage from the EMS may also have a significant effect on redox conditions in the receiving groundwater. The low dissolved gas concentrations and fractionated dissolved gas signature from the EMS contents should re-equilibrate with the atmosphere when the liquid manure is applied to the soil surface in fields. Therefore, manure applied to the soil surface should be distinguished from direct lagoon seepage by having relatively higher dissolved gas concentrations. The dissolved gas constituents are typically non-reactive below the water table and should be transported conservatively. Neon and Ar ratios are sensitive to the addition of excess air or gas stripping (Ne has a lower solubility and higher diffusivity than Ar making it more likely to partition into the gas phase); therefore, groundwater mixed with seepage from an EMS should have lower Ne/Ar ratios. If denitrification occurs at a site, the groundwater would have higher N_2/Ar ratios as a result of N_2 production during denitrification. It may be possible to use a combination of these ratios to distinguish EMS seepage at more distal locations from the EMS. These dissolved gas compositions are unique to EMSs, and have been used to distinguish seepage from an EMS from background groundwater and groundwater beneath fields irrigated with liquid manure from the EMS (Esser *et al.* 2009, 2010). Dissolved gas ratios will be further investigated for use in this study to understand the impact from the individual sources of interest (manure spreading, EMSs, and CFOs).

Although isotopes will be used to age date groundwater and provide additional hydrogeologic information, most isotopes may not be appropriate or effective in source assessment. Boron isotopes have been used to differentiate between different types of animal manure (e.g., hog, poultry, and cattle) and sewage. However, even with an applied multi-isotope approach (nitrate, strontium, and boron), it is not possible to differentiate between different manure sources from the same type of animal (i.e., cattle manure from CFO stock piles versus EMSs) (Widory *et al.* 2004). One possible isotope signature that may be used to identify seepage from EMSs is $\delta^{18}O$. Samples from EMS sites should have elevated H_2O-$\delta^{18}O$ signatures as a result of evaporation. Therefore, $\delta^{18}O$ may be used to differentiate impacts among EMS, CFO, and field sites.

Microbial source tracking, involving microbiological, genotypic, phenotypic and chemical methodology, may be used to trace the origin of fecal matter (Scott *et al.* 2002). The environment below an EMS is anoxic, and anaerobic conditions should prevail until the contaminant plume mixes with oxygenated groundwater. In contrast, the shallow unconfined aquifers below manure spreading areas occur in unweathered, oxic zones. These two environments support different forms of N (i.e., NH_4 below the EMS and nitrate below a manured field) and should also support different colonies of microbes as a result of the presence or absence of oxygen and the availability of a suitable electron donor. Microbial source tracking may assist in determining the initial contaminant contributions to the groundwater environment from an EMS or manure-spreading field.

5.1.3 Source Contribution Assessment

Two methods are proposed to compare the relative risk to groundwater quality posed by the EMS, CFO, and manured field sites: concentration assessment and mass flux and discharge.

Concentration Assessment

Chloride and N concentrations are higher in liquid and solid manure relative to typical groundwater, and they are often used as indicators of agricultural impacts on groundwater quality. Comparisons of Cl^-, nitrate nitrogen (NO_3-N), and ammonia nitrogen (NH_3-N) concentrations will be made among the EMS, CFO, and field sites. Nitrate N and Cl^-, in particular, are highly mobile and can be used as indicators of manure contamination from manured fields. Ammonium concentration is elevated in EMSs; however, ammonium readily adsorbs to sediments and is therefore typically found in groundwater in close proximity to EMSs. It is expected that elevated concentrations of NH_3-N in groundwater will be observed in the immediate vicinity of the EMSs, while elevated concentrations of NO_3^--N will be observed beneath fields with manure application and surrounding the CFOs. Nitrate N may also be present relatively close to EMSs, or originating from the EMSs, where aerobic or oxic conditions are present (e.g., leading edge of the contaminant plume) and nitrification has occurred. Comparisons of concentrations will allow for preliminary assessments of individual source contributions to groundwater, taking into consideration site specific differences in geology and hydrogeology and natural attenuation mechanisms such as sorption and denitrification. Defining the plume boundaries of the EMSs and analyzing concentration patterns and relationships with other groundwater/manure constituent parameters will also be required for comparisons.

Mass Flux and Discharge

Mass flux and discharge can be more important when determining the risk of a contaminant source and plume than are the concentrations as a result of heterogeneity in the groundwater environment and subsequent variability of groundwater flow velocity and chemical gradients (ITRC 2010). Mass flux and discharge estimates can therefore be used to estimate the strength or contribution of a contaminant source, assess potential exposure to a downgradient receptor (e.g., a drinking water well), quantify how readily a dissolved contaminant is attenuated by natural processes, and determine the source term (i.e., the type and magnitude of chemical released) in contaminant transport modelling.

Mass flux (J) is defined as the mass of a chemical that passes through a defined cross sectional area during a period of time and is measured in units of mass per time per area (ITRC 2010). Mass flux estimates utilize two key components of the contaminant plume: how much contaminant is in the groundwater and how fast the water moves through a defined cross-sectional area. Flux estimates account for the magnitude and direction of flow and provide the mass flux across a particular area of groundwater. However, flux estimates do not provide information about the mass of contaminant movement from the source of the plume or the entire extent of the plume.

Mass discharge (Md) is defined as the total mass of a contaminant that moves in the groundwater from the contaminant source and is measured as mass per time. Mass discharge estimates the total mass flux across an entire plume and is not limited to a defined area (i.e., a cross-sectional area). Mass discharge measurements involve measuring the contaminant concentration and groundwater flow along a transect perpendicular to groundwater flow.

Mass flux and discharge estimates is useful in comparing relative impacts of manure spreading and storage activities under different geologic and hydrogeologic settings. For example, mass flux of contaminants may be low even though concentrations are high if the source and contaminant plume is in an area of low permeability (Goltz *et al.* 2007). Conversely, if a source and contaminant plume have lower concentrations but are in a high permeability area, the result may be a relatively larger contaminant mass discharge from the area. Additionally, mass flux estimates at different times and places along a plume illustrates the combined effects of physical, chemical, and biological processes that may alter contaminant concentrations and provide a better understanding of plume dynamics (Nichols and Roth 2004, Basu *et al.* 2006).

Two measurement techniques for mass flux and discharge are proposed for this study: transects based on isocontours and solute transport modelling.

Transects Based on Isocontours. Although transects constructed perpendicular to groundwater flow and across the area of the plume are traditionally used to measure mass flux and discharge from a contaminant source, the current monitoring network that has been established as part of this study can also be used to assess the contaminant source and plume. Transects based on isocontours will be used to estimate mass flux from existing wells. A contour map of groundwater concentrations can be created to provide a best estimate of the distribution of concentrations in a plume (ITRC 2010). Mass flux may also be estimated at individual points within the study sites and used to obtain a mean flux and total mass discharge for the study area perpendicular to the direction of groundwater flow (Goltz *et al.* 2007). Note that the accuracy and precision of the flux and discharge measurements rely upon the number of points characterizing the contaminant source and plume.

Solute Transport Modelling. Solute transport models may also be used to calculate mass flux. These models require groundwater flow and contaminant concentration data. The mass flux estimated from a numerical model is dependent on the accuracy of the flow and contaminant concentration and mass data as well as the amount of data available (ITRC 2010) and the number and accuracy of assumptions made. Also, the site geology and hydrogeology should be accurately represented or the model may oversimplify site conditions. A groundwater flow model and transport model, such as Modflow, will be used to estimate mass flux from the CFO and field sites and compared to mass flux estimates using isocontours.

5.1.4 Site Instrumentation and Geology and Hydrogeology Variability

To more easily compare the relative impacts of manure spreading and storage, CFOs and manured fields should be adjacent to each other. This would allow comparisons under similar geologic and hydrogeologic settings. Depending on whether the manured field was upgradient or downgradient of the CFO and EMS, the site may permit examination of a higher concentration EMS plume (with NH_4^+ as the dominant N species) moving into a background plume from the manure spreading field (with NO_3^- as the dominant N species), or a plume from the manured field intercepted by the plume from the EMS. In addition to understanding the hydrogeology, natural attenuation mechanisms, and parameter concentration patterns and relationships at each site, the rate and amount leached from the manured fields and the plume boundary of the EMSs will be required. Current study instrumentation and limitations are discussed in Sub-section 5.2.

5.2 Current Study Sites

The field sites are instrumented with wells around the periphery of the field, and the CFO sites are instrumented with wells around the EMS and/or catch basin and periphery of the operation. Concentrations of Cl^-, NO_3^--N, and NH_3-N will be compared among field sites and among EMS and CFO sites, to determine the contributions from manure spreading and storage under different hydrogeological settings. Concentrations will also be compared between storage and spreading environments.

The current instrumentation will allow for the estimation of mass flux and discharge from the source (i.e., the field or the CFO); however, this will not permit estimation of mass flux and discharge within a plume or at the leading edges of a plume if the plume has moved downgradient of the field or CFO and cannot assess if attenuation processes, such as denitrification, have occurred beyond the site boundaries. As a result, comparisons of mass flux and discharge estimates from the source, or within close proximity to the source, will be made among the field and CFO sites. Comparisons of mass discharge estimates for the plumes from these sites will not be possible. As well, if the contaminant plume is not fully delineated, the mass flux and discharge estimates may be underestimated at a site if there is a relatively large vertical component to the contaminant plumes in addition to the lateral component. The longer screens of the water table wells instrumented at the sites in addition to deeper piezometers should capture a flow-weighted average concentration; however, may not capture everything if instrumentation does not delineate the entire depth or width of the plume. Mass flux and discharge estimates may be made from the source and potentially the subsequent plume of EMSs, given the relatively more extensive instrumentation. Solute transport modelling will utilize the same data set from the current instrumentation available for the mass flux estimates using isocontours.

The five CFO and four field sites were selected to represent different hydrogeologic conditions. However, they currently do not instrumented manure spreading fields and manure storage adjacent to each other. New instrumentation will occur if a suitable site is found (e.g., elevated soil-test phosphorus in the manured field and the potential for seepage from the EMS based on site characteristics and specifications of the EMS and CFO). As discussed in Subsection 5.1.4, this setup will more easily permit the comparison of manure spreading and storage under similar geologic and hydrogeologic conditions.

5.3 Summary and Future Work

5.3.1 Summary

Data collected from the four field sites, with a history of beef manure application in the Battersea area, and the five CFOs in the Battersea and Lacombe-Ponoka areas, will be used in combination with source assignment and source contribution assessments to compare the relative impacts of manure spreading and manure storage facilities on groundwater quality.

An understanding of the impact from individual manure sources (manured field, EMS, and CFO sites) is required before comparisons can be made. Tracers that are mobile in groundwater and unique to the EMS, CFO, and manured field sites are required to distinguish among these three sources as well as from other anthropogenic sources. The difficulty in finding a unique tracer for the different sources is that the initial source is the same (i.e., manure) and biogeochemical processes and mixing of groundwater may alter the chemical makeup of the plume. Dissolved gas compositions (e.g., N_2, Ar, Ne, and He) may be unique to EMSs, making seepage from an EMS potentially distinguishable from groundwater with background concentrations or groundwater impacted from other sources. Dissolved gas ratios will be further investigated to understand the impact from the individual manure sources (manure spreading, EMSs, and CFOs). Furthermore, liquid EMS samples should have elevated H_2O-$\delta^{18}O$ signatures as a result of evaporation, and this may help to differentiate between impacts from the EMS and the CFO or field. Microbial source tracking may assist in determining the initial contaminant contributions to the groundwater environment from an EMS or manure-spreading field.

Comparisons of Cl^-, NO_3^--N, and NH_3-N concentrations will allow for preliminary assessments of individual source contributions to groundwater, while taking into consideration site specific differences in geology, hydrogeology, and natural attenuation mechanisms. It is expected that elevated concentrations of NH_3-N will be observed in close proximity to the EMSs, while elevated concentrations of NO_3^--N will be measured immediately downgradient of the EMSs (i.e., where water becomes more oxic), beneath the manured fields, and surrounding the CFOs. An understanding of parameter concentration patterns and relationships in addition to flow pathways will be required to differentiate among the three sources as well.

Mass flux and discharge estimates will be used to compare the relative impacts of manure spreading and storage activities under different geologic and hydrogeologic settings. Mass flux and discharge estimates take into account variability in groundwater concentration gradients and groundwater velocities as a result of the heterogeneity of groundwater environments and can also illustrate the combined effects of physical, chemical, and biological processes that may alter contaminant concentrations. Mass flux and discharge will be estimated for CFO, EMS, and manured field sites using isocontours and solute transport modelling. Comparisons of mass flux and discharge estimates from the field and CFO, or within close proximity to these sources, will be made among the field and CFO sites. Comparisons of mass discharge estimates for the plumes from these sites will not be possible but will be estimated for the EMSs.

5.3.2 Future Work

The following work is planned to compare the relative impacts of manure field application and manure storage facilities on groundwater quality:

- Instrument a CFO with an adjacent manured field if a suitable site is found.
- Further investigate the use of dissolved gas ratios for source assessment and collect dissolved gas data at CFO sites if appropriate.
- Investigate the use of biological indicators for comparison of the impacts of field manure application and manure storage facilities on groundwater quality.
- Compare concentrations of Cl^-, NO_3^--N, and NH_3-N, and relationships with and among other monitored parameters, once hydrogeologic conditions are better understood and sufficient data are available for all sites.
- Calculate the mass flux and discharge of Cl^-, NO_3^--N, and NH_3-N (and any other identified parameters) from the five CFO and four field sites to estimate mass discharge from each source. Mass flux and discharge estimates for the CFO sites will be completed once the sites have been instrumented appropriately and sufficient data are available (e.g., plumes fully delineated, vertically and horizontally).