University of Alberta

A Survey of the Hydrogeologic Integrity
of
Earthen Hog Manure Storage Ponds in Alberta

by

William R. MacMillan ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of *Master of Science*

in

Water and Land Resources

Department of *Renewable Resources*

Edmonton, Alberta

Fall 2000

0-612-59838-1

University of Alberta

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Degree: *Master of Science*

Year this Degree Granted: *2000*

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Date: Sept 27/00

ABSTRACT

The hydrogeological integrity of five Earthen Manure Storage (EMS) ponds used for liquid hog manure storage in Central Alberta was investigated. Soil and groundwater quality samples collected were analyzed to determine the extent and severity of lateral down gradient seepage from these ponds. The 9- to 20-y old ponds were constructed in varied soil conditions, including eolian sandy loams to glacial and glacio-lacstrine clays and tills. None of the ponds were lined, other than with the natural in situ materials. The Geonics EM 31electromagnetic induction meter failed to provide reliable results to detect manure seepage plumes under the study conditions. The extent and severity of pond seepage varied with soil conditions, construction practices, maintenance levels and age of the EMS ponds. Considering the age, construction practices and technical input used to build the EMS ponds, remarkably little evidence of seepage was found. The results of the study indicate that a properly constructed and maintained EMS pond is an environmentally safe manure storage alternative from a hydrogeological perspective.

Acknowledgements

The author acknowledges the contributions of the many people and organizations that contributed to this project. The following agencies and the dedicated people within them were instrumental in its completion as follows; Alberta Agriculture, Food and Rural Development (AAFRD), the Prairie Farm Rehabilitation Administration (PFRA), Alberta Pork, University of Alberta (U of A). The Conservation and Development and Livestock Operations Branches of AAFRD also gave significant support through commitments of time, manpower and equipment. The author also acknowledges producers that allowed us to use their private property to conduct the field investigation, without them this work could not have been done.

The following agencies have made significant financial contribution toward the success of this research:

- Alberta Pork and the Canadian Pork Council through the Hog Industry Development Fund (HIDF).
- The PFRA of Agriculture and Agri-Food Canada through the National Soil and Water Conservation Program (NSWCP)
- Research Branch of Agriculture and Agri-Food Canada and the Canadian Pork Council through and the Hog Environmental Management Strategy (HEMS) Program.
- Lacombe County through the Alberta Environmentally Sustainability Agreement (AESA)

Finally, I wish to thankfully acknowledge the academic and technical assistance and support of Peter Llewellyn, Prof. David Chanasyk, Prof. Terry Fonstad, Denise Erickson-Harmon, David Gibbens, Tony Brierley, Darcy Fitzgerald, Jackie Lau, Ken Williamson, Joanna Fyck, Rose Donnely, Jim Pittman, Don Wentz, Leon Marciak, and Gerald Ontkean, without whom this project could not have been done.

Dedication

I dedicate this thesis to the patience, understanding and love of my wonderful and beautiful wife Bonnie and to our amazing children. You all sacrificed more than any of us will ever know to allow me to fulfill my dreams. Thank you all very much, you own my heart, I give you my soul.

Remember; Believe in yourself, follow your dreams, never give up.

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1.0 Introduction

The loss of grain transportation subsidies (i.e., the Crow Rate) and an increased world demand for pork products have prompted expansion of the western Canadian pork industry. The availability of abundant, cheap feed grains and proximity to the Asian markets makes Alberta an excellent location for intensive pork production. Modern hog operations tend to be very large, owing to production economics that include high production and transportation costs and low product prices. Because of this, most modern hog operations use liquid manure systems, which are convenient and reduce labour requirements as well as pest, odour and dust problems. The manure is commonly spread onto cropland as a nutrient source and a soil amendment. Long-term storage of the liquid manure is necessitated by extended periods of cold winter weather conditions that preclude immediate land spreading of manure. To ensure optimal use of manure nutrients, storage facilities are generally constructed to accommodate between 200 and 400 days of manure. Liquid volumes ranging from 10,000 to 35,000 m^3 are typical for large modern confinement hog operations (Fonstad, 1996). Because of their relatively low cost and ease of construction, earthen ponds are commonly used by western Canadian hog producers to store these large volumes of liquid manure. Alternative storage systems, such as concrete and steel tanks, can be up to 20 times more expensive to construct than earthen storage ponds and can represent between 20 – 25% of the total capital cost of a new hog operation (Hodgekinson, 1996).

Public response to the increasing size of hog operations has been quite negative. Opponents of hog operations often cite concerns about groundwater pollution due to seepage from earthen manure storage (EMS) ponds as a major concern. The hog industry in Alberta recognizes that it must answer these concerns before it will be allowed to reach its potential. Seepage from liquid animal manure lagoons and EMS ponds has been the subject of much scientific research over the years but conflicting results have led to inconsistent technical standards and public mistrust (Davis et al., 1973; Chang et al., 1974; Barrington et al., 1983, 1985, 1987b; Fonstad, 1996a, Chang et al., 1974; Lo, 1997; De Tarr, 1979; Barrington et al., 1983, 1985, 1987a;

Maule et al., 1999). Governments, producers and the public are all asking for scientifically based technical standards to ensure that EMS ponds do not cause groundwater pollution. Consequently an evaluation of current site investigation, design and construction practices is needed.

This report focuses on an investigation of five existing ponds in central Alberta EMS. The study sites were selected to represent "typical" operations and construction practices to determine if seepage from these EMS ponds is causing serious groundwater problems. Seepage and contaminant movement were evaluated based on analysis of soil and water samples taken near the EMS ponds. Study methods and evaluation techniques were selected based on a review of previous research.

1.1 Investigation, Siting and Design Criteria

The Code of Practice for the Safe and Economic Handling of Animal Manures defines acceptable practice for the design and operation of EMS ponds in Alberta (AAFRD, 1995). Siting, investigation and design criteria for EMS ponds set out in the Code may be summarized as follows:

Investigation Criteria

- Soil profiles need to be examined and tested to a depth 1 m below the maximum depth of the EMS floor elevation.
- Clay content of the soil should be determined prior to construction as an indication of permeability.
- The investigation should define location and depth of underlying water bearing formations, the quantity and quality of local and regional groundwater sources, the depth to the static water table and the approximate depth to bedrock.

Siting Criteria

- Avoid areas where the watertable is normally less than 1 m below the floor elevation of the storage.
- Locate on soils of sufficient clay content to achieve a hydraulic conductivity of 1×10^{-7} cm/s.
- Do not locate an earthen storage in any area where floodwaters could damage the integrity of the storage.

Design Criteria

- Provide enough storage volume to allow manure spreading on land at optimum times for maximum nutrient benefits and to minimize odour nuisance by reducing the frequency of spreading manure on land.

- Construct side slopes appropriate for the stability of the soil and to not exceed 1.5:1 (run:rise) in parent soil or 2:1 where a clay liner exists.

- Prevent the escape of any material that could contaminate surface or groundwater.

- Divert surface water away from the storage.

- Construct the floor and sides of suitable material and compact to achieve a maximum hydraulic conductivity of 1×10^{-7} cm/s.

- Line the storage with a flexible membrane, concrete or equivalent material if it is sited on highly permeable sands and/or gravel type soils and clay suitable to construct a liner is unavailable.

- A leak detection system may be required in combination with a flexible membrane to ensure early detection in the event of a liner failure.

Although there are no specific legislation or regulations that govern intensive livestock operations (ILOs) in Alberta, about 80% of municipalities in the province require a development permit for new construction or expansion. Most of these have incorporated the Code of Practice (AAFRD. 1995) into their development bylaws that address ILO developments. The Ministry of Agriculture, Food and Rural Development (AAFRD) provides technical assistance to municipalities for environmental impact assessment of ILO development proposals. The technical report provided to the municipality by Ministry staff is essentially a Phase I environmental site assessment that is used to evaluate the need for, and extent of, a site specific investigation. In addition to the Code of Practice and the municipal bylaws referring to ILO development, several other provincial and federal statutes also apply to ILOs. The statutes that apply to the potential release of substances and pollution of surface or groundwater from EMS ponds are the Alberta Environmental Protection and Enhancement Act, the Public Health Act and the Federal Fisheries Act.

A review of the siting investigation, design, construction and regulatory requirements of the Provinces and States on the Great Plains of North America was conducted (Table 1). The jurisdictions reviewed were selected for their geographic and climatic similarity to Alberta. Alberta hog producers are subject to similar technical standards as other producers but no specific legislation addresses the environmental aspects of intensive livestock operations. Fonstad (2000b) concluded that although Alberta provides the least detailed guidance for the design and construction of EMS ponds, significant agency oversight and review of construction applications was in place to prevent environmental impact from these facilities.

Evidence presented by Davis et al. (1973), Hills (1976) and Barrington et al. (1983, 1985, 1987a,b) that soil clogging reduces seepage rates has led to technical standards based on the presence of some prescribed depth of "sealable soils" below the EMS pond. Iowa (1992), Ontario (1994), British Columbia (1991) and Quebec (Gangbazo et al. 1991) are examples of jurisdictions that have used the results and recommendations presented by Barrington et al. (1983, 1985, 1987a,b, and 1989) to develop regulatory standards for the design and construction of hog manure EMS ponds or lagoons. Fonstad (1996) suggested that the geotechnical community is concerned that design standards based on laboratory scale test without appropriate field could lead to undesired results.

Table 1.1 Summary of site investigation, design, construction and regulatory requirements for the states and provinces on the Northern Great Plains of North America[1]

Variables	IO	MN	MT	NE	ND	SD	AB	MB	SK
Use Resource Information	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Soil borings (min #)	3	2	0	0	5	2	Site specific	3	3-6
Surveying	Yes	Yes	No	No	No	No	Yes	Yes	Yes
Piezometers	3 min	N/R	N/R	N/R	N/R	N/R	Site Specific	Site Specific	2 min
Monitoring wells	3		Water wells	Water wells		3	Site Specific	Site Specific	Site Specific
Atterberg limits	PI=10-25	PI=10-30	N/A	N/A	PI=13-16	PI=15	N/A	N/A	PI>10
Grain Size	>20%	>20%	N/A	N/A	N/A	>30%	20-25%	20-25%	>10%
Standard Proctor	95%	95%	90%	95%	90-95%	95%	95%	95%	95%
Min. Permeability (cm/s)	1.8×10^{-6}	5.2×10^{-7}	4.6×10^{-7}	7.3×10^{-4}	3.7×10^{-4}	1.8×10^{-4}	1×10^{-7}	1×10^{-7}	1×10^{-7}
Water content (% of optimum)	100 to +4%	100 to +5%	100 to +4%		Near optimum	+/- 2%	n/a	-1.5 to +3%	100 to +4%
Earth liner	Clay	Clay	Clay	Clay	Clay or Admix	Clay or Admix	Clay or Admix	Clay	Clay
Min. liner thickness (m)	0.3	0.6	0.15	0.6	0.3	0.46	0.6	0.6	0.15
Most common liner thickness (m)	0.6	0.9	0.3	0.9	0.6	0.76	0.9	0.6+	1.2
EMS bottom to water table (m)	1.2	0.6	1.2	0.6	N/A	N/A	0.9	0.9	
Typical dyke width (m)	1.8	1.8	2.4	2.4	1.8	3	2.4	2.4	6
Min interior side slope	2:1	2:1	3:1	2.5:1	2:1	3:1	1.5:1	2.5:1	2:1
Min exterior side slope	3:1	3:1	3:1	4:1	2:1	3:1	1.5:1	5:1	2:1
Min freeboard (meters)	0.6	0.6	0.6	0.3	0.3	0.6	0.3	N/R	0.3
Keyway trench (w x d)	3 x 1.2 m	N/R	N/R	0.3 x 1.8 m	N/R	N/R	N/R	N/R	? x 0.3 m
Storage pond	Max 14 mo.	Max 12 mo.	Max 150 days	Max 12 mo.	Min 180 days	Min 270 days	Min 180 days	Min 200 days	Min 180 days
Synthetic liner types[2]	Yes	Yes	RARE	RARE	RARE	RARE	RARE	GCL	GCL, PVC
Specific Legislation or regulations	Yes	Yes	No	Yes	No	No	No	Yes	Yes
Related Reg.s or Bylaws Apply	No	No	Yes	Yes	Yes	Yes	Yes	No	Yes
Dev. or Const. Permits Requ'd.	Yes	Yes	Yes	Yes		Yes	Yes		Yes
Eng. Site Assessment Req'd	Yes	Yes	Site Specific	Site Specific	Yes	Yes	Yes	Site Specific	Yes
Engineering Design Requ'd	Yes	$1890\ m^{1}$ +	Site Specific	Yes	No	Yes	Site Specific	Yes	Site Specific
Construction Supervision Req'd	Yes	$1890\ m^{1}$ +	Site Specific	Yes	No	Yes	Site Specific	Yes	Site Specific

[1] N/A - means not applicable in this jurisdiction; N/R - means not required; RARE - means this practice is rarely used; Site specific - means the option to require this condition/practice is up to the designing and/or regulating engineer; Admix – means bentonite admix liner .

[2] Common synthetic liner types used for EMS ponds and lagoons are : HDPE = high density polyethylene; PVC = polyvinyl chloride; GCL = geosynthetic clay liner (i.e., Bentomat™, etc.)

2.0 Literature Review

Earthen manure storage (EMS) ponds have become the predominant method of liquid manure storage in Canada and the United States (Fonstad et al., 2000b). Liquid hog manure typically contains unused nutrients, pathogenic microorganisms and other chemicals that, if allowed to enter the groundwater, can pollute it. The literature provides evidence that ponded liquid animal manure has a self-sealing effect on soils and as a result many EMS ponds were built without the benefit of hydrogeological investigations or engineered liners (Hills, 1976; Fonstad, 1996a). Hills (1976) and Fonstad (1996a) reviewed the literature on seepage and sealing of lagoons and EMS ponds and concluded that bottom sealing is frequently inadequate and that hydrogeological investigations for site selection are rare. Many researchers have also shown that seepage below and beside EMS ponds can pose a threat to groundwater in adjacent areas.

Davis et al. (1973) defined soil clogging as the "resistance to flow caused by a change in friction coefficients or in reduced size or volume of pore spaces". Physical sealing of soils, therefore, may result from physical or hydrostatic compaction, smearing of the soil surface or the migration of soil fines before or after water ponding. In most cases though, soil clogging is caused by some combination of physical, biological and chemical interactions at the soil-manure interface (Davis et al., 1973; Chang et al., 1974; Barrington et al., 1983, 1985, 1987b; Fonstad, 1996a). Biological sealing results from the mixing of solid materials with slimes excreted by bacteria during anaerobic metabolism. The interaction of the slimes with the settled solids forms a rubber-like mat of extremely low hydraulic conductivity preventing seepage into the underlying soils (Barrington and Jutras, 1983). Chemical sealing results from soil structure alteration due to chemical reduction reactions or deflocculation of clays. The factors that affect the formation of an effective manure seal are manure solids content, size of manure solids (as affected by animal type) and soil texture and structure (Chang et al., 1974; Lo, 1997; De Tarr, 1979; Barrington et al., 1983, 1985, 1987a; Maule et al., 1999). The degree and rate of infiltration reduction that can be expected from a manure seal is dependent on soil texture, time of ponding, manure solids content, and the integrity of the manure seal (De Tarr, 1979; Barrington et al., 1983, 1985, 1987a; Fonstad, 1996a). The seepage rate from an EMS pond is also governed by seepage hydraulics and scale effects (Fonstad, 1996a).

2.1 Soil Clogging Mechanisms

Early this century municipal engineers attempted to recharge aquifers by ponding treated municipal wastewater on sandy soils. Winterer (1922) observed that infiltration rate was reduced when anaerobic conditions developed in surface soils subjected to prolonged inundation. Allison (1947) concluded that infiltration rate reductions of two to three orders of magnitude were the result of polysaccharide (simple sugars) production by anaerobic bacteria within the soil matrix. McCalla (1951) showed that clogging was due to microbiological activity since low temperatures and antibacterial agents inhibited seal development. Mitchell and Nevo (1964) determined that soil borne Flavobacterium were the source of soil polysaccharide production and that a high C:N ratio substrate caused the preferential production of polyuronides. Polyuronides are polysaccharides combined with uronic acids that are more resistant to deterioration upon drying than polysaccharides alone. Mitchell and Nevo (1963) showed that polysaccharide excretion occurs under anaerobic or reduced soil conditions. Avnimelech and Nevo (1963) showed that while additions of a simple carbon source would induce polyuronide production, additions of sawdust or sewage did not. They theorized that this occurred because the bacteria had difficulty breaking down more complex carbon sources. They determined that an increase in the polysaccharide content in soils actually improved soil aggregation after the affected soils were dried.

Early researchers recognized that ponded animal manure may induce soil clogging since animal manure fits the criterion of an organic soil amendment with a high C:N ratio (Fonstad, 1996a). Hart and Turner (1965) failed to show that liquid chicken, dairy and hog manure cause soil clogging in compacted sandy loam soils. They suggested that the high infiltration rates measured might have resulted from the high depth to area ratio and low solids content of the manure in their experimental lagoons. Davis et al. (1973) suggested that their failure to see the effects of sealing was due to neglected evaporation losses. They showed that evaporation would contribute up to 0.79 cm/d of water loss from the manure ponds in Southern California where Hart and Turner had performed their study. However, Davis et al. (1973) may have over estimated the contribution of evaporation to liquid level declines in their lagoons since they corrected their infiltration rates using Class A pan evaporation measurements. Barrington and Jutras (1983) suggested that surface crusting reduces evaporation losses from manure pond surfaces by 40 – 60 % compared to Class A pan evaporation rates.

While Davis et al. (1973) credited biological sealing mechanisms with the manure sealing effect they observed in their study, Chang et al. (1974) showed that manure sealing is due to a combination of physical and biological effects. They attributed initial permeability reductions to physical entrapment of suspended manure solids at the soil surface. However, microbial slime excretions eventually caused the sludge layer near the soil surface to become more cohesive, which improved the sealing effect of the manure mat. Barrington and Jutras (1983) showed that biological slimes created during bacterial digestion of manure solids cemented the solids, creating a massive structure giving the manure mat a rubbery texture.

Chang et al. (1974) demonstrated that soil-manure sealing is not solely a surface phenomenon by performing permeability tests on sliced sections of manure-saturated soil cores. The hydraulic conductivity of previously inundated soil cores was shown to gradually increase with depth for all soil textures. Lo (1977) came to the conclusion that manure sealing does not occur exclusively at the soil surface. Barrington et al. (1987b) noted that the bubbling action from fermentation within the manure mat caused sedimentation of fine manure solids, especially in hog manure. These finer manure particles were also seen to penetrate through the manure mat and into the soil-manure interface layer, improving the physical seal induced by hog manure.

Culley and Phillips (1982) found manure sealing occurred faster in sandy soils than in clay soils but that all soils eventually developed a similar final hydraulic conductivity after 5 to10 d of being submerged by liquid manure. They hypothesized that the manure solids layer controlled the flow rate of liquid through their soil columns. The rapid sealing rate that they found for sandy soils was attributed to more rapid plugging of the large but less numerous soil pores in the sand relative to the clay soils. Barrington and Madramootoo (1989) demonstrated that the more rapid decline in hydraulic conductivity of sandy soils was the result of a faster accumulation of manure solids in a sandy soil compared to a clay loam soil. Infiltration rate decline was accelerated in two sand columns that were able to entrap manure solids within in the upper 10 cm of the soil surface compared to the one that did not show evidence of manure particle infiltration.

De Tarr (1979) found that the concentration of liquid dairy manure solids was more important than soil type to soil-manure seal formation. He found that manure slurries with more than 0.3% total solids (TS) content reduced infiltration rates to near 3×10^{-8} m/s after four days for all soils tested, except a gravelly sandy loam. Barrington et al. (1987b) found no significant difference in sealing rates for slurries with TS contents >3 %. This is contrary to the findings of Barrington and Jutras (1983), who found significant differences in infiltration rate decline between 3 and 6% TS manure over a 400-h soil column trial. However, differences between infiltration rate decline for the 6 and 9% trails were only significant over the initial 25 h of the test. De Tarr (1979) developed a regression equation relating manure solids content and initial measured infiltration rates of soil with water to a predicted final infiltration rate of soil with manure as follows:

$$I_m = 0.009\, I_w^{0.11} S_t^{-0.67} \qquad \text{Eq. 2.1}$$

where I_m is the infiltration rate with manure, I_w is the infiltration rate with water and S_t is the total solids content of the manure.

Rowsell et al. (1985) showed that physical mechanisms were of primary importance in the creation of a manure seal for beef feedlot manure by comparing the infiltration rates of soils inundated with sterilized and natural beef manure. Barrington and Jutras (1983) credited biological sealing mechanisms with only 1/10,000 of the infiltration reduction caused by dairy slurries. However, Barrington et al. (1987b) showed that biological mechanisms were more important in the sealing process for swine slurries due to weak physical clogging mechanisms related to the nature of the manure solids. They credited biological mechanisms with 1/60th of the soil infiltration rate reduction induced by ponded hog manure. This was confirmed by observations that permeability of the hog manure seal tended to be higher when developed under cool conditions or when the manure was sterilized prior to ponding.

De Vries (1972) concluded that chemical sealing was not a significant factor in seal development in pure sand filters inundated with municipal sewage. He eliminated biological sealing effects by maintaining cold temperatures (2 – 3 ^{0}C) during his infiltration experiments. He reasoned that since soil particle dispersion (deflocculation) would not occur in the pure sands devoid of clay, physical pore plugging was responsible for the infiltration reduction measured in his studies. Chang et al. (1974) determined that permeability reductions in soil submerged in liquid dairy manure were not caused by chemical deflocculation because their permeability rebounded upon drying. Barrington et al. (1983, 1987b) agreed that chemical effects are insignificant since soils with high clay contents performed similarly to sandy soils after being ponded with dairy manure with high salt concentrations. Rowsell et al. (1985) used water solutions that were chemically similar to beef manure slurry to show that soil dispersion did not contribute significantly to the clogging effect in clay loam soil cores.

Chang et al. (1974) demonstrated that clay soils resisted deep penetration of manure because smaller pore openings tended to hinder organic matter penetration. Barrington et al. (1983,1987a) showed a relationship between soil inter-particle void diameter and the effectiveness of manure sealing, and that soil clay content is directly related to soil interparticle void diameter. Manure particle size also affects the sealing process and swine manure was shown to require a finer textured soil than dairy manure to create an effective seal due to the smaller, more granular nature of the solids.

Barrington and Madramootoo (1989) demonstrated that soils with sufficient clay would absorb small manure particles into the upper soil surface, causing physical clogging to occur both at the soil surface and within a thin soil-manure interface layer. Coarse grained soils allowed deterioration of the manure mat through continuous sedimentation of the finer manure particles into the soil matrix. The manure-soil interface layer was effective in reducing the hydraulic conductivity in clay loam soil columns. Hydraulic conductivity varied significantly with depth below the soil surface for clay soils while no difference in with depth was observed for coarse textured soils. The enhanced development of a soil-manure interface in clayey materials was attributed to a higher affinity of clays to absorb manure solids into the upper soil surface. The soil layer that clogged with manure particles has been shown to range between 3 to 5 mm in clay soils and between 5 and 15 mm in sandy soils (Laak, 1970; Barrington and Jutras, 1983; Rowsell et al. 1985; Fonstad, 1996a; Maule et al., 1999).

2.2 Infiltration Rate Reductions due to Clogging

Data from the various research papers reviewed herein are summarized in Table 2.1. These investigators considered soils effectively sealed if the infiltration rate is reduced to 10^{-8} m/s or less. It is notable that this is not the standard used in Alberta, where the Code of Practice specifies that the hydraulic conductivity of the soil must be 10^{-9} m/s or less (AAFRD, 1995). Almost all of the research on soil clogging reviewed shows that manure sealing has occurred within a few weeks after submergence with liquid animal manure. Infiltration rate and hydraulic conductivity reductions due to manure sealing are usually between two and three orders of magnitude below the initial value for the soil, as measured with water.

Hart and Turner (1965) achieved infiltration rate reductions of 20 to 40% after 2 y of manure ponding. The lowest final infiltration rate they measured was about $3.0\text{x}10^{-8}$ m/s under inundation with liquid poultry manure. Davis et al. (1973) recorded a more than 200-fold infiltration rate reduction after flooding with dairy manure for 4 months. Robinson (1973) found that the majority of the seepage rate reduction occurred within three weeks of being submerged with liquid beef manure. However, this 1.67-m thick layered alluvial soil never attained an 'effective' soil seal even after six months of inundation with liquid beef manure. Baier et al. (1974) reported that clay soils required only 10 d, while loamy sand took up to 50 d of continuous manure ponding to develop an effective seal.

Chang et al. (1974) measured hydraulic conductivity reductions in sands of two orders of magnitude, from 3.9×10^{-5} to 4×10^{-7} m/s, over 64 d of ponding with dairy manure. The hydraulic conductivities of loam soil columns were reduced from 7×10^{-7} to less than 1.7×10^{-8} m/s over 17 d of submergence, while that of silty clay soil columns was undetectable by the laboratory method used after 17 d of submergence (i.e., $<1.7 \times 10^{-8}$ m/s). Sandy soils underwent the largest overall reduction in soil permeability over the study but the clay soil reached the undetectable range after only 17 d. Hills (1976) noted an infiltration rate reduction of about one order of magnitude over the last 9 months of a 12-month study. Infiltration rates through compacted soils of varying textures were in the 10^{-9} m/s range before the end of a 4-month experiment. Lo (1977) reported all the soils that he tested sealed within the first 30 min of operation except in the clay material. He noted an exponential decrease in the infiltration rate was noted in his investigation but rate of decline fluctuated considerably for all soils except the clay. The rate of reduction of infiltration rate declined for all soils in the year-long experiment. All columns reached and maintained a relatively steady infiltration rate of approximately 5×10^{-9} m/s after three months of operation.

Rowsell et al. (1985) found that clay soils were effectively sealed ($\leq 10^{-8}$ m/s) after 3 and 10 d of manure ponding for 1 and 5 m of head, respectively. Regression equations developed with experimental data predicted that loam and sand soils would have required 51 and 53 d, respectively, to develop an effective manure seal even under the larger hydraulic head.

Culley and Phillips (1982), Rowsell et al. (1985), Barrington and Madramootoo (1989), Fonstad (1996a) and Maule et al. (1999) all reported an exponential decrease in soil saturated hydraulic conductivity (K_s) or infiltration rates for all soil textures after manure ponding. Barrington and Jutras (1983) found soil sealing due to ponded dairy manure to be instantaneous and efficient. Infiltration rates in small-scale reservoirs decreased from between 1 x 10^{-4} and 1 x 10^{-6} m/s to between 2 x10^{-7} and 1 x 10^{-7} m/s for all sites within a few hours after manure soil contact under field conditions for sand and loam soils, respectively.

Fonstad (1996a) and Maule et al. (1999) measured the apparent saturated hydraulic conductivity (K_a) of seven soils submerged with 0.5 % TS hog manure ranging in texture from sandy loam to clay loam.[1] They measured average K_a values for all columns of 1.1x 10^{-9} m/s between 38 and 73 d of hog manure ponding. Between days 157 and 185, these values had decrease to an average value of 6.9 x 10^{-10} m/s for all soils.

2.3 Soil Texture Effects

Hills (1976) concluded that the amount of infiltration and pollution increases by soil type as follows: clay loam, loam, silt loam sand loam and silt loam. Chang et al. (1974), Barrington et al. (1987a, 1989), Fonstad (1996a) and Maule (1999) all found a correlation between soil clay content and seepage rate (or K_s) reduction. Barrington et al. (1987a, 1989) demonstrated a direct correlation between soil clay content and the reduction in soil hydraulic conductivity due to manure ponding. Fonstad (1996a) noted that the rate of decline of infiltration rate due to manure ponding followed the increase in clay content and soil bulk density. Conversely, Culley and Phillips (1982) reported that the rate of sealing increased in the order of clay<loam<sand, the same order as bulk densities and coarseness of texture. They reported that all the soils tested had sealed within 10 d after ponding with liquid manure and that soil texture had very little effect on the ability of manure seals to form. Rowsell et al. (1985)

[1] USCS Classification of SC to CH

agreed with this, as they found that the rate of decrease in infiltration rate was not significantly different (90% confidence interval) between soils tested.

Phillips and Culley (1985) detected significant NO_3 movement below and beside small-scale EMS ponds in sands. The average nitrate concentrations measured in the groundwater near EMS ponds in these soils were significantly higher ($P<0.001$) than those measured in loam or clay soils. However, no correlation was found between contaminant movement and K_s, as solute transport was found to be greater in clay soils than that in loams. Theoretical calculations based on K_s values would have predicted lower seepage rates in clay soils than for the loam and sand soils. The authors suggested that soil structure may have reduced the effectiveness of the clay soil to contain manure. Barrington et al. (1983,1987a, 1989) and De Tarr (1979) reported poor correlation between initial soil conductivity with water and infiltration rates measured after prolonged submergence with liquid manure. De Tarr stated that although the natural permeability of the soil definitely influences the infiltration rate with liquid manure, there is no direct proportionality. Barrington and Madramootoo (1989) concluded that saturated hydraulic conductivity was not significant in determining the extent of sealing by manure but that soil texture bore direct correlation.

2.4 Soil Texture Criterion for Site Selection and Design

Barrington and Jutras (1985) and Barrington and Broughton (1988) discussed the use of effective soil void diameter as a siting and design tool for EMS ponds. They proposed the use of the maximum "effective soil void diameter" (D_0) as a design criteria for soils used for EMS construction based on the particle size distribution of the animal manure being stored. These authors suggested a $D_0 \leq 2.0$ and 0.45 μm for liquid dairy and hog manure, respectively. Calculations using the methods of Kovacs (1981) indicated that these criteria correspond to minimum soil clay contents of 5 and 15% for liquid dairy and hog manure, respectively. Where these criteria are not met, Barrington and Broughton (1988) suggested conducting compaction tests to determine if the 'native' soils can be compacted to reduce the effective soil void diameter to the desired level. Where this is not possible, they suggested implementing a liner of compacted clay loam soil or use of synthetic or concrete liners as appropriate.

The design methodology suggested by Barrington and Broughton (1988) also requires a groundwater control system that maintains the local watertable below the bottom elevation of the EMS pond. If the watertable is allowed to intrude upon the manure-soil seal, it will infiltrate into the pond, destroying the seal and lowering the solids content of the manure and creating subsequent excessive percolation. They also indicated that drainage systems can be used where excessive seepage is expected or inadequate soil CEC would prevent the filtration of manure contaminants. The drainage system would be designed to capture seepage waters before they entered the subsurface below the pond-drainage system periphery. The drainage waters would be collected in a sump system and pumped back into the reservoir for storage. Where unlined EMS ponds are constructed, Barrington and Broughton (1989) recommended that soils should have a minimum CEC of 30 meq/100 g of soil to ensure that transport of ammonium-N from the EMS pond is retarded due to sorption.

2.5 Seepage Studies

In spite of the evidence of self-sealing due to manure ponding, many researchers have measured movement of manure-related contaminants into soils and shallow groundwater. Fonstad (1996a) suggested that, due to hydraulic gradient effects, seepage will occur at a rate similar to that allowed by the intrinsic conductivity of the soils underlying an EMS pond. Further, many researchers have determined that weathering processes may affect the integrity of manure seals, resulting in pulse flows of contaminants through preferential flow paths within the seal when the pond is refilled after the seal has been exposed to the environment.

Meyer et al. (1972) in California found very little change in soil and groundwater nitrate-N and salt content below nine manure lagoons in soils ranging in texture from sands to clay loams after 15 months of operation with chicken and dairy manure.

They attributed the apparent lack of impact to the filtering and denitrifying qualities of the sludge layer on the bottom of the ponds and low infiltration rates due to manure sealing (i.e., $< 1.2 \times 10^{-8}$ m/s). Based on this, they concluded that no artificial liners were needed below earthen manure ponds. Sewell (1978) observed elevated levels of NO_3-N, chlorides, fecal coliform and fecal streptococci levels in groundwater near a new lagoon built into sandy soils in Tennessee. They noted that NO_3-N and Cl levels increased immediately after system loading but declined to near background levels within three to six months and remained stable for the remaining two years of the study. They attributed the decline of NO_3-N levels to the development of an effective manure seal in the floor of the ponds. Mean nitrate and bacteria levels were 10 mg/L and 90 counts/100 ml, respectively. Ritter et al. (1980) and Phillips et al. (1983) also found that NO_3-N concentrations in the anaerobic environment near EMS ponds decreased due to denitrification.

Fonstad and Maule (1996a,b) investigated six earthen hog manure storage ponds in central Saskatchewan. Detailed soil coring work was conducted for four sites ranging in age from 4 to 11 y located in soils of glacial origin (1 glacio-fluvial, 3 tills). The EMS ponds at the other two sites (Sites 21 and 22) had been in service for 20 y or more. Site 21 was located in a glacio-lacustrine flood plain adjacent to an alluvial flood plain. The data (Table 2.2) suggest that seepage is a concern in glacial clay till materials where fissures, fractures and layering are evident. However, no evidence of seepage was found below or beside an EMS pond constructed into such materials where minimal seepage protection was provided by constructing a 600-mm thick compacted clay liner. It seems that this farmer-built clay liner is successfully preventing manure seepage evident at unlined EMS ponds constructed into similar materials. The combination of a compromised clay liner and poor site characteristics resulted in an extreme seepage problem at Site 22. The authors suggested that the liner was compromised by freeze-thaw action and that the deep coarse soil layer below the compromised liner allowed seepage to occur to depths of at least 9 m below the EMS pond.

Miller et al. (1976) also found that soil samples taken from below 4 lagoons in Ontario were devoid of NO_3-N. However, NH_4-N levels were very high in the fine textured soils but decreased to background levels 20 – 30 cm below the pond bottom. In medium and coarse textured soils, NH_4-N levels remained very high (> 300 μg/g) in cores up to 400 cm deep. Phillips et al. (1983) found that groundwater samples showed a three-to-five fold increase in ortho-phosphate concentrations in all soils under experimental scale manure ponds, while NH_4 or NO_3 concentrations increased only in the sandy soil. Culley and Phillips (1989) showed that the EMS ponds they studied were not effectively containing manure solutes in clay loam, sand loam or sandy soils. They measured increased nitrogen loading up to 1.2 m below experimental and commercial scale lagoons filled with dairy manure. Miller et al. (1976) and Culley and Phillips (1989) concluded that nitrogen attenuation due to sorption of NH_4-N by clays in soils near the bottoms and sides of EMS ponds could represent a serious environmental hazard following abandonment of the EMS ponds. They reasoned that, should these soils become aerobic upon being exposed to the atmosphere for an extended period, the ammonium absorbed may be nitrified and migrate into the local groundwater at an unacceptable rate.

Fonstad and Maule (1996a,b) provided evidence of this phenomenon in their investigation of the EMS pond at Site 21 from their study. Site characteristics at this site were similar to those at the other unlined EMS ponds constructed into clay till soils that they investigated. However, they found NO_3 concentrations of over 2,500 mg/L in soils to a depth of 1.2 m below this EMS pond, which had been abandoned periodically throughout its 20-y history, at one time for about 2 y. The authors speculated that ammonium-N previously accumulated in the clay materials below and beside the pond may have been oxidized during periods of abandonment. Migration of NO_3-N would have been quite free in the clay soils below the manure pond, as the anion is not subject to attenuation by sorption due to its negative ionic charge. Cracking of the soils in the floor of the EMS pond likely occurred during its period of abandonment due to desiccation of the clays, accelerating seepage as the manure pond was refilled. This theory would also explain the elevated levels of other contaminant species found below this EMS pond.

Collins et al. (1975) measured movement of ammonia, chloride and fecal coliforms in groundwater from 3- and 6-m deep observation wells, 3 m from two swine lagoons in sandy loam soils in Virginia. Elevated NO_3-N levels were measured at 15 m from another site with similar soils. Nitrification was attributed to high dissolved oxygen contents and high temperatures in the groundwater in the area. Ciravolo et al. (1979) showed that two swine lagoons in Virginia had minimal impact on local groundwater quality, while concentrations of Cl, NO_3 and NH_4 above the drinking water standard were measured up to 3 m from the lagoon at a third site. These researchers attributed this unexpected seepage and contaminant movement to manure seal rupture due to desiccation and gas bubble movement associated with microbial activity in the soils beneath the seal layer. Ritter et al. (1980) also concluded that sporadic levels of Cl, NO_3, NH_3 and COD in observation wells over a two-year study period were the result of preferential flow and periodic breakdown of the manure seal. Ritter (1983) found that a clay-lined lagoon in permeable soils was causing serious groundwater contamination because an effective manure seal had not developed. He stated that manure lagoons should not be constructed in coarse textured soils even with compacted clay liners. However, he acknowledged that the clay liner was preventing bacterial contamination from the lagoon from becoming widespread.

Phillips et al. (1983) observed that seepage from small manure storages was greater than that from farm-scale EMS ponds under similar soil conditions The watertable in the small-scale ponds was always well below the bottom elevations, while it was consistently above the bottom elevation of the farm-scale EMS ponds. High watertable conditions have been shown to affect manure seal integrity and nutrient movement from EMS ponds (Barrington and Jutras 1983). The difference noted by Phillips et al. (1983) was likely related to hydraulic conditions at the observed sites. Diffusion and unsaturated flow were the only mechanisms of transport available to manure solutes from the small-scale ponds, which are much slower modes of transport than saturated, advective flow. Therefore, it is possible that the solutes simply did not reach the monitoring wells within the 3-y study period.

Westerman et al. (1993b) reported that seepage was evident from two swine manure storage ponds in deep sandy soil in North Carolina after 3.5 - 5 years of operation. The substantial spatial and temporal variations in water chemistry they observed were attributed to cyclic development and breakdown of the manure seal, variations in effluent concentration and pond depth and variations in intrinsic soil qualities throughout the study site. They also indicated that oxidation/reduction reactions were likely a major factor in the variation of NH_3 and NO_3 concentrations found in groundwater.

Korom and Jeppson (1994) found that dairy lagoons in the Heber Valley of Utah were a significant contributor to nitrate pollution. They attributed the highly variable levels of NO_3-N measured near a lagoon constructed into a very coarse gravely loam to desiccation of the manure seal and accelerated nitrification due to high oxygen concentrations in the groundwater. NO_3-N concentrations well above the 10 mg/L drinking water standard were found in groundwater 2.4 m down gradient of a lagoon constructed into a fine montmorillonitic loam soil. Average $N0_3$-N concentrations in groundwater varied significantly with liquid level in the pond built into the coarse material. Groundwater nitrate levels near the clay-lined lagoon were at least an order of magnitude higher than any others found in the literature. The authors strongly discouraged construction of unlined dairy lagoons in coarse textured soils.

Betcher et al. (1996) found chloride movement in groundwater more that 80 m down gradient of an unlined EMS pond in a fine sandy soil with a high watertable. A marked decline in ammonia concentration with distance from the EMS pond was attributed to adsorption of NH_4-N onto the clay fraction of the soils near the lagoon. The failure to detect nitrate-N was attributed to low oxygen concentrations in groundwater and chemical reducing conditions near the EMS pond. No evidence of seepage was found after 2 y of operation near another EMS pond constructed into a similar hydrogeological environment with a 0.9-m compacted clay liner. The authors concluded that EMS ponds should not be constructed into shallow sand aquifers without the benefit of a constructed liner and that properly constructed clay liners can effectively impede seepage and attenuate nitrogen transport from EMS ponds constructed into coarse soils.

2.6 Hydraulics and Scale Effects on Seepage

A sandy loam soil tested by Hills (1976) had an infiltration rate of 10^{-9} m/s after 7 d, which rebounded to10^{-8} m/s before the end of the 4-month study. He proposed that the increase in infiltration rate might have resulted from deterioration of the surface seal due to hydraulic pressure (4.5-m depth) forcing the manure solids into the soil matrix of these highly porous soils. Rowsell et al. (1985) showed that increased hydraulic head accelerated the development of a manure seal in clay soils but had no effect on sand soils. Sewell (1978) noted that bacteria counts that increased with liquid levels indicate that contaminant movement is sensitive to hydraulic gradients. Hills (1976) noted that the concentration of pollutants in the exfiltrate is directly proportional to hydraulic gradient. He concluded that the contamination potential to groundwater from a "properly constructed" anaerobic lagoon is very small, but cautioned that exfiltrate concentration could be significantly affected by hydraulic gradient and the thickness and hydraulic conductivity of liner materials.

Barrington and Madramootoo (1989) measured pressure gradients across the manure mat, the soil-manure interface and the underlying soils to determine the effect of manure sealing on the hydraulic conductivity at different depths within 0.2-m deep soil columns of different textures. Observed infiltration rates were compared to theoretical rates calculated from their data. The average measured infiltration rates through sand columns were nearly an order of magnitude lower than would be expected from theoretical considerations, perhaps due to the development of unsaturated flow conditions at the bottom of these soil columns. Enhanced drainage of the soils near the bottom of the soil column may have been caused by a large pressure drop between the lower piezometer tip and the bottom of the soil column due to the continuous drainage required to collect exfiltrate samples. Miller et al.

(1985) showed that solutes moved into groundwater below a liquid beef manure pond in a sandy soil in spite of manure sealing. Seal development began after 2 weeks and after 12 weeks of ponding. The unsaturated hydraulic conductivity of the soil below the pond was estimated to be less than 1×10^{-9} m/s. Evidence that NH_4, NO_3 and Cl continued to move into soil water below the pond after the pond had hydraulically sealed indicates that diffusion and unsaturated flow are likely effective in transporting manure solutes.

Hills (1976) and Lo (1977) concluded the hydraulic conductivity of soil ponded under anaerobic manure appears to be inversely proportional to the hydraulic gradient. This appears to be a remnant effect related to laboratory soil column experiments. Hills and Lo placed extremely large hydraulic heads on relatively thin layers of relatively low conductivity soils underlain by a coarse filter material. As the leachate was continuously drained, in order to collect exfiltrate samples, a large negative or "suction head" developed below the test soil column. The relatively high hydraulic head relative to the thickness of the test soil may have forced manure solids into the soil surface to create an artificially induced sealing effect (Fonstad, 2000)[2]. This seal is relatively thin (3 – 15 mm) but has a very low hydraulic conductivity of 10^{-10} – 10^{-11} m/s (Fonstad, 1996a). Under the conditions prevalent in small-scale soil columns, this manure seal will have a major effect on infiltration rates through the experimental system but the effect may not be as substantial under field conditions (Fonstad, 2000)[2].

Barrington and Madramootoo (1989) also showed large variations between theoretical and measured infiltration rates for sand soil columns where a soil-manure interface layer was not formed. Majumdar et al. (1996) reported that microscopic observation of the experimental cores used by Fonstad (1996a) revealed that organic matter from swine manure clogged the pore spaces throughout the 200-mm deep sand soil columns after ponding for over 400 d. If manure solids were similarly washed through the sand columns in Barrington's tests, clogging could have

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occurred within the soil layer below the lower piezometer. The resulting reduction in conductivity in that soil layer would have influenced the K_a of the entire column but would not have been detected by the experimental apparatus. This would explain the difference between measured and calculated infiltration rates since the calculations assumed that the conductivity of this layer would remain unchanged from that of the natural soil.

With his soil column experiments, Fonstad (1996a) demonstrated close parallels between measured and calculated K_a values for all soils tested over the early test period (Day 38 – 73). The medium textured soils continued to display a close relationship between measured and calculated K_a values over the longer term (Day 157 – 185). However, the measured and calculated K_a values of both the sandier soils and those with the highest clay content diverged over time. Both treatments showed lower permeabilities according to measured infiltration rates while calculated values held relatively steady. Barrington and Madramootoo (1989) showed a similar trend. Barrington et al. (1987b) suggested that clay soils may absorb manure solids into the upper layer to help form a thicker clogged layer over the long term, helping to explain the long-term reduction in measured K_a values for the clayey soils tested by Fonstad (1996a). Barrington and Jutras (1983) and Rowsell et al. (1985) found that the continued conductivity reduction over the longer term in coarse textured soils was related to the blocking of soil pores with depth (5 – 15 mm). Finer grained manure particulates migrate through the larger pore spaces in the coarse textured soils but eventually become entrapped in smaller pores, causing sealing to occur at some depth below the soil surface. This may be why Fonstad (1996a) showed higher theoretical than measured infiltration rates for sandy soils.

The infiltration rate velocity is directly proportional to the product of the K_a and hydraulic gradient (i) divided by soil porosity. The K_a and the hydraulic gradient are affected by the depth to the wetting front below an EMS pond (Fonstad, 1996a). It follows that if a relatively thick layer of high conductivity, saturated soil exists below the manure seal or a compacted liner, the expected infiltration rate (I_m) of the system is effectively controlled by the K_s value of the thicker, more conductive soil.

Therefore, field scale EMS ponds with 5 - 10 m of highly conductive material underlying a "seal" layer with a maximum potential thickness of 0.005 – 0.05 m would be expected to produce seepage rates similar to that predicted without consideration for the "seal" layer. Fonstad (1996a) found that if one considers the hydraulics of the whole system, a thin manure seal does not exert much influence on long term seepage or contaminant movement. He performed a sensitivity analysis to test the effects of variations in hydraulic head, manure seal hydraulic conductivity, manure seal thickness, subsoil hydraulic conductivity and depth to wetting front on seepage rates from a field scale EMS pond. His results showed that, for the range of values tested:

- K_a is unaffected by hydraulic head
- Flux varies directly with head (i.e., infiltration rate, I_m or v)
- K_a varies closely with K_i (i.e., conductivity of soil-manure interface layer)
- K_a and flux vary closely with the thickness of the soil-manure interface
- K_a and flux remain virtually unaffected by the formation of a manure seal for soil conductivity values of $K_s > 10^{-8}$ m/s
- K_a decreases exponentially as the depth to the wetting front increases (i.e., d_s increases)
- For $K_s = 10^{-7}$ m/s and $K_i = 10^{-9}$ m/s; K_a approaches 10^{-6} m/s as the depth to the wetting front (d_s) approaches 1 m and,
- As d_s increases, the effect of the manure seal layer decreases.

2.7 The Reliability and Integrity of Soil-Manure Seals

De Vries (1972) observed improved permeability associated with aggregation of sand filters upon drying after inundation with municipal sewage. He noted an increase in hydraulic conductivity of the clogged soil layer of about two orders of magnitude. Chang et al. (1974) also observed that the K_s values of cores submerged in dairy manure for up to 64 d rebounded to their original levels or higher upon drying. Hence manure seals may be compromised upon drying. Since the sidewalls of most operational EMS ponds are exposed for a good portion of the year, it is logical to conclude that soil-manure sealing alone cannot be relied upon to prevent seepage from EMS ponds because of temporal variations in seal integrity. Reese and Laudon (1983), in a review of the literature on lagoon seepage, identified the term "initial flush" to describe the movement of contaminants following the initial loading of animal manure lagoons prior to the development of an effective seal. Phillips and Culley (1985) stated that the "initial flush" phenomenon may actually take place between fillings in experimental scale EMS ponds that were left empty to simulate normal farm operating conditions. They attributed the occurrence of the flush phenomena between fillings to weathering effects that cause the manure seal to crack and allow seepage into the underlying soils.

McCurdy and McSweeny (1993) studied the mechanisms responsible for contaminant transport through the side slopes of EMS ponds. They concluded that physiochemical and biological mechanisms were responsible for creating macropores capable of providing pathways for preferential flow. These pathways, they claimed, can significantly affect the long-term viability of earthen-lined manure storage basins. Parker et al. (1999) observed macropore development in the sidewalls of a 22-y-old beef feedlot pond. The high variation of hydraulic conductivity measurements on pond sidewall samples suggested that preferential flow was occurring through these macropores. Soil chemical analysis indicated that sidewall seepage was greater than that through the bottom of the pond. McGauhey and Winneberger (1964) presented evidence that positive drainage of clogged soils will create the aerobic conditions required to induce at least a partial recovery of infiltration capacity. If macropore development on the sidewalls of EMS ponds was substantial, it could conceivably result in sufficient internal drainage of the soils there to generate the aerobic conditions required to initiate breakdown of manure clogged soils.

De Tarr (1979) found that infiltration rates decreased as temperatures increased and increased as temperatures decreased. Barrington et al. (1987a), Fonstad (1996a) and Maule et al. (1999) also recorded a large increase in conductivity in all columns during a short period of cooling system failure during their temperature controlled experiment. De Tarr (1979) and Barrington et al. (1987a) attributed increased seepage rates during warming periods to agitation of the manure mat by air bubbles generated by fermentation of the manure solids. The integrity of the manure mat was thought to have been compromised as entrapped air bubbles were released though the manure mat, causing temporary preferential flow paths through the seal. Other researchers have also hypothesized that air bubble entrapment and release could be one of the mechanisms that compromises the integrity of soil-manure seals (Chang et al., 1974; Ciravolo et al., 1979).

Fonstad and Maule (1996a,b) investigated an EMS pond with a 0.6-m thick compacted clay liner constructed over coarse and gravel materials. They suggested that freeze-thaw action affected the integrity of both the liner and the manure seal, allowing seepage to travel up to 20 m below the floor of the EMS over about 20 y of operation. Benson and Othman (1993) and Othman et al. (1994) showed that freeze-thaw action can increase the hydraulic conductivity of compacted clay liners by three to four orders of magnitude. Fonstad (2000) reasoned that a manure seal could be similarly compromised if it were exposed to the weathering effects of extremely low temperatures.

Barrington et al. (1987a) reported that sandy soils with initial infiltration rates as high as 1.0×10^{-4} and 6.0×10^{-5} m/s demonstrated a reduction in hydraulic conductivity to the 10^{-8}m/s range after 2 weeks in small-scale reservoir studies. These soils demonstrated similar reductions after 2 d of ponding in laboratory column studies. Tests revealed that seepage rates from the reservoirs had been significantly reduced after 52 – 54 weeks of manure ponding and both the reservoirs and the soil columns demonstrated hydraulic conductivity measurements in the 10^{-9}m/s range after one year of submergence. Nonetheless, this example is instructive as to why many engineers have expressed concerns about the potential danger associated with extrapolation of results from soil column studies directly to the field.

2.8 Geophysical Investigations

Over the years many EMS ponds have been constructed without the benefit of proper siting investigation, engineering design or construction supervision. These lagoons were commonly constructed without any type of seepage protection liners other than the natural protection afforded by the native soils and local hydrologic conditions. Today, the industry is beginning to recognise the importance of siting, design and construction to the environmental safety of these common structures. This has led to the recognition of the need to assess the potential environmental impact from existing EMS sites throughout Alberta. The large number of established EMS sites represents a significant challenge since traditional investigation technologies are slow and expensive. Therefore, to accomplish this goal, the need for a fast, effective and inexpensive method of seepage investigation was recognized.

Some investigators have had success tracking seepage plumes from EMS ponds with the use of non-intrusive electromagnetic geophysical techniques (Brune and Doolittle, 1990; Drommerhousen et al.; 1995, Huffman and Westerman, 1995; Larson et al., 1997 and Eigenberg et al. 1998). Based on this knowledge, a cooperative pilot project was initiated to investigate the use of geophysical techniques to investigate seepage and groundwater contaminant movement from EMS ponds under Alberta conditions (Guy et al., 2000). That project, conducted in 1997/98, originally screened 10 Alberta EMS ponds for the presence of seepage plumes using a minimum drilling and analysis program. Three of the sites suspected of leaking were identified for a more detailed investigation, which included geophysical investigation and mapping using the Geonics Ltd. EM 31, EM 34-3 and EM 38. Electrical Resistance Tomographic (ERT) techniques were also employed to obtain cross-sectional data across the locations of the suspected plumes. Results from the EM and ERT surveys were quickly produced in the field in the form of colour-coded site maps that indicated the level of bulk soil electrical conductivity (EC) around and through each site.

Subsurface electrical conductivity anomalies detected by the EM and ERT instruments were interpreted as being seepage plumes. Conventional soil and water analyses were used to confirm that the high EC levels detected by the EM and ERT instruments were actually seepage plumes from the EMS ponds. Elevated levels of NH_3-N, Cl and EC were considered indicative of the presence of liquid hog manure seepage (Westerman et al., 1993a,b). The investigators concluded that the instruments demonstrated varying abilities to detect contaminated seepage plumes from EMS ponds. Furthermore, all the seepage plumes discovered in the pilot study were of limited extent and severity. The researchers speculated that this fact, combined with the observed spatial selectivity of the plumes, indicated that seepage patterns might be affected by preferential flow along soil fractures, soil and bedrock contact features or other unidentified soil anomalies. Results from the pilot scale investigation indicated that a more thorough evaluation was needed to determine the value of EM survey data for the investigation of seepage from EMS ponds. They recommended that further investigation of the EM techniques was warranted to determine if these geophysical technologies could be used to reliably indicate the existence of seepage plume patterns. They also recognised the need to better understand the mechanisms of seepage from these structures in order to develop a protocol for interpretation of geophysical investigation results.

2.9 Summary

The scientific literature on the topic of the seepage and contaminant transport potential of EMS structures is contradictory and can lead to conflicting conclusions. Many investigators have provided evidence that some seepage and contaminant movement can be expected through the bottom and sides of EMS ponds due to advection and diffusion (Collins et al., 1975; Miller et. al., 1976; Sewell, 1978; Ciravolo et al., 1979; Ritter et al., 1980; Dalen et al., 1983; Phillips and Culley, 1983; Culley and Phillips, 1989a,b; Westerman and Huffman, 1993a,b; Korom and Jeppson, 1994; Huffman and Westerman, 1995; Betcher et al., 1996; Fonstad and Maule, 1996 and Maule and Fonstad, 1996). Other researchers have shown that manure/soil interactions can create a "seal" at the surface of the floors and side walls of lagoons and EMS ponds that prevent seepage of liquid manure from EMS ponds and lagoons (Davis et al., 1973; Chang et al., 1974; Baier et al., 1974; Hills, 1976; DeTar, 1979; Culley and Phillips, 1982; Miller et al., 1983; Rowsell et al., 1983; Barrington et al., 1987 a,b; Maule et al., 1999).

The investigations concerning soil and groundwater quality listed above have demonstrated elevated levels of ammonia, nitrates, potassium, chlorides and fecal bacteria below and adjacent to EMS ponds. On the other hand, much of that data shows that levels of the groundwater contaminants tend to vary widely with depth, location and timing of sampling for any given EMS pond or indicator species. Furthermore, the research also indicates that, while some movement may occur through the bottom of an EMS pond, the majority of seepage and contaminant flux tends to occur through the sidewalls (McCurdy and McSweeney, 1993; Westerman et al., 1993a,b; Huffman and Westerman, 1995 and Parker et al., 1999).

Fonstad (1996a) reviewed the literature and conducted laboratory studies of soil clogging by ponded hog manure. He concluded that specifying a depth of "sealable soil" as a design criterion for EMS ponds "appears to be a misinterpretation of the mechanisms involved in the reduction of hydraulic conductivity due to manure". He used hydraulic analysis to demonstrate that increasing depths of saturated soil beneath EMS pond bottoms will eliminate the reduction in "apparent" hydraulic conductivity (K_a) shown to be effective at the laboratory scale. He showed that the difference in K_a caused by advancement of the wetting front below an EMS pond can result in up to a 10-fold increase in the seepage rates from even a well "sealed" pond.

Dye et al. (1984) suggested that while livestock manure provides significant beneficial self-sealing on the bottom and sides of lagoons and holding ponds, this phenomenon should not be counted on as the sole means of protecting groundwater. Fonstad (2000) conducted a comprehensive review of the literature to assist with the development of siting and design standards in Western Canada. He concluded that proper siting is paramount to constructing an environmentally secure EMS pond. He also suggested that while manure does have a natural sealing effect on most soils, it should not be counted on as the sole means of seepage protection.

All negative impacts on groundwater due to EMS seepage may be of concern; nitrate movement is of primary concern. Fortunately, movement of this N species does not appear to be of immediate concern during operation of the EMS due to the anoxic, chemical reducing conditions present below EMS ponds during their operation (Fonstad, 2000)[3]. However, Miller et al. (1976, 1985) and Culley and Phillips (1989) concluded that oxidation of accumulated ammonium beneath liquid manure ponds presents a threat to groundwater quality following decommissioning of the pond. An abandoned long-term EMS pond studied by Fonstad and Maule (1996a,b) showed nitrogen oxidation within two years of abandonment. Further support to this theory was provided by modeling studies conducted by Barbour (2000) who also concluded that post-decommissioning contaminant plumes have the potential to cause serious environmental impact.

In summary:

- The literature is contradictory concerning the integrity and reliability of manure seals under field conditions.
- Some researchers have found that EMS ponds leak under some circumstances.
- Solute movement in soils beneath and adjacent to EMS ponds is highly dependent on the geologic conditions and soil texture and structure.
- The sporadic flow patterns coupled with detection of pathogenic bacteria within groundwater samples may be symptomatic of preferential flow through soil fractures or coarse soil lenses.
- Fonstad (1996a) demonstrated that a thin manure seal has a minimal effect on the seepage hydraulics of field scale ponds.
- Spatial and temporal variations of seepage from EMS ponds may be indicative of periodic manure seal failure.
- Soil-manure seals either do not form effectively or are deteriorated by weathering or other factors that compromise their ability to prevent seepage and contaminant movement.
- Evidence that soil clogging may be inconsistent and somewhat unreliable under field conditions suggests that a healthy scepticism of the so-called "sealing" effect is warranted.
- The combination of anaerobic conditions and cation retention likely results in the accumulation of high concentrations of NH_4 ions immediately below the bottoms and sides of EMS ponds.

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[3] Fonstad, T.A., 2000. Personal communication. Assistant Professor, Department of Agricultural and Bio-Resource Engineering, University of Saskatchewan, Saskatoon

- Nitrogen accumulation below EMS ponds during their operation may become a problem upon abandonment of the facilities if proper reclamation is not carried out.

2.10 Study Parameters

2.10.1 EMS Characteristics

Volumes and dimensions for all EMS ponds in the study were obtained through field measurements and discussion with the producer. The information provided by the producer was checking by matching standard manure production data with producer testament on observed storage periods and volumes (Table 2.3) The age of the pond can be calculated by subtracting the year built from the year tested (i.e., 1999/2000). The data are important to develop observations and comparisons between rates of seepage and contaminant movement observed in the field and those expected from theoretical considerations alone.

2.10.2 Purpose

This research evaluates the hydrogeologic integrity of earthen manure storage ponds in Alberta. Five hog EMS ponds constructed using traditional practices located in Central Alberta were investigated. Movement of manure-related contaminants adjacent to the EMS ponds was evaluated using an EM 31 and traditional soil and water analysis techniques. Physical characteristics of each site were determined using existing data sources and site-specific soil data. Remote data sources were compared to those determined from site-specific investigations to determine the reliability of the former data sources for site characterization. This research also investigated the validity of using the EM 31 to detect suspected seepage from established EMS reservoirs and its utility to help design more efficient soil and water investigation programs of potential seepage from EMS ponds.

Fonstad (1996b) recommended that more emphasis be placed on analysis of geologic site characteristics for the siting and design of EMS ponds. As a result considerable effort was made in this study to define the surficial and bedrock geology and the soil and hydrogeologic characteristics for the sites. Data sources used for this exercise include topographic maps, aerial photography, water well records, quaternary geology, hydrogeology maps and soil inventory database.

2.10.3 Objectives

The objectives of this study are as follows:

1. To determine the extent of seepage and contaminant transport from five EMS ponds located on a variety of soil and geological site conditions typical of Alberta hog operations.
2. To determine the factors that contribute to any seepage or contaminant transport encountered.
3. To determine if existing remote data sources can be effectively used to characterize the physical site conditions that affect seepage and contaminant transport from EMS ponds.
4. To determine if the Geonics EM 31 electromagnetic inductance conductivity meter can be used effectively to assess seepage and contaminant movement from EMS ponds.
5. To determine if the results from geophysical investigations using the Geonics 31 electromagnetic inductance conductivity meter are useful in the design of traditional soil and water investigative drilling programs for investigating potential seepage and contaminant transport from EMS ponds.

Table 2.1 Summarization of data and results from EMS seepage studies and the evaluation of manure as a soil sealant

Source	Soil Texture	Infiltration rate H_2O (m/s)	TS (%)	Infiltration rate of liquid manure (m/s)	Comments by Source (experiment information)
Hart (1965)	sandy loam poultry, dairy and swine	7.93e-7 to 3.23e-7 7.64e-7 to 5.00e-7 2.94e-7 to 1.47e-7	2.5 to 20 (p) 3.8 to 8.3 (d) 2.0 to 6.0 (s)	2 years 6.17e-7 to 2.94e-8 3.52e-7 to 2.06e-7 1.76e-7 to 1.17e-7	'no biological sealing" dairy manure in small scale lagoons
Davis + (1973)	sandy loam	1.39e-5	-	2 wk.: 6.75e-7; 4 mos.: 5.89e-8	'ponds effectively seal' Dairy manure in small scale lagoons
Robinson (1973)	layers of clay loam, silty clay loam and clay	1.31e-6	-	3 mos.: 6.44e-8; 6 mos.: 3.5e-8	'majority of seepage rate reduction within first 3 weeks' Beef manure in small scale lagoons
Baier+ and Meyer (1973)	various soils in 9 ponds, sand to loam	6.9e-7 to 4.9e-6	0.7 to 2.5	<1.17e-8 (all soils)	'all soils sealed', clay soils sealed in 10 days, loamy sand in 50 days
Chang* (1974)+	silica sand sand loam silty clay	Ks* 3.97e-5 6.22e-6 1.94e-6 6.67e-7	-	7 days*: 1.74e-5, 9.44e-8, 1.28e-7, 1.06e-5; 17 days*: 6.39e-5, 2.08e-8, 1.72e-8, --------++	'complete sealing' Dairy manure in implanted columns under field scale lagoon
Hills ' (1976)	Loam clay loam silt loam sandy loam	2.75e-8 5.00e-9 7.78e-8 8.25e-8	0.5 to 0.6	7 days: 2.4e-8, 4.72e-9, 4.28e-8, 6.11e-9; 4 mos.: 8.06e-9, 2.78e-9, 1.11e-8, 1.03e-8	'the amount of infiltration and pollutants increases by soil type as follows: clay loam, loam, sand loam, silt loam' Dairy manure in large scale columns

Table 2.1 Continued. Summarization of data and results from EMS seepage studies and the evaluation of manure as a soil sealant

Source	Soil Texture	Infiltration rate H_2O (m/s)	TS (%)	Infiltration rate of liquid manure (m/s)		Comments by Source (experiment information)
Lo (1977)	Sand Loamy sand Loam Silt loam Clay	- 1.11e-4 6.92e-6 1.07e-6 -	5.0 to 6.0**	27 weeks 4.51e-9 5.55e-9 5.43e-9 7.41e-9 3.47e-9		'Bottom sealing (*for all soils*) is very effective' Average final K_s after ponding was about 4 orders of magnitude lower' Fresh dairy manure mixed 2:1 on pre-compacted laboratory columns
Cully and Phillips (1982)*	Sand Loam Clay	1.7e-4 3.12e-5 4.7e-5		10 Days 1.76e-8 1.57e-8 1.57e-8		'very rapid declines in conductivity' 'sand had fastest sealing rate' Liquid dairy manure in laboratory columns
Barington and Jutras (1983)	Sand Loam Clay	1.00e-4 1.00e-6 1.00e-5		2 weeks 2.65e-8 1.7e-8 -	52 weeks 8.90e-9 0 6.90e-9	'sealing was instantaneous and effective for all sites,...' small scale field reservoirs with dairy manure and soil columns
Rowsell (1985)	Sandy Loam Loam Clay	-	5.0	10 min 1.90e-6 3.24e-6 1.52e-7	30 days 1.10e-8 9.94e-9 4.08e-9	'all soils were sealed after 30 days 'sealed' is defined as having an infiltration rate of 10^{-8}m/s Beef manure in laboratory columns
Barrington et al. (1987a)	Coarse Sand Loam Clay Sand over Clay	3.0 6.0e-5 3.0e-6 9.25e-6 1.5e-5 (sand)	10	0 2 wk 1.0 2.0e-8 2.4 2.9e-8 - 2.4 2.9e-8	52 54 wk 0 1.4e-8 ++ 0 1.8e-8 7e-9 2.3e-8	"Excellent surface sealing' Meets Ontario and Quebec environmental reg.'s ($\leq 10^{-8}$ m/s) Small scale reservoirs under field conditions and soil columns

*Actual measured saturated hydraulic conductivity; ** calculated from fresh as excreted (Krider, 1992) diluted 2:1; + adapted from De Tarr (1979); ++ not detectable with method used; - not reported

Table 2.2 Summarization of data gleaned from Fonstad and Maule, 1996. Soil classifications are Unified Soil Classification System.

Site # (# cells)	Cl^- Plume Detected*	Soil		[Cl^-] mg/l (d = m)		[NH_4^+] mg/l (d = m)	
		Classification	Description/Liner/Age	Below**	Beside**	Below	Beside
1 (1-stage)	Yes	SC and CH	Sand w/clay lenses. No liner. 11 yr.	> 500 mg/l to 1.4 m	> 500 mg/l to 2.0 m	>1000 mg/l to 1.0 m	>1000 mg/l to 1.6 m
3 (1-stage)	No	CL (8 12% clay)	Uniform. 600 mm clay liner. 4 yr.	> 100 mg/l to 0.5 m	> 100 mg/l to 0.6 m	> 100 mg/l to 0.45 m	>100 mg/l to 0.4 m
7 (1-stage)	No	Cl (20% clay)	Layered/fractured. No liner. 11 yr.	≥ 150 mg/l to 1.4 m	> 200 mg/l to 1.4 m	350 to 50 0 mg/l <d> 0.4	180 mg/l to 10 0 <d> 0.4
15 (2-stage)	Yes	SC - CL	Layered silty till. 500 mm liner. 5 yr.	> 300 mg/l to 1.0 m	>200 mg/l to 1.8 m	480 to 500 0<d>0.8	> 300 mg/l to 0.6 m
21 (2-stage)	Seepage to 7.5 m below bottom	SP SW (Liner CL)	Course soils. 600 mm liner of 10 20% clay material. 20 yr.	>BG *** levels to 9.0 m depth		>BG *** levels to 8.0 m depth	
22 (1-stage)	Seepage to about 2.0 m below bottom	Cl (20% clay)	Layered/Fractured. No liner. > 20 yr.	>1000 to 5.0 m depth		>BG *** levels to 2.0 m depth	

*Elevated concentrations of chloride ions detected in groundwater indicating transport of contaminants away from the site.

**Below and Beside refer to measured concentrations of solute ions and the depth to which they were measured in the soil.

*** BG means background levels assumed from observation of apparently unaffected soil cores

Table 2.3 Manure storage data summarized for all study sites.

Site	Year Built	Op. Type*	Spread Time**	# of Animals	Dimensions L x W x D	Side Slopes	EMS Volume	Monthly Production	Storage Period
					(m)		(m^3)	(m^3)	Months
1	1985	F-F	Fall	260	46x44x4	1:1	6800	512	13.3
2	1991	F-F	Fall	120	32x27x3.5	1:1	2400	236	10.2
3	1989	F	Fall	700	50x25x3.5	1.5:1	3400	147	23.1
5	1980	F-F	Fall	150	35x35x4	1.5:1	3400	296	11.5
8	1983	F-F	Fall	110	74x27x2.5	2:1	4100	217	18.9

*Operation type:
F-F = Farrow to finish.
F = Feeder/Finishers.
** Spread Time is the time of year that manure is normally applied to fields.

3.0 Research Methods

3.1 Site Selection

Just over 100, pre-screened potential study cooperators were identified by Alberta Agriculture Food and Rural Development at Red Deer. These producers were known to be actively producing hogs and using an EMS pond to store liquid hog manure. About 35 sites were arbitrarily chosen from this data set as candidates for an EM 31 survey to delineate possible contaminant plumes emanating from the EMS ponds according to mapped soil electrical conductivity readings. Patterns of elevated conductivity levels were used in the design of conventional drilling investigation programs at these sites.

Four of the 35 sites surveyed with the EM 31 displayed unusual EM signatures. These four sites and another four sites that showed no indication of contaminant movement were selected for preliminary investigation. The sites with no anomalies within the EC surface contours were investigated to determine the reliability of the EM 31 to predict contaminant movement from EMS ponds. All eight sites had either three or four piezometer nests installed in a triangular pattern downslope and one positioned upslope of the EMS.

The number of soil sample sites around the EMS pond was limited to three due to budgetary constraints. Soils were analyzed for soil chemical characteristics indicative of manure seepage and soil physical characteristics that permitted estimation of hydraulic properties (i.e., particle size analysis, bulk density, plasticity, etc). Samples sites were positioned to determine the difference between "background" soil chemistry and that downslope of the EMS pond. The "background" sample site was located as much upslope of the EMS pond as was physically possible, depending on site conditions, yet close enough that it would be expected to have soils similar to those near the EMS. Two downslope sample locations were chosen, one immediately below and another somewhat further away, again depending on site conditions, to determine the extent of plume migration downslope of the pond.

Based on the preliminary data collected at each of the eight sites, three sites were eliminated. Site 4 was eliminated because a burial site for dead pigs was affecting the background soil and water sample chemistry. This site also displayed artesian groundwater conditions downslope of the EMS pond. The combination of these two conditions complicated data interpretation. Site 6 was eliminated because the cooperator became reluctant to participate after initially agreeing to participate in the study. The soil texture at Site 7 was heavy clay and no water was found in any of the observation wells during the first observation and no seepage was indicated by either the EM 31 survey or interpretation of soil chemistry profiles. For these reasons and the excessive time, money and effort required to investigate this site due to its location, it was eliminated from the study. This thesis reports on the results from the remaining five sites.

3.2 EM Survey Methods

Electrical conductivity (EC) is an indirect measure of soil and soil pore water salinity. The electrical conductivity of the subsurface is generally a function of soil texture, water content, metal content, soil porosity and pore water quality. In areas of relatively uniform soil type, changes in subsurface electrical conductivity can be attributed to changes in pore water quality or metal content. In areas where the soil and pore water have increased concentrations of dissolved salts, the electrical conductivity will increase. The presence of metals or other highly conductive material will produce a large response in the in-phase component of the received signal. This in-phase response is also sensitive to bulk conductivity changes, but its ability to detect metals makes it useful in the field.

The Geonics EM 31 terrain conductivity meters use electromagnetic induction to obtain measurements of the electrical conductivity of the shallow subsurface (McNeill, 1980). Electrical magnetic inductance (EM) techniques transmit a time-varying magnetic field into the earth, which induces electric current flow into conductive subsurface materials, which in turn affects a secondary magnetic field that can be sensed as it radiates back to the surface (Bentley et al., 1996). By passing an alternating electrical current through a transmitter coil, a time-varying electromagnetic field is induced, which generates electrical eddy currents within the ground. These eddy currents then generate secondary electromagnetic fields that are detected by a receiver coil. The received signal is converted into a reading of conductivity given in mS/m (milliSeimens per meter) units. This value is the bulk electrical conductivity of a hemispherical volume of the subsurface. The EM 31 was operated in the vertical dipole mode because this mode has minimal response to materials within the surface 1.0 m of soil. Peak response in this mode is to depths of 1.5 to 1.8 m. The instrument responds in a negative linear pattern from the peak response depth to its maximum exploration depth of 6.0 m (Figure 3.1).

The EM 31 has been used in other industries for mapping shallow groundwater contaminant plumes where the contaminants are known to be highly conductive or resistive (McNeill, 1983). Resistivity and conductivity surveys are considered the most applicable methods to detect inorganic groundwater plumes from contaminated sites (CCME, 1994). Groundwaters typically found in glacial deposits in the Interior Plains region of Canada and the United States are slightly alkaline brackish with relatively high total dissolved solids (TDS) ranging from 1000 to 10,000 mg/L (Cherry, 1972; Davison, 1976 and Grisak et al., 1976). Fitzgerald (1999) showed that the average TDS content of shallow groundwater found in shallow aquifers in Alberta was about 1100 mg/L. Fonstad (1995) indicated that the TDS content of the hog manures was about 15,800 mg/L. Guy et al. (in progress) found the average EC of liquid hog manure taken from 10 Alberta EMS ponds to be just over 17,600 mS/m (Table 3.1).

The TDS (mg/L) of a water-based electrolyte is linearly related to its EC (mS/m) and may be approximated by the following equation (Dudas, 1997)[1]:

$$TDS = 640 \times EC \qquad EQ.3.1$$

[1] Environmental Soil Chemistry 450, Class Notes, Dept. Renewable Resources, University of Alberta

The calculated TDS for these samples would be 11,000 mg/L (±2300 mg/L), which is many times higher than levels expected for natural shallow groundwater in the study area. Therefore, a leachate plume resulting from seepage of manure from an EMS pond should be distinguished by its contrast with the expected in situ background conductivity of shallow soil water.

EMS ponds are usually between 3 and 5 m deep, which matches well with the 1 to 6 m operational sounding depth of the EM 31. Therefore the EM 31 should be ideally suited for detection of down gradient contaminant plumes emanating from an EMS pond. Other benefits of the EM 31 are that it is lightweight, portable and can be operated, hands free, by a single operator. The operator is able to observe and record ground conductivity readouts while walking about the site at a normal pace.

3.3 EM Field Method

A scaled site sketch was prepared of the EMS pond and surrounding area prior to conducting the EM survey using aerial photographs. The area for survey and the approximate frequency of readings was also predetermined. During the survey, EM readings were written on the sketch at approximately 3 - 4 m intervals. The position of the readings was determined by observation of landmarks on site relative to the site sketch. Typically 3-4 sets of readings were taken, beginning at the inside top of the berm. The survey was then gradually extended in a circumferential pattern away from the EMS pond to the outside top and toes of the berm. Readings were also taken downslope of the manure pond to between 20 and 30 m, depending on site conditions. Extra readings were taken in unusual areas such as wet spots, grassed waterways and in areas where anomalous readings were noted.

3.4 Electrical Conductivity Surfaces

EM data points were digitized onto an orthorectified airphoto of each site surveyed by visual interpretation of the data point locations plotted onto the site sketch used in the field. Kriging was selected as the most appropriate geostatistical method for creating surfaces since data points from the survey were irregularly spaced. Parks and Bentley (1996) described ordinary kriging as an interpolation scheme that estimates the value of a spatially correlated, or regionalized, variable at an unsampled point by a weighted linear combination of neighboring known values. The equation used to estimate the unknown points is:

$$z^* = \sum_{i=1}^{n} \lambda_i z_i(x) \qquad Eq.3.2$$

Where z* is the estimate and 8$_i$ are the individual kriging weights assigned to the n neighboring sample values. z_i (x), used in the estimate. To ensure that z* is a

$$\sum_{i=1}^{n} \lambda_i = 1 \qquad Eq.3..3$$

unbiased estimator (i.e.. the expected value of the residuals, E [z*(x)-z (x)] =0) the weights are chosen so that:

Ordinary kriging requires a model of the spatial continuity of the regionalized variable (Parker and Bentley, 1996). The variogram expresses the spatial continuity of the regionalized variable, z, as a function of the distance separating any two points. This distance, h. is also known as the "lag" vector. It is the maximum allowable value that limits the use of known point values (i.e., z(x)) positioned too far away from the estimated values location (i.e., z*)). The point of inflection of the variogram curve where it flattens out and becomes horizontally linear defines the limiting lag distance. This point is known as the "sill" of the variogram curve.

The electrical conductivity surfaces were created using a Universal Linear Kriging interpolation script installed in ARCView v.3.1 Spatial Analyst Extension. All surfaces have a 1-m grid cell size and are projected to an Alberta 10 Transverse Mercator NAD 83 projection. The program calculates the variogram for the data set and then allows a variable data search to find all known data points within the sill value of the variogram. This limits the number of neighboring points used to calculate the estimated value for any one unknown point (i.e., n in equations 3.2 and

3.3). The program allows point search values between twelve and fifteen radius counts; a value of twelve was used consistently. To avoid calculating too far beyond the edge of the available data, a barrier polygon was created around each set of EM 31 data points. Use of a barrier polygon prevented inclusion of outlying data points and related adverse effects to the created surfaces. Variogram grids created for each surface indicate the level of confidence in the data at any point within the created surface. Observation of the sample variogram (Fig. 3.2) demonstrates that confidence levels decrease with distance to the data points. The EM surfaces created using these techniques are presented as part of the site location plan at the beginning of the results and discussion sections for each site location investigated.

3.5 Background Resource Data

Remote data sources are often used to determine the physical characteristics of prospective hog development sites especially where EMS ponds are proposed. These data are used to evaluate the suitability of a proposed site and to determine the scope of the site-specific investigation required to fully characterize the site. Background resource data were reviewed for each site with a view to evaluate their suitability and reliability for the intended purpose.

Soil survey data (Nikiforuk et al., 1998), surficial geology maps (Shetsen, 1990), water well logs (Alberta Environment, 1998) and hydrogeological maps (Tokarsky, 1987) and other resource data were available for the area around the study sites. The data were reviewed to add to the site characterization information and to determine if that information is useful in understanding the hydrodynamic behavior of the manure storage pond at the site. An interest was also taken in the consistency of the data sources with each other and what was found during the on-site investigation. This would help to determine the value of site characterization data sources for siting manure storage facilities.

3.5.1 Soil Data

Soil survey data in Alberta are now delivered in digital format at the 1:100,000 scale in the form of the Agricultural Region of Alberta Soil Inventory Database

(AGRASID, Nikiforuk et al., 1998). This data source provides basic soil information such as morphological origin, texture, acidity (pH), cation exchange capacity (CEC), hydraulic conductivity and moisture holding capacity. Soil textures of the C horizon of the soil material mapped at each of the study sites was imported into the ARCView GIS environment for purposes of analysis and display. Soil particle analysis data were used to categorize the soil parent material into coarse medium and fine as well as peat and undifferentiated material. The site location was plotted onto a C-horizon texture map of the area and is presented as part of the site location plan at the beginning of the results and discussion sections for each site location investigated.

The soil quality data available for the C horizon soil materials for each of the soil series mapped for each site were extracted from the AGRASID database and the key elements of those data are presented in the section called remote resource data within each site investigation. This information was used for comparison to other remote data sources and site investigation results and is discussed for each site. Soil physical parameters from the soil survey files are compared to soil physical data from the site investigation to determine if soil survey data are a reliable indicator of physical soil properties. Hydraulic conductivity and bulk density data for the site were used with other data sources to determine potential flow and contaminant transport rates for each site. This information was used to help interpret the source of observed soil and water chemistry anomalies.

3.5.2 Surficial Geology

Alberta Research Council publishes maps of the quaternary (surficial) geology of Alberta. Shetsen (1990) constructed a map of the quaternary geology of Central Alberta based on field investigations completed between 1984 to 1986. The information available on this map was used as part of the site characterization exercise for each site. The data presented on the map provide the geologic period of origin, the mode of deposition and a general description of the texture, structure and expected thickness of the documented formation. Data from this map are especially instructive when considering the mode and character of the surface deposit as related to topographic features. These data are compared to information from other sources including soil survey, water well logs and site investigation data. Observations about the reliability of these data sources for site characterization are made.

3.5.3 Water Well Records

Alberta Environment has developed a digital database of all known water wells and investigative subsurface borings in Alberta prior to 1998. This database is available in Compact Disk format as the Groundwater Information Center Water Well Database (Alberta Environment, 1999). Data available include subsurface well log lithologies, static water levels, water well pumping rates and the depth of water bearing formations. The data are useful to determine overburden textures and depths as well as bedrock elevations and type. The data were used for comparison to other data sources and to help characterize the EMS pond site. Observations are made about the reliability of the data source and its usefulness for purposes of characterizing prospective EMS pond sites.

3.5.4 Hydrogeologic Cross-Sections

Hydrogeologic cross-sections for Alberta, available from Alberta Environment (Tokarsky et al., 1987), are useful to determine overburden textures and depths, bedrock elevations and type and expected water yield and chemistry. The data can be compared to water well records as well as soil survey, surficial geology and site investigation information. The cross-section data were analyzed to determine their reliability and usefulness for site characterization for planning and performance prediction for prospective EMS ponds.

3.6 Site-specific Investigation

3.6.1 Soil Data Collection

A one-ton truck equipped with a drill rig equipped with six 102-mm diameter, 1.5-m long augers was used to complete soil borings and sample collection at each of the eight preliminary sites. All soil samples were taken from the auger flights during the drilling process and, as such, are considered to be disturbed samples. Attempts were made to take undisturbed core samples of the soils from the nearest borehole downslope of the EMS pond using 63.5-mm split spoon core sample tubes driven hydraulically by the drill rig. Sample cores should have been useful to obtain soil bulk densities and hydraulic conductivity values. However, due to the nature of the equipment used and the soils encountered, all of the recovered core samples were either compressed or fragmented. Since it was not possible to obtain undisturbed cores, tests for bulk density and hydraulic conductivity were run on reconstructed soil samples.

All boreholes were constructed and field logged to a depth of 7.6 m or to auger penetration refusal. Field soil logs were constructed in the field as the auger with the soil cuttings was extracted from the hole. Field records included visual descriptions and hand texture analysis and noted structural anomalies, water-bearing streaks/fractures and suspected morphological origins. One borehole was placed upslope of the EMS to obtain background samples for subsequent laboratory analysis. Downslope boreholes were placed within the anticipated location of the plume. Sample locations were placed in a triangular pattern to accommodate interpretation of local groundwater hydraulics from piezometric observation wells that were installed into the boreholes subsequent to sample procurement.

3.6.2 Soil Sample Protocol

Soil samples were taken from boreholes at three or more locations at each site for subsequent chemical and physical analysis. Grab samples of soil cuttings were taken from the auger flights for approximately every 0.9 m of soil extracted from the borehole. Sample depths were varied somewhat at each sample site location depending on where soil texture and structure transitions were observed during field logging procedures. Additional samples were taken from the other boreholes where unusual texture or moisture patterns were encountered. Samples were normally taken from the upslope borehole for background purposes, from one borehole immediately downslope of the EMS pond or on the berm within the suspected plume footprint and from the borehole farther downslope of the berm in the direction of the suspected plume footprint.

3.7 Sample Preparation and Analysis

Samples were collected in 2-L zip lock style bags provided by AGAT Laboratories and kept in a cool environment until delivery to the laboratory. No further preparation was required for preservation of the analytes. Soil analysis parameters and references for the methodologies used are listed below (Table 3.2).

3.8 Piezometer Design and Construction

Piezometers were installed at the soil sample borehole locations at each site, which were placed to bracket the suspected plume position. One borehole and piezometer nest was placed upslope of the EMS to obtain background samples of the natural shallow groundwater for the area for comparative purposes. Downslope of the EMS pond, a triangular pattern was used to assist in the interpretation of groundwater gradient and flow direction. Where anomalous signatures were present, the EM survey results were used to position the boreholes. Where no indication of a plume was presented through interpretation of the EM survey results, groundwater gradients were assumed to be topographically controlled, so the boreholes were located immediately downslope of the EMS pond. Typically, two to three boreholes were located along the edge of the toe of the berm and within the suspected plume. An additional one to two piezometer nests were installed further downslope of the upper nests and placed to yield a triangular pattern amongst the piezometer installations.

Piezometer tips were constructed of 500-mm long, 50-mm diameter, 0.002 slot PVC pipe (Figure 3.3). An adapter was connected to the top of the piezometer screen to fit the larger piezometer screen pipe to an 18-mm PVC riser pipe that extended to above ground surface. Piezometer tips were back filled with 1020-silica sand approximately 0.6-m deep. Bentonite chips were used to plug the holes to protect them from surface water intrusion. The silicone sand pack was capped with about 50 mm of soil in an attempt to buffer the water samples from the potential negative chemical effects due to leaching from the bentonite seal materials above.

Between two and four piezometers were installed at each sample location with the well screen (or piezometer tip) at different depths to allow water level measurement and sample extraction from the various soil layers encountered near the EMS pond. Tip locations were selected in the field, based on soil boring logs and, where applicable, were installed into saturated zones, sand streaks and at the interface of distinct soil layers. Where uniform soil conditions or dry holes were encountered, piezometer tips were placed at 2.5 m below ground level, at the midpoint of the borehole depth and at the bottom of the borehole. Piezometer locations generally coincide with soil sample locations but in some instances there are more of one than the other. Piezometer locations at each site are indicated on the site location at the end of each site investigation chapter.

Where possible, two piezometers were installed within one borehole in order to substantially reduce drilling time and expense at each site. When more than one tip was installed into a single borehole, care was taken to ensure that the piezometer screens were sealed off from each other. This was accomplished by physically packing the bentonite seal for the lower installation to ensure contact between the standpipe and the seal pack. Next, a soil "buffer" was packed onto the upper surface of the bentonite seal to prevent intrusion of salts from the bentonite contaminating the sample. After that, the upper observation well was installed as per the procedures given above. However, special attention was given to packing the bentonite seal above the upper piezometer tip and the soil surface due to the potential negative effect that the second stand pipe in the hole could have on the surface seal.

3.9 Water Sampling Procedures

The piezometers installed at each site were used to measure water elevations and to obtain samples of shallow groundwater near the EMS pond. Several weeks after piezometer installation, water depths within each piezometer were measured and used to calculate groundwater elevations and gradients. Several measurements of groundwater levels were taken over the monitoring period to determine if water levels were rising or declining relative to filling and emptying of the EMS pond and precipitation events, etc.

Following water level measurement, water was pumped out of each piezometer and allowed to recover. A single speed Masterflex™ portable peristaltic sampling pump with 5-mm silicon suction tubing was used to retrieve the water samples. The suction hose was flushed with distilled water after each sampling to prevent cross contamination of samples. Piezometers were flushed and allowed to recover twice, at approximately 2 - 3 week intervals prior to initiation of sampling. The hole was flushed to clean it of sediments and other potential contaminants that may have been introduced during the installation process. On the third visit, water samples were collected from the piezometers. At least 1.0 L of water sample was necessary as three separate 0.25-L samples were required for biological, routine chemical and nutrient parameter analysis. Care was taken not to extract water samples from the very bottom of the piezometer tip, as sediment that could contaminate the sample often accumulated there.

At least two sets of water samples were obtained from all five detailed study sites over the monitoring period. Three samples were collected from Site 8 due to availability. Three bottles (0.25-L samples) were collected for each piezometer at each location site. The routine water analysis sample required no special preservation procedure. The sample intended for nutrient analysis required the addition of a stabilizing sulfuric acid preservative that was supplied by the laboratory. The microbiological sample bottle was supplied with a bacterial preservative (sodium orthophosphate) that was added to the bottle prior to collecting the sample. All samples were kept chilled in a portable cooler pack with ice for overnight delivery to the laboratory.

3.10 Water Analysis

The chemical and biological parameters tested for the water samples retrieved from the piezometers at the study sites are listed in Table 3.3. All water analysis was completed by Norwest Laboratories Ltd. using standard methods that adhered to the

American Public Health Association, Standard Methods of the Examination of Water and Wastewater (Greenberg et al., 1999). Water analysis parameters were selected based on those tested in other similar studies of the effects of "lagoon" seepage on groundwater quality (Ciravolo, 1979; Ritter, et al., 1980; Culley and Phillips, 1989 and Huffman and Westerman, 1995).

Preservatives were used to treat the water samples used for analysis of microbiological and nitrogen compounds. Sodium thiosulphate is used to preserve the microbiological sample. Its function is to remove any residual chlorine that may be present due to treatment or from other sources. The sodium thiosulphate has no direct effect on the bacteria and will not alter the sample if it was not chlorinated. Bacteria in the sample can change the concentration equilibrium of nitrogen compounds (i.e., NH_4, NO_2, NO_3, NO, N_2, N_2O, etc.) as well as other nutrients. Sulphuric acid was added to the sample used to detect ammonia concentrations in the groundwater to lower the pH of the sample solution. Acidic conditions slow bacterial activity reducing transformation of ammonia between the time of sampling and the time of analysis. The remainder of the analytes are chemical parameters that do not change over time (e.g., Cl, pH, EC, P, etc.) and do not require any special preservation procedure. All samples were packed in portable coolers with ice packs to keep them cool and were transported over night via courier to the Norwest Labs for analysis.

3.11 Site Survey

Information gained from site inspection, airphoto interpretation and the EM 31 survey was used to identify potential soil sample and piezometer installation locations. The aerial photographs used to develop site location plans were orthorectified to enhance the accuracy of the positioning data for locating soil sample locations. Also in the interest of accuracy, the location of all soil sample and piezometer nest locations was identified with the use of a Trimble AgGPS 132, backpack style Differential Global Positioning System (DGPS) unit. The unit provides a horizontal accuracy of ∀0.5 m and real-time differential correction data are received via a geosynchronous satellite transmitter radio broadcast. The positions of the soil sample and piezometer locations were plotted onto the orthorectified airphotos with the benefit of this information.

Groundwater flow was assumed to follow the surface gradients so, except where anomalous EM 31 data suggested otherwise, soil and water sample sites were arranged in a triangular pattern downslope of the EMS pond. A background soil sample location was drilled at each of the study sites to identify background soil chemistry parameters. Where it was physically possible, the background sample site was located upslope of the EMS pond site. In some locations it was not possible to locate the "background" piezometer nests upslope of the EMS pond because access was limited access by buildings, terrain or owner permission. In these cases background piezometers were located to the side of the EMS pond, and as much upslope as possible given site constraints. In some cases the soil sample location was placed considerably upslope of the pond site due to the constraints.

EM 31 readings were taken using real-time DGPS at Sites 2 and 8. EC readings were synchronized to the real time DGPS positions by entering the EM reading into a spreadsheet on a HP palmtop computer running a Windows CE version of FieldWorker Pro. DGPS positions were sent to the computer in digital form via electronic cable link while EM readings were added to the spreadsheet manually through the palmtop keyboard. This procedure provides more accurate positioning of the EM 31 relative to the EMS pond site. A comparison of data display using manual digitization and DGPS positioning methods was conducted to determine the value of the extra cost and effort involved in using the DGPS procedure.

3.12 Engineering Survey

In spite of having a horizontal accuracy of $\pm$0.5 m, the DGPS has a vertical accuracy of only $\pm$2 m. As this level of accuracy is unacceptable for determine surface and groundwater gradients, traditional survey methods were employed. A total station survey instrument was used to determine relative elevations of the piezometers. A cross-section of the area above and below the EMS pond was also taken to determine the general slope of the landscape of the study site. Surveys included a line starting about 50 m upslope of the EMS pond, the top and toe of the berm where one was present, and continued down the prevailing slope about 30 m beyond the farthest piezometer nest.

3.13 Data Presentation and Analysis

Soil data are presented in tabular form for each study site. Discussion of these data revolves around a comparison of the different data sources. Conclusions are made about the reliability of remote data sources for determining on-site soil characteristics. The physical data were also used to estimate the hydraulic properties of the soil. The hydraulic soil properties were used, in conjunction with hydraulic gradient data, to estimate the potential migration distances for seepage water and potential soil and water contaminants downslope of the EMS pond.

Watertable elevation data are presented for each study site. Watertable elevation data were used to determine hydraulic gradients at each study site. These results are also discussed in terms of fluctuations over the monitoring period as they relate to lagoon level and seasonal variations.

The main chemical and biological indicator species considered pertinent to seepage of hog manure were analyzed, using studies by previous researchers in the field to guide analysis. Soil chemistry data are presented and the results discussed from each study site as concentrations vs. depth to reflect the sample intervals selected for each sample site location. Sample intervals are, at a minimum, for each 1.0 m of soil excavated. Where distinct layering was noted for the soil profile, sample intervals varied somewhat or extra samples were taken. Soil samples were taken from piezometer boreholes that were not logged at regular intervals where textural or moisture anomalies were noted in the field sample logs. Comparisons of soil chemistry data were made between the upslope or "background" soils analysis and what was found downslope of the EMS pond.

Data from the sample site location further downslope of the EMS pond are used to determine seepage migration distance. Where suspicious soil chemistry results were found, calculations were performed for a variety of hydraulic soil properties to determine the likelihood that the anomalies are related to seepage of manure from the EMS pond. This comparative analysis is also useful to verify the bulk hydraulic conductivity and porosity of the soils near the EMS. Glacial till soils often have internal features that promote preferential flow paths such as coarse texture seams or inter-till soil fractures related to layering or weathering processes. These features affect the hydraulic behavior of soils. Downslope soil and water quality data were used to verify the soil hydraulic properties and the presence or likelihood of preferential flow vectors. Water quality values at different depths and locations were compared to show if preferential flow vectors are causing exaggerated seepage migration relative to that expected from the equivalent porous media.

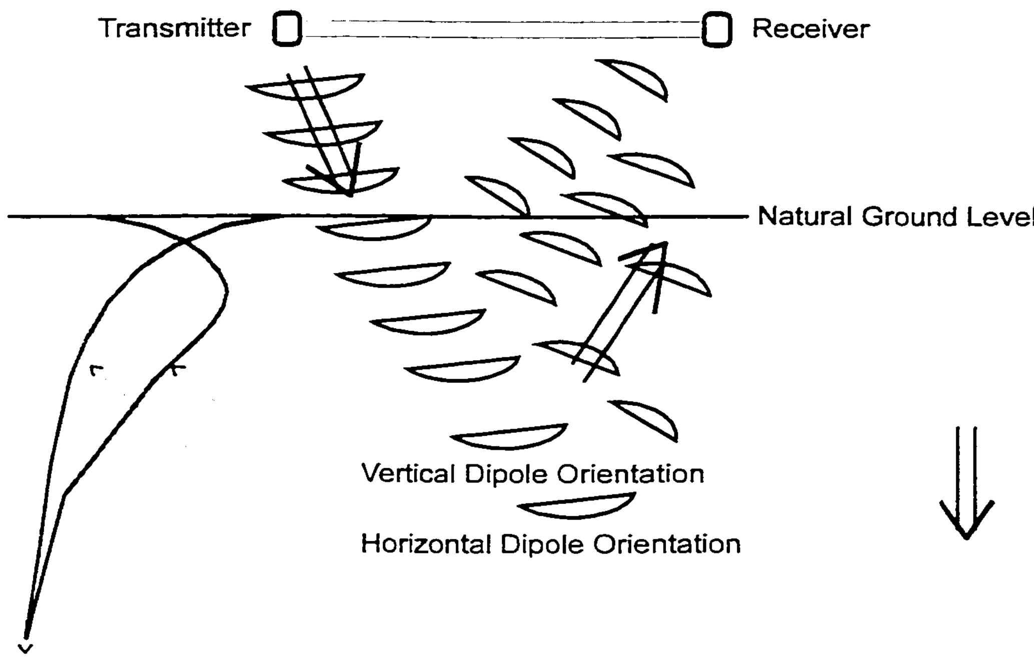

Figure 3.1 Schematic of EM 31 operation and instrument response relative to soil profile depth (adapted from Guy et al., in progress)

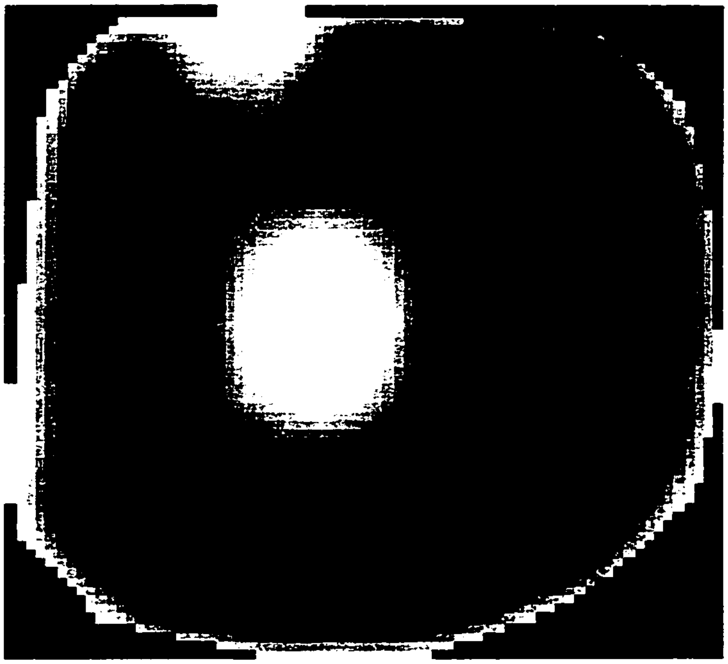

Figure 3.2 Variogram surface for Site #2. Darker areas indicate actual EM/EC sample points from survey, while increasing lighter colours indicate lower confidence in predicted values as related to distance from sample point.

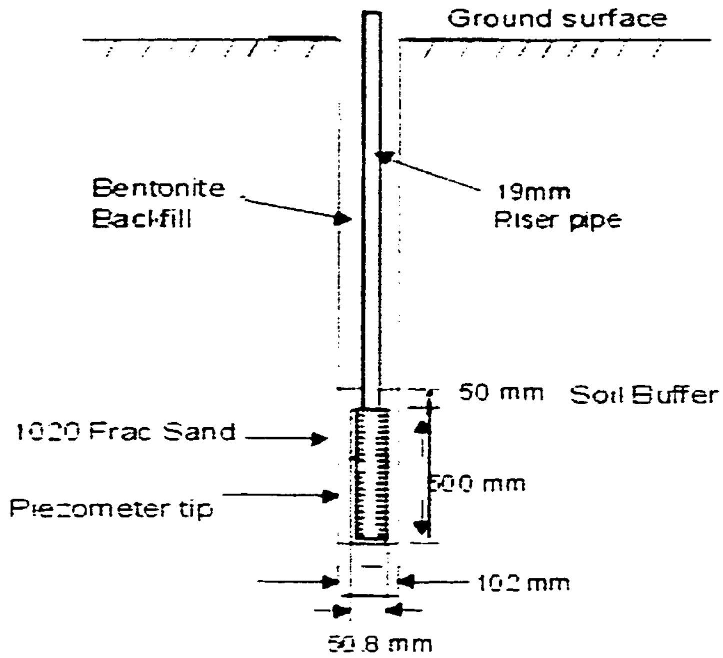

Figure 3.3 Schematic view of a typical piezometer type observation well installed at the EMS pond study sites.

Table 3.1 Chemical characteristics of swine manure at ten Alberta hog operations (adapted from Guy et al., in progress)

Site	Moisture	pH	EC	Na	TKN	NH_4
	(%)		(mS/m)	(%)	(%)	(%)
B1	99.07	7.8	2100	0.09	0.23	0.19
B2	99.19	7.5	2060	0.1	0.24	0.22
B3	98.84	7.3	2120	0.13	0.27	0.24
B4	99.38	7.5	12560	0.05	0.16	0.14
B5	99.23	7.28	1680	0.06	0.19	0.17
R1	99.02	7.6	1840	0.04	0.28	0.24
R2	95.27	7.7	2390	0.09	0.4	0.31
R3	98.17	7.9	1910	0.07	0.28	0.25
R4	99.24	7.6	1390	0.06	0.19	0.15
R5	99.44	7.4	916	0.01	0.13	0.11
Average	98.7	7.6	2897	0.07	0.24	0.20
Std. Dev.	1.25	0.2	3421	0.03	0.08	0.06

Table 3.2 List of soil sample analysis parameters and references used for the study.

Physical tests	
• Visual Classification	No reference
• Soil Texture	SCDC S007
• Moisture Content	McKeague (1978) 2.411
• Bulk Density	ASA 13 – 2.2
• Atterberg Limits	ASA 9 – 31-3
• 2.0 mm Sieve Analysis	McKeague (1978) 2.13
• 3-point Hydrometer	Can. Agr. Eng. 33:211-215
• Permeability	Mott (1979), pp. 25-90
• Hydraulic Conductivity	Mott (1979), pp. 25-90
Chemical tests	
• Cation Exchange Capacity (CEC)	McKeague (1978) 3.34
• Soluble Salts: Ca, Mg, Na	McKeague (1978) 3.21
• Sodium Absorption Ratio	McKeague (1978) 3.26
• pH	McKeague (1978) 3.14
• Electrical Conductivity (EC)	McKeague (1978) 4.13/3.21
• Chloride	McKeague (1978) 3.21
• Ammonia-N	ASA 33-3.2
• Nitrate-N	SCDC S001
• Potassium	Carter (1993) 5, pp. 39-42
• Phosphorus	SCDC S001

Table 3.3 Water analysis parameters used in the study and the units of measurement and preservative required for each species tested

Species	Units	Preservative
pH	N/A	N/A
EC	mS/cm	N/A
Chloride	mg/L	N/A
TDS	mg/L	N/A
Phosphorus	mg/L	N/A
Potassium	mg/L	N/A
Ammonia-N	mg/L	Sulphuric acid
Nitrate-N	mg/L	Sulphuric acid
Nitrite-M	mg/L	Sulphuric acid
Total Coliform	CFU/100ml	Sodium thiosulphate
Fecal coliform	CFU/100ml	Sodium thiosulphate
DO	%	N/A

4.0 Investigation of Site 1

4.1 Site Description and Construction Methods

The EMS pond at Site 1 services a 240-sow farrow-to-finish operation. The pond was built in 1985, hence it had been in service for about 14 years at the time this study was conducted. The EMS dimensions are 46 m x 44 m x 4 m (L x W x D) with side slopes that are approximately 1:1. A standard trapezoidal volume formula calculates the storage capacity of the pond as 6800 m^3. Manure production volumes were estimated using unit manure production volumes provided in the Alberta Code of Practice (Anonymous, 1995). The pond will provide just over 13 months of storage capacity for the expected manure production from this facility. The area in the immediate vicinity of the EMS pond slopes steeply to the south-southwest of the pond location. While little is known about the construction practices used to build the EMS pond, it was likely constructed using a bulldozer and a towed scraper. It appears that soil was excavated by pushing it down the slope to the south and using that soil to build a berm on the south and west sides of the pond. The producer indicated a compacted clay liner was constructed on the bottom and sides of the pond; however, no evidence of a liner was found during any of the site visits.

4.2 Background Resource Data

Shetsen (1990) described the quaternary geology of the area at Site 1 as eolian deposits from the Pleistocene and Holocene eras. Wind deposited longitudinal and parabolic dunes of fine to medium grained sand and silt up to 7 m thick form an undulating to rolling landscape in the area surrounding the site location. These sand dunes were likely deposited here from the shores of the many glacio-lacustrine lakes apparent on the Quaternary geology map to the northwest of the study site. Nikiforuk et al. (AGRASID v1.0, 1998) identified the soils at this location as having characteristics that fall within the Redwater soil series. Parent materials are identified as glacial fluvial Orthic Dark Gray Luvisolic soils that are medium to coarse textured, moderately calcareous and well drained. Soil particle distribution given in the AGRASID database for the Redwater soil series is 65% sand, 25% silt and 10%

clay. Cation exchange capacity (CEC), K_s, and bulk density for the soil is expected to be 6 meq/100 g, 2. 8 x 10^{-5} m/s and 1500 kg/m^3, respectively. Soil porosity is about 43%, which provides a soil water holding capacity of 0.25 to 0.30 m^3 H_2O/m^3 soil. The location of the site with respect to the local C-horizon soil textural classification (as per Nikiforuk et al., 1998) is shown on the site diagram (Figure 4.1). Subsoil textures are quite variable in the area local to the study site.

Inspection of the topographic map for the area (NTS 83-B8, not shown) shows that the EMS pond is located near the top of a hill sloping southwest. The topographic map also shows that there is a watercourse that includes a series of sloughs at the bottom of the slope. The airphoto for the area (AS – 4970-116 LN24) shows that this watercourse is located in the southwest corner of the quarter section and drains water from the site to the southeast toward the Medicine River. The airphoto shows that the area consists of longitudinal sand dunes arranged in a northwest to southeast orientation. These dunes were likely laid down by the prevailing northwest winds in the area. The origin of the wind blown sands is not documented but likely is from the shores of glacial and post-glacial lakeshores. This analysis is confirmed by Shetsen's (1990) determination of the surficial geology as eolian silt and sand drift materials.

Five water wells have been drilled on this section of land since 1977 according to Groundwater Information Center records (Alberta Environment, 1999). Water well drilling records providing lithological information were found for all five wells. Well logs for the three wells drilled on the quarter section where the EMS pond is located show that the upper sand layer is 2 - 15.5 m thick. The drill log from the water well on the land location directly to the north of the site indicates that about 10 m of sandy materials inter-bedded with clay is overlying brownish green shale and sandstone. The airphoto suggests that the residences at these locations are likely on the northeast edge of the dune deposit. Drill logs from quarter sections to the south and east of the site show clay and clay till material from the surface to about 5 m where shale and sandstone bedrock were encountered. The airphoto indicates that two residences are located just off the dune deposit. The depth of the sand layer is likely dependent on the actual location of the drilling point. The sand deposit appears to be a longitudinal, parabolic dune that occupies most of the section of land where the study site is located and extends slightly into the quarter sections to the north and south. This is consistent with the local surficial geology (Shetsen, 1990).

There are two potential groundwater sources below the site. Two of the three wells are constructed into a 10-m thick grey, medium grained, sandstone deposit about 35 m below surface with a narrow (2-m thick) shale stringer near its center. The non-pumping static water level in these wells is about 23 – 26 m below surface, indicating that they are under about 4 – 12 m of upward static pressure. One of these water wells was completed into a 9-m thick, inter-bedded, shale deposit that was encountered just below 6.4 m of sand and sandy clay material. The non-pumping static water level in this well is 6.0 m below surface, indicating that the shallow shale deposit is saturated. Pumping rates for all wells on the site are indicated on the drill logs at about 1.5 L/s.

This study site is located on a local eolian sand dune deposit with a maximum thickness of about 18 m. The sand overlies a clay till layer about 6 m thick that appears to have a chunk of drift deposited shale inter-bedded within its mass according to the local water well records. Bedrock is about 20 to 25 m below surface and is shale and sandstone of the Paskapoo formation (Tokarsky et al., 1987) that has potential water bearing sandstones at a depth of between 30 and 60 m. This groundwater source has a potential pumping rate of about 1.5 L/s. The shale inter-bedded in the upper till deposit also appears to have potential as a water source. Water in this aquifer is likely vulnerable to contamination from any seepage that may occur from an EMS pond at the site.

4.3 Chronology of Events in the Site Investigation

February, 1999 — Initial contact with producer

- Producer indicated willingness to participate in project.
- Site contained EMS of sufficient size and age and soil conditions.

April, 1999 — Confirmation of parent material suitability

AGRISID parent material data were used to confirm soil as coarse textured.

June 15, 1999	EM 31 survey • Post survey analysis did not indicate seepage.
August, 1999	Site selection for intensive investigation • Site was selected as an apparent non-leaking site.
Sept 29-30, 1999	Initial drilling • One piezometer nest upslope and three downstream, as per protocol. • Soil samples were taken from one representative borehole, immediately downslope of the berm. • One borehole was drilled on top of the berm.
Dec. 2, 1999	Flushing of piezometers • Water elevations recorded for all piezometers.
Dec. 3, 1999	Water sampling. Samples were taken in the deepest piezometer of the three downslope nests. All other piezometers, including the upslope nest, were dry. • Due to the high flow rate refilling the piezometer pipes, it was determined that natural groundwater flow was a suitable flushing process. • Water elevations taken for piezometers prior to sampling.
Dec. 13, 1999	Additional soil sampling. Two of the piezometer nest locations were profile sampled. • More complete soil sampling information was needed to analyze the site. • Sampling boreholes included upslope and far downslope.
April 25, 2000	Topographic survey of site. • Data includes location of piezometer nests, top and toe of each side of the berm, in the middle of each side, a cross-section line through the EMS pond in the general direction of the local slope, and several recognizable landmarks to serve as airphoto reference points.
May 9, 2000	GPS survey of the site Second water sampling. Same three locations contained water • Same sample locations.

- Manure storage had been emptied in the middle of April.
- Dissolved oxygen was measured for each sample.

4.4 Site-specific Results

4.4.1 Site Survey

The site diagram (Figure 4.1) shows an orthorectified aerial photograph of the hog operation with the sample site and piezometer nests locations. Survey data from the site show that ground slopes below the berm are about 0.11 m/m. Locations 1 and 3 are about 10 and 60 m downslope of the inside edge of the downslope berm of the EMS pond, respectively. Location 4 is about 30 m upslope and to the northeast of the east edge of the EMS pond, which is at natural ground surface. Location 4 is intended to provide comparative background soil chemistry data for the site. Location 3 is about 4 m below Location 1 and nearly 8 m below Location 4.

4.4.2 Site Hydraulics

Water levels were measured three times between December 2, 1999 and May 9, 2000 (Table 4.1). No water was found in any of the piezometers installed at Location 4 or in the shallow piezometers at the other sample locations over the monitoring period. Although the pond was emptied for land spreading in early April 2000, the watertable tended to remain relatively steady over the winter monitoring period. Groundwater gradients did not follow surface slopes within the sand dune locations since the surface slope is about 0.11 m/m, while the watertable gradient is only 0.005 m/m.

4.4.3 EM 31 Survey

The results of the electrical conductivity (EC) survey of Site 1 with the EM 31 are shown in Figure 4.1. No indication of a seepage plume emanating from this manure storage was apparent from the EM survey; instead, elevated EC levels appear in the berm surrounding the pond. The investigation at this site was intended to be a check of the instrument results. The fact that no plume was noticed in these sandy soils was also of interest to the investigation.

4.4.4 Soil Physical Data

All soil samples from this study site were classified as USCS (Table 4.2; Universal Soil Classification System grouping SC – SM), indicating non-plastic silty to clayey sand (i.e., plasticity index < 3%). Field and laboratory hand texture sample analyses indicated that all soils in the upper soil zones were sandy loams or loamy sands, while some of the soils in the lower soil zones were sandy clay loams or clay loams. Soils from Location 1 had an average sand content of just over 80% while average silt and clay contents were 9 and 10%, respectively (Table 4.2). Soils at Location 4 had characteristics similar to those at Location 1, and standard deviations for all particle sizes were less than 2.5% for both holes. This agrees well with the AGRASID database values for the Redwater soil series of 65%, sand 25% silt and 10% clay. The average measured bulk density for the soil samples at Location 1 was 1581 kg/m^3, which also agrees well with the AGRASID database that suggested a soil density for the Redwater soil series of 1500 kg/m^3.

The clay content of soils at Location 3 increased considerably below the 4-m depth. Location 3 was situated about 4 m downslope of Location 1 and consequently entered a lower soil zone than any of the other borings. Soils from the lower extent of the borehole (5.5 – 6.1 m depth) at this location hand textured as a clay loam and the drilling report suggested that this soil is a glacial till. The soils at this location had higher silt and clay contents below 4.0 m than above. Clay and silt contents ranged between 20 - 30 % in the samples from the lower 3 m of the borehole at Location 3, suggesting that the eolian sand deposit likely overlies glacial clay till soils deposited during an earlier time period. This is consistent with data derived from water well records and surficial geology maps of the area, as discussed above.

The laboratory-determined, disturbed sample, hydraulic conductivity data (not shown) appear to be low by several orders of magnitude for what one would expect from the soil texture and particle analysis data. Freeze and Cherry (1979) suggested that the hydraulic conductivity of a silty sand would not be less than 10^{-7} m/s and could be as high as 10^{-3} m/s. Soil survey data taken from the AGRASID database (Nikiforuk et al., 1998) suggested that the saturated hydraulic conductivity of this

Redwater soil series is 10^{-5} m/s. The hydraulic conductivity values determined in the laboratory for the soil samples taken at this site were 10^{-8} to 10^{-9} m/s, low for a sand soil of eolian origin with low clay content. This result may be due to compaction of the disturbed samples.

Samples were disturbed because they were collected from drill auger flights and then packed into airtight plastic containers for transport to the laboratory. Once they arrived at the laboratory, the samples were prepared for testing by compacting the soil into cylinders. Although attempts were made to avoid over compaction of the samples, it was difficult to reproduce field soil conditions. Since permeability is dependent upon soil density, the saturated hydraulic conductivity data provided for this site should be viewed skeptically. In the future, field tests should be performed to estimate the actual saturated hydraulic conductivity of soil materials to allow calculation of theoretical flow velocities and travel times. Such calculations are useful to verify if seepage could have reached a point of interest. The data would also make it possible to use computer models to predict seepage and contaminant transport rates.

4.4.5 Soil Chemistry

Soil chemistry data are tabulated for each parameter measured in Table 4.3. The EM 31 did not indicate any elevated EC levels at this site (Figure 4.1). However, a small EC spike is noticeable in the 4.0 – 4.9 mbgl sample interval at Location 4 (i.e., background; Table 4.3). The pronounced EC spike at Location 3 is at an elevation approximately 6 m below the EC spike at Location 4 and thus they are likely unrelated. The EM 31 measures average EC levels to a depth of about 6 m but instrument sensitivity is highest near the 3-m depth. This may explain why the EM missed the higher EC values at this depth. Furthermore, none of the soil EC values determined from saturated paste extracts were unusually high, with the highest value being about 1.6 mS/cm at the 2 – 3 m sample interval at Location 3 (Table 4.3), which probably partially explains the lack of plume detection by the EM 31 survey.

Soil chemical concentrations were similar throughout the 7.6-m profile logged at Location 1 (Table 4.3) while soil moisture content increased slightly with depth from about 11% to almost 15% (Table 4.2). Moisture content, clay content and CEC in samples taken from the soil boring at Location 3 were markedly higher at depths beyond 4 m (Tables 4.2 and 4.3). Relatively high levels of chloride (Cl) and nitrate (NO_3-N) were apparent in the upper 3 m of the soil profile at Location 3. The Cl concentration in the 2.1 – 3.1 mbgl sample interval was 266 mg/L but then declined with depth to 6.66 mg/L in the 6.1 – 7.6 mbgl sample (Table 4.3). An NO_3 concentration of nearly 50 μg/g (i.e., ppm) was observed in the 1.2 – 3.1 m sample interval but was much lower in all other samples from Location 3. The nitrate-N level in the upper meter of soil was only about 2 ppm, which only represents about 3 kg-N/m^3 of soil (BD = 1580 kg/m^3). Ammonium-N (NH_4) concentrations in the upper soil zone at Location 3 were also extremely low (3 ppm) in the upper 4 m of soil but increased with depth to range between 6.7 and 9.4 ppm in the sample intervals between 4.0 and 7.6 mbgl (Table 4.3).

Potassium (K) concentration was highest beyond 4 m (125 –198 ppm) at Location 3 (Table 4.3). High concentrations of K of up to 198 μg/g found in the soils in the bottom portion of the borehole at Location 3 coincided with high soil clay content and CEC values. There was a slight increase in K concentration between the 1.2 and 3.1 mbgl sample interval (i.e., $71 < 80 > 64$), that may be an indication of minor seepage from the EMS pond (Table 4.3). However, this increase also coincides with an increase in CEC at that depth, which may indicate sorption of K from percolating surface waters. Spikes of sodium (Na), calcium (Ca) and magnesium (Mg) concentrations were observed for both Locations 3 and 4, but the spikes were of much greater magnitude in the downslope boring (i.e., Location 3).

4.4.6 Water Chemistry

The first set of water samples was taken from the groundwater observation wells when the EMS pond was full of manure; water samples collected on May 9, 2000 were taken about a month after the pond had been emptied.

The pH of the groundwater samples remained near neutral over the observation period (Table 4.3). Electrical conductivity was quite low (1.3 – 2.3 mS/m; Table 4.4) but the total dissolved solids (TDS) concentrations in the water at Location 2, as calculated from the EC reading, exceeded the drinking water guideline of 1000 mg/L by over 300 mg/L (Health and Welfare Canada, 1989). ECs and TDS values remained relatively constant but increased slightly at Location 2 over the observation period (Table 4.4).

The highest Cl concentration detected in the groundwater at this site was 237 mg/L at Location 2 during December (Table 4.4). Fitzgerald (1999) measured average Cl concentrations in shallow groundwater in Alberta of 66 mg/L, but concentrations of up to 3000 mg/L were measured. Therefore, the high readings seen at Location 2 are not considered unusual. No "background" water data were available for this site because no water was ever found in the observation wells at Location 4. However, Cl concentrations in the water samples taken from piezometers at Locations 1 or 3 in December (1.5 and 20.7 mg/L) were an order of magnitude lower than at Location 2 (Table 4.4). Chloride levels remained highest at Location 2 over the monitoring period, but dropped, compared to the earlier reading at that location. In contrast, Cl concentrations increased slightly in the water sample at Locations 1 and 3 over time (Table 4.4).

The water from Location 2 showed only trace amounts of nitrate-N, but concentrations at Locations 1 and 3 indicated elevated nitrate levels compared to those at Location 2. None of the NO_3-N levels exceeded the drinking water guideline of 10 mg/L for this chemical species (Health and Welfare Canada, 1989) on that sampling date. NO_3 concentration levels at sample Locations 1 and 2 remained relatively constant but nearly doubled to 16.1 mg/L, exceeding the drinking water guideline of 10 mg/L, on the spring sampling date at Location 3. Relatively high dissolved oxygen levels were measured at this site on the second sampling date (6.0 – 7.8 mg/L). This may explain why ammonium concentrations in the water samples were at or below detection limits throughout the monitoring period, since NH_4 would likely be oxidized to NO_3 at the dissolved oxygen concentrations found in the groundwater at this site.

Samples taken on December 02/99 at Locations 2 and 3 showed high concentrations of total coliform bacteria (400 and 20 CFU / 100 ml, respectively) while that from Location 1 (8 CFU / 100 ml) was within the drinking water guideline of 10 CFU / 100 ml suggested by Health and Welfare Canada (1989). Total coliform bacteria counts were generally lower and within the drinking water guideline for all locations in May 2000 with the exception of Location 2 (33 CFU / 100 ml). Groundwater samples from all sample locations contained fecal coliform bacteria on at least one of the two samplings at this site. The fecal coliform count in water samples from Location 2 (12 CFU / 100 ml) is considered very high and far exceeds the drinking water guideline of 0 CFU / 100 ml for this water quality indicator species (Health and Welfare Canada, 1989).

4.5 Discussion

The most striking feature of this site is that the soils surrounding the reservoir contain about 80% sand. The literature suggests that under sandy soil conditions, even where hydraulic sealing does occur, manure nutrients are transported into the surrounding environment (Hart and Turner, 1965; Barrington and Jutras, 1987; Ciravolo et al., 1979; Phillips et al., 1983 and Phillips and Culley, 1985). Based on the observations of others, one would expect to observe seepage and contaminant movement from the storage pond under these soil conditions.

Neither the soil nor water chemistry data taken at Location 1 indicated any manure seepage from the sampling site, in spite of its proximity (10 m) and downslope position from the EMS pond. In retrospect, Location 1 may be out of the main flow path of groundwater from the EMS pond. The main slope, at this location, is to the south-southwest and, thus it is conceivable that the drill hole was constructed slightly south of the expected groundwater flow path through the EMS location. This may explain why generally stronger evidence of seepage was seen in the data from Locations 2 and 3.

Water sample data from Location 2 gives some indication of possible seepage effects due to high Cl and TDS readings. However, the presence of some very high total and fecal coliform bacteria counts on both sampling dates at this Location provides more compelling evidence that some seepage may be occurring from this EMS. Oddly though, NO_3 levels in the water at this location were very low. The EMS pond was nearly full at the time of the first sampling, while the second sampling took place about a month after the pond was emptied. Following the emptying of the EMS, the seal was likely exposed and allowed to dry for a month before the second sample was taken. This may mean that fecal coliform bacteria were allowed to escape from the EMS after manure seal breakdown due to preferential flow to the piezometer at Location 2.

Cl concentrations observed in the groundwater from Location 2 may have decreased because this conservative tracer species had passed that sampling point over the sampling period. This explanation is consistent with the slight increase in chlorides noted at Location 3, which may also be related to the flush of seepage waters caused by the breakdown of the manure seal after the EMS pond was emptied in early May. The flush waters would be expected to have a high concentration of Cl, but dilution, due to mixing with existing groundwater, could explain the small degree of increase measured. The highly variable nature of the water chemistry and microbiology data at this site may be resulting from periodic manure seal breakdown that causes periodic contaminant flushes from different locations within the EMS.

The opposing patterns exhibited for the two nitrogen species with depth at Location 3 are likely an indication of denitrification to ammonium-N in the deeper soil zone. The increase in NH_4-N, and subsequent decrease in NO_3-N concentrations, also coincided with increases in moisture and clay content in these soils. Saturated conditions could allow oxygen to become limiting, which would lead to reducing conditions that would cause denitrification in the presence of facultative heterotrophic or autotrophic bacteria. The activity of these two bacterial species is dependent on whether organic carbon or nitrate-N is the limiting factor to their metabolism. Unfortunately, no measurements were made of the organic carbon content of the soil in this investigation.

The hydraulics of seepage at this site provides some insight into the observed anomalies in the soil chemistry data at Location 3. Calculated travel distances (Table 4.5) show that the K_s of the soil needs to be at least 5×10^{-7} m/s for seepage waters to have reached Location 3 within the 14 y that the EMS pond has been in operation. Conductivity values of this order of magnitude may be possible for the coarse-textured soils at this site since soil survey data suggest values in the order of 10^{-5} m/s. Average laboratory measured K_s values were in the order of 5×10^{-8} m/s but, as previously mentioned, these values are suspiciously low for this soil texture.

Because the soil in the 4 m between the EMS pond and the watertable is unsaturated, an estimate of the unsaturated hydraulic conductivity at this site was conducted using Soil Vision software. The average water content was estimated to be 14%, which predicts an unsaturated hydraulic conductivity of approximately 1.4×10^{-6} m/s for the soil properties found at this site (Campbell (1985) and Fredlund and Xing (1994)). Therefore, the solutes could easily have traveled the distance required to the observation well at Location 3, 60 m from the EMS pond, by unsaturated advective flow under the assumed conditions (Table 4.5). There are three weaknesses in the assumptions used for the calculations made above. First, the estimated hydraulic gradient between the points is likely less than that expressed by the piezometric surface conditions and second, since the EMS pond is not always full, the driving hydraulic gradient is variable throughout the year. Furthermore, since the EMS pond is emptied at least once per year, steady state flow conditions do not exist. Factors that give rise to unsaturated flow at this site are difficult to predict. However, given that hydraulic conductivity is the largest factor in determining advective flow velocities, it is likely that the manure solutes could have reached the observation well at Location 3 in the time elapsed.

At Site 1, silty sand material overlies an impermeable clay till layer. A perched watertable has developed over the clay till layer because it acts as a seepage barrier for water infiltrating through the overlying sand. Due to the permeable nature of the sand material, seepage flows almost vertically through the sides and bottom of the EMS pond to the perched watertable below. Since the silty sands are not saturated, diffusion and unsaturated flow are the mechanisms of solute transport. The nitrogen within the manure in the pond is in the form of ammonium, so seepage fluids contain only NH_4. Fonstad and Maule (1996) noted ammonium tends to collect within a bulb of soil near the bottom and sidewalls of EMS ponds constructed in clayey soils, since clay minerals are negatively charged and positively charged ions dissolved in groundwater are attenuated due to sorption effects. The average clay content and CEC of the silty sand soil at this site is about 10 – 12% and 12-meq/100 g, respectively. Although this is a relatively low CEC, some attenuation of ammonium would still be expected in these soils.

Nitrification of ammonium is a membrane-associated oxidization reaction carried out by heterotrophic soil bacteria, which is often assumed when investigating groundwater nitrate sources where a sufficient amount of organic carbon is available (Korom, 1992). These organisms have also been known to produce nitrate from inorganic sources where insufficient carbon is available (Paul and Clark, 1996). Nitrification is an aerobic process, therefore, moisture conditions and soil structure, temperature and pH can also control this biological process, but it will occur readily within a temperature range of 5 to 35 ^{o}C, with 30 to 35 ^{o}C being optimum (Hendry et al., 1984 and Paul and Clark, 1996). Both high and low pH values will decrease nitrification, with pH values of 6.6 to 8.0 being optimum (Fonstad, 2000). Since the soils at the outer edge of this NH_4 bulb are unsaturated, and the temperature and pH of the soil water are within the range for nitrification to occur, membrane-associated oxidization of the ammonium in the soil below the EMS pond at Site 1 is possible. That is, the ammonium near the outer edge of the bulb may be being transformed to NO_3-N. Once nitrate is present in soil or aquifers, it is mobile since its negative ionic charge resists adsorption to clay minerals. Excessive amounts of nitrate will be leached to lower areas or the watertable by soil water movement (Korum, 1992 and Paul and Clark, 1996). Once the nitrate has reached the perched watertable below, it is likely carried down gradient of the EMS pond by advective flow to Location 3 where it was detected.

Nitrate levels near or above the drinking water guideline levels were detected in water in the observation well at Location 3, while the levels in the wells closer to the EMS pond always remained below the guideline (Locations 1 and 2; Table 4.4). It is possible that the nitrate detection at Location 3 is related to plug flow from the EMS pond during the "initial flush" that has been shown to occur from manure ponds situated in sandy soils before a manure seal is established (Reese and Laudon, 1983). Cully and Phillips (1989) showed evidence that seepage also occurs from EMS ponds constructed in sandy soils where the manure seal breaks down due to weathering effects or bubble action. The anecdotal evidence provided by Williamson[1] (2000) supports this theory, since the producer claimed that the EMS pond leaked substantially when it was first constructed 14 y prior to the investigation. Manure seals have been shown to take up to 6 months to form in sandy soils under field conditions (Miller et. al., 1976; Sewell, 1978 and Ciravolo et al., 1979).

The very high potassium concentrations ([K] = 198 ppm) found in the one soil sample obtained from the till material underlying the sand deposit at this site may have been caused by vertical seepage from this EMS pond. This cation may have moved with seepage water over the years through unsaturated flow and diffusion into the perched watertable below. This would have caused a build-up of K in the groundwater there that would be available for ion exchange into the surface of the clay layer below by sorption and diffusion processes. This theory is supported by the elevated K level found in the groundwater sample at Locations 1 and 3 during the spring sampling (Table 4.4).

4.6 Conclusions

There was no data found at this site that could lead to the conclusion that this EMS pond is leaking to any great extent or that there is a continuous, severe contaminant

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[1] Williamson, K., 2000. Personal Communication. ILO/Water Specialist, AAFRD, Red Deer

plume emanating from the at this site. However, the erratic nature soil chemistry and groundwater data found here may be interpreted as an indication that some seepage is occurring from this EMS pond. The presence of insecure site characteristics makes it easy to believe that seepage from the EMS pond is the most likely cause of the elevated nitrates and fecal coliforms found in groundwater samples taken from this site.

No doubt, the single strongest indication of seepage is the presence of fecal coliform bacteria found in groundwater samples. Consistently high chloride levels in the groundwater at Location 2 provide additional evidence of manure seepage from the EMS pond. Finally, elevated levels of NO_3-N in the water at sample Locations 1 and 3, especially during the second sampling, confirm that some seepage has occurred at this site. However, the sporadic and fluctuating nature of the data suggests that seepage is likely spatially and temporally variable and likely occurs through preferential flow paths during periods that the manure seal is weak or non-existent. Breakdown of the manure seal has resulted from weathering due to environmental exposure or bubbling effects due to movement of soil gases from under the bottoms and sides of the manure pond (Chang et al., 1974; DeTar, 1979; Barrington and Jutras, 1983 and Fonstad and Maule, 1996).

Elevated cation, chloride and nitrate-N levels in the upper soil zones at Location 3 may have resulted from periodic seepage pulses from the EMS pond over the long term. The fact that this boring is about 60 m downslope of the EMS pond raises doubt about this conclusion. However, consideration of basic hydraulic theory suggested that it is possible that seepage could have traveled that far over the operation time frame of 14 y of this EMS pond. Further, anecdotal evidence from a local government official[2] confirmed that the original owner of this operation at one time admitted that this EMS pond visibly leaked for some time after it was constructed before it appeared to seal. Therefore, it is most likely that the nitrate in the groundwater was either the result of the initial seepage event or the culmination

[2] Ken Williamson, June, 2000. Personal Communication. AAFRD Red Deer.

of many tiny seepage events as the manure seal underwent a cyclic pattern of development and deterioration.

Considering the results of the investigation at this site, the conclusions are:

- Some evidence of seepage and contaminant movement was detected at this site.
- Seepage appears to be having a negative impact on the perched groundwater table within the upper sand soil layer.
- A continuous, severe contaminant plume from the manure pond is not evident.
- The fact that most, if not all, of the seepage from the manure pond must occur through unsaturated flow and diffusion is likely slowing the process considerably.
- Manure sealing is likely occurring and preventing the development of a major continuous plume from this site.
- Preferential flow during periods when the manure seal has broken down is likely responsible for much of the contaminant movement at this site.
- The presence of a 6-m deep clay layer between the surface sand soil deposit and underlying bedrock aquifers will likely prevent serious contamination of deep groundwater in the area from these sources, due to sorption and denitrification processes in the aquitard.
- A review of the remote site characterization data at this site, under today's standards, would have resulted in, at a minimum, a recommendation to conduct a site-specific investigation at this site.
- A thorough site-specific investigation by a qualified professional would have resulted in a recommendation for a pond liner at this site or perhaps even a steel or concrete tank.

Figure 4.1. Site 1 layout and location diagram showing the location of the soil sample and piezometers, the EM 31 electrical conductivity surface and the C-horizon soil parent material map for the area from the AGRASID database (Nikiforuk et al. 1998)

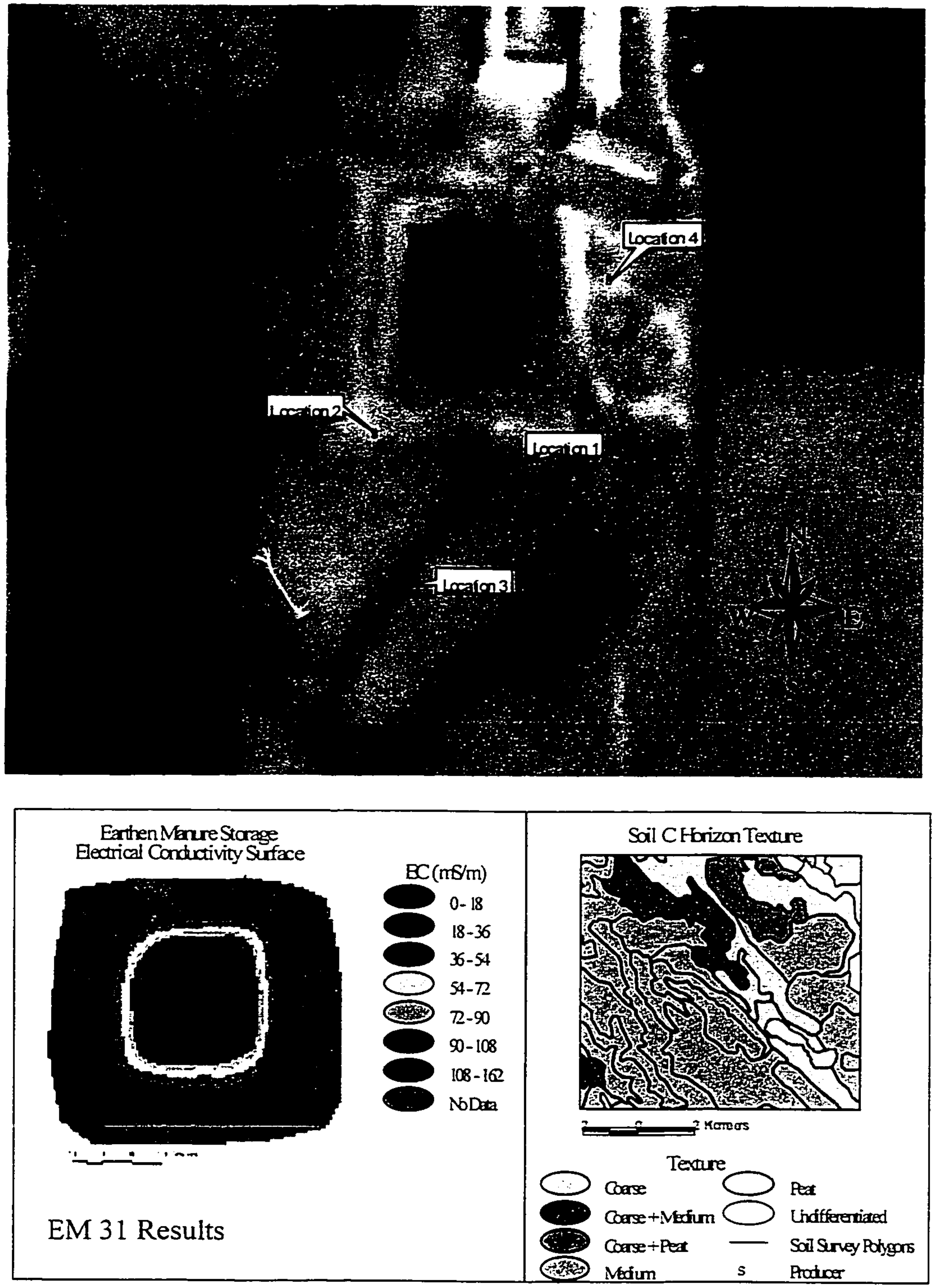

Table 4.1. Piezometric Data for Site 1

Date				02-Dec-99	10-Apr-00	09-May-00
Location Well ID	Piezo. Depth (m)	Surface Elev. (m)	Tip Elev. (m)	Water Elevations		
1/H	3.8	965.030	961.2	dry	3.0	dry
1/L	7.6	965.030	957.4	958.1	958.0	958.0
2/H	5.1	964.070	959.0	dry	dry	dry
2/L	7.2	964.070	956.9	958.1	958.0	957.7
3/H	2.8	961.372	958.6	dry	dry	dry
3/L	4.5	961.372	956.9	958.0	957.9	958.0
4/H	3.0	968.192	965.2	dry	dry	dry
4/M	4.7	968.192	963.5	dry	dry	dry
4/L	7.0	968.192	961.2	dry	dry	dry

Table 4.2. Select soil physical properties for Site 1

Location	Depth (m)	MC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	BD (kg/m³)	Plasticity (%)	USCS Class.
Location 1 (10 m down slope of EMS)									
1/1	0.25-.4	3.20	0.05	82.00	11.00	7.00	1338.0	NP	
1/2	0.6-1.2	11.50	0.16	79.80	7.70	12.30	1400.0	NP	
1/3	1.5-2.1	11.40	0.06	80.90	8.20	10.80	1479.0	NP	
1/4	2.4-4.0	13.50	0.00	77.00	10.70	12.30	1661.0	NP	
1/5	6.7-7.6	15.20	0.52	81.50	9.47	8.53	2029.0	NP	
Average		11.00	0.16	80.20	9.41	10.20	1581.0		SC-SM
Standard Deviation		4.13	0.19	1.77	1.31	2.11	248.7		

Location	Depth (m)	MC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	BD (kg/m³)	Plasticity (%)	USCS Class.
Location 3 (60 m downslope of EMS)									
3/1	0.3-1.2	8.80	14.00	62.40	9.30	14.30	831.0	7.00	
3/2	1.2-2.1	12.50	0.30	82.10	9.40	8.20	1480.0	NP	
3/3	2.1-3.1	12.50	0.20	82.20	7.90	9.70	1540.0	NP	
3/4	3.1-4.0	16.00	0.10	85.50	5.60	8.80	2040.0	NP	
3/5	4.0-4.9	20.00	0.20	58.50	21.00	20.40	1920.0	14.00	
3/6	4.9-5.8	18.00	1.80	40.80	30.70	26.70	914.0	15.00	
3/7	5.9-6.7	17.20	0.90	55.70	22.20	21.20	967.0	14.00	
3/8	6.7-7.6	18.60	0.00	41.60	29.20	29.20	907.0	13.00	
Average		15.40	2.20	63.60	16.90	17.30	1325.0	12.60	SC-SM
Standard Deviation		3.58	4.50	16.82	9.43	7.70	454.3	2.87	

Location	Depth (m)	MC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	BD (kg/m3)	Plasticity (%)	USCS Class.
Location 4 (30 m upslope of EMS)									
4/1	0.3-1.2	7.02	0.00	78.60	9.50	11.90	859.0	NP	
4/2	1.2-2.1	8.17	0.00	78.60	9.50	11.90	725.0	NP	
4/3	2.1-3.1	8.58	0.04	80.60	7.50	11.90	716.0	NP	
4/4	3.1-4.0	10.80	0.05	79.60	8.50	11.90	771.0	NP	
4/5	4.0-4.9	9.54	0.00	76.60	11.20	12.20	765.0	NP	
4/6	4.9-5.8	9.66	0.00	77.60	9.80	12.60	731.0	NP	
4/7	5.9-6.7	9.10	0.00	78.60	9.20	12.20	750.0	NP	
4/8	6.7-7.6	10.40	0.05	81.60	8.10	10.40	759.0	NP	
Average		9.16	0.02	79.00	9.20	11.90	760.0		SC-SM
Standard Deviation		1.15	0.02	1.48	1.07	0.62	41.9		

Table 4.3. Select soil chemistry properties for Site 1

Location	Depth (m)	pH	EC (dS/m)	Cl (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	NO_3-N (µg/g)	NH_4-N (µg/g)	K (µg/g)	PO_4-P (µg/g)	CEC (meq/100g)
Location 1 (10 m downslope of EMS)												
1/1	0.25-.4	6.5	0.151	7.20	16.7	3.03	16.7	<0.50	1.45	49.0	NSQ	6.13
1/3	0.6-1.2	6.9	0.181	12.40	18.3	3.58	18.7	<0.50	1.70	99.8	4.21	16.40
1/3	1.5-2.1	6.4	0.194	21.00	15.7	3.97	18.2	<0.50	1.30	70.5	5.94	12.00
1/4	2.4-4.0	5.8	0.168	17.90	14.6	3.48	14.1	<0.50	1.65	85.0	6.07	13.80
1/5	6.7-7.6	7.7	0.318	9.02	41.4	8.13	14.9	0.94	0.95	43.2	0.47	6.90

Location	Depth (m)	pH	EC (dS/m)	Cl (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	NO_3-N (µg/g)	NH_4-N (µg/g)	K (µg/g)	PO_4-P (µg/g)	CEC (meq/100g)
Location 3 (60 m downslope of EMS)												
3/1	0.3-1.2	6.4	0.716	187.00	74.8	8.15	64.8	2.13	3.03	90	12.00	16.1
3/2	1.2-2.1	6.7	1.470	173.00	185.0	30.20	68.7	46.90	2.78	71	8.62	13.4
3/3	2.1-3.1	6.2	1.630	266.00	231.0	30.20	46.0	48.90	2.53	80	7.17	14.4
3/4	3.1-4.0	7.6	0.631	59.00	92.0	5.70	17.9	14.50	2.53	64	1.83	10.0
3/5	4.0-4.9	7.4	0.550	36.60	74.5	6.70	23.5	7.70	6.73	121	0.78	17.4
3/6	4.9-5.8	7.5	0.380	9.80	48.0	2.80	16.8	5.26	9.43	157	0.60	21.7
3/7	5.9-6.7	7.5	0.510	21.10	50.4	3.84	44.3	5.34	6.73	128	0.71	19.1
3/8	6.7-7.6	7.7	0.484	6.66	69.2	8.59	17.4	5.36	10.20	198	<5.00	26.5

Location	Depth (m)	pH	EC (dS/m)	Cl (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	NO_3-N (µg/g)	NH_4-N (µg/g)	K (µg/g)	PO_4-P (µg/g)	CEC (meq/100g)
Location 4 (30 m upslope of EMS)												
6/1	0.3-1.2	7.3	0.530	8.05	37.6	<2.00	20.6	2.80	2.68	88	3.44	11.6
6/2	1.2-2.1	7.6	0.385	7.66	50.8	<2.00	23.6	3.36	2.73	83	2.06	12.8
6/3	2.1-3.1	7.6	0.375	7.45	41.4	<2.00	25.7	3.04	3.08	88	1.18	12.8
6/4	3.1-4.0	7.6	0.277	NSQ	41.7	<2.00	18.9	2.80	2.93	92	1.36	12.3
6/5	4.0-4.9	7.6	0.565	8.18	73.0	7.33	33.3	3.08	3.03	94	1.08	12.1
6/6	4.9-5.8	7.5	0.355	6.99	41.4	<2.00	18.9	3.29	2.73	88	0.98	12.7
6/7	5.9-6.7	7.6	0.384	NSQ	48.3	2.36	23.8	2.75	2.68	94	1.09	12.3
6/8	6.7-7.6		0.301	4.75	36.6	<2.00	18.5	3.31	2.48	85	0.99	10.9

Table 4.4. Select water chemistry and microbiology properties for Site 1

Sample		**Location 1**		**Location 2**		**Location 3**	
Location	Units	1/L		2/L		3/L	
Tip depth	(m)	7.6		7.2		4.50	
Surf. Elev.	(m)	965.03		964.07		961.37	
Tip Elev.	(m)	957.43		956.87		956.87	
Sample Date		02-Dec-99	09-May-00	02-Dec-99	09-May-00	02-Dec-99	09-May-00
pH		7.15	6.94	7.01	6.54	7.32	7.13
EC	mS/cm	1.37	1.36	2.06	2.33	1.26	1.32
TDS	mg/L	877.00	850.00	1318.00	1560.00	806.00	820.00
Chloride	mg/L	1.50	13.30	237.00	176.00	20.70	43.90
Phosphorus	mg/L	<0.03	0.06	0.29	0.23	0.04	0.07
Potassium	mg/L	3.00	12.40	4.60	4.40	3.10	18.20
Ammonia	mg/L	<0.05	<0.01	<0.05	<0.01	<0.05	0.05
Nitrate	mg/L	6.16	6.15	0.06	0.15	8.21	16.10
Nitrite	mg/L	0.24	NT	<0.05	NT	0.32	NT
Dis. Oxy.	mg/L	NT	6.00	NT	7.80	NT	7.50
T. Coliform	CFU/100mL	8.00	<1.00	400.00	33.00	20.00	2.00
F. Coliform	CFU/100mL	4.00	<1.00	<4.00	12.00	2.00	<2.00

Table 4.5 Travel velocities and distances for the physical parameters determined for Site 1.

Assumptions are:

i) saturated flow conditions exist
ii) soil porosity is 0.43 (BD=1580 kg/m^3)
iii) hydraulic gradient is 0.115 (land surface slope)
iv) steady state conditions exist (the EMS pond is full at all times)

K_s (m/s)	Darcy Velocity (m/s)	Linear Velocity (m/day)	Travel Distance (m)
1.00E-05	1.15E-06	2.46E-01	1.26E+03
1.00E-06	1.15E-07	2.46E-02	1.26E+02
1.00E-07	1.15E-08	2.46E-03	1.26E+01
1.00E-08	1.15E-09	2.46E-04	1.26E+00
1.00E-09	1.15E-10	2.46E-05	1.26E-01
1.00E-10	1.15E-11	2.46E-06	1.26E-02
1.00E-11	1.15E-12	2.46E-07	1.26E-03

5.0 Investigation of Site 2

5.1 General Site Description and Construction Methods

The layout of this study site is depicted in the general site diagram (Figure 5.1). The 2400-m^3 EMS pond provides just over 10 months of storage capacity for a 120-sow farrow-to-finish operation, according to standard manure production calculations (Table 2.3). The reservoir was constructed in 1991, and had been in operation for just over 8 y at the time of the investigation. The dimensions of the EMS are fairly typical for this size of operation. It is approximately square (32 x 27 m) is slightly longer in the north-south direction and has a depth of about 3.5 m. The general slope of the land at the site is to the east. The EMS pond was constructed using a large backhoe and consequently its side slopes are quite steep. Side slopes on all four sides were assumed to be 1:1 for the purpose of volume estimation. A 2.5-m high berm was constructed on the downslope side (i.e., east and north) of the pond to match the elevation of its upslope side to maximize storage capacity with minimum excavation. Extra material from the excavation was placed on the east side of the berm to extend its width to nearly 20 m downslope of the full supply level of the EMS pond. The berm was compacted somewhat during construction by the weight of the backhoe repeatedly travelling across the excavated materials placed there as they were removed and placed during construction. No liner was constructed and no extra effort was made to compact the natural pond liner or the berm. Topsoil was not removed prior to construction of the berm.

5.2 Background Resource Data

The Quaternary Geology of Central Alberta map shows that the area in the vicinity of the EMS pond at this site is a transition zone between draped and stagnation moraine deposits (Shetsen, 1990). These typical glacial till deposits consist mostly of unsorted clay, silt, sand and gravel materials that may contain localized water-sorted materials and bedrock outcrops. The stagnation moraine can be expected be up to 30 m thick but the draped moraine is generally less than 10 m thick. The depth of both materials is generally affected by surficial topography. In the case of draped moraine, the underlying bedrock generally controls the surface topography, i.e., the overburden is thinner at local topographic high points and thicker in the valleys. On the other hand, depositional thickness controls the topography of a stagnation moraine, with topographic high points indicating thicker deposits of till materials. Draped moraines tend to exhibit flat-to-undulating topography while the hummocks of a stagnation moraine produce a rolling landscape. No obvious hummocks are apparent at the study site and the surficial features are better described as undulating than rolling. Therefore, the surficial deposit at the site is most likely a draped moraine that is expected to be less than 10 m thick.

The soil survey report shows that the soil materials at the study site display the characteristics typical of the Markerville soil series (AGRASID, v1.0, Nikiforuk et al., 1998). The Cygnet soil series is co-dominant within the soil polygon at this site. The Cygnet soil is classified as an Eluviated Black Chernozem, while the Markerville soil is an Orthic Dark Gray Luvisol. For our purposes it is inconsequential under which series, order or great group the soils at this site fall. Rather, we are trying to determine if the physical properties predicted by inspection of the soil survey data match with those found at the site. As there is little difference between these soils in terms of hydraulic or textural properties, no further differentiation seems necessary.

The C-horizon soil texture map (Figure 5.1) shows that the study site is located within a large area of medium-textured subsoil materials. The soil survey data indicate a sand, silt, clay content of 40%, 30% and 30%, respectively. The predicted hydraulic conductivity of this material is expected to be 2.78 x 10^{-6} m/s. The bulk density of the Markerville series parent material is about 1400 kg/m^3, while that of the Cygnet soil is slightly higher at 1500 kg/m^3. The porosity of the soil at the study site should therefore be between 43 and 47%. The field capacity water content is predicted to be between 43 and 45 m^3 H_2O / m^3 soil. The soil is non-saline and the subsoils are weakly calcareous.

Three of the six water well records found for the land location of the study site provided fairly extensive lithology data for the site to a depth of about 40 mbgl (meters below ground level). Two of these driller reports indicated that about 10 m of sandy yellow clay material overlies a hard sandstone layer. Layers of soft shale and sandy clay materials with coal streaks underlie this sandstone layer. The well logs also showed that the underlying materials are bluish in color, indicating that the zone is wet and chemically reduced. Based on this, it is likely that the deeper materials are water-weathered shale capped with a thin calcareous sandstone material. The other water well record from a well drilled within the same legal subdivision as the study site showed alternating layers of yellow clay till and boulders to about 35 mbgl. This well services a community hall upslope and to the west of the study site. Since the site seems to sit within a natural drainage path, the coarse fractions could be remnants of a post-glacial melt water channel that was filled by repeated glacial advances and recessions. This theory is supported by the fact that the site sits just off a stagnation moraine deposit (Shetsen, 1990), which, by definition, means that the terminus of the glacier sat just to the southwest of the site. A glacier would normally advance and recede several times near its terminus during natural periods of warming and cooling before its final recession at the end of the last ice age.

Other water well logs in the area showed that the glacial till cover gets thinner to the north of the study site and thicker to the south. The topographic map and the local air photographs show that the house on the quarter section to the north is directly across the road from the study site and sits somewhat uphill on the edge of the ridge where the study site sits. That bedrock is closer to the surface there is consistent with the idea that this is a draped moraine that thins out near high points and thickens in lower areas. The house to the south sits in a low drainage area, similar to the location of the study site. The till cover there is also of similar type and depth as that near the study site, with 10 m of brown and blue clay material over a sandstone-capped shale bedrock. Well records to the south and east of the study site show that the till cover becomes thicker there (~ 15 m), consistent with the quaternary geology maps and the airphotos that show the hummocky terrain indicative of the stagnation moraine deposits that begin there.

The aquifer used in the area is a sandstone formation about 30 – 40 mbgl, with the water available at rates between 1.0 - 1.5 L/s. The static water level in the water wells near the study site is 12 – 15 mbgl, which indicates that the water in the confined aquifer is under pressure and has a tendency to move upward when the confining aqitard is punctured. However, there is no indication that artesian or flowing wells occur in the area immediate to the site. An area of artesian flow and a spring are noted on the Alberta Environment's Hydrogeology of the Red Deer Area map, 5 km east and 3 km south of the site. The hydrogeology map indicates that the direction of groundwater flow at the site is northeast (LeBreton and Green, 1970).

5.3 Chronology of Events for the Site Investigation

The following is a time-based listing of events and procedures carried during the investigation of this site:

February, 1999	Initial contact with producer • Producer indicated willingness to participate in project. • Producer site contained EMS of sufficient size and age and soil. Conditions.
April, 1999	Confirmation of parent material suitability • AGRISID parent material data was used to confirm basic soil type as medium textured.
July 7, 1999	EM 31 survey • Post survey analysis indicated potential seepage plume off the northeast portion of the east side berm.
August 1999	Site selection for intensive investigation • Site was selected as an apparent leaking site.
Oct. 5-6, 1999	Initial drilling • One piezometer nest parallel to the berm and general flow direction due to local land use constraints. • Four piezometer nests downstream, as per protocol. • Soil samples were taken from one borehole, immediately downslope

of the berm.

- Intermittent soil samples taken in several other boreholes, corresponding to soil conditions not apparent in the first two.

Dec. 14, 1999 Additional soil sampling. Two piezometer nest locations were profile sampled.

- More complete soil sampling information was needed to analyze the site.
- Sampling boreholes included parallel-to-berm and far downslope.

Jan. 5, 2000 Flushing of Piezometers

- Water elevations recorded.

Jan. 19, 2000 Second flushing of piezometers

- Water elevations recorded.

Feb. 3, 2000 GPS survey of the site

Water sampling.

- Water elevations recorded
- Samples were taken in the deepest piezometer of nests 2, 3, 4, and 5. All other piezometers were dry.

April 27, 2000 Topographic survey of site.

- Data include location of piezometer nests, top and toe of each side of the berm, in the middle of each side, a section line through the EMS in the general direction of the local slope, and several reference points on landmarks recognizable on an airphoto.

May 31, 2000 Additional soil sampling.

- More complete soil sampling information was needed to analyze the site.
- Sampled boreholes included on top of the downslope side of the berm and far upslope.

May 31, 2000 Second water sampling.

- One additional sample location. Piezometer in suspected plume remained dry.
- Manure storage had been emptied in the middle of May.
- Dissolved oxygen was measured for each sample.

5.4 Site-specific Investigation

5.4.1 Site Survey Data

The observation wells at this site were located using real-time DGPS considered accurate to $\pm$ 0.5 m. This information was used to plot the locations of the piezometer nests onto the orthorectified airphoto (Figure 5.1). Several survey lines were carried out at this site using a total station survey instrument to document distances between piezometer nests and the general ground slope near the EMS pond to enable the calculation of groundwater elevations and gradients at and between the observation well sites.

The EMS pond at this site sits on a ridge so the ground slope near the pond is relatively flat ($\simeq$ 0.014 m/m) above the EMS pond and dips noticeably at its upslope side ($\simeq$ 0.059 m/m). The gradient flattens out for about 35 m below the EMS pond beyond piezometer nest 2 to piezometer nest 4 (0.024 m/m). The terrain then dips again between observation wells 4 and 5 at a gradient of 0.065 m/m. Piezometer nest 5 sits in a natural waterway that channels surface water to the north into the bush. The owner reports that there is periodic spring located within this bush area where water flows to the surface during and after periods of rain or snowmelt.

5.4.2 Site Hydraulics

The water level data and piezometer elevation data for this site are found in Table 5.1. Fewer piezometers were installed at this site than was desirable because the boreholes tended to slump quickly after one or more of the saturated sand layers (found within most of the test holes) were penetrated. One sample of this material, taken from the 6.1 – 6.7 mbgl interval, shows a sand content of nearly 49% while the sample taken from the 2.1 – 2.7 mbgl interval from borehole 3 had a sand content of 54%.

Two piezometer tips were installed at each of Locations 2 and 4 at this site (Figure 5.1). The water elevations within the piezometers at Location 2 show that the vertical direction of groundwater flow was upward on January 5, 2000 but downward on May 31, 2000. At the initial observation, the water level at Location 4 was equal at both piezometer depths monitored. The water level at this location dropped steadily over the winter monitoring period but recovered somewhat on May 31. The deeper piezometer recorded a lower head than the shallower piezometer on May 31, indicating that groundwater flow was in the downward direction at this Location at that time. Conversely, head measurements at Location 2 on May 31 showed that groundwater was flowing upward at that location at that time. This rise in the water levels and the erratic trends in groundwater movement was likely due to spring recharge effects and lateral movement of water within the sand lenses noted in the field drilling logs rather than seepage from the EMS pond since the pond had been emptied in early May.

Only one shallow observation well was installed at Location 5 because slumping in the borehole prevented installation of additional piezometers. A saturated 0.1-m thick sand layer was found in this borehole at 1.1 – 1.2 mbgl. The borehole was drilled and soil samples were taken to 7.6 mbgl, but the sandy materials from the upper zone had entered and filled the hole before a piezometer could be installed. Monitoring records show that the water level in this borehole was initially below that at monitoring station 4, upslope of Location 5. However, as the water levels receded over the winter months at Location 4 they remained relatively steady at Location 5 (Table 5.1). This resulted in a hydraulic gradient toward the EMS pond, suggesting that the groundwater would flow toward the pond.

The water level at Location 5 rose between February 3 and May 31, 2000 as it did in all of the other observation wells, except Location 2 (Table 5.1). Observation of the drill logs of the upslope boreholes shows that the sand layer is thicker there than at the downslope positions. Hence the sand lens likely pinches out near Location 5, allowing a hydraulic back pressure effect to develop, similar to that that occurs in pipe flow hydraulics due to sudden pipe size reduction. This could cause groundwater to move upward at the downslope position as a result of saturation of the sand lens. Since there was only one piezometer depth monitored at Location 5, this theory cannot be confirmed at this time. However, the cooperating producer indicated that there is a flowing spring about 100 m downslope of Location 5 that flows only after a period of heavy rain or snowmelt. This is consistent with the theory that discharge conditions may have prevailed at Location 5 on May 31, 2000.

5.4.3 EM 31 Survey

The electrical conductivity (EC) surface generated with the use of the EM 31 survey data shows that a potential seepage plume from the EMS pond on the downslope side of the pond (Figure 5.1). The high EC signature was located approximately 10 m south of the north end of the EMS pond. The EC of the area where the suspected seepage plume exists was between 45 and 54 mS/m while the area surrounding it was between 36 and 45 mS/m. As a result of the EM investigation, the boreholes and piezometer nests were arranged to sample the soil and groundwater from the location of the suspected seepage plume. The background water samples were taken at Location 3 on the assumption that the area there was not affected by seepage from the EMS due to low EC response as indicated by the EM 31 survey (i.e., EC = 18 – 36 mS/m). Background salinity for the soils at this site is considered to be about 35 – 37 mS/m.

5.4.4 Soil Physical Data

The soil physical properties data for this site are given in Table 5.2. Soil physical analysis was conducted on the soil samples taken from Locations 1, 3, 5, 6 and 7. Locations 1, 3 and 5 were drilled in October 1999, while Locations 6 and 7 were drilled in May 2000. The extra drilling was used to confirm the earlier data. Further, samples taken from within the downslope berm were used to better determine the extent of seepage from this EMS pond. All soils taken from the test boreholes at this site during the investigation were visually inspected and hand-textured on site. Nearly all of the field hand texturings were clay or clay loam. Every borehole logged at this site showed streaks or lenses of coarse materials of varying depths and thickness throughout the soil profiles. Sand lenses tend to be thicker near the EMS pond and thinner farther downslope. This was interpreted to mean that, if the structure is continuous, it tends to pinch out as it extends downslope of the EMS pond.

The clay content of most of the soil samples taken at this site was usually above 25%, and often greater that 30%. The clay content was as low as 14% within a sand lens found at Location 3 within the 2.1 - 2.7 mbgl sample interval (data not shown). Sand content of the soils ranged widely from 12.4 % in the 6.8 – 7.9 mbgl sample interval at Location 7 to 64% in a sand lens found within the berm in the 1.5 – 2.4 mbgl sample interval at Location 6. The latter sample had a near-average amount of clay material in it for the site, at 27.8 %, but had the lowest silt content of any other sample (8.2%). The other samples had a silt content between 21.5 and 47.4%, and averaged about 32% across the entire site.

Bulk densities at this site were highly variable among sample locations. Samples from Locations 1, 6 and 7 had bulk densities in the range of 1280 to 1830 kg/m^3. The average bulk densities from these locations were 1780, 1625 and 1516 kg/m^3, respectively, with a standard deviation of 125, 98 and 161 kg/m^3, respectively. Soils from Location 5 show an unexpectedly low average bulk density of 908 kg/m^3 and a very low coefficient of variation of about 42%. The average bulk density of the soils at Location 3 was 1187 kg/m^3 and showed the largest standard deviation (440 kg/m^3). According to the soil survey data (Nikiforuk et al., 1998) the bulk density of the soil series expected at this location is between 1400 and 1500 kg/m^3. The average bulk density for all samples taken at this site was 1390 kg/m^3 and that for all samples except those from Location 5 was 1511 kg/m^3. Soil porosity ranged from 26 to 68% and averaged between 43 and 47% among boreholes at this site.

5.4.5 Soil Chemistry

Soil chemistry data for this site are found in Table 5.3. Soil chemistry analysis was done for the soil samples taken from Locations 1, 3, 5, 6 and 7. Locations 1, 3 and 5 were drilled in October 1999, while Locations 6 and 7 were drilled in May 2000. Originally, the soil and water chemistries from Location 3 were intended as background data. After a preliminary examination of the data, a second background soil sample data set was taken at Location 7. Data from farther upslope of the EMS pond were used for comparison to ensure that the soil chemistry data from Location 3 were not affected by seepage from the EMS pond. Results clearly show that the chemistry profiles from Location 3 are similar to those from Location 7 and are therefore unaffected by seepage from the EMS pond (Table 5.3). This is also important since the piezometers at Location 3 were used to collect "background" groundwater water data.

Soil chemistry profiles for all major indicator species are similar for all sample locations, except for Location 6, which was drilled into the downslope berm about 3.0 m from the full supply level of the EMS pond. The chloride (Cl) profile for Location 6 varied substantially compared to that at all other sample locations. Nitrate, ammonium and EC profiles of the samples taken from the berm also varied compared to those at the other locations. Nitrate concentrations at Location 6 were substantially higher than background in the near-surface (0.75 – 1.5 mbgl) interval and diminished to background, in a linear pattern, at the 3.4 – 3.8 mbgl sample interval. The soil EC profile at this location followed a similar pattern to that of nitrate, but did not diminish to background levels until the 3.8 – 4.6 mbgl sample interval. Soil ammonium concentrations, on the other hand, were all at, or near, background levels for all samples taken at Location 6, except those within the 3.4 - 3.8 mbgl interval. The NH_4 concentration within that sample interval increased two orders of magnitude from the sample directly above and one order of magnitude compared to the sample interval directly below. The increase in ammonium concentration here coincides with the layer immediately below the topsoil layer noted within the field logs for that borehole. This topsoil layer was likely left under the berm during construction of the EMS. Remnants of vegetation and root matter were also noted within this 1.0-m thick layer. An increase in soil moisture within this soil profile was noted within the soil analysis data where the topsoil layers were recorded in the field notes.

5.4.6 Water Chemistry

The water chemistry data for this site are found in Table 5.4. Such data for this site are limited due to difficulties encountered during installation of the piezometers during the site investigation. Boreholes slumped in very quickly after the drill auger was removed from the hole, making it difficult to insert the piezometers. As a result, only one piezometer was installed at Locations 3 and 5, while two of the instruments were installed at different depths at Locations 2 and 4. Samples were taken from each of the piezometers on two dates: February 3, 2000 while the EMS pond was full, and on May 31, 2000 after the EMS pond had been empty for about a month. All piezometers were installed in October 1999, and were pumped out twice prior to commencing sampling. Pre-sampling pump outs were performed to ensure that any contamination introduced into the observation well during installation was removed prior to initiation of sampling.

Water chemistries appear relatively uniform across all the sample locations and the sample dates for all the indicator species tested. Total dissolved solids (TDS) was one exception to this, with the TDS concentrations at the downslope observation wells between 2 to 4 times that of the background samples. The TDS concentration in the background water samples was 476 and 525 mg/L for the February and May sampling dates, respectively. Chloride levels in all water samples taken were quite low, ranging between 4.2 mg/L in the 7.1-m deep well at Location 2 to 61.7 mg/L in the 2.8-m deep well at Location 4, both on the February sampling date. Background Cl concentrations from Location 3 were 9.2 and 11.0 mg/L for the two sampling dates. The concentrations of both ammonium and nitrate nitrogen was less than 2.0 mg/L in all samples taken at this study site. Phosphorous and potassium levels are also considered to be within the normal range of expected values.

5.4.7 Microbiological Indicators

The water sample microbiology data for this site are found in Table 5.4. No fecal coliform bacteria were found within any of the water samples obtained from this site. Total coliform counts observed at this site are generally considered low to normal relative to that found at the other study sites. The background samples (Location 3) taken in February had a count of 5 CFU/100 ml but by May there were < 1 coliform bacteria in the water samples. Fairly high counts of total coliform bacteria (210 and 330 CFU / 100 ml) were observed in the samples taken from Locations 4 and 5 in February. By May 31, however, the total coliform concentrations in samples taken from those observation wells had dropped to 29 and 62 CFU/100 ml, respectively (the drinking water guideline for total coliform bacteria is 10 CFU/100 ml). Considering that no fecal coliform bacteria were ever present and the distance of these wells from the EMS pond, it is questionable whether seepage is occurring from the EMS pond. This is especially true since there were no other anomalous indicators observed in the samples from these wells to corroborate contamination from seepage.

5.5 Discussion

The only evidence of seepage or contaminant movement found at this site is the elevated EC and Cl, NO_3 and NH_4 concentrations in the soils in the berm. All the other soil chemistry profiles taken match well with the background sample sites and each other. The prime indicator species recommended by Huffman and Westerman (1995) for water chemistry comparisons are Cl, NO_3, NH_4, pH and EC. There is no evidence of seepage at this site according to these indicators.

TDS was the only water chemistry parameter that showed elevated levels downslope of the EMS pond, compared to that at the background observation well (Location 3). The concentrations found in the downslope wells were 2 to 4 times those of the background samples and ranged from 865 to 1920 mg/L compared to 476 and 525 mg/L at Location 3. The TDS concentrations found in the downslope water samples are within the normal range for groundwater in Alberta according to Fitzgerald (1999). He gave a range for TDS concentrations of 134 to 5,652 mg/L, with an average value of 1,107 mg/L for water samples taken from 816 farmstead water quality survey sites in Alberta.

The lower concentrations found in samples from Location 3 may be due to dilution effects. The quantity of water flowing through the sand lens was likely substantial. During construction of the well, water filled the hole almost instantaneously after the water-bearing sand lens, located between 2.1 and 2.7 mbgl, was penetrated by the drill rig. Water was flowing into the hole at such a rate that the sandy material from the sand lens also filled the 7.6-m deep hole to a depth of 3.0 mbgl before the piezometer tip could be inserted into the borehole. It is also possible that the lower TDS readings relate to the sandy soil in the layer where the piezometer tip was installed. These soils have a CEC of only 17.0 meq/100 g and would therefore be expected to allow salts to move relatively freely into the water. This theory is supported by the soil chemistry data, since the Ca, Na and Mg concentrations are lower in the soils in the corresponding sample interval at Location 3 than at Locations 1 or 5.

The water samples from the February sampling date from the 5.8-m deep well at Location 4 and the 1.5-m deep well at Location 5 showed elevated levels of total coliform bacteria. The levels of the bacteria measured at these locations at that time were about 20 – 30 times greater than the 10 CFU/100 ml allowed by the Canadian Drinking Water Guidelines (Health and Welfare Canada, 1989). However, the levels of coliform bacteria had dropped substantially by May 31. The bacteria count in the wells closer to the EMS pond also declined over the same time period. At the same time, there was a rise in the groundwater level at the site, as indicated by the rise in water level recorded in both of these piezometer nests. That bacterial counts declined at a time when groundwater levels were rising suggests that the bacteria in the wells likely resulted from a source other than seepage from the EMS pond. Furthermore, it is easier to believe that the piezometer tip somehow became contaminated during installation than that coliform bacteria could have survived and traveled 74 m from the EMS pond to the piezometer at Location 5. The declining numbers of bacteria over time supports the theory that the source of the bacterial contamination occurred during installation since an isolated population would be expected to die off over time as the food supply in the water dwindled.

The nature and texture of the soil materials found at this site were well predicted by the soil survey data (Nikiforuk et al., 1998) and the surficial geology map (Shetsen, 1990). Soils at the site were, in fact, medium textured, sandy clay tills. Thin sand layers and undifferentiated rock fragments were found throughout the soil profiles sampled. Flowing water was found in these sand layers and the clay till soils below these features tended to be very moist-to-saturated and showed the tell-tale grey coloration of chemically-reduced, water logged soils. With the exception of one sample location, the soils here exhibited bulk density and porosity values similar to those predicted for the C-horizon soil materials purported to be at this site according to the soil survey data. A bedrock shelf appears to lie at about 6.7 mbgl at Locations 1 and 2. This is consistent with the notion that the soils are a draped moraine deposit as per Shetsen (1990). Soil cover depths located upslope and farther downslope from the EMS pond were thicker than those near the pond, consistent with the theory that the pond is sitting on the edge of a bedrock shelf. A ridged topography that follows the bedrock topography is also consistent with the attributes of a draped moraine.

The water well records reviewed show that local deposits of water sorted materials exist within the 40-m thick glacial till overburden material at this site. Thinner till layers were found near topographic high points, which suggests that this is a draped moraine. Water well records also show that the water-bearing structure being used by the residents of this area is a sandstone bedrock layer about 30 – 40 mbgl depending on the well's position on the landscape. The well log data showed inconsistencies within the till materials surrounding the EMS pond.

Had a preliminary site investigation been carried out prior to construction of this EMS pond under the siting criteria used today, a site-specific investigation would have be required. Identification of the local sand layers near the EMS site during the investigation would have prompted the need for a compacted clay liner at this site and better quality control would have been required for berm construction than was apparent from this investigation.

The construction methods used to build the EMS pond at this site were not what would be recommended by today's standards but are fairly typical of those used for manure pond construction in the early 1990s. The side slopes of the EMS are steeper than most of the other sites investigated but do not appear to be slumping upon inspection after the pond was emptied in spring 2000. The volume of the EMS pond is > 6 months of storage recommended by AAFRD's Code of Practice (Anonymous, 1995), but less than the 12 months normally recommended by a practicing engineering professional today. The two main flaws in the construction of the EMS pond are related to the downslope berm. The topsoil was not stripped prior to construction and the berm was not properly packed as it was being constructed. If the berm had been constructed properly using a sheepsfoot packer and compacted to at least 95% of standard Proctor density in 15-cm lifts, there would likely have been no seepage at this site.

Even the watertable downslope of the EMS pond does not appear affected by pond seepage, since the watertable dropped over the winter months while the pond remained full. Conversely, the soils near the pond showed signs of waterlogging and chemical reduction, indicating that there is likely a naturally high watertable in this area. Perhaps the hydraulic gradient out of the pond is being neutralized by the pore pressures within these saturated, high clay content soils to prevent seepage from occurring. The fact that only about half of the downslope depth of the pond is below natural ground elevation and that the pond is only full for a short period of each year may also acts favorably to prevent seepage into the subsurface.

Seepage occurring into the berm materials is likely due to the unsaturated and unconsolidated nature of the soils there. The manure in the EMS pond is forcing its way into the berm materials during periods when the EMS pond is full, but after the pond is emptied, the seepage must move by diffusion and unsaturated flow mechanisms. The extremely thick berm is likely also helping to limit seepage through the berm.

The soils at this site have an almost ideal texture for construction of an EMS pond. The soil sample taken from the sample interval immediately adjacent to the bottom of the EMS pond in the borehole into the berm shows a sand, silt clay content of 35, 35 and 30%, respectively. This clay content is coincident with the ideal soil material recommended in Technical Note 716 (USDA-SCS, 1993). The clay content of all of the soils found at this site is above the minimum recommended by Barrington et al. (1983, 1987b and 1989) of 15% clay to allow manure sealing with hog manure. It is therefore very likely that manure sealing combined with the natural watertight nature of the soils is preventing seepage and contaminant movement from this EMS.

The CEC of the soils at this site do not meet the design requirements proposed by Barrington et al. (1987b, 1989) of 30 meq/100g but appear to be adequate to absorb the ammonium-N leaching into the topsoil layer below the berm from this EMS. Some evidence of downward movement is seen in the soil chemistry data from this borehole, but appears to extend to a maximum depth of 0.8 m below the seepage zone. The fact that this nutrient is not moving rapidly through or below the berm is attributed to sorption by the clayey soils at this site.

Although improved quality control at the construction stage would have resulted in a better, more secure product at this site, the almost total lack of evidence that this EMS pond is leaking after 9 y of operation brings into question the ever increasing engineering design requirements being imposed on hog producers constructing EMS ponds today. There was evidence of the presence of sand layers throughout the soil profile, some of which were in the soils near the pond and even in the berm. Logically seepage would have been expected into these coarse textured soil fissures but that does not appear to be the case. This suggests that some other factor, perhaps manure sealing, is preventing seepage from the EMS from entering the potential preferential flow paths identified at this Site.

This site has only been in operation for about 9 y. According to the soil logs from the borehole into the berm, there is about 2.0 m of clay material above a water-bearing sand layer. Assuming the soils below the floor of the EMS pond have a hydraulic conductivity of $1\text{x } 10^{-8}$ m/s and the porosity of the soil is 45%, means that the seepage rate from this EMS pond should be about 2.0 m/y. Over the 9 y of operation then, seepage should have penetrated to depth of 20 m below the floor of the EMS pond. Even if the hydraulic conductivity of the material was $1 \text{ x } 10^{-9}$ m/s, the seepage would have penetrated the 2.0-m thick clay layer and begun to supply some level of contaminant to the shallow groundwater. No evidence of this was found. Therefore, either the natural conductivity of the soil below the EMS pond is much lower than expected by its textural qualities or some level of manure sealing is occurring within this EMS pond.

5.6 Conclusions

There is no evidence that manure seepage from this EMS pond is entering the shallow groundwater. Evidence of elevated TDS levels in the water samples taken downslope of the EMS pond were attributed to natural sources due to the absence of any corroborating seepage indicators in the water samples. Elevated total coliform counts found in observation wells 47 and 50 m east of the EMS pond were attributed to contamination of the observation wells during installation.

Some seepage is occurring periodically into the downslope berm of the EMS pond according to the soil chemistry profile of the borehole into the berm, located approximately 3.0 m from the full supply level of the pond. No evidence of seepage was noted within the soil chemistry profiles at sample Location 1, located at the downslope edge of the berm, about 15 m east of the edge of the EMS pond. Therefore, seepage into the berm remains within the berm, likely due to the clayey nature and the relatively high CEC of the soils at this site. In fact, the nearly total absence of seepage or contaminant movement at this site is attributed to the watertight nature of the clay materials and the likelihood that a manure seal is developing at the bottom of this EMS pond. Hydraulic calculations performed using classic reservoir hydraulic theory showed that seepage should have occurred through the floor of the pond by now. The lack of evidence of this occurrence suggests that a manure seal may be preventing seepage at this site.

The remote resource data for this site provided a good overall picture of the nature and characteristics of the soil and geologic materials found at this site during the site-specific investigation. Soil survey and quaternary geology data predicted the presence of a relatively shallow glacial till soil with a clay content of about 30%, confirmed by the site-specific investigation. A review of these data prior to construction of the EMS pond would likely have prompted a preliminary site investigation and perhaps better EMS pond design and construction. However, the improved quality control during construction this would have resulted in only a marginal decrease in seepage and contaminant movement into the downslope berm of this EMS pond.

Figure 5.1 Site 2 Layout and location diagram showing the location of the soil sample and piezometers, the EM 31 electrical conductivity surface and the C-horizon soil parent material map for the area from the AGRASID database (Nikiforuk et al. 1998)

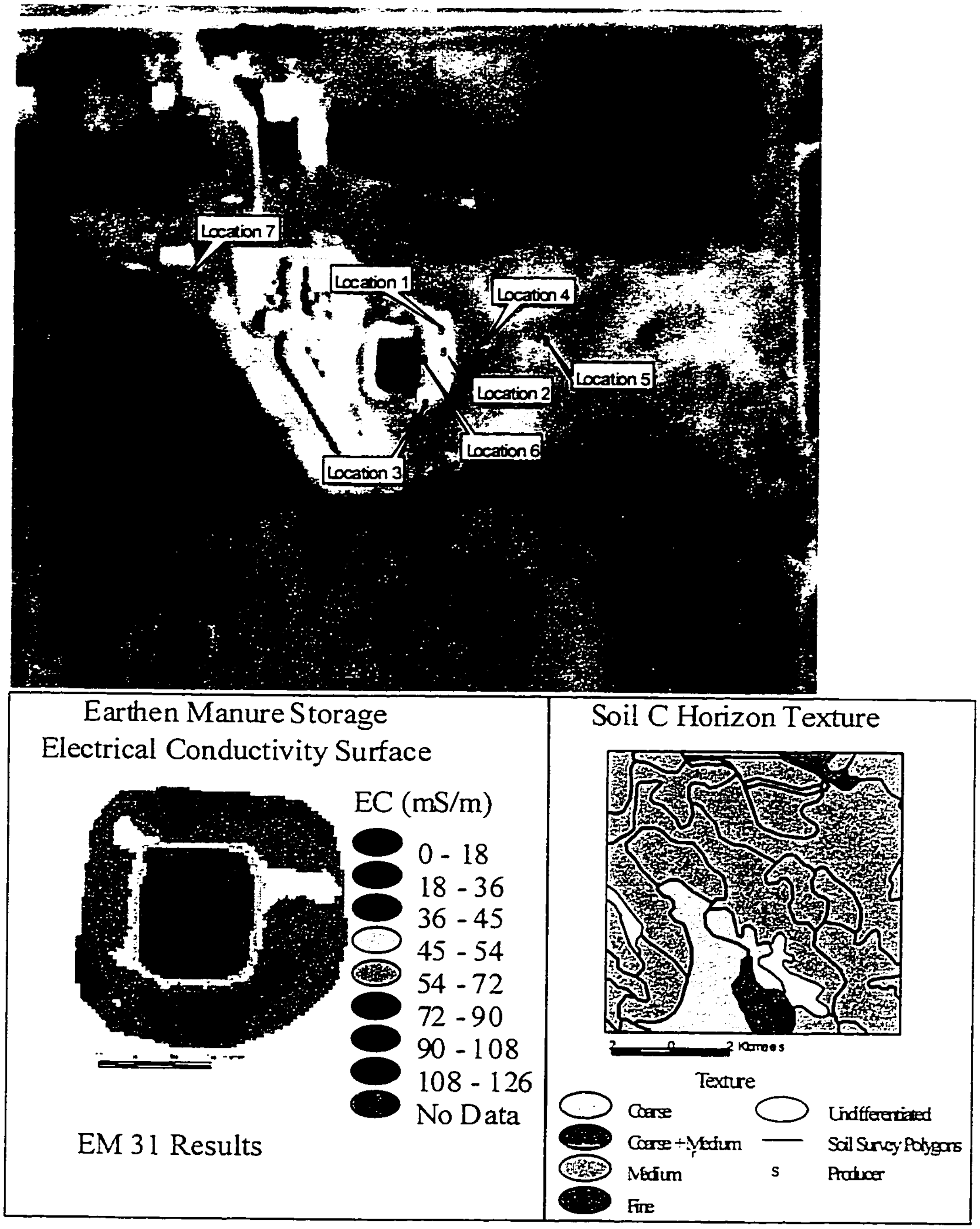

Table 5.1 Select Piezometric Properties for Site 2

Date				5-Jan-00	19-Jan-00	3-Feb-00	31-May-00
Location Well ID	Piezo Depth	Surface Elev.	Tip Elev.	Water Elevation			
1/L	5.9	856.28	850.4	dry	dry	dry	dry
2/H	6.0	856.28	850.3	850.3	dry	dry	853.6
2/L	7.1	856.28	849.2	849.8	854.5	855.0	855.0
3/H	3.0	856.26	853.3	854.6	854.3	854.5	854.9
4/H	2.8	855.58	852.8	854.1	853.1	dry	854.6
4/L	5.8	855.58	849.8	854.1	852.6	852.0	852.7
5/H	1.5	853.34	851.8	852.3	852.3	852.2	852.8

Table 5.2 Select Soil Physical Properties for Site 2

Location	Depth (m)	MC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	BD (kg/m³)	Plasticity (%)	USCS Class.
Location 1 (15 m down slope of EMS)									
1/1	0.3-1.0	15.6	2.10	30.9	39.80	27.20	1677.0	17.00	
1/2	1.0-1.5	21.2	3.00	19.0	44.30	33.70	1703.0	22.00	
1/3	1.5-3.1	21.4	1.60	24.4	42.70	31.30	1632.0	20.00	
1/4	3.1-4.6	19.9	1.00	40.0	32.60	26.40	1854.0	22.00	
1/5	4.6-6.1	19.8	0.50	37.5	34.80	27.20	1891.0	21.00	
1/6	6.1-7.6	19.2	5.50	32.5	34.00	28.00	1926.0	23.00	
Average		19.5	2.30	30.7	38.00	29.00	1781.0	21.00	ML
Standard Deviation		2.1	1.79	7.9	4.91	2.88	124.5	2.21	

Location	Depth (m)	MC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	BD (kg/m³)	Plasticity (%)	USCS Class.
Location 3 (9 m down slope of EMS)									
3/1	0.3-1.2	19.50	1.10	41.60	33.1	24.4	878.0	13.00	
3/2	1.2-2.1	21.60	2.40	39.80	36.3	21.6	1836.0	13.00	
3/3	2.1-2.7	18.70	0.40	53.60	32.1	13.9	1950.0	7.00	
3/4	3.1-4.0	16.80	0.80	38.80	34.5	25.9	936.0	16.00	
3/5	4.0-4.9	16.30	1.40	45.80	28.9	23.9	948.0	16.00	
3/6	4.9-5.8	20.00	1.20	51.40	21.5	25.9	930.0	17.00	
3/7	5.8-6.7	16.00	0.70	42.90	31.3	25.1	1050.0	15.00	
3/8	6.7-7.6	14.80	0.50	42.80	32.1	24.7	966.0	14.00	
Average		18.00	1.00	44.60	31.2	23.2	1187.0	14.00	ML
Standard Deviation.		2.34	0.63	5.36	4.5	4.0	439.6	3.18	

Table 5.2 (continued) Select Soil Physical Properties for Site 2

Location	Depth (m)	MC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	BD (kg/m³)	Plasticity (%)	USCS Class.
Location 5 (74 m down slope of EMS)									
5/1	0.3-1.2	18.10	3.50	36.20	38.40	22.00	873.0	15.00	
5/2	1.2-2.1	16.30	0.60	41.00	32.50	25.90	896.0	14.00	
5/3	2.1-3.1	16.00	0.70	40.70	32.50	26.10	930.0	16.00	
5/4	3.1-4.0	15.40	1.30	37.10	35.50	26.10	931.0	16.00	
5/5	4.0-4.9	15.80	1.10	34.30	36.10	28.50	945.0	18.00	
5/6	4.9-5.8	16.80	1.10	17.30	47.40	34.20	966.0	23.00	
5/7	5.8-6.7	22.80	0.50	34.90	36.10	28.50	875.0	29.00	
5/8	6.7-7.6	24.40	0.40	21.00	44.40	34.20	845.0	26.00	
Average		18.20	1.10	32.80	37.90	28.20	908.0	20.00	ML
Standard Deviation.		3.46	0.99	8.81	5.40	4.22	41.7	5.63	

Location	Depth (m)	MC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	BD (kg/m³)	Plasticity (%)	USCS Class.
Location 6 (berm, 3 m)									
6/1	0.75-1.5	13.90	0.20	41.00	29.20	29.60	1310.0	16.50	
6/2	1.5-2.4	19.20	0.00	64.00	8.20	27.80	1580.0	12.00	
6/3	2.4-3.4	25.40	0.10	37.10	35.00	27.80	1280.0	12.00	
6/4	3.4-3.8	23.10	2.40	32.80	35.40	29.40	1520.0	11.40	
6/5	3.8-4.6	21.10	0.70	37.30	30.60	31.40	1580.0	14.00	
6/6	4.6-5.3	18.00	1.00	39.60	28.80	30.60	1660.0	10.60	
6/7	5.3-6.1	20.60	9.50	33.70	30.60	26.20	1590.0	7.30	
6/8	6.1-6.9	16.30	14.40	29.40	24.20	32.00	1830.0	6.90	
6/9	6.9-7.6	17.20	18.80	23.80	25.40	32.00	1610.0	13.10	
6/10	7.6-8.5	21.00	6.50	31.30	26.40	35.80	1540.0	12.30	
6/11	8.5-9.4	18.60	2.30	34.30	26.00	37.40	1670.0	14.10	
Average		19.50	4.40	32.80	28.40	31.90	1625.0	13.20	ML
Standard Deviation		2.32	2.97	4.85	3.69	3.51	97.8	0.90	

Location	Depth (m)	MC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	BD (kg/m³)	Plasticity (%)	USCS Class.
Location 7 (110 m up slope of EMS)									
7/1	1.1-1.9	15.30	2.30	31.30	39.00	27.40	1340.0	9.10	
7/2	1.9-3.0	13.60	5.80	53.40	25.20	15.60	1650.0	12.00	
7/3	3.0-4.0	12.50	3.80	49.60	22.60	24.00	1680.0	12.70	
7/4	4.0-5.0	18.10	8.60	22.00	23.60	45.80	1480.0	9.10	
7/5	5.0-6.0	22.80	6.80	33.00	15.20	45.00	1360.0	7.40	
7/6	6.0-6.8	21.20	5.60	20.20	34.80	39.40	1600.0		
7/7	6.8-7.9	22.40	2.40	12.40	38.20	47.00	1700.0	4.70	
7/8	8.3-9.0	27.40	5.50	13.30	27.80	53.40	1320.0		
Average		19.20	5.10	29.40	28.30	37.20	1516.0	9.20	ML
Standard Deviation		5.17	2.17	15.53	8.37	13.28	160.7	2.95	

Table 5.3 Select Soil Chemistry Properties for Site 2

Location	Depth (m)	pH	EC (dS/m)	Cl (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	NH_4-N (μg/g)	No_3-N (μg/g)	K (μg/g)	PO4-P (μg/g)	CEC (meq/100g)
Location 1 (15 m down slope from EMS)												
1/1	0.3-1.0	7.45	0.68	47.9	73.6	<2.00	24.4	6.49	8.60	262	NSQ	33.8
1/2	1.0-1.5	7.70	0.83	49.8	59.4	<2.00	62.8	6.70	15.9	221	NSQ	41.7
1/3	1.5-3.1	7.60	0.76	28.9	14.6	<2.00	117	3.30	13.2	301	NSQ	41.1
1/4	3.1-4.6	7.90	0.91	3.19	3.00	<2.00	198	<0.500	12.4	238	NSQ	28.0
1/5	4.6-6.1	8.45	1.18	17.2	1.10	<2.00	276	1.79	16.5	262	NSQ	25.3
1/6	6.1-7.6	8.40	1.00	13.4	3.00	<2.00	237	2.41	17.1	266	1.32	25.9

Location	Depth (m)	pH	EC (dS/m)	Cl (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	NH_4-N (μg/g)	No_3-N (μg/g)	K (μg/g)	PO4-P (μg/g)	CEC (meq/100g)
Location 3 (9 m Down slope of EMS)												
3/1	0.30-1.22	7.55	0.47	5.49	42.9	9.98	39.9	6.49	3.43	166	0.54	26.2
3/2	1.20-2.10	7.95	0.47	23.30	26.4	<2.00	29.1	2.37	6.35	121	<0.50	25.5
3/3	2.10-2.70	7.85	0.44	20.90	25.4	<2.00	17.3	3.08	5.45	95	0.54	17.0
3/4	3.05-3.96	7.60	0.39	7.68	29.2	3.96	39.9	3.07	9.63	130	1.18	22.7
3/5	3.96-4.88	7.70	0.78	9.99	60.5	16.30	84.8	3.59	14.00	152	1.71	17.8
3/6	4.88-5.79	7.80	0.94	3.90	70.0	18.60	122.0	3.52	16.00	170	1.62	17.3
3/7	5.79-6.71	7.90	0.92	9.93	49.3	8.51	154.0	3.10	15.70	171	1.39	17.5
3/8	6.71-7.62	7.80	0.93	4.34	39.5	5.10	176.0	3.20	16.50	189	1.22	19.7

Location	Depth (m)	pH	EC (dS/m)	Cl (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	NH_4-N (μg/g)	No_3-N (μg/g)	K (μg/g)	PO4-P (μg/g)	CEC (meq/100g)
Location 5 (74 m down slope of EMS)												
5/1	0.30-1.22	7.60	0.45	14.30	44.00	7.47	39.6	5.59	2.48	107	1.13	28.8
5/2	1.22-2.13	7.80	0.45	9.620	27.20	5.88	75.8	2.90	4.43	129	1.07	23.3
5/3	2.13-3.05	7.80	0.73	11.90	25.80	4.64	130.0	2.99	7.13	151	0.99	22.1
5/4	3.05-3.96	7.90	0.89	12.60	20.40	<2.00	190.0	3.49	9.28	168	1.29	23.4
5/5	3.96-4.88	7.95	0.92	11.90	23.10	<2.00	184.0	4.22	11.40	183	1.29	24.0
5/6	4.88-5.79	8.25	0.83	2.66	5.83	<2.00	195.0	4.53	18.80	207	<0.500	30.2
5/7	5.79-6.71	8.20	0.82	10.20	<3.00	<2.00	192.0	4.71	21.20	233	<0.500	38.3
5/8	6.71-7.62	8.15	0.83	3.18	<3.00	<2.00	207.0	3.82	25.10	301	<0.500	36.1

Table 5.3 Select Soil Chemistry Properties for Site 2 (continued)

Location	Depth (m)	pH	EC (dS/m)	Cl (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	NH_4-N (µg/g)	No_3-N (µg/g)	K (µg/g)	PO4-P (µg/g)	CEC (meq/100g)
Location 6 (on berm)												
6/1	0.75-1.5	7.7	2.98	127.6	306.6	114.2	121.8	0.87	77.0	238	<5.0	17.1
6/2	1.5-2.4	7.8	2.22	290.7	250.5	76.6	96.6	1.70	31.3	146	5.2	23.2
6/3	2.4-3.4	7.6	1.56	269.4	158.3	42.5	73.6	7.04	16.0	310	16.0	21.2
6/4	3.4-3.8	8.1	1.58	315.5	110.4	38.9	137.9	233	<0.5	228	17.0	17.9
6/5	3.8-4.6	8.3	1.23	258.8	77.4	31.6	133.3	15.50	<0.5	67	6.3	16.7
6/6	4.6-5.3	8.2	0.92	184.4	85.4	36.5	36.8	6.59	3.4	158	<5.0	19.2
6/7	5.3-6.1	8.2	1.31	280.1	117.2	47.4	69.0	3.65	2.0	141	6.3	18.9
6/8	6.1-6.9	8.5	0.81	85.1	53.9	15.8	101.2	4.60	<0.5	153	<5.0	15.8
6/9	6.9-7.6	8.6	0.88	78.0	40.3	10.9	142.5	5.31	<0.5	41	<5.0	19.2
6/10	7.6-8.5	8.9	0.51	28.4	14.0	3.6	96.6	15.60	<0.5	265	<5.0	25.1
6/11	8.5-9.4	8.9	0.73	53.2	19.2	4.9	137.9	13.20	<0.5	235	<5.0	21.5

Location	Depth (m)	pH	EC (dS/m)	Cl (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	NH_4-N (µg/g)	No_3-N (µg/g)	K (µg/g)	PO4-P (µg/g)	CEC (meq/100g)
Location 7 (-110 m up slope of EMS)												
7/1	1.1-1.9	7.9	0.340	21.3	35.9	8.5	25.3	0.71	<0.5	162	<5	17.0
7/2	1.9-3.0	8.1	0.470	21.3	59.5	14.6	20.7	0.41	<0.5	74	<5	11.4
7/3	3.0-4.0	8.3	0.460	14.2	41.1	12.2	39.1	1.8	<0.5	166	<5	14.7
7/4	4.0-5.0	8.6	1.340	7.1	68.3	17.0	220.7	15.8	<0.5	296	<5	28.2
7/5	5.0-6.0	9.7	0.620	7.1	11.2	2.4	119.5	31.0	<0.5	277	<5	40.2
7/6	6.0-6.8	8.6	1.246	14.2	9.6	2.4	193.1	19.1	<0.5	333	<5	26.4
7/7	6.8-7.9	9.2	0.890	7.1	20.2	4.9	485.1	29.8	<0.5	262	<5	24.4
7/8	8.3-9.0	8.7	1.900	10.6	12.2	2.8	385.4	65.1	<0.5	80	<5	38.1

Table 5.4 Select Water Chemistry and Microbiology Properties for Site 2

Sample		**Location 2**			**Location 3**	
Location	Units	2/H	2/L		3/H	
Tip Depth	m	6.0	7.1		3.0	
Surface elevation	m	856.28	856.28		856.26	
Tip elevation	m	850.3	849.2		853.3	
Sample Date		31-May-00	3-Feb-00	31-May-00	3-Feb-00	31-May-00
pH		7.97	7.45	8.07	7.57	8.15
Conductivity	dS/m	2.55	1.98	1.97	0.743	0.818
TDS	mg/L	1920.00	1267.00	1370.00	476.00	525.00
Chloride	mg/L	7.30	4.20	8.70	9.20	11.00
Phosphorus	mg/L	<0.03	<0.03	<0.03	<0.03	<0.03
Potassium	mg/L	9.60	7.30	7.30	1.50	2.10
Nitrate	mg/L	1.74	<0.004	<0.004	1.24	1.31
Ammonium	mg/L	0.80	0.77	0.92	0.06	<0.01
Dissolved O_2	% saturation	17.10	NT	13.50	NT	21.00
Dissolved O_2	mg/L	2.20	NT	2.00	NT	2.30
Total Coliforms	CFU/100mL	1.00	90.00	1.00	5.00	<1.00
Fecal Coliforms	CFU/100mL	<1.00	<1.00	<1.00	<1.00	<1.00

Sample		Location 4			Location 5	
Location	Units	4/H	4/L		5/H	
Tip Depth	m	2.8	5.8		1.5	
Surface elevation	m	855.58	855.58		853.34	
Tip elevation	m	852.8	849.8		851.8	
Sample date		31-May-00	3-Feb-00	31-May-00	3-Feb-00	31-May-00
pH		7.69	7.24	7.69	7.93	8.00
Conductivity	dS/m	1.71	2.53	2.44	2.04	1.33
TDS	mg/L	1210.00	1619.00	1730.00	1306.00	865.00
Chloride	mg/L	61.70	17.50	15.80	43.40	33.70
Phosphorus	mg/L	<0.03	<0.03	<0.03	<0.03	<0.03
Potassium	mg/L	6.00	7.60	8.60	3.10	2.70
Nitrate	mg/L	<0.004	<0.004	<0.004	0.800	0.235
Ammonium	mg/L	0.06	0.63	0.69	0.10	0.02
Dissolved O_2	% saturation	42.80	NT	27.10	NT	30.40
Dissolved O_2	mg/L	4.90	NT	2.80	NT	3.30
Total Coliforms	CFU/100 mL	56.00	210.00	29.00	330.00	62.00
Fecal Coliforms	CFU/100 mL	<1.00	<1.00	<1.00	<1.00	<1.00

6.0 Investigation of Site 3

6.1 General Site Description

The EMS pond at Site 3 was constructed in 1989 and has provided continuous service to a 700-feeder-hog operation for about 11 years. The pond has a capacity of about 3400 m^3, which allows for storage of nearly two years of manure production (Table 2.3) according to standard manure production volumes in the 1995 Alberta Code of Practice (AAFRD, 1995). The pond was excavated using a bulldozer, material was pushed out of the hole to the north and east to construct a berm along those sides of the EMS pond. The height of the berm was constructed to match the approximate elevation at the southwest corner of the pond to create a level pond surface. Extra borrow material was placed at the far downslope end of the pond and remains there in a loosely packed, disordered pile.

The general site plan drawing is an orthorectified aerial photograph that defines the site location and the position of the soil borings and piezometer locations relative to the EMS pond at the site (Figure 6.1). Also shown on the general site plan drawing are the EM 31 survey results and near-site C-horizon textures classified using data from the AGRASID soil survey database (Nikiforuk et al., 1998).

This site is located approximately one half mile south and across the road to the west of study Site 5. Oddly, the surficial geology and soils at this site are remarkably different than these at that site.

6.2 Background Resource Data

Shetsen (1990) described the Quaternary geology of the area at Site 3 as coarse deposits of sand and silt of Pleistocene and Holocene origin. These lacustrine deposits may be up to 80 m thick and form an undulating topography that may be locally modified by wind action. Nikiforuk et al. (1998) identified the soil at the site as having characteristics that conform to those of the Caroline soil series. This soil series is reported as a Brunisolic Gray Luvisol. These soils have no native Ah and Bt horizons and show poor natural morphological maturity. These soils are glacio-fluvial in origin, which is not totally consistent with, but correlates fairly well with, the Quaternary geologic description of the surficial materials here. The Caroline soil series is characterized as a well-drained soil with equal portions of sand and silt ($\simeq$ 40%) and about 20% clay content. The hydraulic conductivity of this soil is suggested to be 8.33 x 10^{-6} m/s, the bulk density to be about 1500 kg/m^3 and the porosity to be about 43%. The cation exchange capacity of this soil is rated at 18 meq/100g.

The general slope of the area near the site is to the northeast, with a gradient of about 0.013 m/m. Site inspection and airphoto interpretation reveals local topographic highs. Interpretation of site investigation data and local airphotos suggest that the local high points are likely due to bedrock ridges that were not eroded by glacial action. Airphoto interpretation also indicates that this site is located between two bedrock ridges within the local post-glacial valley floor.

Soil materials at the site are deltaic, fluvial glacial (Nikiforuk et al., 1998). According to Shetsen (1990), this suggests coarse deposits of gravel, sand and boulders with minor silt beds and including local till and bedrock exposures. This description appears to match the materials found within the area upon review of 48 water well drillers reports from Alberta Environment's Groundwater Information Center database (Alberta Environment, 1999). These well logs show that soils in the area range in texture from sand and gravel to clay and clay till, while overburden thickness varies from 4 to 50 m, depending on the position of the well relative to the localized ridges and valleys in the area. The closest published hydrogeologic cross section to the site is Rocky Mountain House 83B, F – F' (Tokarsky et al., 1987). The information from that source indicates that the underlying bedrock is of the Paskapoo formation, which is expected to be composed of sandstone, siltstone and coal. The hydrogeologic cross-sections for the area indicate that the overburden materials at this location are glacial till materials.

Many of the well logs show layers of coarse gravel, large rock and boulders deposited within the substrata, indicative of fluvial materials deposited within glacial melt water channels. These melt water channels appear to be scattered throughout the local area and so may have meandered throughout the glacial valleys during the meltdown event or may be the result of several advances and recessions of the glaciers. This would have resulted in the creation of a series of different melt water channels. The glaciers in the area of the study site came from the Rocky Mountains to the west (i.e., Cordilleran Ice Shields) and there could easily have been several advances and recessions of the glaciers. This would also account for the unusual mixture of coarse and fine deposits scattered throughout the study area. The surface material within the localized valley floors is a mixture of fine sandy silt and clay deposits, indicating that a glacial lake probably covered the area during the last glacial melt event.

Shell Canada Ltd. drilled a well at the study site location in 1954; this is the only water well record found for the study site land location. The water well log shows that the well was constructed into sandstone bedrock overlain with 12 m of clay and boulders. The sandstone bedrock is the water-bearing formation and the well was rated to produce about 0.01 L/s. Two water wells were drilled on the legal location directly to the south of the study site; the more recent of these was drilled in 1988 and shows about 23 m of mixed coarse and fine materials as follows; clay over boulders, over sand and pea gravel, over gray sandy clay and gravel, over blue-grey shale bedrock. Well casing perforations extended upward into the lower overburden layer to about 1.0 m above the bedrock and downward to the bottom of the well at 40 mbgl. The non-pumping static water level in the well was 6.4 mbgl and a 2-h long pump test removed water at a rate of 0.034 L/s to cause a total drawdown of about 23 m. The other well at the same location was drilled in 1968 and showed similar overburden lithology and static water level but was rated for 0.14 L/s. The aquifer in this case was a grey sandstone layer at about 21 mbgl.

6.3 Chronology of Events

The following table chronicles the events and procedures used to investigate this site.

June 4, 1999	Initial contact with producer • Producer indicated willingness to participate in project. • Site contained EMS of sufficient size, age and soil conditions.

June 7, 1999	EM-31 survey • Post-survey analysis indicated potential seepage plume off the northeast portion of the east berm.
August, 1999	Confirmation of parent material suitability • AGRASID parent material data were used to confirm basic soil type as medium textured.
August, 1999	Site selection for intensive investigation • Site was selected as an apparent non-leaking site.
Oct. 7, 1999	Initial drilling • One piezometer nest upstream and three downstream, as per protocol. • Intermittent soil samples were taken from several locations, primarily because of poor drilling conditions (i.e., very stony and firm till).
Dec. 13, 1999	Additional soil sampling. Two of the piezometer nest locations were profile sampled. • More complete soil sampling data were needed to analyze the site. • Sampling boreholes included upslope and far downslope.
Jan. 6, 2000	Flushing of piezometers • Water elevations recorded.
Jan. 24, 2000	Second flushing of piezometers Water elevations recorded.
Feb. 23, 2000	Water sampling. • Water elevations recorded. • Samples were taken in the deepest piezometer of nests 1, 2, 3, 4, and several of the intermediate piezometer tips.
April 10, 2000	Water elevations measured GPS survey of the site.
April 26, 2000	Topographic survey of site. • Data include location of piezometer nests, top and toe of each side of the berm, in the middle of each side, a section line through the EMS pond in the general direction of the local slope, and several reference points on landmarks recognizable on an airphoto.
May 30, 2000	Additional soil sampling. • More complete soil sampling information was needed to analyze the site. • Sampled boreholes included top of the downslope side of the berm and far upslope. • Second water sampling. • One additional sample location. Piezometer in suspected plume remained dry. • Manure storage had been emptied in the middle of May.

6.4 Site-specific Investigation

6.4.1 Site Survey Data

A site survey was undertaken using a total station to determine the elevation of each piezometer nest and the general slope of the land above and below the pond in the assumed direction of groundwater flow. The horizontal location of the piezometer nests was determined using real-time GPS and plotted to the orthorectified airphotos using that information. The survey data were used to calculate land surface and horizontal hydraulic gradients and relative temporal and spatial watertable elevation. The calculated overall land slope across the survey section is 0.030 m/m, while the land slope between piezometer nests 1 and 4 is slightly steeper at 0.044 m/m. Surface and tip elevations of the piezometers and the measured elevations of the watertable over the monitoring period are provided in Table 6.1.

6.4.2 Site Hydraulics

The hydraulic gradients were derived from measurements taken in the deepest observation well at each piezometer nest location (Table 6.1). The watertable at this site decreased in elevation upslope of the EMS pond, but increased downslope of the pond over the monitoring period. The initial overall hydraulic gradient between Locations 1 and 4 was slightly steeper that the ground surface slope between the two points (0.037 m/m). Between January 6 and May 30, 2000, the head at Location 3 had risen 0.8 m and 1.4 m in the 4.7-and 3.1-m deep observation wells, respectively. The rise in piezometric head at this location altered the gradient across the pond from the upslope position to become nearly flat (0.007 m/m). However, the gradient between the measured water elevations in the mid-level observation wells across these two points increased slightly from 0.032 m/m in January to 0.035 m/m in May. The gradient between Locations 3 and 4 increased between January 6 and 24, but then remained relatively steady for the remainder of the monitoring period until May 9, 2000. Between May 9 and 30, the water level at Location 4 rose faster that that at Location 3, decreasing the hydraulic gradient between those two points (0.043 m/m).

The hydraulic gradient between Locations 1 and 2 also decreased over the winter monitoring period but then rebounded by May 30. The decreased gradient over the winter months was essentially due to a steady increase in piezometric head at Location 2 while that at Location 1 remained relatively stable. By May 30, however, levels increased at both Locations 1 and 2, which resulted in a relatively flat gradient between those two points at that time (0.0038 m/m). The gradient on May 30 between the mid-level observation wells, however, was still relatively steep (0.03 m/m), showing that different flow regimes exist within the various substrata below this site. Field investigation logs show that the soils where the mid-level piezometer tips are installed are sandy clay till materials, while those near the deeper observation wells were logged as saturated gravel materials with large stones and sand.

The upslope piezometer nest (Location 1) showed consistently higher water levels in the deeper well tip than in the shallower wells, indicating recharge conditions (i.e., a net downward movement of groundwater). No water was observed in the shallow observation well at Location 1. At Location 2, a higher water elevation was consistently found in the lower piezometer than that in either the mid-level or shallow observation wells at that location, indicating that discharge conditions (i.e., a net upward movement of groundwater) exist 15 m north of the full supply level of the EMS pond. Water levels in the piezometers indicate that discharge conditions also prevail at Location 3, 6 m to the east of the high water mark of the EMS pond. However, at Location 4, 48 m northeast of the pond, the water levels in both the deep and mid-level observation wells are equal, indicating no vertical movement of groundwater at this location.

6.4.3 EM 31 Survey Data

The electrical conductivity readings observed using the EM 31 were plotted onto the orthorectified airphoto of the study site and a surficial distribution was constructed using a geostatistical Kriging technique (Figure 6.1). There appears to be a minor seepage plume emanating from the west side of the EMS pond, heading toward the northwest, in the expected direction of groundwater flow according to the observed ground surface slope at the site. According to the distribution scale used to develop the conductivity surface, EC readings within the supposed plume could be up to three times that of the surrounding locations. Considering discharge conditions at

Location 3, the identified area of high EC readings could also be the result of wet conditions or the upward movement of natural salts from the subsurface. Observation of darker coloration on the airphoto of the site suggests that the area where high EC readings were detected by the EM 31 is also an area of high soil moisture.

6.4.4 Soil Physical Data

The soil physical properties for the samples collected at this site are presented in Table 6.2. The soil materials at this site appear to be glacial tills since some small stones were observed throughout the soil profile. However, no rocks were observed on the soil surface in the area surrounding the site and only one streak was detected in the field drilling logs at the site.

The background soil sample site (Location 5) was located upslope of the EMS, about 15 m to the southwest. Soil materials near the surface (1.2 – 1.5 m sample interval) showed streaks of bentonitic clay. Below that, a major sand lens was found between 1.5 and 2.5 mbgl and orange-brown in color, indicating oxidation within the zone. Below that, a layer of sandy clay till about 1.3 m thick was encountered before auger met penetration refusal due to what appeared to be a boulder or siltstone bedrock. Soil particle analysis shows that the soil in the upper sample intervals had a sand content of about 37% and a clay content in the 34 – 35% range. The sand lens had a sand content of over 80% while silt and clay contents were 11 and 8.6% respectively. The soil below the sand lens had silt and clay contents of just over 25%, while the sand content was nearly 47%. The soil bulk density ranged from 1650 kg/m^3 near the surface to nearly 1900 kg/m^3 within the sand layer. The average bulk density was 1800 kg/m^3 giving the soil an average profile porosity of 34%.

Soil logs from boreholes 1, 2, 3 and 6 show that the EMS is situated in a sandy clay soil material with between 40 and 45% sand and between 25 and 30% clay and silt. At about 4-5 mbgl, a sandy gravel material with some very large stones or boulders was encountered in all test holes. This material was saturated and in some cases, overlain with very dense sandy clay materials with a bulk density of over 2000 kg/m^3. Gravel materials were encountered in the test hole into the berm at about 4.6

mbgl . The berm here is about 1.8 m deep and the EMS pond is estimated to have a depth of about 3.5 m. This means that there is just over 1 m of clayey soil between the bottom of the pond and the saturated sandy gravel that underlies the area where the pond is situated.

Soil tests of samples from borehole at Location 6 show that the berm had a variable sand content (27 – 42%) but the natural soils below the berm had about 45% sand and clay contents between 24 and 28%. The field log shows that topsoil was encountered at 1.5 – 1.8 mbgl in the borehole on the berm. Therefore, the topsoil had not been removed prior to construction of the berm. Furthermore, the materials within the berm were loosely packed and very moist, indicating poor construction practices and possible seepage through the berm.

The soils at Location 1 had over 50% sand content with only about 20% clay. Field logs from Locations 1 and 2 show that there is a thin ($\simeq$ 0.3 m thick) layer of silty material just below the surface at these locations. Soils at borehole Location 4, about 48 m southeast of the berm, are a sandy clay material with between 38 and 48% sand and 15 and 30% clay. The sample between 3 and 4 mbgl was somewhat anomalous, showing only 15% clay, 44% sand but nearly 40% silt content. Samples from other depths averaged only about 30% silt content.

6.4.5 Soil Chemistry

The cation exchange capacity of the soil materials at this site ranged between 3.7 and 23.5 meq/100 g (Table 6.3). The low CEC reading was recorded in the sand lens at Location 5 and in the sandy gravel material at the deep sample intervals at Location 6 (i.e., in the berm). The other soil samples had a fairly narrow range in CEC, between 14 and 24 meq/100 g.

Chloride (Cl) ions are generally considered a conservative species to trace manure seepage movement since they are typically not adsorbed to soils. Typical liquid hog manure chloride concentrations are 1000 – 2000 mg/L, much higher than normally found in soils or shallow groundwater on the prairies. Background soil samples from upslope Locations 1 and 5 show that the expected concentrations of Cl ions in the soils at this site are between 10 and 100 mg/L (saturated paste extract). The higher Cl concentrations in the background samples are within the sand lens at Location 5, indicating that there is some natural movement of Cl within the soils where water movement occurs. The Cl profile from the soil samples taken into the downslope berm at this site (i.e., Location 6) show higher than expected values within the 1.5 – 3.1 m sample interval. The sample depths with high soil Cl concentrations coincide with the depth of the EMS pond (i.e., 3.5 m), thus indicating that some seepage and contaminant movement is occurring from this pond. However, no Cl movement was detected at Location 4, demonstrating that seepage from the pond has not traveled the 48 m to that sample site over the 11 y that this EMS pond has been in service.

Nitrate is also mobile in the soil environment, since it too has a single negative valance. Soil chemistry profiles of this element show very similar patterns to those of the Cl profile (Table 6.3). The NO_3 profiles from the immediately upslope and far downslope positions are virtually identical. The NO_3 signature from Location 5, farther upslope of the EMS, shows even lower NO_3 concentrations. A noticeably higher $N0_3$ concentration was observed at Location 5 in the 1.5 – 2.5 mbgl sampling interval compared to those of the other sampled depths. The increased concentration within this sample interval coincides with the bulge in chloride concentration and the depth where the soils had over 80% sand. This likely indicates that some nitrate leaching is occurring from the surface due to fertilization of the upslope pasture and some fairly intense periods of pasturing of a local dairy herd at this location. It also means that the sand lens detected at this sample location is in an aerobic state, which confirms that the red coloration of the sandy material is due to oxidation reactions. Observation of the moisture content profile corroborates this theory since the layer is not saturated (10% moisture content), which would have led to reducing conditions. Soil samples from the sample intervals 0.5–1.5, 1.5–1.8 and 1.8–2.4 m at Location 6 show NO_3 concentrations of 11, 15 and 12 μg/g, respectively. These higher than expected values of NO_3 coincide with the sample interval within the constructed berm on the downslope side of the EMS pond.

Electrical conductivity profiles at this site (Table 6.4) follow the same trends noted for Cl and NO_3. This is expected, as many soil salts are compounds of chloride and sulfate anions and many of these salts are of neutral valence and thus relatively mobile in the soil environment. However, soil profile EC values do not match well with the EM 31 survey results. The EM survey shows a higher EC reading for the area near Location 4 than that for sample Locations 1, 5 or 6, while the soil profile EC values portray the opposite trend. This lends support to the theory that the cause of the high EM 31 reading was high moisture content in the clay soils due to discharge conditions observed where the high EC readings were recorded using the EM technique. Observed soil moisture profiles do not bear out this theory, however, as all soil moisture measurements were similar (Table 6.2), except for the measurement within the sand lens at Location 5.

The soil chemistry profiles for NH_4 show that the concentrations for Locations 1 and 4 were similar, with concentrations between 3.0 and 6.9 μg/g that were essentially uniform with depth (Table 6.3). The concentrations of this species are actually higher in the upslope soil sample than in the downslope samples. The concentration profile from sample Location 5 shows a sharp spike in soil NH_4 concentration for the sample interval immediately below the sand lens found there, contrary to the NO_3 results. This was expected, since signs of reduction reactions were observed within the clays beneath the sand lens. Nitrogen leaching in NH_4 form into the clays is likely reduced within the anoxic environment of the deep clay till soils to produce the high NH_4 concentrations (7.49 μg/g) measured here. The samples from the borehole into the downslope berm show a small spike in NH_4 concentration in the 1.5 to 1.8 mbgl sample interval, but all other NH_4-N soil sample concentrations from this sample location are lower than those from the other sample locations at this site. The concentration spike within the NH_4 concentration profile at Location 6 (i.e., in the berm) coincides with the depth interval shown in the field drilling investigation log as a layer of topsoil that was not removed prior to construction of the berm.

6.4.6 Water Chemistry

Water samples were taken from the piezometers at this site on February 23, 2000 and on May 9, 2000 (Table 6.4). Location 1 is considered as the background data location due to its upslope position relative to the EMS pond. Unfortunately, samples were only available from the deep observation well at this location due to low watertable conditions at the time of sampling. Samples were only available from the shallow and mid-level piezometers at Location 2 on May 9, 2000. Samples were taken from the deep and mid-level observation wells at both sampling dates at Locations 3 and 4.

Water samples from all observation wells at all sampling times exhibited a neutral to slightly alkaline pH of 7.0 to 7.4. Electrical conductivities of the water samples here were generally low (< 1.8 mS/cm), but were slightly higher in samples from the background observation wells than those downslope of the EMS pond. TDS concentrations in the water samples ranged from 370 mg/L at Location 4/L on May 9 (far downslope position) to 1,150 mg/L at Location 3/M (immediately downslope of the EMS pond) on the same date. TDS concentrations of the background water samples were 928 and 970 mg/L for the February and May sampling dates, respectively. Similarly, the observed background Cl concentrations were within the normal range expected for shallow groundwater in these non-saline soils for all water samples taken. Relatively high Cl concentrations were noted within samples from the background sample observation wells (Location 1; 165 and 149 mg/L on Feb 29 and May 9) but did not exceeded the Canadian Drinking Water Guideline of 250 mg/L. The highest chloride ion concentrations were found at Location 3 in the 3.1-m deep piezometer: 298 and 234 mg/L for the February and May sampling dates, respectively. Only on the Feb 23 sample date at Location 3 was the Cl drinking water guideline exceeded by any of the water samples taken at this Site.

Nutrient concentrations (P, K, NO_3 and NH_4) in the water samples taken at this site were not very high (Table 6.4). Phosphorous and NH_4 concentrations were less than 1.0 mg/L for all samples taken. Potassium concentrations in the background samples were slightly higher than those found in the water downslope of the EMS pond but are not considered unusual. This trend was also realized for NO_3-N concentrations, where concentrations of this species were 5.91 and 2.27 mg/L for the February and May sampling dates, respectively. All NO_3 concentrations in the groundwater samples taken from downslope observation wells were below the average nitrate concentration of shallow groundwater in Alberta of 2.19 mg/L (Fitzgerald, 1999).

6.4.7 Microbiological Indicators

Data from the water sample analysis for microbiological indicator species are presented in Table 6.4. The highest counts of total coliform bacteria recorded at this site were 24 and 19 CFU/100 ml in the samples from the deep observation wells at Locations 3 and 4 on May 9, 2000. These are considered low counts of total coliform bacteria, since the background sample had a concentration of 7 CFU/100 ml for the same date. All other samples had concentrations of this indicator species of less than 5 CFU/100 ml. Fecal coliform counts in the water samples at this site were scant. Only the samples from shallow and mid-level observation wells on May 9, 2000 showed any fecal coliforms. Two CFU/100 ml were detected in the water at Location 2/H and 1 CFU/100 ml was found at Location 2/M. No other detections of fecal coliform bacteria were made in the water samples taken at this site.

6.5 Discussion

The lack of quality control used to construct the EMS pond at this site is likely representative of the construction methods used to build many of the liquid hog manure storage ponds 10 to 20 y ago in Alberta. Two major construction flaws contributed to manure seepage found at this site. First, topsoil was not removed prior to construction of the berms of the reservoir and second, the berms themselves were not well compacted during construction.

The background site characterization data reviewed for this site indicated that the soils in the area should be glacio-lacustrine (Shetsen, 1990) or glacio-fluvial (Nikiforuk, 1998). These two data sources correlate fairly well since post-glacial lakes often contain fluvial remnants that developed during the draining of the lakebed. The difference between the information is likely related to the scale of the data source, as Shetsen's map was at 1:250,000 while the soil survey data is available at 1:100,000. Therefore, the soil survey data (Nikiforuk et al., 1998) were able to differentiate the surficial materials to a greater degree than did the Quaternary geology data. Water well drillers' logs were helpful to determine the patterns in the surficial material and to assist with the development of a theory of geomorphological development for the area. The water well logs indicated a wide range of surficial cover materials and overburden thickness. The range of overburden thickness indicated by the drillers' reports was 4 – 50 m. Correlation of the drillers' logs to airphotos of the area showed that the overburden thickness is related to slope position. Thicker deposits were found in the low areas and on the sides of the bedrock ridges while shallower deposits are located on the top of the ridges.

Review of the water well drillers' reports. and the soil survey and Quaternary geology maps, indicated that there is a complex mixture of soil and rock material deposits interspersed throughout the area. The physical data obtained from the site-specific investigation of this EMS pond were consistent with the expected findings from the review of the background site characterization data. Viewing the site-specific data in tandem with the remote data resources enabled the development of a comprehensive picture of the physical setting and geomorphology of this site. A thorough review of the available information resources prior to construction of this EMS pond would have confirmed the need for a site-specific investigation to confirm the physical characteristics and design requirements, which would have resulted in a more environmentally secure EMS pond.

The surface land at the site slopes to the northeast at a gradient of between 0.03 and 0.044 m/m and the EMS pond is situated on the bench near the grade break. The position of the EMS pond on the slope and the construction style used here minimized the depth of excavation required to obtain adequate storage volume for the manure production of the operation. The shallow depth of the pond prevented penetration of the EMS floor into the underlying layer of coarse sand and gravel material. The layer of dense sandy clay material just over 1.0 m thick underlies the EMS floor and seems to be protecting the underlying layer of coarse saturated material from the effects of seepage or contaminant movement. The underlying layer of coarse materials appears to be fluvial in origin, perhaps a remnant of a post-glacial streambed that formed during a period of glacial meltdown.

The borehole at Location 5, 15 m upslope of the EMS pond, showed a thick layer of sand at about 1.5 mbgl. This sand is underlain by a layer of very coarse gravel and boulders that seems to extend downslope underneath the EMS floor. The sand layer appears to diminish near the EMS pond and then reappear at sample Location 4, 48 m downslope of the EMS pond. The borehole log at Location 6 (in the berm) shows that the layer of gravel and boulders under the EMS pond is about 3.0 m thick. No gravel/boulder layer was found below the sandy materials at Location 4. The EMS pond is situated on top of an old streambed that was subsequently covered with a finer textured clay till material, likely from a later ice advancement. The presence of the clay till material is preventing seepage from the EMS pond into the coarse underlying materials.

Water level data from the piezometers at this site show a seasonal fluctuation related to the spring snowmelt event. The measured piezometric head data show that the area upslope of the reservoir is a recharge zone while the area surrounding the EMS pond shows a net upward movement of the groundwater there. Farther downslope, the water elevations in piezometers at Location 4 showed the same elevation for all tip depths, indicating a true watertable here that fluctuates seasonally with infiltration and evaporation. This lends support to the theory that the coarse material underlying the EMS pond pinches out downslope of the pond. Thus the discharge conditions near the manure pond are likely related to a back pressure that develops within the coarse material layer as it is recharged with springmelt water. The water is unable to escape as fast as it is recharged due the termination of the material into clay till materials of lower hydraulic conductivity. This results in a pressure buildup within the confined layer, increasing piezometric head and the upward movement of groundwater in the area near the EMS pond. This phenomenon is likely also helping to prevent seepage from the pond, since the direction of groundwater movement near the pond is into, rather than out of, the pond.

Soil chemistry profiles for Cl, EC and NO_3 show that seepage is occurring through the berm on the downslope side of the EMS pond. This seepage appears to be related to poor construction practices. The berm is poorly compacted and the topsoil layer was not removed before the berm was placed onto the soil surface beside the excavated portion of the EMS pond. The water chemistry of samples taken from 10 m downslope of the EMS pond did not provide any evidence that seepage was occurring from the EMS pond. The possible exception to this was the appearance of fecal coliforms in the water samples in the shallow and deep piezometers on May 9, 2000. In the absence of any corroborating water chemistry data, however, it is more likely that these fecal coliform detections are related to contamination of the well tips during construction. The lack of previous detection in these wells is due to the fact that there was no water in these piezometer tips prior to May 9.

That the berm is very poorly constructed and loosely packed suggests that more seepage should be occurring than is evident from the data. Soil moisture profiles and field logs show that the soil in the berm is also very dry (~ 11% moisture). Thus manure sealing may be preventing seepage through the berm, causing seepage to be periodic and controlled by unsaturated flow phenomena. Most of the seepage appears to leak into the seepage channel created by the layer of topsoil that was left under the berm during construction. This seepage introduces NH_4-N to the soil environment there. This is supported by the observation of a small increase in ammonium-N concentration also within this soil layer. An increase in moisture content within this sample interval also supports this theory. However, the increase in moisture and ammonium here is not large enough to suggest that there is continuous seepage into the zone. The periodic development and breakdown of a manure seal could explain why there is not continuous seepage into this layer.

This theory is supported by the fact that elevated levels of NO_3, Cl and EC were found within the same soil layer as was the increased moisture and concentration of NH_4. The manure-laden water that has periodically seeped into the topsoil layer created the increased NH_4, which is then converted to NO_3. The NO_3 moves downward with water as it seeps into the soil below. This accounts for the decreasing

NO_3 concentration in the soil directly below the topsoil seepage zone. The Cl concentrations increase within the soil layer immediately below the seepage zone while the NO_3 concentrations decrease. This is expected since chlorides travel uninhibited with seepage and are not biodegraded. NO_3, on the other hand, is subject to degradation by denitrification, which may account for its concentration decrease through the next 1.0 m of the soil profile. Chloride concentration remains steady down to the 3.1-m sample interval, where it dramatically declines to background levels (85 μg/g). This likely indicates the extent of the depth of vertical transport, which is matched by the evidence of a wetting front to the same depth according to the soil moisture profile. The EC profile is better matched to the NO_3 profile than is the Cl profile. This is expected since downward salt movement would be retarded due to sorption of the cationic chemicals that are typical of salts.

6.6 Conclusions

Quaternary geology maps, soil survey data and water well drillers' reports were useful to assist with site characterization. The variable nature of the data points to the need for a site-specific investigation prior to construction of an EMS pond at this location. A site investigation would have resulted in a better understanding of the site and a recommendation for proper design and better quality control for a compacted liner and berm at this site. This would likely have resulted in elimination of all seepage from the manure storage pond.

Soil and water chemistry data from this site show that little seepage or contaminant movement is occurring from the EMS pond at this site. There are some indications that minor seepage is occurring into the poorly constructed berm. However, downslope soil and water sampling shows that very little, if any, of the seepage into the berm is moving beyond that point or into the shallow groundwater in the area. The fact that soil NO_3 concentrations are one of the main indicators of seepage through the berm suggests that the soil environment there is unsaturated and aerobic. This implies that the berm is very loosely packed.

The EMS pond is constructed within an area of localized groundwater discharge. This hydraulic condition and the presence of a ± 1.0 m thick, very dense sandy clay layer that forms the EMS floor are likely combining to prevent seepage through the bottom of this EMS pond.

Seepage into the topsoil layer under the berm is elevating NO_3, Cl and salt concentrations within that soil zone. Elevated levels of these chemicals in the soils immediately below the seepage zone indicate downward movement of the seepage waters. Elevated chloride levels to the depth of 2.4 – 3.1 m indicate that the downward movement of the seepage front extends to this depth. The lack of a major increase in either moisture content or NH_4 concentration within the seepage zone suggests that seepage into the berm is periodic. This may imply that manure sealing is preventing seepage from occurring continuously into the topsoil seepage zone from the EMS pond. Seepage likely occurs for an indefinite period after the EMS pond is filled to the level where the topsoil layer exists until the manure can clog the soil and prevent further seepage from occurring. This likely occurs intermittently as the EMS pond is emptied and filled, resulting in a pulse flow into the topsoil layer. This would also result in periodic oxidation of the NH_4 as the soil would dry during periods of no seepage, thus accounting for the zone of high nitrate surrounding the topsoil seepage zone.

Figure 6.1 Site 3 layout and location diagram showing the location of the soil sample and piezometers, the EM 31 electrical conductivity surface and the C-horizon soil parent material map for the area from the AGRASID database (Nikiforuk et al. 1998)

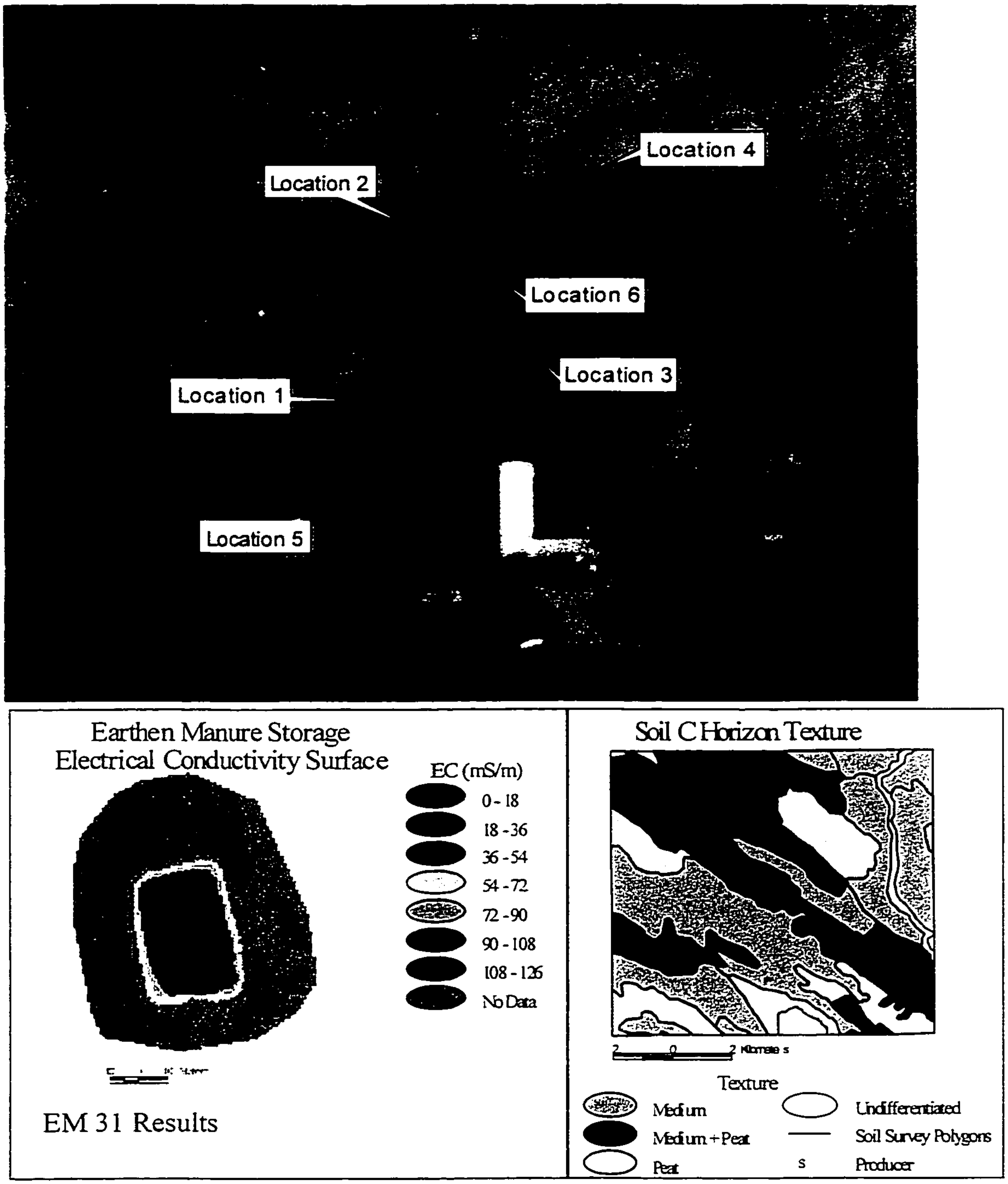

Table 6.1 Piezometric Data for Site 3

Date				01-Jan-99	24-Jan-00	23-Feb-00	10-Apr-00	09-May-00	30-May-00
Location Well ID	**Piezo. Depth (m)**	**Surface Elev.(m)**	**Tip Elev. (m)**	**Water Elevations**					
1/H	1.5	989.67	988.2	dry	dry	dry	dry	dry	dry
1/M	2.8	989.67	986.9	987.6	987.5	987.3	987.0	987.1	988.6
1/L	4.0	989.67	985.7	987.7	986.9	986.7	986.9	986.9	987.5
2/H	1.8	986.86	985.1	dry	dry	dry	dry	986.1	986.3
2/M	3.4	986.86	983.5	985.1	985.1	985.0	985.4	986.1	986.3
2/L	5.2	986.86	981.7	986.6	986.6	986.6	986.6	986.6	987.2*
3/H	1.5	987.62	986.1	dry	dry	dry	dry	dry	986.6
4/M	3.1	987.62	984.5	985.8	985.8	985.7	985.9	986.4	986.6
3/L	4.7	987.62	982.9	985.7	986.6	986.6	986.6	987.0	987.1
4/H	1.7	985.68	984.0	dry	dry	dry	dry	dry	985.0
4/M	4.0	985.68	981.7	983.8	983.7	983.6	983.7	984.2	985.0
4/L	6.3	985.68	979.4	983.7	983.7	983.7	983.7	984.2	984.9

* On 30-May, this piezometer exhibited artesian flow

Table 6.2 Select soil physical properties for Site 3

Location	Depth (m)	MC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	BD (kg/m3)	Plasticity (%)	USCS Class.
Location 1 (8 m up slope of EMS)									
1/1	0.3-1.2	11.70	1.6	39.80	32.50	26.10	926.0	14.00	
1/2	1.2-2.1	13.90	4.9	52.50	22.80	19.80	1020.0	12.00	
1/3	2.1-3.1	15.00	4.6	53.80	18.70	22.90	970.0	12.00	
1/4	3.1-4.3	12.80	24.6	29.80	25.80	19.80	1030.0	13.00	
Average		13.40	8.9	44.00	25.00	22.10	987.0	12.75	SM
Standard Deviation		1.42	10.6	11.37	5.82	3.03	48.1	0.96	

Location	Depth (m)	MC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	BD (kg/m3)	Plasticity (%)	USCS Class.
Location 4 (48 m down slope of EMS)									
4/1	0.3-1.2	16.30	0.90	38.40	31.50	30.10	958.0	16.00	
4/2	1.2-2.1	15.20	3.80	47.40	30.50	22.10	1000.0	13.00	
4/3	2.1-3.1	14.10	3.80	48.40	27.90	23.70	1060.0	13.00	
4/4	3.1-4.0	14.10	4.30	44.40	39.70	15.90	898.0	14.00	
4/5	4.0-4.9	11.30	3.40	41.40	36.50	22.10	800.0	13.00	
Average		14.20	3.20	44.00	33.20	22.80	979.0	14.00	ML
Standard Deviation		1.86	1.35	4.16	4.80	5.09	68.3	1.41	

Location	Depth (m)	MC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	BD (kg/m3)	Plasticity (%)	USCS Class.
Location 5 (15 m up slope of EMS)									
5/1	0.25-1.2	14.90	0.10	37.3	28.60	34.0	1650	20.3	
5/2	1.2-1.5	15.70	0.50	36.9	27.40	35.2	1880	20.7	
5/3	1.5-2.5	9.20	11.40	69.0	11.00	08.6	1890		
5/4	2.5-3.8	14.50	3.50	43.3	25.80	27.4	1730	13.0	
Average		13.60	3.90	46.6	23.20	26.3	1788	18.0	SM
Standard Deviation		2.96	5.24	15.2	8.21	12.3	117	4.3	

Location	Depth (m)	MC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	BD (kg/m3)	Plasticity (%)	USCS Class.
Location 6 (3 m down slope of EMS)									
6/1	0.5-1.5	10.80	0.20	42.20	30.20	27.40	1330.0	16.50	
6/2	1.5-1.8	19.00	0.00	27.40	43.00	29.60	1190.0		
6/3	1.8-2.4	16.00	0.10	28.70	47.20	24.00	1750.0	12.10	
6/4	2.4-3.1	18.00	2.40	39.00	30.00	28.60	1690.0	12.00	
6/5	3.1-3.8	14.50	0.70	44.70	28.60	26.00	2010.0	11.30	
6/6	3.8-4.6	15.40	1.00	43.40	28.20	27.40	2050.0	13.30	
6/7	4.6-5.3	14.40	9.50	35.90	29.40	25.20	1840.0	10.60	
6/8	5.3-6.1	12.20	14.40	16.00	47.00	22.60	1900.0	7.50	
6/9	6.1-7.5	14.50	18.80	32.60	27.20	21.40	1950.0	6.90	
Average		14.98	5.23	34.40	34.50	25.80	1746.0	11.00	SM
Standard Deviation		2.56	7.18	9.32	8.53	2.75	300.3	3.08	

Table 6.3 Select soil chemistry properties for Site 3

Location	Depth (m)	pH	EC (dS/m)	Cl (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	NH_4-N (µg/g)	No_3-N (µg/g)	K (µg/g)	PO4-P (µg/g)	CEC (meq/100g)
Location 1 (8 m up slope of EMS)												
1/1	0.3-1.2	7.55	0.434	33.9	50.8	5.26	28.2	4.53	4.17	128	<0.500	22.2
1/2	1.2-2.1	7.55	0.441	59.7	52.0	5.79	16.4	5.13	3.73	104	<0.500	16.4
1/3	2.1-3.1	7.45	0.397	46.4	44.7	4.75	16.7	6.93	3.75	118	<0.500	19.0
1/4	3.1-4.3	7.45	0.471	68.3	53.6	7.28	18.3	5.83	4.42	107	<0.500	17.4
Location 4 (48 m down slope of EMS)												
4/1	0.3-1.2	7.50	0.280	10.60	25.7	<2.00	24.1	4.53	3.41	119	<0.500	23.5
4/2	1.2-2.1	7.50	0.299	10.70	32.9	2.62	21.0	6.03	3.21	115	<0.500	19.5
4/3	2.1-3.1	7.60	0.286	10.60	26.3	<2.00	20.2	5.98	2.82	103	<0.500	19.5
4/4	3.1-4.0	7.80	0.279	7.80	39.4	4.87	21.4	3.03	3.17	90	<0.500	20.4
4/5	4.0-4.9	7.80	0.301	5.72	26.8	<2.00	22.6	3.08	2.48	91	<0.500	19.9
Location 5 (15 m upslope of EMS)												
5/1	0.25-1.2	7.8	0.54	17.7	50.1	10.1	59.8	0.71	<0.5	329	<5	18.6
5/2	1.2-1.5	8.1	0.56	14.2	55.7	11.0	62.0	0.47	<0.5	120	<5	17.0
5/3	1.5-2.5	8.2	1.01	99.3	95.4	21.2	85.3	1.30	5.0	44	<5	3.7
5/4	2.5-3.8	8.0	0.70	95.7	82.8	23.5	15.8	7.49	0.9	132	<5	14.8
Location 6 (3 m down slope of EMS)												
6/1	0.5-1.5	8.0	0.71	56.7	79.4	21.6	37.1	0.67	11.0	135	<5.0	16.1
6/2	1.5-1.8	7.8	1.11	205.6	133.3	36.6	42.2	2.00	15.0	186	5.8	20.9
6/3	1.8-2.4	7.9	1.37	251.7	1272.5	326.7	282.2	0.42	12.0	103	<5.0	13.2
6/4	2.4-3.1	7.9	1.12	248.2	1054.1	288.0	248.0	0.73	8.0	113	<5.0	15.3
6/5	3.1-3.8	8.0	0.52	81.5	43.1	12.3	11.8	0.88	2.0	128	<5.0	15.9
6/6	3.8-4.6	8.1	0.51	70.9	42.9	12.3	11.6	0.83	2.8	130	<5.0	14.8
6/7	4.6-5.3	8.2	0.57	88.6	48.1	13.9	11.5	1.20	0.6	109	<5.0	15.7
6/8	5.3-6.1	8.3	0.63	120.5	50.7	15.5	13.1	1.00	<0.5	91	<5.0	11.2
6/9	6.1-7.5	8.3	0.56	95.7	45.1	13.3	13.2	1.20	<0.5	92	<5.0	9.4

Table 6.4 Selected water chemistry and microbiology properties for Site 3

Sample		**Location 1**			**Location 2**		
Location	Units	1/L		2/H	2/M	2/L	
Tip Depth	m	4.00		1.80	3.40	5.20	
Surface Elevation	m	989.67		986.86	986.86	986.86	
Tip Elevation	m	985.70		985.10	983.50	981.70	
Sample Date		23-Feb-00	09-May-00	23-Feb-00	09-May-00	23-Feb-00	09-May-00
pH		7.28	7.13	7.10	7.210	7.360	7.330
EC	mS/cm	1.45	1.47	1.07	0.659	0.700	0.485
TDS	mg/L	928.00	970.00	6950	425.00	448.00	280.00
Phosphorus	mg/L	0.06	0.04	<0.03	<0.030	<0.030	0.050
Potassium	mg/L	2.40	16.80	3.20	2.20	2.200	2.600
Chloride	mg/L	165.00	149.00	14.00	2.60	8.200	4.800
Ammonium - N	mg/L	0.09	0.07	0.02	0.080	0.060	0.020
Nitrate - N	mg/L	5.91	2.27	1.43	<0.004	0.149	0.019
DO	% Sat.	NT	45.00	100.00	31.200	NT	34.500
DO	mg/L	NT	4.30	7.50	4.200	NT	5.700
Total Coliforms	CFU/100mL	1.00	7.00	2.00	2.00	<1.00	<1.00
Fecal Coliforms	CFU/100mL	<1.00	<2.00	2.00	1.00	<1.00	<1.00

Sample		Location 3				Location 4			
Location	Units	3/M		3/L		4/M		4/L	
Tip Depth	m	3.10		4.70		4.00		6.30	
Surface Elevation	m	987.62		987.62		985.68		985.680	
Tip Elevation	m	984.50		982.90		981.70		979.40	
Sample Date		23-Feb-00	09-May-00	23-Feb-00	09-May-00	23-Feb-00	09-May-00	23-Feb-00	09-May-00
pH		7.170	7.010	7.250	7.070	7.310	7.150	7.400	7.260
EC	mS/cm	1.790	1.780	1.00	1.020	0.757	0.762	0.650	0.649
TDS	mg/L	1146.00	1150.00	640.00	615.00	484.00	440.00	416.00	370.00
Phosphorus	mg/L	0.050	0.040	0.040	0.030	0.040	<0.030	<0.030	<0.030
Potassium	mg/L	2.600	2.700	4.00	5.400	2.700	2.500	3.800	3.700
Chloride	mg/L	298.00	234.00	81.400	83.400	16.300	17.00	2.500	2.700
Ammonium - N	mg/L	0.090	0.210	0.330	0.330	0.250	0.090	0.190	0.190
Nitrate - N	mg/L	0.426	0.126	0.075	<0.004	<0.004	<0.004	<0.004	<0.004
DO	% Sat.	NT	32.00	NT	28.00	NT	28.00	NT	20.200
DO	mg/L	NT	3.400	NT	3.500	NT	2.900	NT	2.400
Total Coliforms	CFU/100mL	3.00	<1.00	4.00	24.00	2.00	2.00	<1.00	19.00
Fecal Coliforms	CFU/100mL	<1.00	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	<1.00

7.0 Investigation of Site 5

7.1 Site Description and Construction Methods

The EMS pond at Site 5 was constructed in 1980, and has provided continuous service (~ 20 y) to a 150-sow farrow-to-finish operation. The pond has a capacity of about 3400 m^3, which allows for just under a full year of manure production from the facility according to manure production estimates (Table 2.3). The area has a general slope of about 0.013 m/m to the northeast. A peat bog is situated about 0.8 m downslope to the east of the EMS pond. The EMS pond was excavated using a bulldozer and buggy and the majority of the material was removed and used to develop the building site. Consequently, the EMS pond is mostly in-ground with berm heights of about 0 – 0.5 m up and downslope of the pond, respectively. The owner reports that a layer of hard clayey sand material was encountered at the bottom of the pond during construction. This material seemed to peel off in layers when excavated with the bulldozer blade. No attempt was made to construct a liner at this site but the in situ materials were compacted in place to some degree by equipment traffic during excavation of the pond.

7.2 Background Resource Data

Shetsen (1990) described the quaternary geology of the area at Site 5 as lacustrine deposits from the Pleistocene and Holocene era. Surficial materials are projected as coarse deposits of sand and silt, up to 80 m thick, forming an undulating surface that may be modified in places by wind. Nikiforuk et al. (AGRASID v1.0, 1998) identified the soils at this location as having characteristics that fall within the Codner soils series, which is an Orthic Humic Gleysol with glacio-lacustrine, silt loam to clay loam parent materials classified with a medium texture (Figure 7.1).

The C horizon of this soil series has two distinct layers: the upper layer being a highly reduced Cg horizon showing characteristics of mottling and grey coloring and the lower reduced, but with a higher calcium carbonate content than the upper layer, due to leaching (Nikiforuk et al., 1998). The two subsoil layers are also differentiated by textural differences. Due to sorting during deposition by water, the upper layer of the C horizon has a lower sand content and a higher silt content than does the lower C horizon, while clay content remains about equal between the two layers. The particle size distribution for upper layer for the soil series is given as 6% sand, 62% silt and 32% clay, while that of the lower is 15% sand, 55% silt and 30% clay. The estimated bulk density of these subsoils is about 1400 kg/m^3, with a porosity of about 47%. Water holding capacity is 0.25 m^3 H_2O/m^3 of soil and the bulk hydraulic conductivity is predicted to be 2.8 x 10^{-6} m/s. The soil is classified as non-saline with a CEC of about 20 meq/100g (Nikiforuk et al., 1998).

Water well records (Alberta Environment, 1999) show that interspersed clays and sands, about 15 to 20 m thick, overlie a shale bedrock in the area of the study site. Bedrock lithologies show a thin shale layer overlying a deeper sandstone that has inter-bedded layers of coal throughout. The closest published hydrogeologic cross section to the site is Rocky Mountain House 83B, F – F' (Tokarsky et al., 1987). The information from that source indicates that the underlying bedrock is of the Paskapoo formation, which is expected to be composed of sandstone, siltstone and coal. A closer look at the quaternary geology map of the area reveals that these glacio-lacustrine soils may contain local ice-rafted stones within the deposit, which may explain the thin shale layer that lies just above the expected sandstone formation.

Water well logs from the farmstead at the study site location show the variable nature and thickness of the overburden nearby. Records for the water well used to supply the hog barn (dated June 1984) indicate that about 14 m of sand overlie a 5-m thick shale bedrock layer that is underlain by sandstone that extends to about 40 mbgl. The domestic water supply well (well log dated 1973) shows 7 m of clay material overlying 12 m of clayey sand and gravel with an underlying shale bedrock with inter-bedded coal that extends to about 34 mbgl. Airphoto (AS4473-21, 1993) interpretation revealed longitudinal striations throughout the area that were determined to be bedrock ridges covered with glacial till soils by matching water well record lithologies with the locations of these ridges. Well logs show that the lower positions in the area are composed of the coarse lacustrine deposits indicated by the surficial geology maps (Shetsen, 1990). The alternating pattern of glacial tills on high points and coarse lacustrine materials in low spots is likely related to the water levels attained during the last glacial melt event that occurred in the area. Water levels probably did not reach the tills sitting on the bedrock highs, while the tills in the lower areas were eroded and sorted by water action.

The static water level in the wells at the study site farmstead was 6 – 7 mbgl, while those in wells on the same land location, to the north and east of the study site, are as shallow as 2 mbgl. The wells displaying these shallow water levels were built with perforated casings extending into the clay overburden. This may mean that water levels in the wells were affected by a perched watertable in the overburden rather that upward pressure from the lower bedrock formations. Pumping rates for the bedrock aquifers in the area are 0.05 to 0.1 L/s, where wells are developed into the sandstone deposit, but are much lower where they extend only into the upper shale formation.

7.3 Chronology of Events

The following is a chronicle of the events and procedures used to investigate the EMS pond at Site 5.

February, 1999	Initial contact with producer • Producer indicated willingness to participate in project. • Site contained EMS pond of sufficient size, age and soil conditions.
June 4, 1999	EM 31 survey • Post-survey analysis indicated potential seepage plume off the northeast portion of the east berm.
August, 1999	Confirmation of parent material suitability • AGRASID parent material data were used to confirm basic soil type as medium-peat textured. EMS pond and farm buildings are all located within the medium textured portion of the quarter.
August, 1999	Site selection for intensive investigation • Site was selected as an apparent leaking site.
Oct. 14, 26, 27, 28, 1999	Initial drilling • One piezometer nest upstream, one parallel to slope, three on the downslope berm, and one far downslope. • The borehole parallel to the slope was sampled. Intermittent soil samples were taken from several locations, primarily because of poor drilling conditions (i.e., very stony and firm till).

Dec. 14, 1999	Additional soil sampling. One of the piezometer nest locations was profile sampled. • More complete soil sampling data were needed to analyze the site. • Sampling boreholes was immediately downslope of the berm.
Jan. 6, 2000	Flushing of piezometers • Water elevations recorded.
Jan. 24, 2000	Second flushing of piezometers • Water elevations recorded
Feb. 23, 2000	Water sampling. • Water elevations recorded. • Samples were taken in all but the shallow piezometers of each of the six nests.
April 10, 2000	Water elevations measured GPS survey of the site.
April 26, 2000	Topographic survey of site. • Data include location of piezometer nests, top and toe of each side of the berm, in the middle of each side, a section line through the EMS pond in the general direction of the local slope and several reference points on landmarks recognizable on an airphoto.
May 24, 2000	Second water sampling. • Water levels measured • Another set of water samples collected.
May 30, 2000	Additional soil sampling. • More complete soil sampling information was needed to analyze the site. • Sampled boreholes included on top of the downslope side of the berm, far upslope, and far downslope.

7.4 Site-specific Investigation

7.4.1 Site Survey

The site is defined in the layout and location diagram in Figure 7.1. Sample locations were plotted onto an orthorectified aerial photograph to identify the relative location of the soil sample and piezometer installation at the study site. Piezometer installations were located using real-time GPS with sub-meter (i.e., $\pm$ 0.5 m) accuracy. A site survey was conducted to determine surface slope and piezometer nest elevations (Table 7.1). Piezometric elevations and horizontal hydraulic gradients for the study site over the monitoring period were recorded and plotted to determine flow directions and velocities from the EMS pond. Piezometer tip elevations and piezometric heads were determined by measuring with a water well sounding device (Table7.1). The site survey shows that the surface slope near the pond grades to the northeast at about 0.02 m/m upslope and below the pond to Location 6, where the grade increases to nearly 0.4 m/m beyond that point.

7.4.2 Site Hydraulics

Water elevations in all piezometers were equal for all observations, regardless of piezometer tip depth (Table 7.1), indicating that there was no vertical hydraulic gradient near the EMS pond at this site.

The EMS pond was emptied in the fall 1999, and fluid levels in the pond rose over winter as the manure pit was gradually filled. In contrast, watertable elevations declined over the winter monitoring period, followed by a substantial rise following springmelt. Hydraulic gradients downslope of the EMS pond remained relatively steady over the monitoring period in spite of the increasing elevations. The hydraulic gradient between Locations 1 and 4 followed the general direction of the surface slope and averaged about 0.029 m/m over the monitoring period. Oddly, the watertable gradient between Locations 4 and 6 grades contrary to the ground surface slopes, i.e.. it grades toward, instead of away from the manure pond.

The reverse gradient may result from an increase in slope of the underlying bedrock below the EMS pond, followed by another decrease in the bedrock gradient. Water flowing across the surface of the bedrock materials (in the saturated, fractured till and weathered bedrock materials) may be flowing at a relatively high velocity compared to that where the bedrock surface decreased in slope. The reduction in velocity could create a back pressure within the materials above the bedrock surface and a corresponding increase in the piezometric head due to energy dissipation. This theory is supported by the fact that the reverse hydraulic gradient increased as the watertable rose, showing that increased flow volumes increased the level of hydraulic back pressure exerted on the piezometers near the bottom of the slope. Groundwater levels decreased until mid-April, after which a dramatic rise took place.

Thus the watertable rise was the result of spring snowmelt recharge rather than seepage from the EMS pond.

7.4.3 EM 31 Survey

The results of the electrical conductivity (EC) survey of the site are shown in Figure 7.1. The largest areas of elevated bulk EC readings at this site are slight increases at the southeast and northwest corners of the EMS pond. Neither of these EC level anomalies are consistent with the expected direction of groundwater flow and are therefore not considered a result of EMS pond seepage. Ground surface slope is to the northeast at about 0.02 m/m and this is the direction that a contaminant plume would be expected from the pond. To the east of the EMS pond, the data exhibit a uniform bulb along the downslope perimeter of the pond rather than a classical parabolic plume. This could be due to the high clay content of the soils encountered at the site that tends to adsorb positively charged ionic species (i.e., salts, NH_4). The unusual extension of the high EC zone is noted at the northwest corner of the pond, which was suggested by airphoto interpretation to be due to high moisture contents related to a low spot in the land surface there, rather than contaminant plume development. The area near the EMS pond has very high EC readings. However, it is difficult to know if these readings are related to the soils below the pond edge or are merely due to an edge effect related to the proximity of the very saline manure within the pond. It is conceivable that the reddish colors shown near the pond are actually indicative of soil salinity. This will be confirmed or refuted by the soil chemistry analysis.

7.4.4 Physical Soil Data

The results of the soil physical analysis for the soil samples taken at this Site are presented in Table 7.2. Field drilling logs are consistent within this site in that all logs show that there is a layer of clay till between 3.0 to 4.5 m thick overlying a thin layer of weathered bedrock, depending on the position of the borehole. Borehole logs show that the till layer has some thin sand streaks within it at depths between 1.5 and 2.0 m in all but the upslope borehole. Some thicker sand lenses were noted in the till layer just above the bedrock in the boreholes immediately downslope of the EMS pond, at Locations 2, 3, 4 and 5. These sand lenses are very moist or saturated and also quite stony, indicating that water is perched in the lower zone of the till material just above the bedrock. One sample taken from 2.4 –3.0 m from Location 4 had a 65% sand content. The average silt content in soils from all boreholes analyzed was about 30%.

In general, the till layer is thicker on the lower slopes and thins out near the crest of the bedrock high point. The till material showed indications of oxidation – reduction cycles above the 3.0-m depth. Below that depth the soils and the upper bedrock layer appear to be reduced, having a blue grey color and signs of mottling due to saturation. Soil textural analysis revealed that the soil is coarser than indicated by the field logs, having sand contents in the order of 35 – 50% and a coarse fraction (> 2.0 mm) between 2 and 16%. Soil clay contents ranged from 10 to 20% in the downslope borehole samples and decreased with depth. The upslope borehole (Location 7) increased in sand content (43% - 53%) with depth interval while decreasing in clay content. The sample taken at the 5 – 6 m depth at the background sample site (Location 7) had no clay and was saturated. Water rose in the hole during drilling and filled it to a 1.8-m depth.

The drill logs indicate that the EMS pond is located near the crest of the local bedrock high point. As mentioned earlier, the farmer reports having hit a clayey sand layer near the bottom of the pond during construction and this material peeled off in layers when excavated with a bulldozer blade. This observation is consistent with the material being weathered bedrock. The drill logs also show the presence of shallow bedrock layer between 3 and 4 mbgl and that the upper layer of the bedrock is weathered and reduced. According to the laboratory textural analysis of soils at Locations 2 and 4, the bedrock appears to be a layered sandstone formation with about 45% sand and only about 10% clay.

Logs from water well records showed that the sandstone formation extends to a depth of about 30 to 40 mbgl. Some larger stones were found embedded in the bedrock material near its upper surface and into the formation to the extent of the depth of the test boreholes. Drilling into this material was very difficult and a number of hardened drill bits were destroyed in the process. Laboratory results indicate that the bedrock material is very dense, with a bulk density of nearly 2100 kg/m^3. This is likely a good indication that the sandstone is highly consolidated and not heavily fractured, consistent with the theory that the local shallow groundwater and any EMS pond seepage that may occur is perched on top of the bedrock and traveling along its surface.

7.4.5 Soil Chemistry

The results of the soil chemistry analysis for the soil samples taken at this site are presented in Table 7.4. The cation exchange capacity of the soils at this site ranged between 6.4 – 20.7 meq/100 g for all test holes except Location 4. Soils from this latter location show low CEC values between 4.5 and 7.6 meq/100 g. This sample location is downslope of the EMS pond, which bodes poor ion retention in the event that seepage is occurring at this site. Soil borings from Location 8, located at the northeast corner (on the berm ~ 3 m from FSL), revealed that the soil there is not very well compacted and had a CEC of only 11.8 – 14.3 meq/100g, so some ionic transport could be expected through the structure during high water periods. A 40-mm thick sand lens was encountered at about 4 mbgl, just before the drill reached very hard sandstone bedrock and could not penetrate further. The sand layer was likely weathered bedrock that had been softened due to water action. The sand layer was blue green in color, indicative of reduction in the zone.

Chloride is considered a conservative indicator of manure seepage since it is not absorbed to soils and the typical chloride content of manure is much higher than would be expected in natural soils or water (i.e., 1000 – 2000 mg/L, Fonstad, 2000). The background soil samples from this site show a Cl content of 145 mg/L in the surface sample, declining linearly to near 7.0 mg/L at about 2.0 mbgl and remaining at that level to a depth of 7.0 m. However, all of the soil samples taken from boreholes immediately downslope of the EMS pond show an increasing trend in Cl with depth to the 4.0-m depth, which is where bedrock was encountered in these borings. Chloride levels were low(10.6 mg/L) for all samples in Location 6 between 1 – 5 mbgl, the site farthest downslope of the EMS pond.

NO_3 levels are relatively low at all soil sample locations (except Location 8) and are virtually zero at both the background and 40-m downslope locations. The samples taken from Location 8 and those from Location 4 have noticeably higher NO_3 levels than those taken either upslope or farther downslope of the EMS pond. NO_3 concentrations in samples taken at Location 2 match better with those of the upslope and downslope soil profiles than the other nearby sample locations. Samples from Location 4 had a NO_3 concentration of just over 20 μg/g in the near-surface interval, with a decreasing trend with depth to the 4.9-m depth where the concentration reached 8.1 μg/g and then increases slightly over the next 0.9 m. NO_3 levels at Location 8 show a steep and steady decline with depth to where that boring meets bedrock at 4.0 m. The concentrations in the upper surface samples are quite high (73.8 μg/g), and decrease linearly to 10 μg/g over the 4.0-m deep profile. NH_4 concentrations at this location show the opposite trend, with NH_4 increasing with depth to the bottom of the profile. This is consistent with the signs of reduced conditions in the lower portion of the berm profile.

The soil analysis from boreholes at Locations 2 and 4 revealed bulges of NH_4 at the 1.8 – 2.4 m and 1.2 - 2.1-m depths, respectively. The elevation of the borehole at Location 2 is about 1.5 m above that at Location 4, so the concentration increases occur at about the same elevation. The one sample taken at Location 3, which was taken because of indications of sand lenses and high moisture content, also showed high concentrations of NH_4. These observations indicate that there is a general zone of nitrogen movement way from the EMS pond at the SE corner of the pond, likely due to a zone of saturation related to the sand lenses observed in the soil profiles as noted in the field drilling logs.

All of the chloride ion concentration profiles are similar to those of NH_4-N with the exception of Location 2. Here the Cl concentration patterns are opposite to that of ammonium. This is likely because transport of NH_4 is being retarded by the clayey soils in the upper zone of the soil profile, while Cl, which would not be retained through sorption, had likely passed the observation point.

7.4.6 Water Chemistry

The water chemistry analysis results for the water samples taken at this Site are presented in Table 7.5. Water samples were taken on February 23 and on May 24, 2000. Due to low watertable levels, it was not possible to take samples from the shallowest piezometers tips at any of the sample locations on the February observation date. However, the watertable had risen into the upper level piezometers at Locations 2, 3 and 6 by May 24.

Location 1 is considered the background sample site for this study site. The watertable never rose into the upper sampling zone at the background location where the shallowest piezometer tip was located to collect groundwater from the 1.1 to 1.6 mbgl soil zone. The water chemistry at this location remained stable over the sampling period and showed low concentrations of the indicator species tested for in this study. The shallow groundwater here is slightly alkaline with a pH of 7.4 –7.5. TDS readings ranged from a high of 501 mg/L at the 4.6 mbgl depth on February 23 to a low of 375 mg/l at the 5.9- mbgl sampling depth on May 24. Nitrate levels at this location were at or below the observed average of 2.19 mg/L for shallow groundwater in Alberta (Fitzgerald, 1999). No fecal or total coliforms were found in the background water samples at the 5.9-m sample depth during either sampling. Some above normal levels of bacteria were observed for both sample dates in some of the observation wells at this location. Seepage through preferential flow paths is the most likely explanation for coliform movement here. A slight increase was also noted over the observation period but this result may be due to late fall manure spreading on the field surrounding the EMS pond.

Location 2 is downslope and to the north of the EMS pond. Water taken from the mid-depth piezometer at this location displayed a noticeable green tinge at the time of sampling. The location of the piezometer nests here is coincident with a stand of small poplar trees growing into the berm on the side of the EMS pond. The poplar is a suckering tree so the roots may have penetrated through the berm and into or near the EMS pond foundation, creating a preferential flow path carrying manure-laden water to the piezometer tip. High TDS and Cl levels are present in the samples from this piezometer tip and in those from the May 24 sampling from the shallower observation well. An NO_3 concentration of 26.8 mg/L, representing a level 2.7 times the Canadian Drinking Water Guideline of 10 mg/L, was also found in the shallow observation well on the second observation date at this location. Madison and Burrnett (1985) indicated that any NO_3 concentration above 3.0 mg/L found in groundwater can be suspected to be anthropogenic in origin. This was the highest level of NO_3 found at this site. The elevated NO_3-N concentration here coincides with a higher measured dissolved oxygen content and lower pH of the water, indicating that the NO_3 may be the result of oxidation of NH_4 during nitrification reactions. The high NO_3 concentrations likely result from preferential flow along the tree root paths. However, the NO_3 concentration level is not considered high enough or widespread enough to seriously threaten local groundwater supplies, since denitrification would likely occur as the water percolated into the deeper soil zones and into the bedrock.

Piezometer nests at Locations 3, 4 and 5 had similar concentrations for all chemical species tested for, especially when considered within sampling depth. With few exceptions, all water samples from the deepest piezometer tips showed similar ionic concentrations to those of background water samples. The notable exceptions were fairly extreme TDS levels on May 24 at Locations 3/L and 5/L (4890 and 3070 mg/L, respectively). However, neither of the deep samples with high TDS readings had any other anomalous values. Since these piezometer tips penetrated into the shallow bedrock, the high TDS values might be due to the natural chemistry of the bedrock materials.

The shallow and mid-depth observation wells situated along the edge of the EMS pond showed high TDS levels coincident with Cl ion concentrations a full order of magnitude higher that those from the same depth at the background sample position (Location 1). This is a fairly strong indication that seepage is occurring along the eastern edge of the EMS pond, likely through sand fissures detected in the field soil logs.

Water quality analyses for samples from the piezometer nest at Location 6, 40 m downslope of the EMS pond, look very similar to those taken from the "background" sample location. The only notable water chemistry anomaly here was a high nitrate-N concentration from the May 24 sampling of the water from the 6/H location. The high NO_3-N level (14.9 mg/L) in the shallow well could be related to leaching from the upper soil surface. Manure was applied to the field in fall and nitrogen in soluble form may have been leached to the 2.0-m deep piezometer during springmelt. The NO_3 contamination may also have been caused by leakage into the well due to poor sealing of the bentonite plug after installation of the observation well.

7.4.7 Microbiological Indicators

The results of the microbiological analysis of water samples taken from this site are presented in Table 7.5. Relatively high levels of total coliforms were found in the two shallower observation wells at Location 2 (74 and 45 CFU/100 ml) on May 24, 2000 but not in the deeper piezometer. No fecal coliform bacteria were found in any of the water samples from this piezometer nest. A high total coliform count was detected in Location 6/VL on May 24 but again no fecal coliforms were found. The presence of total coliforms alone is not usually confirmation of contamination from manure (Fitzgerald, 1999) so it seems unlikely that the EMS pond is the source. Perhaps the rising watertable that occurred during spring melt recharge flushed some dormant bacteria from the substrata into the well. The sample may have also become contaminated at some point during handling in the field or in the laboratory.

7.5 Discussion

Neither the degree nor the extent of seepage from the EMS pond at this site appears to be extensive. Some indications that seepage occurs into minor sand lenses, along tree roots or at the interface between the soil and the bedrock were observed in the soil chemistry data. Samples taken from the berm show increasing levels of NH_4 and Cl with sampling depth, likely indicating poor compaction of the berm. There were also indications of movement of manure-related ions out of the pond into the interface layer between the soil and bedrock. Increased concentrations of the Cl ion with depth at Location 4 indicated that movement of contaminant had proceeded 10 m downslope of the berm. The same trend was not observed for NH_4 or NO_3 ions at this location. Movement of NH_4 ions appears to be contained in isolated sand streaks within the soil profile.

At Location 2 the most likely cause of the ammonium concentration peak in the 2.1 – 3.1-m sample interval is transport along preferential flow paths created by tree roots. No notable difference in nitrate-N concentrations were observed in any of the downslope soil profiles with the possible exception of the profile taken into the berm. Here the NO_3-N concentrations are fairly high at the initial sample depth (1.2 – 2.1-mbgl) but decrease rapidly and linearly with depth. This decreasing trend in NO_3 concentrations is opposed by NH_4 concentrations that were non-existent in the upper layers but increase to about 1.3 μg/g in the 3.1 - 4.0 m sample interval. Peak concentrations of NH_4-N ions at this sample location coincide with the interface between the soil and the bedrock, indicating that seepage is occurring from the EMS pond into this layer.

Differences between the NH_4-N and Cl ion concentrations of background soil samples and those at Locations 2, 4 and 8 were the strongest indicators of seepage observed at this site. The increased concentrations of NH_4-N ions at Location 2 and 4 appear to follow preferential flow paths created by the presence of tree roots and sand streaks within the soil profile. Location 8 is within the downslope berm near the northeast corner of the pond. Ammonium-N concentrations there increased linearly from 0.0 μg/g at the starting sample interval between 1.2 - 2.1 mbgl to 1.35 μg/g in the sample from the 3.1 – 4.0- mbgl sample interval. However, even the highest concentration level is within the range of that from the background sample NH_4-N concentration profile.

The degree of variation observed between the upslope and downslope measurements of indicator species at this site is not large enough to suggest that there is any substantial, long-lasting degradation of groundwater due to seepage after 20 y of continuous operation. Soil quality parameters taken immediately downslope of the northeast corner of the EMS pond show some minor periodic seepage may occur from the pond, indicating that manure sealing is preventing seepage after prolonged submersion. Chang et al. (1974) showed that even sand will seal due to manure ponding after 64 d, while Lo indicated that all the soils tested were effectively sealed within about 30 min of manure ponding. Barrington and Broughton (1989) suggested that hog manure would seal soils with a clay content of more that 15%. All soils above the bedrock layer at this site have more than 15% clay so they are expected to seal according to their design criteria, and so should be expected to seal.

NH_4 is the most abundant nitrogen species in liquid hog manure in the EMS pond and so should migrate within the seepage profile (Fonstad and Maule, 1995). However, since it is a positively charged ion, its transport is retarded by adsorption to clay particles within the soil. Cl ions, on the other hand, move freely in the soil environment. Cl was the only indicator species tested that showed a variation of close to an order of magnitude between the upslope and downslope soil concentrations, giving a strong indication that the seepage plume had reached Locations 2 and 4, 10 m downslope of the EMS pond. In fact, low concentrations of Cl and high concentrations of NH_4 at the 2.1 – 3.1 mbgl sample interval at Location 2 most likely indicates that the conservative tracer species (Cl) had already passed that sample location within that soil zone. The ammonium must be traveling within sand streaks or along tree root pathways within the soil profile here to have traveled 10 m over a 20-y operational period.

None of the soil samples taken from within the bedrock layer indicate that manure seepage is entering the bedrock below the EMS pond. This is unusual since it is a standard engineering recommendation that EMS ponds be located a substantial distance above the bedrock layer (i.e., 3 – 10 m). The very hard, calcareous and un-fractured nature of the bedrock surface at this location likely explains why there is no seepage entering the bedrock layer.

The rise in the watertable between April 10 and May 24 did not appear to affect groundwater quality near the EMS pond, as there are no substantial variations in water quality over the observation period. The exception to this is the substantial increase in TDS levels in water samples from the deep observation wells at Locations 3 and 5 on May 24. No similar rise in the other indicator species was noticed here which, however, leads to the prospect that the effect may have been caused by dissolved solids from the local bedrock during the springmelt recharge. Another possibility is that the bentonite seal had not been sufficiently dampened to seal the well casing properly before the watertable rise and salts from the bentonite may have flushed into the deep piezometer tip causing the high TDS readings on May 24.

TDS and chloride concentrations in water samples taken from the mid-level and shallow piezometers immediately downslope of the EMS pond are substantially different than those of the background samples. In contrast, the water quality of samples taken from the deep observation wells appears to be independent of sample location or time of sampling with the exception of the anomalous TDS readings discussed above. A higher-than-expected nitrate reading in the deep piezometer at Location 6 in February had dissipated by May. Since none of the more shallow observation wells at this location show similar results, it is highly likely that this reading may have been due to a poor seal between the bentonite plug and the riser pipe of this well. The nitrate could result from movement of manure down along the riser pipe from fall spread manure.

The sample taken from the shallowest observation well at Location 2 also had an unexpectedly high nitrate reading. In this case the nitrate was evident in May. There are three possible explanations for the nitrate-N in this sample: 1) ammonium-N in the found in the deeper soil (2.1 – 3.1-mbgl) at this location moved upward with the rising watertable between April 10 and May 24 and nitrified due to the highly oxygenated state of the shallow groundwater (14.5 mg/L at the time of sampling); 2) tree root paths and sand lenses combined to allow seepage waters to travel very rapidly from the EMS pond to the shallow piezometer after the upper soil profile became saturated due to the rise in watertable around the time of sampling; and 3) the nitrate source is surface-applied manure from the previous fall that was leaching from the soil surface during the springmelt. It may also have run down the side of the riser tube from the surface if it were not properly sealed.

It is unlikely that seepage from the EMS pond could have traveled 10 m to the piezometer at Location 2 in the 44 days between observation dates (Table 7.6). Therefore, a very direct transport route, like a tree root pathway, must have been available to allow the seepage to reach this point within that time frame. It is just as unlikely that NH_4 was dissolved, transported 1.5 m upward and nitrified within that short time period. Therefore, the latter explanation given above seems the most logical since the watertable was obviously recharged during springmelt and there is evidence from other sample locations that the bentonite seal may not have been secure at all the piezometer installations. The presence of higher-than-expected coliform bacteria counts in the water samples from this location and sampling date also supports the theory that seepage may have occurred from the surface due to an improperly sealed observation well.

Consideration of the hydraulics of seepage between the EMS pond and Location 4 confirms that it is unlikely that seepage water from the EMS pond would have traveled 10 m to that location without the aid of a preferential flow path. The soil survey data suggests that the hydraulic conductivity of the Codner Series subsoil is in the order of 2.8×10^{-6} m/s. Estimations of the hydraulic conductivity for the soil by correlating the soil textures found for soils at this site to a large database of laboratory test using the Soil Vision software system predicted that the hydraulic conductivity of the soil at this site is in the order of $5 \times 10^{-6} - 3 \times 10^{-7}$ m/s (Table 7.3). The results of the hydraulic calculations shown in Table 7.6 used the measured hydraulic gradient between Location 2 and 4 (0.0378 m/m, Table 7.1). Under the conditions described above, seepage from the EMS pond could have traveled the required 10 m to Locations 2 and 4 over its 20-y operational period. However, since the soil chemistry profile indicated that elevated levels of NH_4 are only apparent within a narrow band of soil at these sample locations, that ion must only be moving within preferential flow pathways. On the other hand, in view of the above hydraulic analysis, the observation of higher Cl levels with depth in the soils at Locations 2 and 4 likely shows that seepage is occurring to at least 10 m downslope of the EMS at this site.

7.6 Conclusions

Indications that Cl ions have moved to a distance of 10 m downslope of this EMS pond is a strong indication that this pond is leaking. Elevated levels of TDS and CL in the mid-level and shallow water samples immediately downslope of the EMS pond are indicative of the adverse effect that the seepage is having on the shallow groundwater at this site. Soil quality profiles from immediately downslope of the EMS pond show that NH_4 movement from the pond is correlated to depositional anomalies or tree roots within the soil profile. These preferential flow paths appear to be allowing unexpectedly high seepage rates within these confined pathways. As expected, chloride is moving freely with the water near the front of the plume, while ammonium is trailing the plume due to sorption effects. Low Cl concentrations at Location 2 relative to NH_4 is suggestive of a cyclic, stop-and-start seepage pattern. It is speculated that the apparent temporal nature of the seepage is related to the development and breakdown of the manure seal along the sidewalls of the EMS pond. The intermittent nature of the soil and water chemistry data at other sample locations supports the contention that seepage from this EMS pond is periodic and isolated within minor preferential flow paths.

In high concentrations, NO_3 can cause groundwater pollution. High NO_3 concentrations in the shallow observation well at Location 2 may have been related to EMS pond seepage, but could also have been caused by nitrogen in surface recharge waters during springmelt. If this NO_3 observation was caused by seepage from the EMS pond, it must also have been related to the rising spring watertable, suggesting that its presence is temporal in nature. With the exception of one sample from the deep observation well at the extreme downslope sample location (Location 6), none of the other water samples were found to have high NO_3 levels. Hydraulic calculations show that it is very unlikely that this NO_3 anomaly is related to EMS pond seepage since it is too far away from the source. It is thought to be related to another source (40 m downslope). This NO_3 anomaly is attributed to leakage of surface-applied fertilizers and manure into an inadequately sealed piezometer. This problem will correct itself over time as the bentonite pellets used to seal the borehole are wetted and expand to develop a more secure seal. Therefore, it is reasonable to conclude that nitrogen movement, due to EMS seepage, in the local soil environment at this site will not generate enough NO_3-N to cause any serious problems with local groundwater.

Virtually no evidence was found to show that any movement of microbiological indicators is occurring at this site. None of the water samples showed any fecal bacteria and all of the total coliform bacteria counts from samples down gradient of the EMS pond were within the same numerical range as those found in the background samples. The lack of bacterial movement at this site is likely due to the well-graded, fine-textured soils. Soil pore spaces must be smaller than sizes that are smaller than the cell diameter of the microbiological indicators used.

Summary of conclusions:

- No evidence of a massive, continuous seepage plume from the EMS pond was found at this site.
- No clear evidence of NO_3 or bacterial movement was observed at this site.
- Some limited seepage and contaminant movement is occurring from the northeast corner of this EMS pond.
- Elevated chloride concentrations in the soils and shallow groundwater down gradient of the manure pond indicate that seepage may be occurring from this EMS pond.
- The elevated levels of NH_4 in sand lenses and other preferential flow pathways at this site are thought to be resulting from EMS seepage.
- Evidence that seepage is occurring through the north side of this EMS pond suggests that tree roots may be creating preferential flow paths that allow seepage to occur from this EMS.

- Seepage into the sand lenses, the bedrock interface and tree root pathways from this EMS pond is likely being limited by a periodic development and breakdown of a manure seal in this EMS.
- Evidence that seepage is occurring through sand streaks and along the bedrock interface supports the idea that a soil buffer should be present between the bottom of the EMS ponds and the bedrock layer.
- The seepage mechanisms here show the importance of proper siting and engineering design of EMS ponds located in variable soil conditions.

Figure 7.1 Site 5 Layout and location diagram showing the location of the soil sample and piezometers, the EM 31 electrical conductivity surface and the C-horizon soil parent material map for the area from the AGRASID database (Nikiforuk et al. 1998)

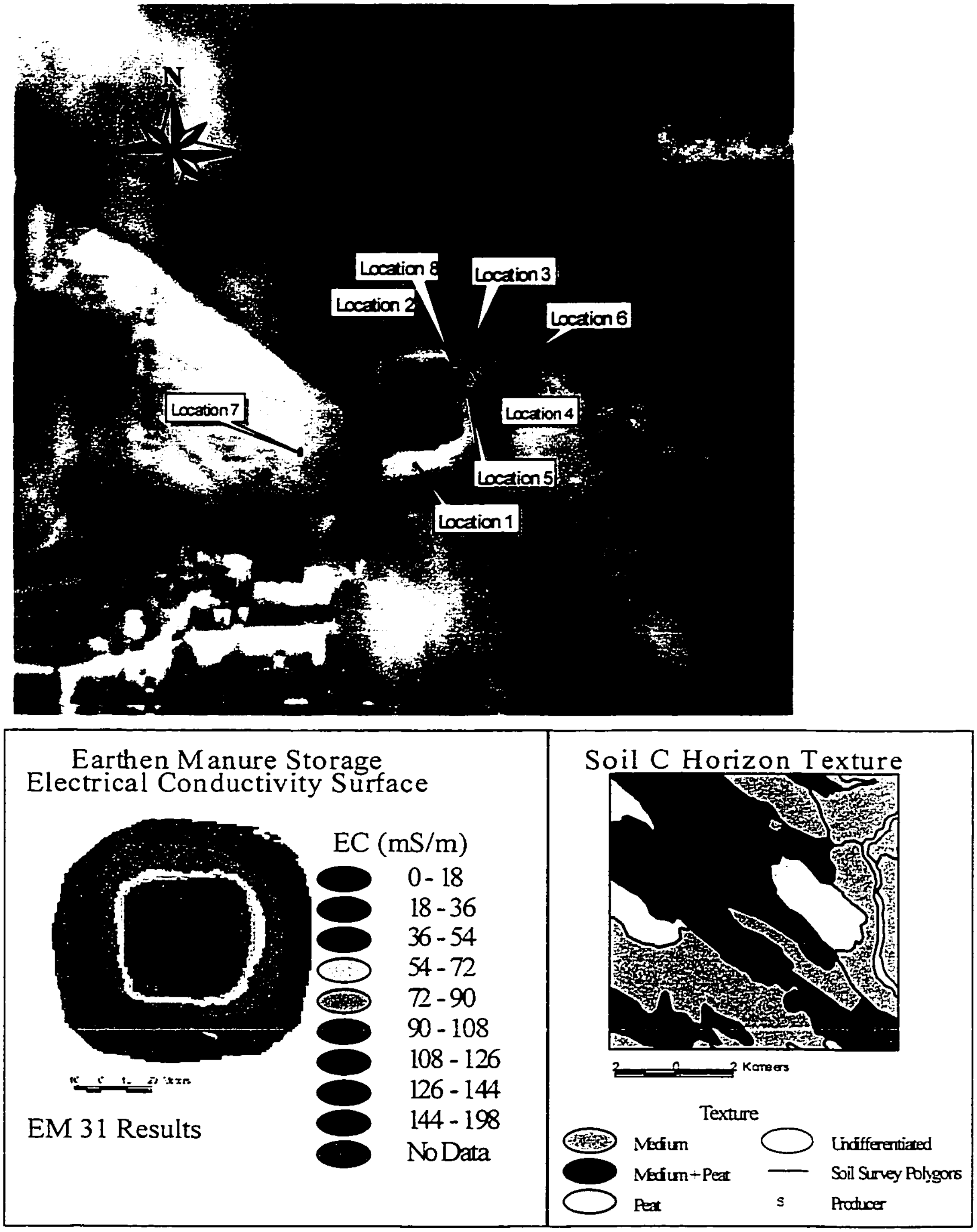

Table 7.1 Piezometric data for Site 5

Date				06-Jan-00	24-Jan-00	23-Feb-00	10-Apr-00	24-May-00
Location Well ID	**Piezo. Depth (m)**	**Surface Elev. (m)**	**Tip Elev (m)**	**Water Elevation**				
1/H	1.6	984.67	983.1	dry	dry	dry	dry	dry
1/M	4.6	984.67	980.1	982.2	982.0	981.7	981.6	983.3
1/L	5.9	984.67	978.8	982.2	982.1	981.7	981.6	983.3
2/H	1.8	984.513	982.7	dry	dry	dry	dry	983.4
2/M	4.2	984.513	980.3	982.1	982.0	981.6	982.5	983.2
2/L	6.4	984.513	978.1	982.2	982.0	981.7	981.6	983.3
3/H	3.2	983.044	979.8	980.7	980.5	980.2	dry	981.9
3/M	4.8	983.044	978.2	980.5	980.5	980.3	979.9	981.9
3/L	7.7	983.044	975.3	980.5	980.5	980.3	979.9	981.7
4/H	1.7	983.275	981.6	dry	dry	dry	dry	dry
4/M	3.3	983.275	980.0	980.8	980.6	980.5	dry	981.7
4/L	6.1	983.275	977.2	980.8	980.6	980.5	980.1	981.9
5/H	1.7	982.761	981.1	dry	dry	dry	dry	dry
5/M	3.1	982.761	979.7	980.5	980.3	980.1	980.0	981.4
5/L	6.0	982.761	976.8	980.4	980.3	980.1	979.9	981.4
6/H	2.0	982.753	980.8	dry	dry	dry	dry	982.0
6/M	3.8	982.753	979.0	980.8	980.7	980.4	980.2	982.1
6/L	5.3	982.753	977.5	980.8	980.7	980.5	980.2	982.2
6/VL	7.2	982.753	975.6	980.8	980.8	980.5	980.3	982.2

Table 7.2 Select soil physical properties for Site 5

Location	Depth (m)	MC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	BD (kg/m³)	Plasticity (%)	USCS Class
Location 2 (10 m down slope of EMS)									
2/1	1.2-1.8	16.10	1.77	51.60	30.70	15.90	1319	53.0	
2/2	1.8-2.4	12.80	4.90	41.50	33.80	19.80	1605	33.0	
2/3	3.7-4.3	14.90	0.63	51.80	37.90	9.70	1435	20.0	
2/4	5.2-6.1	13.10	11.60	45.80	32.90	9.70	2096	30.0	
Average		14.20	4.72	47.70	33.80	13.80	1614	34.0	SM
Standard Deviation		1.56	4.93	4.97	3.01	4.97	342	13.8	

Location	Depth (m)	MC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	BD (kg/m³)	Plasticity (%)	USCS Class
Location 4 (10 m down slope of EMS)									
4/1	0.3-1.2	20.00	1.62	32.80	43.50	22.10	831	13.0	
4/2	1.2-2.1	12.50	3.63	45.80	31.60	19.00	991	12.0	
4/3	2.1-3.1	11.60	24.80	39.60	19.70	15.90	1100	10.0	
4/4	3.1-4.0	18.80	4.67	51.70	31.60	12.00	1320	4.0	
4/5	4.0-4.9	15.50	16.90	46.50	25.30	11.30	1270	5.0	
4/6	4.9-5.8	12.10	11.60	49.80	27.30	11.30	1170	7.0	
Average		15.10	10.50	44.40	29.80	15.30	1215	7.0	SM
Standard Deviation		3.63	9.02	7.03	8.01	4.56	99	2.6	

Location	Depth (m)	MC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	BD (kg/m³)	Plasticity (%)	USCS Class
Location 6 (40 m down slope of EMS)									
6/1	0.25-1.0	20.20	0.50	43.10	28.60	27.80	1780	10.20	
6/2	1.00-2.0	14.20	1.10	42.50	29.00	27.40	2070	13.70	
6/3	2.00-3.0	12.80	3.60	41.00	30.20	25.20	1870	10.30	
6/4	3.00-4.0	11.20	4.90	43.10	30.40	21.60	1530	8.40	
6/5	4.00-5.0	9.60	6.10	44.50	28.20	21.20	1730	6.70	
Average		13.60	3.20	42.80	29.30	24.60	1796	9.90	ML
Standard Deviation		4.07	2.41	1.26	0.98	3.12	197	2.61	

Table 7.2 (continued) Select soil physical properties for Site 5

Location	Depth (m)	MC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	BD (kg/m^3)	Plasticity (%)	USCS Class
Location 7 (30 m up slope of EMS)									
7/1	0.25-1.0	15.60	2.30	41.10	34.60	22.00	1780	9.10	
7/2	1.00-2.0	12.70	5.80	40.20	32.00	22.00	1730	12.00	
7/3	2.00-3.0	12.30	3.80	39.60	29.40	27.20	1660	12.70	
7/4	3.00-4.0	10.20	8.60	34.20	34.20	23.00	1610	15.20	
7/5	4.00-5.0	11.20	22.00	27.20	33.00	17.80	1630	7.40	
7/6	5.00-6.0	13.60	5.60	56.80	26.80	10.80	1910		
7/7	6.00-7.0	11.10	2.40	49.20	33.20	15.20	1970	4.70	
7/8	7.00-7.6	12.10	5.50	47.90	29.40	17.20	1720		
Average		12.40	7.00	42.00	31.60	19.40	1751	10.20	ML
Standard Deviation		1.68	6.40	9.22	2.76	5.16	130	3.84	

Location	Depth (m)	MC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	BD (kg/m^3)	Plasticity (%)	USCS Class
Loaction 8 (on berm)									
8/1	1.0-2.0	23.60	0.40	42.20	29.40	28.00	1480	19.00	
8/2	2.0-3.0	15.60	1.40	48.20	27.20	23.20	1900	8.00	
8/3	3.0-4.0	13.10	3.80	41.40	28.80	26.00	1970	12.20	
Average		17.40	1.90	43.90	28.50	25.70	1783	13.10	ML
Standard Deviation		5.48	1.75	3.72	1.14	2.41	265	5.55	

Table 7.3 Permeability modeling results from Soil Vision software based on soil physical properties (i.e., texture, bulk density, porosity and plasticity)

Location	K_s range (m/s)	
	Lower	Upper
2	3.57E-07	9.05E-06
4	4.22E-07	6.88E-06
6	5.96E-06	3.04E-04
7	7.66E-07	9.31E-05
8	3.04E-06	1.67E-04

Table 7.4 Select soil chemistry properties for Site 5

Location	Depth (m)	pH	EC (dS/m)	Cl (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	NH_4-N (µg/g)	No_3-N (µg/g)	K (µg/g)	PO_4-P (µg/g)	CEC (meq/100g)
Location 2 (10 m down slope of EMS)												
2/1	1.2-1.8	7.60	0.708	175	97.0	23.0	11.0	2.20	5.22	57.0	<0.500	18.20
2/2	1.8-2.4	7.55	0.603	145	77.0	20.0	7.0	4.20	2.66	85.0	<0.500	20.70
2/3	3.7-4.3	7.45	2.090	226	356.0	124.0	43.0	0.95	1.70	49.0	<0.500	7.83
2/4	5.2-6.1	7.55	1.330	224	184.0	68.0	46.0	2.55	1.22	54.0	<0.500	8.42

Location	Depth (m)	pH	EC (dS/m)	Cl (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	NH_4-N (µg/g)	No_3-N (µg/g)	K (µg/g)	PO_4-P (µg/g)	CEC (meq/100g)
Location 4 (10 m down slope of EMS)												
4/1	0.3-1.2	7.70	0.540	131	30.2	<2.0	12.1	1.68	21.3	3.84	<0.500	6.3
4/2	1.2-2.1	7.50	0.601	158	33.7	<2.0	12.3	2.93	18.4	2.99	<0.500	7.6
4/3	2.1-3.1	7.60	0.609	206	83.7	10.9	17.1	1.63	14.8	2.72	<0.500	5.3
4/4	3.1-4.0	7.70	0.785	247	88.6	16.9	20.7	0.98	11.0	2.90	<0.500	4.5
4/5	4.0-4.9	7.70	0.823	199	89.7	21.4	25.2	1.08	8.1	2.45	<0.500	4.5
4/6	4.9-5.8	7.75	0.754	161	73.3	20.5	30.8	1.78	11.0	2.65	<0.500	6.3

Location	Depth (m)	pH	EC (dS/m)	Cl (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	NH_4-N (µg/g)	No_3-N (µg/g)	K (µg/g)	PO_4-P (µg/g)	CEC (meq/100g)
Location 6 (40 m down slope of EMS)												
6/1	0.25-1.0	8.1	0.44	28.4	123.1	21.4	19.5	0.50	1.0	1.1	<5	15.8
6/2	1.00-2.0	8.2	0.32	10.6	75.1	14.4	9.1	0.70	0.7	1.9	<5	14.6
6/3	2.00-3.0	8.1	0.30	10.6	35.2	8.2	5.3	0.97	<0.5	2.0	<5	13.9
6/4	3.00-4.0	8.5	0.40	10.6	28.6	7.6	6.2	1.10	1.2	1.8	<5	11.0
6/5	4.00-5.0	8.5	0.40	10.6	27.5	7.6	6.6	1.40	<0.5	1.8	<5	9.1

Location	Depth (m)	pH	EC (dS/m)	Cl (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	NH_4-N (µg/g)	No_3-N (µg/g)	K (µg/g)	PO_4-P (µg/g)	CEC (meq/100g)
Location 7 (30 m up slope of EMS)												
7/1	0.25-1.0	8.0	1.13	145.4	32.4	8.8	8.3	0.71	6.6	2.00	<5	12.6
7/2	1.00-2.0	8.1	0.71	60.3	24.5	8.8	8.1	0.97	2.0	3.00	<5	13.0
7/3	2.00-3.0	8.1	0.36	7.1	43.2	10.2	6.3	1.30	<0.5	1.30	<5	13.7
7/4	3.00-4.0	8.2	0.32	7.1	30.1	7.7	6.1	0.78	4.5	1.60	<5	11.4
7/5	4.00-5.0	8.3	0.33	7.1	24.3	7.1	5.8	0.90	<0.5	1.80	<5	10.8
7/6	5.00-6.0	8.5	0.38	10.6	30.3	9.2	10.3	1.20	<0.5	2.00	<5	7.4
7/7	6.00-7.0	8.6	0.34	7.1	27.7	9.9	14.7	1.50	<0.5	3.00	<5	6.4
7/8	7.00-7.6	8.3	0.47	17.7	51.7	18.0	13.6	1.70	<0.5	4.55	<5	7.5

Location	Depth (m)	pH	EC (dS/m)	Cl (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	NH_4-N (µg/g)	No_3-N (µg/g)	K (µg/g)	PO_4-P (µg/g)	CEC (meq/100g)
Location 8 (on berm)												
8/1	1.0-2.0	7.9	1.51	60.3	189.1	41.7	36.5	<0.30	73.8	2.2	<5	14.3
8/2	2.0-3.0	7.9	2.00	117.0	239.0	51.6	65.2	0.83	40.2	3.5	<5	11.8
8/3	3.0-4.0	7.9	1.38	237.5	153.0	36.8	42.2	1.30	10.0	4.4	<5	12.8

Table 7.4 Select water chemistry and microbiology properties for Site 5

Sample		Location 1					Location 2			
Location	Units	1/M		1/L		2/H	2/M		2/L	
Tip Depth	m	4.60		5.90		1.80	4.20		6.40	
Surface Elevation	m	984.67		984.67		984.51	984.51		984.51	
Tip Elevation	m	980.10		978.80		982.70	980.30		978.10	
Sample Date		23/02/99	24/05/99	23/02/99	24/05/99	24/05/99	23/02/99	24/05/99	23/02/99	24/05/99
pH		7.440	7.510	7.430	7.430	7.19	6.96	7.00	7.500	7.690
EC	dS/m	0.783	0.803	0.660	0.652	2.58	2.92	2.90	0.835	0.704
TDS	mg/L	501.000	465.000	422.000	375.000	1660.00	1869.00	1930.00	534.000	410.000
Chloride	mg/L	39.200	0.800	7.700	8.100	422.00	629.00	680.00	26.900	11.500
Phosphorus	mg/L	<0.030	<0.030	<0.030	<0.030	0.04	0.33	0.27	0.040	<0.030
Potassium	mg/L	3.300	3.100	3.200	3.100	4.40	4.20	3.60	4.800	4.400
Nitrate - N	mg/L	1.840	2.190	<0.004	0.130	26.80	<0.02	<0.02	<0.004	<0.004
Ammonia - N	mg/L	0.250	0.030	0.120	0.010	0.10	0.12	0.18	0.050	0.300
Dissolved O_2	mg/L	NT	2.800	NT	2.400	14.50	NT	3.10	NT	2.600
Total Coliform	CFU/100mL	2.000	19.000	<1.000	1.000	74.00	30.00	45.00	1.00	6.000
Fecal Coliform	CFU/100mL	<1.000	<1.000	<1.000	<1.000	<1.00	<10.00	<1.00	<1.000	<1.000

Sample		Location 3					Location 4		
Location	Units	3/H	3/M		3/L		4/M	4/L	
Tip Depth	m	3.2	4.8		7.7		3.3	6.1	
Surface Elevation	m	983.04	983.04		983.04		983.28	983.28	
Tip Elevation	m	979.8	978.2		975.3		980.0	977.2	
Sample Date		24/05/99	23/02/99	24/05/99	23/02/99	24/05/99	24/05/99	23/02/99	24/05/99
pH		7.370	7.220	7.210	7.610	7.590	7.170	7.510	7.550
EC	dS/m	1.820	1.400	1.540	0.773	0.723	2.480	0.906	0.829
TDS	mg/L	1100.000	896.000	890.000	495.000	4890.000	1580.000	580.000	465.000
Chloride	mg/L	294.000	212.000	229.000	35.100	24.900	502.000	100.000	86.900
Phosphorus	mg/L	<0.030	0.070	0.060	0.030	<0.030	<0.030	0.040	<0.030
Potassium	mg/L	2.500	2.900	2.800	5.400	5.600	1.800	3.600	3.800
Nitrate - N	mg/L	0.016	<0.004	<0.004	<0.004	0.016	0.328	<0.004	0.012
Ammonia - N	mg/L	0.220	<0.050	0.070	0.150	0.110	0.090	0.060	0.010
Dissolved O_2	mg/L	9.600	NT	10.000	NT	3.000	3.700	NT	3.600
Total Coliform	CFU/100mL	6.000	2.000	2.000	33.000	4.000	40.000	<1.000	15.000
Fecal Coliform	CFU/100mL	<1.000	<1.000	<1.000	<1.000	<1.000	<1.000	<1.000	<1.000

Sample		Location 5				Location 6			
Location	Units	5/M		6/H		6/M	6/L	6/VL	
Tip Depth	m	3.10		2.00		3.80	5.30	7.20	
Surface Elevation	m	982.76		982.75		982.75	982.75	982.75	
Tip Elevation	m	979.70		982.00		979.00	977.40	977.60	
Sample Date		23/02/99	24/05/99	23/02/99	24/05/99	23/02/99	24/05/99	23/02/99	24/05/99
pH		6.95	7.78	7.460	7.520	7.620	7.660	7.860	7.860
EC	dS/m	2.85	1.04	0.619	0.644	0.641	0.632	0.644	0.627
TDS	mg/L	1824.00	755.00	396.000	420.000	410.000	415.000	412.000	435.000
Chloride	mg/L	598.00	23.70	21.900	26.800	5.800	4.700	0.600	1.100
Phosphorus	mg/L	0.13	<0.03	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Potassium	mg/L	4.00	3.70	1.900	1.700	3.200	3.400	4.800	4.500
Nitrate - N	mg/L	<0.02	14.90	0.582	1.040	<0.004	0.030	19.400	0.020
Ammonia - N	mg/L	<0.05	0.15	0.060	0.040	0.070	0.050	0.050	0.180
Dissolved O_2	mg/L	NT	13.50	NT	5.900	NT	6.400	NT	2.000
Total Coliform	CFU/100mL	1.00	2.00	<1.000	<1.000	1.000	12.000	1.000	110.000
Fecal Coliform	CFU/100mL	<1.00	<1.00	<1.000	<1.000	<1.000	<1.000	<1.000	<1.000

Table 7.5 Potential travel distance for seepage from the EMS at Site 5 based on the average measured hydraulic gradient between piezometer nest #2 and piezometer nest #4 over the monitoring period (Table 7.1).

K_s (m/s)	Darcy Velocity (m/s)	Linear Velocity (m/day)	Travel Distance (m)
1.00E-05	3.78E-07	9.11E-02	6.65E+02
1.00E-06	3.78E-08	9.11E-03	6.65E+01
1.00E-07	3.78E-09	9.11E-04	6.65E+00
1.00E-08	3.78E-10	9.11E-05	6.65E-01
1.00E-09	3.78E-11	9.11E-06	6.65E-02
1.00E-10	3.78E-12	9.11E-07	6.65E-03
1.00E-11	3.78E-13	9.11E-08	6.65E-04

8.0 Investigation of Site 8

8.1 Site Description and Construction Methods

The layout of this study site is depicted in the general site diagram (Figure 8.1). The 3900-m^3 EMS pond provides over 18 months of storage capacity for a 110-sow farrow-to-finish operation, according to standard manure production calculations (Table 2.3). The reservoir was constructed in 1983, hence the site had been in operation for about 16 y at the time of the investigation. The EMS pond is long and narrow, but relatively shallow, having approximate dimensions of 76 x 26 x 2.5 m (l x w x d) and is oriented north-south. The pond is lined only with the natural subsurface materials and was excavated using a bulldozer and scraper. A berm located at the downslope end of the manure storage was constructed using the excavated materials to improve the storage capacity and grade of the EMS pond. The remainder of the excavated material was used to construct the building site. No effort was made to compact the natural pond liner materials or the berm. Evidence from drilling into the berm site shows that the topsoil was not removed prior to construction of the berm.

8.2 Background Resource Data

Alberta Research Council's Quaternary Geology of Central Alberta map shows that the area in the vicinity of the EMS pond at this site is comprised of glacial till deposits from a stagnation moraine (Shetsen, 1990). These deposits consist mostly of unsorted clay, silt, sand and gravel materials and may contain localized water-sorted materials and bedrock outcrops. The till deposits may be up to 30 m thick, but their depth is generally reflected by topography within the rolling to undulating hummocky morainal landscape. The surrounding surficial deposits are similar, but display less surficial relief and are generally thinner deposits that those within the site location. As the mapping scale for the AGRASID soil inventory is only 1:100,000, caution is advised in this interpretation. The thicker till deposits may or may not be located within the actual EMS site location.

The soil polygon that covers this area has co-dominant parent materials displaying characteristics typical of the Kavanagh and Camrose soil series (AGRASID, v1.0, Nikiforuk et al., 1998). There is a small polygon of Angus Ridge series soil materials mapped within the section of land where the manure pond is located. The Camrose and Angus Ridge soils are derived from the same parent material and have similar textural qualities but the Camrose series is classified as saline-sodic soil, owing to upward movement of saline waters from the underlying marine shale bedrock. Consequently, the Camrose soil is classified as a Black Solodized Solonetz while the Angus Ridge series is an Eluviated Black Chernozem. The Kavanagh soil series, on the other hand, consists of soft weathered shale bedrock that shows moderately saline characteristics. On-site investigation showed that the soil near the EMS pond was not a Solodized Solonetz but did display saline characteristics. Therefore, it seems most likely that the soils are of the Kavanagh soil series.

Soils of that series are expected to have a sand, silt and clay content of 28%, 38% and 34%, respectively, with a hydraulic conductivity of 2.8 x 10^{-6} m/s, which is similar to that predicted for the other potential soil parent materials for this site. The predicted bulk density of these soils is 1300 kg/m^3 with a porosity of about 51% and a water holding capacity of 0.43 m^3 H_2O/ m^3 soil. These soils are classified as moderately saline with a predicted EC of 5.0 dS/m. The C-horizon soil texture map (Figure 8.1) shows that there is a large area of medium to coarse textured soil immediately downslope of the study site. This is likely a local deposit of water-sorted materials that are common to stagnation moraines as noted on the quaternary geology maps for the region (Shetsen, 1990). Site investigation later verified that it is a local deposit of glacial outwash material.

A number of water well reports are available for the area surrounding the EMS pond; two wells were drilled on the same land location where the pond is located. Water well logs indicate the variable nature and thickness of the overburden material in the area. Records from the study site location show 16 – 18 m of clay and sandy clay material over inter-bedded shale and sandstone bedrock. The log from the water well on the adjacent land to the east shows 6.0 m of brown clay over 4.6 m of blue clay (indicative of water logged conditions) over a sandy shale bedrock material. One well record directly north of the study site shows 4.6 m of brown sandy clay and 24 m of soft gray till over gray shale and siltstone bedrock materials. Records from wells to the immediate northeast of the study site show that, while one well penetrated 14.6 m of clay material, two others encountered 9 – 10 m of sand before hitting a waterlogged clay material that overlies a sandstone bedrock structure below.

Water well logs and hydrogeologic cross-sections of the area indicate that the bedrock depth is variable (Tokarsky et al., 1987). Two hydrogeologic cross-sections of the area near the study site are available, P-P' 83A crosses the area just south of the site in the east-west direction, while C-C' 83/A intersects that cross-section and terminates just south of the study site. The hydrogeologic cross sections show that the bedrock underlying the study site is of the Edmonton Formation, which is a marine shale deposit often overlain by a thin gravel deposit under the surficial glacial till soils that predominate the area. The low transmissivity of the bedrock deposit results in water well yields in the order of 0.1 – 0.4 L/s according to local water well records. The exception is the domestic water supply for the farm at the study site, which is finished into a 20-m thick soft sandstone formation about 30 mbgl that yields about 6 L/s with a static water level of only 8.5 mbgl. The other wells in the area seem to be constructed into somewhat deeper formations that display highly variable static water levels between 4.6 - 25 mbgl. The most common comment in the well reports was that the water was soft, indicating that high TDS and salt concentrations are expected in the local groundwater.

The background resource data for this site, with the exception of the soil survey data, lead to the expectation that the site-specific investigation will find about 16 – 20 m of sandy clay till overlying a sandy marine shale bedrock material at the study site. However, there is evidence of local areas of coarse glacial outwash materials in the area so the EMS pond could have been constructed in one of those deposits. All sources indicate that variable thickness of surficial deposits are controlled by the undulating to rolling nature of the bedrock topography in the area. The underlying bedrock is a sandy marine shale deposit that yields low quantities of soft, brackish groundwater. Soil survey, surficial geology and water well record data indicate that the soils here may be either of the Kavanagh (soft weathered shale) or Angus Ridge soil series (Eluviated Black Chernozem).

8.3 Chronology of Events

February, 1999	Initial contact with producer • Producer indicated willingness to participate in project. • Site contained EMS of sufficient size, age and soil conditions.
July 22, 1999	EM 31 survey • Post-survey analysis indicated a potential seepage plume off the southern half portion of the east side berm.
August, 1999	Confirmation of parent material suitability • AGRISID parent material data were used to confirm basic soil type as coarse-medium textured. EMS pond and farm buildings are all located within the medium textured portion of the quarter.
August, 1999	Site selection for intensive investigation • Site was selected as an apparent leaking site.
Nov.16-17, 1999	Initial drilling • One piezometer nest upstream, three immediately downslope, and one far downslope. • Soil samples were taken from one borehole immediately downslope and upslope of the EMS.
Dec. 9, 1999	Flushing of piezometers • Water elevations recorded.
Jan. 28, 2000	Second flushing of piezometers • Water elevations recorded. • GPS survey of the site.
Feb. 14, 2000	Water sampling. • Water elevations recorded. • Samples were taken in all but some of the shallow piezometers of the five nests.
April 27, 2000	Topographic survey of site. • Data include location of piezometer nests, top and toe of each side of the berm, in the middle of each side, a section line through the EMS pond in the general direction of the local slope, and several reference points on landmarks recognizable on an airphoto.
May 10, 2000	Second water sampling. • Water elevations recorded. • Samples were taken in all but some of the shallow piezometers of the five nests.
May 29, 2000	Third water sampling.

- Water levels measured.
- Same set of water samples collected.

Additional soil sampling.

- More complete soil sampling information was needed to analyze the site.
- Sampled boreholes included on top of the downslope side of the berm, far upslope, and far downslope.

8.4 Site-specific Investigation Results

8.4.1 Site Survey Data

The site diagram (Figure 8.1) shows an orthorectified aerial photograph of the hog operation. The EMS pond is located on the quarter section directly to the south of the barns. The piezometers were located using a real-time GPS unit capable of $\pm$ 0.5 m accuracy in the horizontal plane. This information was used to plot the piezometer nest locations onto the orthorectified airphoto. A total station survey was conducted to determine the ground slope and piezometer elevations. The survey data provided accurate vertical positioning of the piezometers and permitted calculation of watertable elevations and watertable gradients adjacent to the EMS pond. The elevation data also allowed comparison of investigative soil boring logs and the physical and chemical soil test data, that were taken at regular and random sample intervals, as per their relative elevation. The surface gradient downslope of the EMS pond between Locations 2 and 4 is 0.0117 m/m. The gradient between the upslope site Location 5 and the downslope Location 2 is only 0.0007 m/m.

8.4.2 Site Hydraulics

The water level elevation data taken for this site is presented in Table 8.1. The shallow groundwater near this study site exhibited constant piezometric elevations independent of the depth of the piezometer tip, showing that no vertical gradient exists in the immediate area surrounding the EMS pond and that a true watertable exists. The watertable elevation generally dropped over winter across the measured profile. The water level in the extreme downslope observation wells dropped to a greater degree than that closer to the pond, perhaps indicating mounding of the watertable near the pond due to the influence of local seepage. If this is so, then the sphere of influence of seepage from the pond is in the order of 10 m from the edge of its full supply level. However, the watertable rose quite substantially in the downslope observation wells after the spring snowmelt event, indicating that local groundwater recharge has a large influence on watertable levels near the site. For example, the water level in the piezometers at Location 2 rose 0.4 m while the upslope piezometers showed a 0.3-m watertable rise between February 24 and May 10, indicating that the watertable fluctuations at this site are seasonal. Furthermore, although the EMS pond was not completely emptied in fall 1999, the watertable dropped substantially over the winter observation period, confirming the lack of influence that pond level has on the surrounding watertable at this site. The seasonal nature of watertable fluctuations is corroborated by signs of oxidation-reduction reactions within these soil zones during the drilling investigation.

8.4.3 EM 31 Survey

The EM survey indicated that there were zones of high bulk electrical conductivity in the general area to the west of the pond and within an area near the southeast corner of the pond (Figure 8.1). Site inspection revealed that the area to the west of the pond that showed high EC readings is swampy and wet and, according the producer, remains that way throughout most of the year. Therefore, the high readings taken at that location were attributed to the influence of wet, clay materials. The area of high EC downslope of the EMS pond, however, showed no signs of standing water upon inspection. The producer claimed that the area does get some standing water after a heavy runoff event but tends to drain with a week or so of ponding. Therefore, the anomalous EC reading at this location were not attributed to moisture effects. The EC anomaly recorded by the EM 31 begins at the side of the EMS pond and narrows out as it extends to the east giving it a plume-like shape indicative of seepage from the EMS pond. Therefore, it was assumed that seepage was the cause of this EC anomaly, and consequently the piezometer network was designed with this in mind.

8.4.4 Soil Physical Data

The hand textures noted for the soils extracted from the boreholes from the site-specific investigation at this site were sandy clay till or silty sandy clay till (Table 8.2). The soil classification of this soil by hand texturing, according to the field logs and the laboratory analysis, is clay loam to clay. USDA classification of these soil materials ranged from loam to loamy sand, while the Unified Soil Classification for all soils was ML (Low Plastic Silt) according to laboratory results (Table 8.2). Sand streaks and lenses were noted in the field logs of boreholes at Locations 1, 2, 3, 5 and 6. The fracturing noted at the 2.7-m depth at Location 4 was credited with transporting water into that hole at that depth. Flow rates within these fractures were fairly substantial since enough water was available in these shallow piezometers to permit water sampling on each sampling date. Soils taken from borehole into the berm (Location 7) showed similar physical properties as those taken from other locations at the study site.

A thick layer of water-sorted sand and gravel was found at Location 8 between about 1.0 and 9.1 mbgl. A sandy clay till material, similar to that found in the other boreholes, was encountered below the coarse material and logged to the extent of the boring at just over 10.5 mbgl. The material in this borehole is thought to be an example of the water-sorted glacial outwash material that the quaternary geology map suggested would be found within the stagnation moraine deposit (Shetsen, 1990). The C-horizon texture map in the site diagram (Figure 8.1) also suggests that the subsoils at Location 8 could just as easily have been medium to coarse textured materials, but, fortunately the EMS pond was not located within these materials.

The sand content of the soils extracted from the five boreholes used for sampling ranged from 36 - 81.4 %. The 81.4 % analysis was in a soil taken from a fairly substantial sand lens found at the 1.5 - 2.1 mbgl sample interval at Location 2. The sand content from all other samples averaged about 40% and generally ranged between 36 and 43%. Clay content in the samples taken was generally between about 20 - 30%. Samples from Locations 4, 6 and 7 averaged in the upper 20% range while the samples from Locations 2 and 5 averaged in the low 20% range. Silt content from all samples was in the 30% range but where clayey materials were encountered, silt content tended to drop accordingly, while sand content remained relatively steady.

The measured bulk density of the soil samples tested was greater for the finer textured samples and lower for the coarser materials. The soils from the borehole at Location 2 had some unexplainably low bulk densities. These results are likely unreliable since the textures are not much different than those found within the other locations. The site-averaged bulk density, using results from all soils tested, is 1400 kg/m^3, which matches with that predicted for an Angus Ridge soil parent material (Nikiforuk et al., 1998). Ignoring the results from Location 2 yields an average bulk density value near 1500 kg/m^3, which matches with that predicted for a Camrose soil (Nikiforuk et al., 1998). None of the site averaged bulk densities matched with that of the Kavanagh soil series, which was 1300 kg/m^3. Soil particle analysis and bulk density values from the laboratory analysis (Table 8.2) match best those given for the Angus Ridge series. Consequently, a soil porosity of about 47% was calculated using a bulk density value of 1400 kg/m^3. The predicted hydraulic conductivity of an Angus Ridge subsoil should be between 10^{-5} and 10^{-6} m/s (1 cm/h) according to the soil survey inventory (Nikiforuk et al., 1998). This value seems high for the texture, porosity and bulk density found for the soils at the study site so caution is recommended when using the permeability values from the AGRASID soil survey database (Nikiforuk et al., 1998).

SoilVision software was used to predict the hydraulic conductivity of the soils at this study site based on a clay and sand content of between 22.5 - 28% and 38 – 44%, respectively (Table 7.3). The software predicts soil permeabilities by matching physical soil properties with an extensive database of measured permeability values. The hydraulic conductivity was predicted to be 10^{-5} - 10^{-6} m/s at the 95% confidence interval. This is a large range that would affect predicted advective solute transport distance from the EMS pond in these soils (i.e., porosity = 47%) by up to an order of magnitude over a year. The importance of, and difficulty in, predicting soil hydraulic conductivity illustrates the unpredictability of seepage rates based on that parameter. Field testing is recommended to determine the soil permeability to enhance confidence in seepage and solute transport rate predictions.

8.4.5 Soil Chemistry

The results of the soil chemistry analysis from samples taken at this site are presented in Table 8.3. Soil chemistry profile values for the nitrogen indicator species tested for (i.e., NH_4, NO_3) appear to match fairly well with background sample values with a few exceptions. The NH_4 concentrations in soils at Locations 2 and 5 were higher that those from the background soil profile at Location 6. However, the values are not so high as to indicate that major NH_4 movement is occurring from the EMS pond to these sample sites. The NH_4-N values of Location 4, 36 m downslope of the EMS pond, matched well with those of the background sample site. The NH_4 profile at Location 7, into the berm about 2.5 m from the full supply level of the EMS pond, showed a large spike within the 2.1 – 3.1 m sample interval. The spike in NH_4-N content here coincides with the depth at which topsoil was noted in the drill logs. Apparently the topsoil was not removed prior to construction of the downslope berm of this EMS pond and this layer is allowing seepage and ion transport through this zone. No indication of nitrate-N movement is apparent within the soil profile data.

Profiles of soil chloride concentrations show general agreement with each other and with the background concentrations with the exception of Locations 2 and 7. Location 2 shows a large spike in the Cl concentration at the 1.5 to 2.1 soil sample interval, corresponding to the location of a sand lens within the soil profile as documented in the laboratory results for that test hole. The sand content within that sample interval at Location 2 was over 80%, while the clay content there was only 7.5%. The other anomalous Cl concentrations found at this site were within the upper 4.0-m sample interval taken from the berm. The Cl concentrations spikes found in the 1.2 – 2.1 m sample interval at Location 2 and in the upper profile at Location 7 (in the berm) are over an order of magnitude higher that those found for the other samples taken, including those from the background sample and at the extreme downslope position.

The high CL concentrations in the berm sample profile match with the spike in NH_4-N concentrations at that location which, as stated above, matches with the depth in that soil profile where the topsoil layer was found below the berm. Together, these indicators suggest that some major amount of seepage is occurring through the berm at this site. The chloride spike at Location 2, on the other hand, could also be an indication of seepage from the EMS pond, but is more likely due to vertical seepage of nutrients from the soil surface since there were no other corroborating indications of seepage from the EMS pond at this location. Cl concentrations also decreased with depth at this location, which is usually an indication of downward solute movement.

8.4.6 Water Chemistry

With few exceptions, the water chemistry at this site was uniform across sampling locations and dates (Table 8.4). Anomalies appear to correlate to sand lenses or fractures within the till material where the EMS pond was constructed as detected within the field drilling logs.

Very high total dissolved solids concentrations (TDS) were found in almost all of the samples taken over the entire monitoring period. TDS readings ranged from 1901 mg/L at Location 4/L in February to as high as 10,500 mg/L at Location 2/H on May 10. Fitzgerald (1999) found that TDS concentrations in shallow groundwater in Alberta averaged 1,107 mg/L and ranged between 134 and 5,652 mg/L, indicating that the TDS levels at this site were high. However, the fact that the highest-recorded TDS levels were taken at Location 2 (up gradient of the EMS pond) refutes the theory that these readings are related to seepage from the lagoon.

Consistently high TDS levels across the site are likely related to the saline-sodic nature of the soils here. Soil EC levels above 4 dS/m classify the soil as saline, while soils with an exchangeable sodium percentage (ESP) greater than 15 are classified as sodic (Hausenbuiller, 1982). Soil SAR values at this site ranged between 7 and just over 15, which translates to ESP values in the order of 10 to 19%. Soil EC readings for the site generally ranged between 4 and 8 dS/m, with some as high as 12 dS/m. This indicates that the soils at this site are saline and moderately sodic, which corroborates the theory that the high TDS values in the water samples are related to soil conditions. Water samples from this site also have high EC readings relative to those found for the other study sites, which also suggests that the TDS levels are site related as opposed to seepage related. Finally, the saline nature of the soil and water at this location is expected due to the relatively thin surficial cover combined with the effects of the underlying saline marine shale bedrock (i.e., Edmonton Formation) at this location.

Chloride concentrations in the water samples are generally within the expected range. However, the samples from the shallow observation wells at Locations 2 and 3 are higher than expected, and exceed the Canadian Drinking Water Guideline of 250 mg/L. These high Cl values also coincide with some extremely high NO_3 concentrations (398 – 502 mg/L) in the shallow observation well at Location 3. In fact, all of the water samples from all sample depths at Location 3 exceeded the drinking water guideline maximum concentration level of 10 mg/L for NO_3. In fact, all shallow water samples from the observation wells immediately downslope of the EMS pond showed high levels of NO_3. Only some of these readings were matched with a correspondingly high Cl concentration level. No indication of elevated NH_4, P or K concentrations was found in any of the water samples from any of the observation wells.

8.4.7 Microbiological Indicators

Results from the microbiological analysis of water samples taken at this Site are presented in Table 8.4. Very few indications of unusual total or fecal coliform concentrations were observed in the water samples from this site. Eight of 37 samples had total coliform counts that were higher that the drinking water guideline of 10 CFU/100 ml; three of these high coliform counts were at the extreme downslope location, 36 m away from the EMS pond. One of these was the highest level recorded, 1000 CFU/100 ml, which was observed in the 5.9-m-deep well at Location 5 on May 29. The next highest total coliform observation, 220 CFU/100ml, was in the sample from the deep observation well at Location 2 on February 14. All other higher than expected total coliform observations were in the 110 – 140 CFU/100 ml range, just over the drinking water standard. Only the deep sample from

Location 4 showed high total coliform readings on both dates. All the other high readings were one-time observations that were not consistent between date or depth of observation wells.

Fecal coliform bacteria were observed in only two of the observation wells over the monitoring period. Both of these observations were found during the first sampling of the observation wells at Location 3, the highest of which was found at the mid-level well depth (i.e., 4.6 mbgl). One other observation of fecal coliform bacteria was made at Location 5 in the deep well on May 29. However, this result is suspect since it shows that <10 CFU/100 ml was found. The "less than" symbol attached to this result means that not enough sample was available for a true count during the analysis. No reason for the shortage of sample can be justified since a full water sample was taken in the field and the sample was couriered overnight to the laboratory in a sealed container in a sealed cooler.

8.5 Discussion

Nitrate-N and chloride levels higher than the drinking water guideline were observed in the water samples taken from all the shallow piezometers immediately downslope of the EMS pond. The level of nitrate in the shallow observation well at Location 3 is considered very high, while the levels of NO_3 in the deeper observation wells at this location are considered moderately high. All the NO_3 concentrations found in the shallow observation wells at all other sampling locations, except the background location, are considered moderately high. The high NO_3 levels observed are all of concern if they are the result of seepage from the EMS pond.

The shallow piezometer tip at Location 3, that showed extreme NO_3 concentrations, was constructed into a soil layer that had saturated sand streaks during the drilling investigation. This could indicate that the NO_3 came from seepage from the EMS pond through these sand fissures. Oddly, although the nitrate-N levels in the neighboring observation wells (i.e., Locations 1 and 2), the same distance from the EMS pond, are relatively high, they are not extreme like at Location 3. This is even more suspicious since each of the neighboring boreholes also showed water-bearing features that could have transported seepage to those piezometers. Another difference between the water quality at Location 3 and those at its neighboring sample sites was in the Cl concentrations. The water from observation wells at Location 3 had very high Cl concentrations while the others did not. The exception to this was Location 2, where the chloride levels were high but the NO_3 levels were moderate. High nitrate levels do not correlate well with dissolved oxygen concentrations in the groundwater either, which is odd, since oxygen is required for the nitrification reaction to occur.

This curious situation leads to some confusion about the potential source of the very high nitrate level at Location 3. Consequently, an investigation into other possible sources for the nitrate was undertaken. A discussion with the producer revealed that the EMS had experienced an overflow during a period of heavy rain in July 1999. The overflow temporarily flooded the area where the observation wells were installed later that fall. With this in mind, another look at the data suggested that the nitrate levels in the shallow wells downslope of the EMS may have resulted from this surface manure-flooding event. The following points lead to this conclusion:

- Only shallow water samples downslope of the EMS pond showed coincidentally high Cl and NO_3-N concentrations,
- Soil nitrate concentrations were only seen to be high in the near surface sample interval in the soil sample taken at Location 2 and
- The NO_3-N and Cl concentration levels in the water samples at Location 3 tend to decrease with sample depth for all of the three observation dates.

The neutral pH values of the water samples lend support to this theory. The vast majority of the nitrogen in the EMS pond is in NH_4 form. When nitrification of NH_4 to NO_3 occurs, some acidification of the groundwater usually results due to the release of free hydrogen ions during the oxidation reaction. No evidence of this was observed from inspection of the water pH data, where all of the water samples show stable neutral or slightly basic pH values. Therefore, the high NO_3 levels in the shallow observation wells at this site are attributed to progressive downward movement of ions, as opposed to the lateral movement that would be expected from a seepage plume. The extreme levels in the shallow well at Location 3 (398 – 502 mg/L) and the high levels in the deeper wells (23 – 67 mg/L) at this location are likely due to vertical seepage of NO_3 from the surface related to the manure spill in the area earlier that summer.

Total and fecal coliform levels in several of the observation wells were higher than acceptable, according to drinking water guidelines. Three of the high coliform counts were at the extreme downslope sample location, 36 m away from the EMS pond. One of those three was the highest level recorded, at 1000 CFU/100 ml, which was observed in the 5.9-m deep well on May 29. As this is the only observation within this range of concentration and there are no other indications that seepage was entering this observation well, it seems unlikely that this is a true reading. Rather, it is likely due to contamination during sampling or analysis procedures. Similarly, the observation of 220 CFU / 100 ml in the deep sample well on February 14 at Location 2 may have resulted from contamination during installation. This observation was from the first sampling date after drilling after which the coliform counts tend to decline to near-normal levels. Since the surface soils at this site are known to have been recently inundated with hog manure, the piezometer tip may have been contaminated through contact with the ground surface during well installation.

The other higher-than-expected total and fecal coliform counts are coincident with the observed higher nitrate concentrations. It is possible that the bacteria may have entered the observation wells through leakage along a poorly-sealed well casing or through vertical fractures in the soil that are often present in the top 10 m of clay till materials of the type found at this location (Barbour, 2000).

8.6 Conclusions

Several indications of seepage from the EMS pond at this study site were found within the available soil and water data. However, recent pond overflow was likely the cause of many of the signs of seepage found at this site.

Nonetheless, there is some fairly strong evidence that some seepage is occurring through the berm at the downslope end of the EMS pond. This is likely due to poor construction practices, including inadequate compaction and failure to remove the topsoil and vegetation layer at the soil surface prior to construction.

Some minor seepage is likely also occurring into a major sand layer detected in the 1.5 to 2.1 m sample interval at Location 2. High NH_4 concentrations in the soil there and high chloride and nitrate levels in the water taken from the piezometer installed into this formation could be related to EMS pond seepage into this sand layer.

No major impact on the local soil or groundwater is expected to occur as a result of the seepage detected from the EMS pond at this site, since it does not appear to affect either resource much beyond the perimeter of the EMS berms. The indications of seepage from this pond appear related to poor site conditions and poor construction techniques. Sand lenses and fissures and fractures within the till material appear to be carrying some contaminants into the surrounding subsoil. A proper site investigation prior to construction of this EMS pond would have detected the sand and fracture layers and lead to improved EMS pond design and construction. A compacted clay liner and better construction of the berm would likely have prevented seepage from this EMS pond over its 20-y operational period. Professional construction supervision may have been sufficient to obtain adequate quality control for berm construction at this site. The results from this site investigation emphasize the need for better siting, design and supervision of the construction of these structures.

In summary;

- No major continuous seepage plume from the EMS pond exists at this site.
- A sand layer near Location 2 is appears to be acting as a conduit for some minor localized seepage but the extent of this localized seepage could not be determined by the investigation procedures used in this study.
- Poor construction techniques, such as poor compaction of the berm and burying topsoil below the berm, appear to be responsible for some seepage and contaminant movement through the berm at the west end of this EMS pond.

- Soil and water chemistry anomalies initially attributed to EMS seepage appear to be better explained by a major manure spill that occurred in July 1999.
- Contamination of the soil and water at this site due to the spill event confounded the interpretation of study results at this site.
- A Phase I site assessment with remote resource data would have identified the need for a site-specific investigation to assess the environmental security of this site.
- A proper site investigation prior to construction of this EMS would have identified the inherent problems with this site that are the cause of the minor seepage found here.
- A properly constructed liner and berm would have prevented the seepage shown to occur from the EMS pond at this site.

Figure 8.1 Site 8 Layout and location diagram showing the location of the soil sample and piezometers, the EM 31 electrical conductivity surface and the C-horizon soil parent material map for the area from the AGRASID database (Nikiforuk et al. 1998)

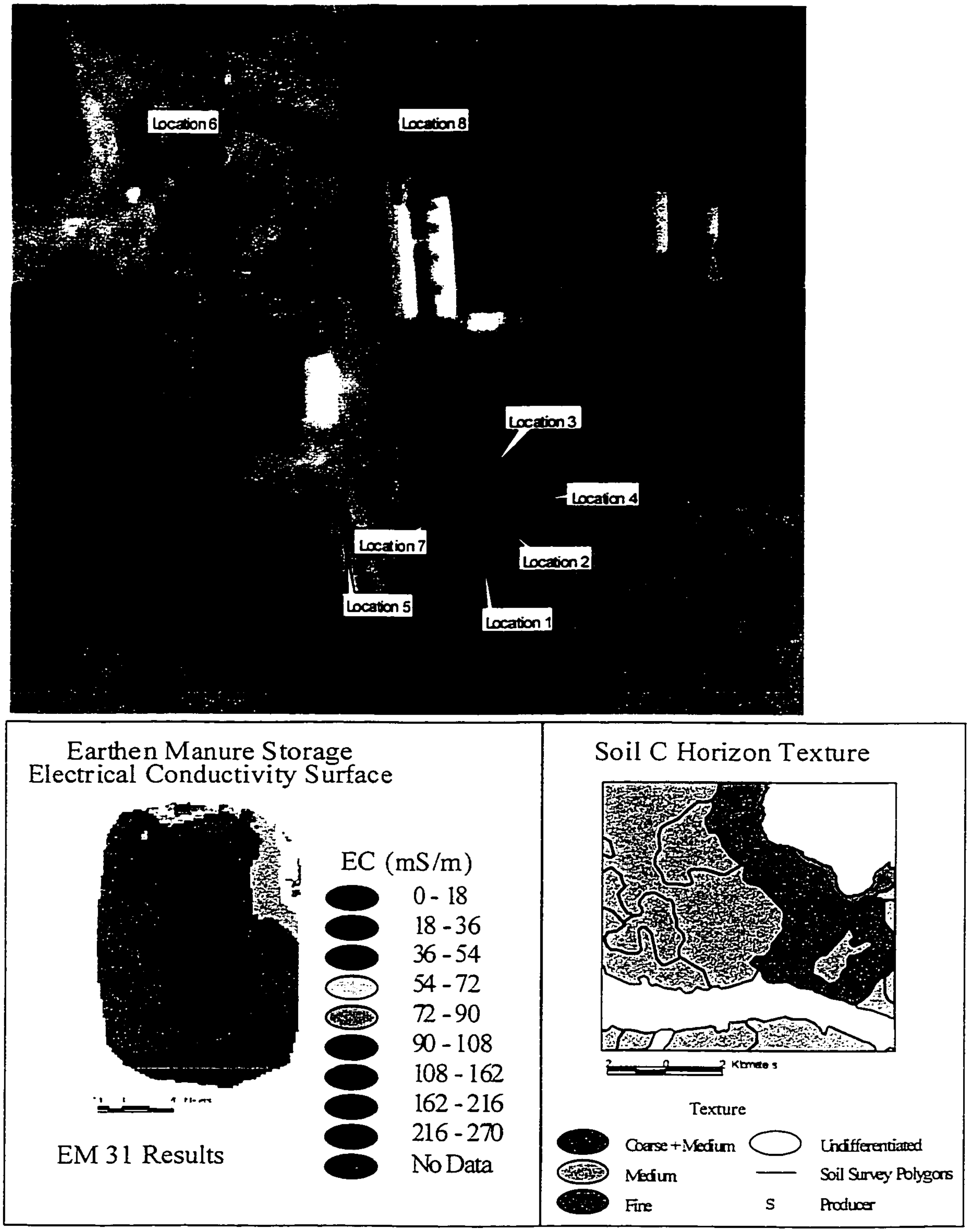

Table 8.1 Piezometric data for Site 8

Date				9-Dec-99	28-Jan-00	14-Feb-00	10-May-00	29-May-00
Well ID Location	**Piezo. Depth (m)**	**Surface Elev. (m)**	**Tip Elev. (m)**	**Water Elevation**				
1/H	2.4	740.71	738.3	dry	dry	dry	dry	dry
1/M	4.6	740.71	736.1	736.6	738.2	737.1	738.4	738.4
1/L	6.7	740.71	734.0	734.5	738.5	737.5	738.4	738.5
2/H	2.5	740.46	738.0	738.9	738.8	738.5	738.9	739.0
2/M	4.5	740.46	736.0	736.3	737.8	736.8	738.5	738.9
2/L	6.7	740.46	733.8	738.8	738.7	738.7	738.9	738.9
3/H	2.8	740.88	738.1	738.9	738.7	738.7	739.0	739.2
3/M	4.6	740.88	736.3	738.9	738.7	738.7	738.7	739.0
3/L	7.2	740.88	733.7	739.0	738.8	738.7	738.7	738.9
4/H	2.7	740.11	737.4	738.9	738.5	738.4	739.0	739.0
4/M	4.6	740.11	735.5	738.7	738.4	738.3	738.9	738.8
4/L	7.5	740.11	732.6	738.8	737.9	738.4	738.4	738.8
5/H	1.5	740.16	738.7	739.3	dry	dry	739.2	739.4
5/L	5.9	740.16	734.3	739.5	739.1	739.0	739.3	739.7

Table 8.2 Select soil physical properties for Site 8

Location	Depth (m)	MC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	BD (kg/m^3)	Plasticity (%)	USCS Class
Location 2 (10 m downslope of EMS)									
2/1	0.3-1.2	15.2	2.1	43.4	31.3	25.3	868.0	18.0	
2/2	1.2-2.1	17.4	0.4	81.4	11.1	7.5	1896.0	16.0	
2/3	2.1-3.1	16.2	1.1	38.4	35.5	26.1	937.0	3.0	
2/4	3.1-4.0	16.1	1.2	39.4	36.1	24.5	910.0	16.0	
2/5	4.0-4.9	15.3	1.8	36.4	38.3	25.3	1038.0	19.0	
2/6	4.9-5.8	15.9	0.5	41.4	32.5	26.1	967.0	15.0	
2/7	5.8-6.7	16.4	2.5	37.4	38.9	23.7	939.0	17.0	
2/8	6.7-7.6	16.8	0.8	36.4	40.7	22.9	995.0	16.0	
Average		16.2	1.3	44.3	33.1	22.7	1069.0	15.0	ML
Standard Deviation		0.7	0.7	14.2	8.8	5.8	316.4	4.7	

Location	Depth (m)	MC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	BD (kg/m^3)	Plasticity (%)	USCS Class
Location 4 (36 m downslope of EMS)									
4/1	0.25-1.0	16.6	2.7	34.7	31.4	31.2	1420.0	18.0	
4/2	1.0-2.0	15.9	0.0	39.0	30.8	30.2	1440.0	61.0	
4/3	2.0-3.0	16.9	0.8	39.2	30.4	29.6	1410.0	16.0	
4/4	3.0-4.0	18.6	0.0	36.0	33.2	30.8	1490.0	14.0	
4/5	4.0-5.0	18.0	0.0	40.0	32.8	27.2	1440.0	20.0	
4/6	5.0-6.0	16.9	0.0	40.0	34.6	25.4	1570.0	14.0	
4/7	6.0-7.0	17.0	0.1	38.9	35.4	25.6	1590.0	21.0	
4/8	7.0-7.6	16.5	0.6	42.4	32.8	24.2	1520.0	18.0	
Average		17.1	0.5	38.8	32.7	28.0	1485.0	23.0	ML
Standard Deviation		0.8	0.9	2.3	1.6	2.6	64.6	14.7	

Location	Depth (m)	MC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	BD (kg/m^3)	Plasticity (%)	USCS Class
Location 5 (23 m upslope of EMS									
5/1	0.25-1.0	15.9	0.8	51.4	33.5	15.1	1413.0	10.0	
5/2	1.0-2.0	19.9	1.0	37.4	40.5	22.1	1086.0	15.0	
5/3	2.0-3.0	19.6	1.0	40.4	38.3	21.3	1164.0	15.0	
5/4	3.0-4.0	17.5	3.9	41.4	35.7	22.9	972.0	17.0	
5/5	4.0-5.0	20.2	3.0	44.4	35.8	19.8	1846.0	15.0	
5/6	5.0-6.0	19.6	1.8	38.4	37.9	23.7	1021.0	18.0	
5/7	6.0-7.0	17.9	1.2	40.4	39.0	20.6	1034.0	15.0	
5/8	7.0-7.6	18.1	1.6	41.4	38.8	19.8	927.0	13.0	
Average		18.6	1.8	41.9	37.4	20.7	1183.0	15.0	ML
Standard Deviation		1.4	1.0	4.1	2.1	2.5	287.4	2.3	

Table 8.2 (continued) Select soil physical properties for Site 8

Location	Depth (m)	MC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	BD (kg/m^3)	Plasticity (%)	USCS Class
Location 6 (106 m up slope of EMS)									
6/1	0.25-1.0	14.9	3.1	39.5	27.2	30.2	1820	18.0	
6/2	1.0-2.0	14.9	0.0	44.0	28.4	27.6	1640	16.0	
6/3	2.0-3.0	15.6	2.4	35.6	32.2	29.8	1560	19.0	
6/4	3.0-4.0	17.1	0.0	37.0	31.0	32.0	1580	17.0	
6/5	4.0-5.0	17.5	0.0	40.0	30.0	30.0	1730	17.0	
6/6	5.0-6.0	16.8	0.1	37.9	32.2	29.8	1830	14.0	
6/7	6.0-7.0	17.8	0.2	37.8	34.0	28.0	1730	18.0	
6/8	7.0-7.6	17.9	0.1	35.9	36.0	28.0	1910	12.0	
Average		16.6	0.7	38.5	31.4	29.4	1725	16.0	ML
Standard Deviation		1.2	1.2	2.5	2.7	1.4	117	2.2	

Location	Depth (m)	MC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	BD (kg/m^3)	Plasticity (%)	USCS Class
Location 7 (2.5 m down slope of EMS)									
7/1	0.25-1.0	14.9	0.0	44.0	24.6	31.4	1480.0	24.0	
7/2	1.0-2.0	15.3	0.0	42.0	28.4	29.6	1570.0	14.0	
7/3	2.0-3.0	16.4	0.3	41.7	30.6	27.4	1710.0	17.7	
7/4	3.0-4.0	17.1	0.7	35.3	34.4	29.6	1570.0	18.0	
7/5	4.0-5.0	15.3	1.6	39.4	32.0	27.0	1450.0	20.2	
7/6	5.0-6.0	16.3	0.6	38.4	35.2	25.8	1630.0	17.3	
7/7	6.0-7.0	16.1	2.9	32.1	38.0	27.0	1510.0	21.2	
7/8	7.0-7.6	17.1	0.1	35.9	35.6	28.4	1550.0	23.6	
Average		16.1	0.8	38.6	32.4	28.3	1559.0	20.0	ML
Standard Deviation		0.8	0.9	3.7	4.1	1.7	78.0	3.2	

Table 8.3 Select Soil Chemistry Properties for Site 8

Location	Depth (m)	pH	EC (dS/m)	Cl (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	NH_4-N (µg/g)	No_3-N (µg/g)	K (µg/g)	PO4-P (µg/g)	CEC (meq/100g)
Location 2 (10 m down slope of EMS)												
2/1	0.3-1.2	7.95	7.15	64.40	484.0	396.0	1216	1.67	56.30	177	1.85	26.8
2/2	1.2-2.1	8.20	6.33	322.00	189.0	227.0	1315	1.17	8.57	81	1.51	11.0
2/3	2.1-3.1	7.95	3.40	49.30	78.6	91.0	676	3.32	3.69	152	0.73	22.2
2/4	3.1-4.0	8.30	3.46	12.60	101.0	99.9	699	6.72	2.86	163	2.22	22.9
2/5	4.0-4.9	8.20	4.50	7.98	151.0	159.0	723	7.57	2.97	171	2.03	21.8
2/6	4.9-5.8	7.90	3.26	8.66	67.6	85.9	673	5.72	3.92	148	1.23	22.5
2/7	5.8-6.7	8.00	2.98	6.68	93.3	63.7	617	9.42	2.75	148	1.80	21.7
2/8	6.7-7.6	8.00	2.90	0.26	86.6	48.7	603	6.97	2.54	146	1.63	22.3

Location	Depth (m)	pH	EC (dS/m)	Cl (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	NH_4-N (µg/g)	No_3-N (µg/g)	K (µg/g)	PO4-P (µg/g)	CEC (meq/100g)
Location 4 (36 m down slope of EMS)												
4/1	0.25-1.0	8.2	0.80	17.7	50.6	12.7	153	0.96	2.0	182	<5	16.0
4/2	1.0-2.0	8.2	1.43	24.8	29.3	33.3	246	1.40	2.0	184	<5	15.3
4/3	2.0-3.0	8.0	2.23	31.9	95.8	68.8	385	0.84	0.9	174	<5	19.2
4/4	3.0-4.0	8.0	2.02	7.1	78.6	42.1	390	1.70	<0.5	181	<5	19.1
4/5	4.0-5.0	8.4	2.32	7.1	127.0	55.9	408	2.10	<0.5	185	<5	16.6
4/6	5.0-6.0	8.6	2.49	7.1	136.0	46.4	382	2.50	<0.5	156	<5	14.5
4/7	6.0-7.0	8.6	2.63	10.6	149.0	51.1	402	3.07	<0.5	164	<5	15.7
4/8	7.0-7.6	8.5	2.29	7.1	115.0	30.5	374	4.79	<0.5	171	<5	11.1

Location	Depth (m)	pH	EC (dS/m)	Cl (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	NH_4-N (µg/g)	No_3-N (µg/g)	K (µg/g)	PO4-P (µg/g)	CEC (meq/100g)
Location 5 (-23 m up slope of EMS)												
5/1	0.25-1.0	7.60	5.50	14.10	522	301.0	797	2.77	3.57	194	8.31	22.3
5/2	1.0-2.0	7.50	5.10	10.40	391	279.0	750	4.27	3.59	171	3.59	26.2
5/3	2.0-3.0	7.70	3.89	9.48	181	148.0	638	3.92	3.52	156	2.34	24.0
5/4	3.0-4.0	7.70	4.34	7.56	282	182.0	699	4.87	3.91	151	1.73	25.5
5/5	4.0-5.0	8.00	4.88	13.90	421	212.0	753	6.02	3.81	151	1.58	23.3
5/6	5.0-6.0	8.10	3.75	7.73	282	119.0	642	7.02	2.71	162	1.72	22.4
5/7	6.0-7.0	7.85	3.16	6.89	238	79.5	536	8.62	2.58	144	1.55	18.8
5/8	7.0-7.6	7.75	2.78	7.76	183	57.9	486	8.87	2.39	144	1.93	19.7

Location	Depth (m)	pH	EC (dS/m)	Cl (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	NH_4-N (µg/g)	No_3-N (µg/g)	K (µg/g)	PO4-P (µg/g)	CEC (meq/100g)
Location 6 (106 m up slope of EMS)												
7/1	0.25-1.0	8.3	11.79	386.4	445	563	2223	0.71	84.0	234	<5	12.2
7/2	1.00-2.0	8.1	7.91	329.7	521	487	1063	1.50	19.0	184	<5	13.1
7/3	2.00-3.0	8.3	7.02	361.6	500	536	805	10.40	2.0	173	<5	14.9
7/4	3.00-4.0	8.1	6.39	265.9	432	324	914	2.10	0.6	230	<5	16.1
7/5	4.00-5.0	8.2	7.17	35.5	486	409	1055	1.70	<0.5	169	<5	16.5
7/6	5.00-6.0	8.8	5.19	14.2	188	214	892	2.20	<0.5	183	<5	14.8
7/7	6.00-7.0	8.9	4.95	10.6	164	186	871	3.64	0.7	170	<5	15.6
7/8	7.00-7.6	8.9	4.27	7.1	136	124	770	5.25	<0.5	163	<5	16.4

Table 8.3 (continued) Select soil chemistry properties for Site 8

Location	Depth (m)	pH	EC (dS/m)	Cl (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	NH_4-N (µg/g)	No_3-N (µg/g)	K (µg/g)	PO4-P (µg/g)	CEC (meq/100g)
Location 7 (2.5 m down slope of EMS)												
6/1	0.25-1.0	7.9	6.59	21.3	470	313	1001	1.90	<0.5	164	<5	13.8
6/2	1.0-2.0	8.0	7.75	28.4	485	326	1337	0.82	<0.5	144	<5	14.2
6/3	2.0-3.0	7.8	5.57	17.7	486	220	759	1.20	2.0	156	<5	14.2
6/4	3.0-4.0	7.8	5.58	17.7	440	235	781	0.96	3.3	155	<5	14.3
6/5	4.0-5.0	7.8	5.87	10.6	466	277	813	1.50	2.0	153	<5	16.4
6/6	5.0-6.0	8.3	5.27	7.1	438	241	709	2.30	<0.5	154	<5	15.3
6/7	6.0-7.0	8.5	4.95	10.6	379	198	710	3.16	<0.5	160	<5	15.1
6/8	7.0-7.6	8.6	3.63	7.1	236	108	544	4.69	<0.5	167	<5	16.6

Table 8.4 Select water chemistry and microbiology properties for Site 8

Sample		Location 1					
Location	units	1/M			1/L		
Tip Depth	m	4.6			6.7		
Surface Elevation	m	740.71			740.71		
Tip Elevation	m	736.1			734.0		
Sample Date		**14/02/00**	**10/05/00**	**29/05/00**	**14/02/00**	**10/05/00**	**29/05/00**
pH		7.44	7.55	7.41	7.11	7.24	7.12
EC	mS/cm	9.14	10.50	10.30	5.36	6.58	5.70
TDS	mg/L	5850.00	9420.00	9890.00	3430.00	5800.00	5300.00
Chloride	mg/L	103.00	181.00	196.00	9.10	5.00	4.00
Phosphorus	mg/L	0.05	<0.03	0.04	0.06	0.03	<0.03
Potassium	mg/L	24.40	19.40	25.50	15.50	11.80	14.00
Nitrate - N	mg/L	11.10	20.60	22.40	<0.02	<0.04	<0.04
Ammonium - N	mg/L	0.18	0.61	0.30	0.51	0.89	0.85
Dissolved O_2	% saturation	NT	26.50	19.90	NT	22.50	17.60
	mg/L	NT	3.40	2.00	NT	2.50	1.80
Total Coliforms	CFU/100mL	3.00	5.00	4.00	30.00	20.00	12.00
Fecal Coliforms	CFU/100mL	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00

Sample		Location #2								
Location	units	2/H			2/M			2/L		
Tip Depth	m	2.5			4.5			6.7		
Surface Elevation	m	740.46			740.46			740.46		
Tip Elevation	m	738.0			736.0			734.8		
Sample Date		**14/02/00**	**10/05/00**	**29/05/99**	**14/02/00**	**10/05/00**	**29/05/99**	**14/02/00**	**10/05/00**	**29/05/99**
pH		7.36	7.55	7.42	7.40	7.43	7.30	7.15	7.26	7.15
EC	mS/cm	10.80	11.08	10.90	7.18	10.20	10.00	6.59	8.30	7.78
TDS	mg/L	6912.00	10500.00	10100.00	4595.00	9650.00	10300.00	4218.00	7480.00	7580.00
Chloride	mg/L	556.00	795.00	539.00	13.30	35.70	17.30	6.10	10.10	12.30
Phosphorus	mg/L	0.15	0.18	0.16	<0.03	<0.03	0.03	0.05	0.05	0.03
Potassium	mg/L	38.60	32.00	41.70	25.50	22.80	30.70	19.70	15.30	20.50
Nitrate	mg/L	11.40	7.34	5.62	1.26	0.23	1.57	<0.02	<0.04	<0.04
Ammonium	mg/L	0.05	0.17	0.02	0.16	0.22	0.41	0.51	0.98	1.06
Dissolved O_2	% sat.	NT	28.10	23.20	NT	18.60	16.30	NT	32.00	16.20
	mg/L	NT	2.80	2.40	NT	2.30	2.00	NT	4.30	2.00
Total Coli.	CFU/100mL	1.00	8.00	1.00	50.00	7.00	24.00	220.00	30.00	10.00
Fecal Coli.	CFU/100mL	<1.00	<4.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00

Table 8.4 (continued) Select water chemistry and microbiology properties for Site 8

Sample		Location 3								
Location	units	3/H			3/M			3/L		
Tip Depth	m	2.8			4.6			7.2		
Surface Elevation	m	740.88			740.88			740.88		
Tip Elevation	m	738.1			736.3			733.7		
Sample Date		**14/02/00**	**10/05/00**	**29/05/00**	**14/02/00**	**10/05/00**	**29/05/00**	**14/02/00**	**10/05/00**	**29/05/00**
pH		7.27	7.44	7.36	7.47	7.57	7.46	7.37	7.49	7.34
EC	mS/cm	8.56	9.59	9.00	5.50	5.93	5.93	5.27	5.61	5.31
TDS	mg/L	5478.00	7490.00	7400.00	3520.00	5100.00	5410.00	3373.00	4710.00	4700.00
Chloride	mg/L	728.00	816.00	868.00	133.00	175.00	175.00	116.00	91.10	84.10
Phosphorus	mg/L	0.19	0.19	0.14	0.12	0.06	0.04	0.06	0.04	0.04
Potassium	mg/L	34.00	28.70	34.90	26.20	19.40	23.30	15.90	12.40	14.40
Nitrate	mg/L	398.00	502.00	492.00	53.60	60.80	67.30	46.30	31.30	23.20
Ammonium	mg/L	0.07	0.29	0.29	0.10	0.26	0.20	0.61	0.91	0.81
Dissolved O_2	% sat.	NT	55.10	19.90	NT	31.40	23.10	NT	37.10	20.20
	mg/L	NT	6.90	2.00	NT	4.80	2.60	NT	4.70	2.40
Total Coli.	CFU/100mL	7.00	3.00	<1.00	23.00	140.00	14.00	29.00	50.00	3.00
Fecal Coli.	CFU/100mL	1.00	<2.00	<1.00	11.00	<1.00	<1.00	<1.00	<1.00	<1.00

Sample		Location 4								
Location	units	4/H			4/M			4/L		
Tip Depth	m	2.7			4.6			7.5		
Surface Elev.	m	740.11			740.11			740.11		
Tip Elevation	m	737.4			735.5			732.6		
Sample Date		**14/02/00**	**10/05/00**	**29/05/99**	**14/02/00**	**10/05/00**	**29/05/99**	**14/02/00**	**10/05/00**	**29/05/99**
pH		7.43	7.56	7.50	7.26	7.33	7.26	7.12	7.25	7.17
EC	mS/cm	2.56	3.32	3.29	3.38	4.19	3.67	2.97	4.29	3.93
TDS	mg/L	1638.00	2550.00	2700.00	2163.00	3450.00	3190.00	1901.00	3470.00	3500.00
Chloride	mg/L	21.30	47.50	50.10	11.70	14.30	18.00	<0.50	5.20	10.50
Phosphorus	mg/L	0.04	<0.03	<0.03	0.05	0.03	<0.03	0.04	<0.03	<0.03
Potassium	mg/L	15.70	13.60	17.30	15.50	13.10	15.50	14.00	10.80	13.70
Nitrate	mg/L	4.86	9.76	10.70	0.47	<0.04	<0.04	<0.04	<0.04	<0.04
Ammonium	mg/L	<0.05	0.11	<0.01	0.05	0.50	0.08	0.38	0.78	0.63
Dissolved O_2	% sat.	NT	35.80	18.90	NT	37.30	16.20	NT	20.40	11.70
	mg/L	NT	4.80	2.3.00	NT	5.10	1.90	NT	2.90	1.40
Total Coli.	CFU/100mL	58.00	140.00	19.00	4.00	19.00	120.00	35.00	26.00	140.00
Fecal Coli.	CFU/100mL	<1.00	<1.00	<1.00	<1.00	1.00	<1.00	<1.00	<1.00	<1.00

Sample		Location 5			
Location	units	5/H	5/L		
Tip Depth	m	1.5	5.9		
Surface Elevation	m	740.16	740.16		
Tip Elevation	m	738.7	734.3		
Sample Date		**29/05/00**	**14/02/99**	**10/05/99**	**29/05/00**
pH		7.12	7.04	7.23	7.29
EC	mS/cm	5.57	5.79	6.14	9.19
TDS	mg/L	5270.00	3706.00	5340.00	8970.00
Chloride	mg/L	11.20	5.60	8.60	44.90
Phosphorus	mg/L	<0.03	0.05	<0.03	0.06
Potassium	mg/L	16.80	18.90	14.70	38.50
Nitrate - N	mg/L	<0.04	<0.02	<0.04	0.22
Ammonium - N	mg/L	0.68	0.42	0.65	0.18
Dissolved O_2	% saturation	17.10	NT	26.50	15.50
Dissolved O_2	mg/L	2.00	NT	3.40	1.90
Total Coliforms	CFU/100mL	110.00	35.00	130.00	1000.00
Fecal Coliforms	CFU/100mL	<1.00	<1.00	<1.00	<10.00

9.0 Synthesis

9.1 Study Summary

Given the outdated construction techniques, poor maintenance and poor siting of the EMS ponds investigated in this study, there seems to be remarkably little seepage. However, results for Site 1 indicate that seepage can be a concern where EMS ponds are constructed into coarse soils. This is consistent with the literature reviewed prior to the commencement of the study (Collins et al., 1975; Miller et. al., 1976; Sewell, 1978; Ciravolo et al., 1979; Ritter et al., 1980; Phillips and Culley, 1983; Culley and Phillips, 1989a,b; Westerman and Huffman, 1993; Korom and Jeppson, 1994; Betcher, et al., 1996). Therefore, siting EMS ponds where such soils exist should be strongly discouraged unless seepage mitigation under the supervision of a qualified professional is implemented.

The evidence of seepage and contaminant movement found at Site 5 indicates that seepage may also be a concern in glacial clay till soils under some circumstances. Although, no major contaminant plume was detected at this site, seepage appeared to be occurring through preferential flow paths related to sand fissures, tree roots and the soil-bedrock interface layer. In fact, all of the EMS ponds constructed in glacial till soils investigated in this study showed some evidence of seepage into the permeable subsurface soil anomalies common to glacial deposits. Fonstad and Maule (1996) studied EMS ponds in similar geologic settings in Saskatchewan. They also found that seepage can occur into the coarse textured materials layers and lenses commonly found within these materials.

Although seepage may occur into these subsurface coarse material anomalies, no evidence has been found to suggest that a major contaminant plume will develop due to seepage movement via these preferential flow paths. Contaminant plume development due to seepage into permeable soil anomalies is likely limited by their extent and continuity. Typically, these features are confined within unsaturated materials of very low permeability that restrict flow and attenuating contaminant movement away from the more permeable solute laden anomalies. These factors appear to be preventing a serious threat to groundwater from the EMS ponds studied in this investigation. However, where stringers of coarse material are large and contiguous, a threat to groundwater could develop. Evidence that seepage can occur into these soil anomalies and the inability to thoroughly characterize the nature of the subsurface suggests that some level of artificial seepage protection is prudent where EMS ponds are constructed in glacial till soils.

Seepage from the EMS ponds investigated in this study occurred due to poor construction of the berms. Improper compaction of berm material gave rise to solute movement at all sites where boreholes were placed into the berms (Sites 2, 3, 5, and 8). Buried topsoil was found under the berms at three of the sites (Site 2, 3 and 8) and seepage occurred into this layer from the EMS ponds, illustrating the need for improved techniques and quality control for EMS construction.

The release of manure solutes through the preferential pathways that developed due to tree root growth into the berm at Site 5 illustrates the need for vigilant maintenance of these structures. Trees will naturally exhibit a hydrophilic response when grown near a high nutrient water source such as a reservoir of liquid animal manure. Therefore EMS berms must be kept free of woody plants to avoid seepage through root paths such as those found at this site. Other maintenance procedures, such as inspection of berms and liners for signs of deterioration from agitation and pumping equipment or burrowing animals, should also be given careful attention.

The seepage that was evident along the layer of weathered bedrock at the soil-bedrock interface at Site 5 demonstrates the dangers of placing EMS structures on or near bedrock. Seepage from this EMS into the underlying bedrock is limited by its over consolidated and cemented structure. Many of the sandstone bedrock formations in Alberta are highly fractured in their upper zone. If this had been the case at this site, much more seepage and contaminant movement would likely have resulted. Therefore, in spite of the lack of evidence of seepage into the bedrock Site 5, it is recommended that a buffer soil layer of some depth be maintained between the floor of an EMS pond and the underlying bedrock.

Identification of the thickness of the soil buffer required between an EMS pond and the bedrock is dependent on site characteristics and the desired level of protection. Barbour (2000) showed that the seepage front from an EMS pond constructed into typical glacial clay till soil materials would reach a depth of between 6 and 10 m within 50 y of commencement of operation, depending on soil properties. The degree of seepage protection desired at any site should depend on the sensitivity of the water source or aquifer being protected. Therefore, it is suggested that the approval authority provide guidelines concerning the degree of protection required for a particular site based on its hydrogeologic characteristics. The designer of the EMS pond should then provide calculations based on the physical properties of the site to prove that the desired level of protection is being met. This allows for realistic levels of protection to be set depending on the sensitivity of the aquifer being protected and some flexibility for the siting and design of EMS ponds.

9.1.1 Manure Seals

The development of a manure seal could act to limit seepage into preferential flow pathways within the subsurface materials below and adjacent to EMS ponds. However, contaminant movement will still occur when the manure seal breaks down. Manure seals have been shown to deteriorate upon exposure to the enviironment due to desiccation (Chang et al., 1974) and freeze-thaw action (Fonstad, 2000) and as the result of the release of entrapped air bubbles below the seal (De Tarr, 1979 and Barrington and Jutras, 1983). The evidence of seepage found in this study suggests that manure seals must indeed be subject to periodic breakdown.

Because many factors affect manure seal integrity, most scientists and engineers do not recommend relying on the manure seal as the sole means of preventing seepage from EMS ponds. Dye et al. (1984) and Wall et al. (1998) concluded that although sealing may be expected in all soils within six months of manure ponding, caution should be used when constructing lagoons in areas with permeable soils, high watertables or fractured bedrock. Dye et al. (1984) suggested that these holding ponds should be constructed in relatively impermeable soils. Fonstad (1996, 2000) and Fonstad and Maule (1996) also cautioned against reliance on manure seals for seepage prevention from EMS ponds. The evidence of EMS pond seepage found in this study lends support to the conclusion that manure seals should not be relied upon as the sole source of seepage protection from EMS ponds.

9.1.2 Hydraulic Considerations

Piezometric measurements were conducted at all sites to determine vertical and horizontal hydraulic gradients. Only Site 3 showed any substantial vertical hydraulic gradient, where hydraulic recharge conditions were apparent upslope of the EMS pond but discharge conditions were seen below it. The discharge conditions below the pond were especially apparent after springmelt recharge. This was determined to be a response to recharge of a coarse fragment formation that was present beneath the EMS and that terminated below the pond. Saturation of the coarse material formation likely created a hydraulic back pressure that was measured in the piezometers near the pond. The hydraulic discharge conditions likely contributed substantially to reducing the seepage potential from the EMS pond at this site. Without upward hydraulic pressure, seepage would have been expected to occur into the underlying coarse materials since they were protected by only about 1.0 m of dense clay till on the floor of the EMS.

Water levels in the piezometer nests installed at the other sites were equal, indicating no vertical movement of the shallow groundwater. Water levels at all the sites except of Site 1 rose to near or within the depth of the EMS pond following the spring snowmelt event. This quick hydraulic response was not expected based on estimated soil permeabilities. The rise in the watertable due the recharge event may indicate fracturing near the surface of the glacial tills at these sites, but may have been the result of limited wetting of the nearly saturated clays.

Many of the EMS sitng standards reviewed suggest a minimum depth to the watertable below the EMS floor (Table 1.1). However, water chemistry results do not indicate that the rise in water levels near the EMS resulted in increase seepage. This leads to the conclusion that seepage was not sensitive to the depth to the watertable at these sites. This may be due to a reduced hydraulic gradient between the EMS pond and the surrounding soils. That is, since the piezometric surface was rising, the hydraulic gradient was upward and therefore toward the EMS pond. This inward gradient would prevent rather than promote seepage from the EMS during groundwater recharge. Saturation may also cause swelling of the clay materials, which could close off soil fractures and slow potential seepage during watertable recession following the recharge event. This would not have been the case at a site with coarse textured soils where high hydraulic conductivity and a change in the hydraulic gradient would have allowed seepage to occur as the watertable receded.

The observation that seepage does not appear sensitive to watertable depth brings into question the common requirement that EMS ponds be located some distance above the seasonal high watertable (Table 1.1). While depth to watertable may be a concern in coarse-textured, high-permeability soils, it is less likely to be a problem in soils with lower conductivity. In fact where EMS ponds are constructed into saturated, low permeability soils pore water pressure could create a neutralizing effect that would actually serve to reduce EMS seepage. Therefore, it is recommended that, rather than specifying a required separation of the EMS floor to the seasonally high watertable, this design specification should be left to the designer and the approval agency involved on a site-specific basis. Hydraulic analysis should be conducted to show that a watertable will not cause seepage concerns where an EMS pond will be constructed near a high watertable. This would involve demonstration that recharge conditions are not present at the site.

9.2 Seepage Indicator Species

9.2.1 Chloride

The high chloride content of liquid animal manure and the negative ionic charge of the chloride ion makes it a good tracer of the movement of manure solute seepage. Huffman and Westerman (1995) and Fonstad and Maule (1996) showed that chloride was an effective seepage indicator species in water and soil samples collected in their studies. Elevated chloride concentrations were found in the soil and water chemistry data at all the sites where seepage was thought to occur in this study as well.

A statistical analysis of chloride concentrations in water data that followed the mixed, nested model:

$$Y_{ijkm} = Site_i + Location\ (Site)_{ij} + Depth\ (Location(Site)_{ijk} + \gamma_{ijkm},$$

was analyzed using the general linear model (PROC GLM) in the SAS statistical analysis system. Where, Y_{ijkm} is the variation in the Cl levels in the soil water as effected by the factors; Site, Location within Site and Depth within Location and Site.

The mean values for chloride varied significantly between Depths within Site and Location but not between Location within Site or between Sites at the 5% confidence interval. A simple pair-wise t-test was conducted to determine which of the concentrations between depth within site and location were actually different. Chloride tended to be higher in water samples from the upper and mid-level piezometers than from those at deeper levels. The shallower observation wells were often placed within coarse material fissures so this result confirms that seepage was occurring into these features and that downward movement from these seepage zones was likely controlled by the confining materials below.

The water sampling dates were taken as uncorrelated, repeated measure data in this analysis, which made the error term larger than it should be since the water quality observations taken at separate dates are not actually independent variables. This may have prevented detection of more subtle variations between site and location within site.

9.2.2 Nitrogen

The nitrate form of nitrogen is the water chemistry parameter of greatest concern re groundwater quality. Concern for this ion in groundwater is based on studies released in 1945 that implicated nitrate (NO_3) for the development of methemoglobinemia (cyanosis or "blue baby"), a condition that blocks oxygen transport in infants (Korom, 1992). Hendry (1988) pointed out that there has been only one documented infant death from cyanosis in the past 20 y but most jurisdictions still set the safe drinking water limit for nitrate nitrogen at 10 mg/L (Korom, 1992). Fonstad (2000) stated that the groundwater supplies of most concern are those in unconfined aquifers below intensive agriculture areas.

Like chloride, nitrate nitrogen varied significantly only between Depths within Site and Location. High nitrate concentrations at Site 8 were attributed to an overflow of the manure pond. The elevated concentrations at Location 6, Site 5 were thought to have been caused by seepage of surface applied manure into the observation well. Poor seal development between the well casing and the bentonite plug may have been a problem since the concentrations had declined to background levels by the second sampling. Nitrate at Location 2, Site 5 was attributed to either downward movement of nitrate-N from the soil surface during spring recharge or nitrification of NH_4-laden seepage waters as the watertable rose into an aerobic soil zone during the recharge event. The NH_4 seepage to that location was caused by preferential flow from the EMS pond along tree root paths. Elevated nitrate levels at Location 3, Site 1 were attributed to seepage from the EMS pond.

Madison and Burnett (1985) claimed that nitrate levels in groundwater >3.0 mg/L are likely of anthropogenic origin. Groundwater samples from two locations (1 and 3) showed concentrations, averaged over the two sampling dates that were above that level, giving further support to the conclusion that seepage is occurring from the EMS pond at that site. A hit above the 3.0 mg/L benchmark was also found at Location 1, Site 3. This is the background well for that site so it is unlikely that this anomaly is related to manure seepage from the EMS pond. All other elevated NO_3 concentrations found at this site have been previously explained.

Soil nitrate, by comparison to other soil chemistry indicator species, was a poor indicator of seepage. This is probably due to chemical reducing conditions found below and beside EMS ponds, where redox potentials in the order of –300 to –600 mV are common (Fonstad, 2000).[1] Appelo and Postma (1996) showed that under neutral pH conditions NH_4 is the most common form of nitrogen found under these redox conditions. The liquid manure in the EMS pond is anaerobic due to the high chemical and biological oxygen demand of the manure. Reducing conditions exist beneath the bottom and side of EMS ponds due to waterlogging from seepage and lack of exposure to the atmosphere. Therefore, there is no source of nitrate nitrogen and no opportunity for ammonium nitrogen to convert to nitrate below an EMS pond. This fact accounts for the scarcity of nitrate found in the soils near the EMS ponds in this study.

Ammonium is the most abundant species of nitrogen in liquid hog manure in an EMS pond (Fonstad and Maule, 1995) and is therefore expected to be the species that would be most likely detected in seepage waters from that source. However, very little indication of this ion was found in the water samples from any site. The statistical analysis (see Cl discussion for model description) showed that variation of this parameter was significant only for Depth within Site and Location. However, even the largest average measurement, at Site 2, Location 2 and Depth 2, was only 0.85 mg/L and the measurements at that location match well numerically with the background ammonium concentrations.

In contrast to NO_3, ammonium in soil samples was a fairly good indicator of seepage. This is related to the concentration of NH_4 within the manure in the EMS pond and the fact that ammonium is a positively charged ion readily adsorbed to clay minerals. The ammonium near the EMS ponds tended to be within or near seepage zones caused either by sand fissures or by poor construction of berms.

9.2.3 Microbiological Indicators

The variation of total coliform count was significant by Location within Site according to the statistical model described above (see chloride). This should signify that this parameter is a good indicator of seepage from an EMS pond since it was the variation between water samples that were taken downslope of the EMS pond compared to those taken from the background observation well. However, only two time-averaged readings taken for this parameter were significantly different.

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[1] Fonstad, T.A., 2000. Personal Communication, Assistant Professor, University of Saskatchewan,

Location 5 at Site 8 had the highest reading for total coliform bacteria recorded in the study and that sample was taken from the background observation well, located up gradient of the EMS pond. Therefore, it is unlikely that this hit was related to EMS pond seepage. The other significantly different hit was at Site 1, Location 2. This hit was attributed to seepage from the EMS pond due to the downslope location of that observation well and the coarse textured soils at that site. One water sample taken at Site 2, Location 5 had a time-averaged total coliform count (196 CFU/100 ml) above the drinking water guideline of 100 CFU/100 ml of water. That sample location was down gradient of the EMS pond but was 74 m away. The elevated bacterial levels were attributed to this observation well being located in a cow pasture. Fitzgerald (2000) also found that total coliforms were a poor indicator of groundwater contamination because of high natural variations of the parameter and the possibility of bacterial contamination of water samples during handling.

Fecal coliforms varied significantly at the 5% confidence level only between site. Not surprisingly the site that had time-averaged fecal coliform counts significantly different than the others was Site 1, where coarse soil conditions with large enough soil pores that would allow easy transport of the bacteria. Other high levels of fecal bacteria were found in water samples from various sample locations and depths but they nearly all occurred during the initial sampling. These fecal coliforms hits were attributed to contamination of the piezometer tip during installation. Vigilance during installation of groundwater wells is required especially in studies where fecal bacteria are used to determine the likelihood of seepage for EMS ponds or other sources. It also points out the need to be aware of the different vectors that could contribute fecal material to the well.

Observation wells were pumped out twice prior to sampling in an attempt to flush the wells of contaminants. This was apparently insufficient. An alternative to simply flushing observation wells with groundwater infiltration is to inject a disinfectant into the well before sampling for fecal bacteria. However, this can lead to long-term sterilization of the well and falsely low readings. Therefore, it is recommended that a

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long-term trend be established for fecal coliform and other microbiological indicators at a site before a determination of the source of the bacteria is attempted.

9.3 EM 31 Survey

Two of the objectives of this study related to the usefulness of soil electrical conductivity readings from an EM 31 site survey for detecting seepage plumes from EMS ponds and for the design of traditional soil and water drilling/sampling investigation. An EM 31 survey was carried out at each of the five sites investigated in this study and colour contour surfaces of EC readings were produced using a kriging technique available for the ARCView GIS software package to determine soil conductivity patterns. These contour surfaces were interpreted to determine if a seepage plume was evident at each site. Where a noticeable plume pattern was evident, the network of soil borings and piezometer nests at each site was patterned to match the suspected plume.

Three of the five sites investigated showed a noticeable plume pattern according to the EMS 31 survey (Sties 2, 3 and 8), while two did not (Sites 1 and 5). The two sites that showed no evidence of seepage according to the EM survey were found to be the sites that had the most severe indications of seepage according to the soil and water samples collected from the site investigation. This clearly indicates that the EM 31 survey was not useful in detecting seepage from EMS ponds. Furthermore, it indicates that the seepage patterns indicated by the EM 31 survey are not useful to design traditional soil and water site investigation programs. In fact, an alternative reason for seepage patterns noted by the EM survey is plausible. At Sites 2 and 3, the supposed seepage pattern was determined to be an indication of soil moisture related to surface and groundwater movement not associated with seepage from the EMS pond. At Site 8 the indicated seepage pattern was the location of a recent manure spill that was not brought to our attention prior to the commencement or completion of the site investigation. At this site, the use of the EM signature to design the soil and water investigation was counter productive as it placed the sample locations within the spill area, making data interpretation difficult due to the confounding influence of manure contaminants from the spill. It also placed the boreholes and observation wells at positions that cross at right angles to the major slope at the site. If the investigation had been carried out using conventional hydrogeologic techniques, perhaps the outcome of the investigation would have been different. This postulation is especially poignant if one considers that one of the largest sand lenses detected at the site was at Location 1 near the downslope end of the EMS pond, where the sample sites would have been placed under conventional methodologies.

At least a partial explanation of why the EM survey was not useful for determining seepage patterns may be found within the statistical analysis performed on the EC values for the water data. The statistical model used for this analysis was the same as the one explained for chloride ions described above. For water sample EC, the variation amongst samples was significant for all factors considered; that is between Sites, Location within Site and Depth within Site and Location. This means that EC is essentially a site-specific parameter that can vary according to the intrinsic soil or bedrock properties or groundwater movement patterns at the site that are not related to EMS pond seepage.

Illustration of this point is shown by considering that the EC of water samples from Site 3 was significantly different than those from Sites 2, 4 and 5, while Site 1 was only different than Site 5. Also, Site 8 had the highest EC levels, which is expected where the glacial till overburden is developed over marine shale, but only samples from Locations 3 and 4 were significantly different from one another within that site. Since these observation wells were located side-by-side downslope of the berm it is questionable whether the difference was related to seepage from the EMS pond. Furthermore, the variation between Depth within Site and Location was highest at Site 8 but was also significant at all other Sites.

Further explanation for the inability for the EM 31 to detect manure seepage from EMS ponds is found by considering the vertical and horizontal spatial variabilities of seepage detected at the glacial till sites. Essentially all the seepage detected at these sites occurred through preferential flow paths. Since the EM 31 provides only a weighted average of the bulk EC of the soil to a depth of about 6 m, it would not be expected to differentiate small variations in salinity caused by minor flow patterns. On the other hand, seepage from the EMS at Site 1 is suspected to be nearly vertical, through the sand into the watertable at about 10 m. Therefore, the EM survey adjacent to the site would not have detected EC differences adjacent to the Site since none would be expected. Furthermore, potential changes in salinity in the perched watertable below the EMS at this Site would not have been detected since that groundwater was at a depths beyond the vertical range of the instrument.

The obvious, but unfortunate, conclusion to this aspect of the study is that the EM 31 is neither useful nor reliable to detect seepage from EMS ponds under the landscape conditions tested in this study. Neither was it useful to assist in the design of the soil and water sampling programs for the detection of seepage from EMS ponds.

9.4 Construction Methods

Storage volumes provided by the EMS ponds in this study appear adequate for the manure produced from each of the operations they are servicing. However, evidence of a fairly major spill at Site 3 shows that either the producer neglected to empty the lagoon at the anticipated time or that larger volumes of liquid entered the EMS pond than expected over the storage period. This EMS pond is located at the bottom of a fairly substantial slope and is constructed more or less in-ground, with aboveground berms only at its downslope end. The producer indicated that the overflow occurred during a period of heavy rains that prevented manure spreading. The inability of the producer to empty the EMS pond in a timely manner due to weather conditions, combined with the addition of some extra influent from local runoff, likely created the conditions for EMS pond overflow. This points out the need for a runoff diversion plan, adequate freeboard to account for emergency situations and diligent management of an EMS pond.

The construction methods used at all the sites were similar, in that none of the EMS ponds were 'engineered' to any extent and none were lined. Three of the five were constructed with a bulldozer and scraper while one was built with a bulldozer only and one was built with a large backhoe. Two of the three sites built with a bulldozer and scraper were found to leak but seepage was not directly related to construction method. Rather, seepage at all sites was related to poor site conditions, the lack of engineering input and poor construction practices. Site problems are related to the soil and geological characteristics. The lack of engineering input resulted in the owner and the construction contractor not having an adequate knowledge of site conditions or proper construction practices being used. Poor construction practices resulted in poor compaction of the berm at all sites and topsoil being left under the berm at three of the five sites. These two factors resulted in minor seepage at two of the sites investigated. Engineering input and construction supervision would have resulted in better construction and less seepage from those two EMS ponds. Engineering input prior to construction at each site would likely have resulted in the recommendation that the EMS ponds be lined with a compacted clay liner. A liner may have been unnecessary at the other three sites, according to the data collected in this study. However, a liner would have prevented seepage from occurring at Site 5 and would have prevented or minimized seepage at Site 1.

The results of this study indicate that better construction practices for EMS pond construction would improve the security of these facilities. It is recommended that on-site construction supervision and engineering certification should be required to obtain a permit for EMS construction.

9.5 Site Characterization

9.5.1 Background Resource Data

One of the objectives of this study was to evaluate the reliability of remote resource data to evaluate site characteristics for the planning of EMS ponds. Each site was characterized using available data such as surficial (Quaternary) geology maps, soil survey data, water well reports, hydrogeology maps and cross-sections, air photos and topographic maps. Each piece of data, in combination with airphoto interpretation, was useful in determining the overall characteristics and geomorphology of the area surrounding the site. However, the data from each individual source was not particularly reliable in identifying the soil and hydrogeological characteristics at a specific site. This is expected, since the resource data are not intended to be used for site-specific identification, rather they are most useful for regional scale planning or as a framework to provide an idea of what to expect during the site-specific investigation[2].

Only at Site 1 did field investigation results match closely with the site characteristics expected from review of the existing remote data sources. That is, the surficial geology, soil survey and water well records all agreed that the soils at this site should have been deep silty sand and this is what was found in the field investigation. At the other sites, at least one of the remote data sources was contradictory to the others. Furthermore, while the data from the site-specific investigation usually closely resembled the site characteristics expected from review of the remote resource data, surprises invariably arose, most likely due to the scale of the available data. Soil survey data are presented at the 1:100,000 scale which means construction from sample points taken approximately every 2.6 km^2 or one sample per section of land. The surficial geology data are available at 1:250,000 scale which means that one data point per approximately 4000 ha or, a density of approximately two data points per township (Mapping Systems Working Group, 1981).

Water well records logs should be considered point data only. There is also a large degree of variability in soil identification skill level amongst drillers and the use of soil identification terminology is not standardized within that industry. Since the often erroneous results within these drill logs can be due to intangible factors, the accuracy of the logs should be viewed with some skepticism. Nonetheless, where water well drilling logs are available in sufficient density near or at a proposed EMS pond, the data are very valuable to characterize the expected texture and depth of overburden materials and the static watertable in the area. Information about the depth to water bearing formations, the nature of the bedrock and expected water yield are also very valuable for planning an EMS pond and the rest of the hog production facility. The data are also invaluable for site characterization when used in tandem with the other remote resource materials, including hydrogeology maps and cross-sections. They give perspective on the bedrock type and structure and the

[2] Tony Brierley, July, 00. Personnel Communication. AAFRD, Edmonton

depth to local water bearing formations. The available remote resource data for hydrogeological information are more useful when used in conjunction with local water well logs. Unfortunately, water well records are often sparse or even unavailable in some of areas.

Because of the variable nature and availability of remote data resources, they cannot be used to conclusively characterize any EMS pond site. Therefore, site-specific data are recommended to confidently characterize the subsurface conditions at any site where an EMS pond is planned.

9.5.2 Site-specific Investigation

Data collection for site characterization for an environmentally sensitive facility, such as a hog manure EMS, is one situation where "more is better". However, it is often cost prohibitive to collect the amount of site characterization data necessary to understand the complex lithology often present within glacial landscapes. This study and others, investigating seepage and from EMS ponds on the Canadian prairies have shown that fractures, fissures and stringers of coarse material provide pathways for contaminant movement. The variability in thickness, extent and continuity of these features are difficult if not impossible to quantify within the constraints of a reasonable and cost effective site investigation.

Design, construction and regulatory requirements from the different states and provinces with similar geologic and climatic characteristics as Alberta identified the site investigation criteria used in other jurisdictions. The jurisdictions that had recommendations for site investigations generally use data from remote resource sources similar to those used in this study, in combination with a minimal site-specific investigation. The number of soil borings required to characterize site by the jurisdictions reviewed ranged between two to six. Most of these jurisdictions reserve the right to ask for more than the minimum data required within their codes or regulations. Fonstad (1996b) recommended that a minimum of five boreholes be drilled for an EMS site investigation, with one borehole each at the midpoint and near the outer edge of each side and one in the center of the proposed EMS pond location.

At least one reference suggested that backhoe pits provide a better opportunity to examine the soils and are more likely to identify the small but important areas of permeable soil that were shown in this study to cause seepage from EMS ponds (USDA-SCS, 1993). Farmers often prefer test pits to drilling investigations due to the ready availability and low cost of equipment necessary to conduct these investigations. Unfortunately the depth of soil pit investigations is limited to about 3 – 5 m depending on the equipment used. The maximum depth of boreholes used in this study was 10 m but most of the test holes were to a depth of 7.6 m or less. The 10-m deep probes did not appear to reveal much more about the site than did the 7.6-m boreholes. However, Fonstad (2000) suggested that the investigation should be conducted to at least 10 m below the proposed elevation of the floor of the EMS pond.

The results from this study, in combination with the above considerations, lead to the conclusion that four to five investigative boreholes are sufficient to characterize site conditions. At least one borehole should probe to a depth of 10 m below the proposed elevation of the floor of the EMS pond. Test pits may be useful for preliminary investigation of a prospective site and to identify structural anomalies in the soils. However, once a site is selected with some confidence, a proper engineering site investigation should be conducted to determine soil lithologies and properties.

9.5.3 Soil Properties

Field soil logs should be kept from all site investigations for EMS ponds. These field logs provide invaluable information about soil profile lithologies and structure. In addition to visual inspection of the soils as they are extracted from the ground, hand evaluations of soil moisture and texture are often invaluable. In this study the field logs were often useful to identify the locations of small sand fissures that were not apparent in the laboratory analysis results. Because of the value of the field logs, using an experienced drill crew for the EMS site investigation is highly recommended.

Early attempts in this study to obtain soil hydraulic conductivity values proved futile. Hydraulic conductivity tests using disturbed samples gave inconsistent and unreliable results. Attempts to obtain undisturbed soil cores for bulk density and hydraulic conductivity analysis also met with failure. Soil cores of moist clay materials tended to be compressed, while cores of coarse materials tended to fracture. In both cases, the soil cores were unrepresentative of actual soil conditions and so were useless for evaluation of soil density and hydraulic properties. Considering the high cost of these tests, they are not generally recommended.

There are two potential alternatives to laboratory testing to determine soil permeabilities. The most reliable of these is field testing using piezometer slug tests or simple auger hole methods. These methods are limited by the availability of shallow groundwater unless more sophisticated pump in methods are used. However, time and expense may also limit use of these tests. The other alternative for determination of soil hydraulic conductivity is the use of book values or computer models. Both of these methods are based on correlation of soil texture, density, porosity, plasticity and other properties to evaluate a range of soil permeability. Due to the difficulty and expense involved in obtaining site-specific soil permeabilities, this is a commonly used practice in the industry.

Laboratory analysis of properties such as texture (i.e., sand, silt and clay faction analysis), bulk density and plastic limits are useful to develop a classification of the soil materials at an EMS site. These data can be used to determine an estimated soil hydraulic conductivity, as discussed above. Hydraulic conductivity values in combination with soil porosity are useful to estimate travel times of seepage to points of interest such as an underlying aquifer or fractured bedrock or a down-gradient surface water body. Soil texture and plastic limits are needed to evaluate the utility of the soil as a cohesive soil liner or a secure above-ground berm from the materials excavated from the EMS pond. The cost of these laboratory tests is generally not prohibitive for most modern hog operation developers.

9.5.4 Hydrogeological Parameters

In addition to soil properties, the site investigations in this study identified the depth to the watertable and character of the underlying bedrock. These data were useful to help characterize the site and to determine if there was an immediate risk of contamination of local groundwater. The vertical and horizontal hydraulic gradients were also determined at each site. Hydraulic gradient determination was useful for estimation of vertical and horizontal seepage rates. Estimates of vertical seepage rates are necessary to determine travel times to underlying bedrock or aquifers. The depth and expected yield of potential water-bearing formations below and adjacent to the EMS pond were also determined. These data were useful to determine critical travel distances aquifers to give meaning to seepage rate determinations. Aquifer yield data are also useful to determine if an adequate water supply is available for the planned hog operation. If water supply rates were inadequate to sustain the operation, it should not be built, in which case an EMS pond site investigation would be redundant.

Measurement or estimation of hydrogeological parameters is critical to the evaluation of EMS pond performance. Therefore, it is recommended that these parameters should be determined to evaluate the security of a planned EMS pond development.

9.5.5 Summary

Site characterization is critical to the evaluation of the security of an EMS pond at a particular location. Remote data resources should be identified and documented to provide a framework for what to expect during the site-specific investigation. A site-specific investigation is necessary because the remote data resources are not reliable at the scale necessary to assess the security of an EMS pond. Use of remote resource data in tandem with site-specific data allows visualization of the site in perspective of its surroundings.

The benefits of proper site-specific investigation for the characterization of EMS ponds are:

- Improved environmental security and reduced future environmental liability,
- Enhanced probability of community acceptance of the proposed operation due to improved confidence of neighboring residents,
- Improved probability of acceptance by regulatory and approvals agencies and
- Peace of mind for the future success of the operation.

In all cases, a qualified professional should conduct the site investigation. The intensity of any detailed site investigation is the responsibility of the designer and the responsible permitting or approval agency.

9.6 EMS Design

In this study most of the sites that were constructed in glacial tills also showed signs of seepage and contaminant movement through the sand fissures discovered during the field investigation. No signs of major seepage plumes were found where EMS ponds were situated in deep glacial till soils. Fonstad and Maule (1996) showed that, of the four EMS sites situated in deep glacial till soils that they investigated, only the one that had a minimal compacted clay liner did not show signs of seepage.

Fonstad (2000) recommended that EMS ponds should only be used where secure site conditions prevail and concluded that compacted clay liners subjected to freeze-thaw action will not prevent seepage from manure seepage constructed over granular soils. He suggested that proper siting and engineering design will reduce the potential for seepage from EMS ponds to impact groundwater quality and recommends that siting characterization investigations should be conducted to a depth of at least 10 m below the proposed bottom elevation of an EMS.

This study also shows that proper engineering design and construction supervision would improve the security of properly sited EMS ponds. The evidence demonstrates that poor construction practices such as burying topsoil beneath berms, poor compaction of berms and building EMS ponds in glacial till soils without the benefit of a liner can lead to detrimental effects on the surrounding subsurface environment. Reliance on manure seals to prevent seepage is not recommended under any circumstance. However, it is felt that EMS ponds are a safe storage option if a conscientious effort is made in siting design and construction quality control when developing earthen manure storage.

9.7 EMS Abandonment

Although this study did not address the issue of EMS pond abandonment directly, some observations on the topic are warranted. Culley and Philips (1989) and Fonstad and Maule (1996) showed evidence that a massive bulb of ammonium nitrogen accumulates below and adjacent to EMS structures throughout their life span. Fonstad and Maule (1996) showed evidence that this NH_4 is nitrified during periods of EMS abandonment due to oxidizing conditions that develop when the side slopes and floor of the EMS are exposed to the atmosphere. Miller et al. (1976, 1985), Culley and Philips (1989) and Fonstad and Maule (1996) all suggested that oxidation of the ammonium built up under manure storage structures could present a serious threat to groundwater following abandonment.

Therefore, it is recommended that further research be conducted to determine the best method of EMS site abandonment to avoid the risks associated with oxidation of the NH_4-N and subsequent transport of nitrate nitrogen to groundwater.

10.0 Conclusions and Recommendations

10.1 General Study Conclusions

This is the first intensive environmental security survey of EMS ponds conducted in Alberta. Therefore no protocols on which to model the study on existed, so the investigation methods were iterated throughout the study as the data revealed new aspects that needed to be considered when investigation these structures. One of the key products that came out of this study was the development of a protocol for EMS seepage site investigation. The study also identified key questions not answered by the results of this initial investigation. This suggests the need for further study and continued development of investigation protocol.

Considering the age, outdated construction techniques, poor maintenance and poor site choices made, there was remarkably little seepage occurring from these EMS ponds. Some seepage and contaminant movement was found at every site. The highest level of seepage and contaminant movement was at Site 1, where poor soil and site conditions allowed seepage to occur. Although the level of seepage was cause for concern, there was far less evidence of contaminant movement than was expected considering the site conditions. Manure sealing (soil clogging) may have minimized seepage from this EMS pond to some degree. Unsaturated soil conditions are also likely reducing seepage rates from this EMS pond. Regardless of the mechanisms that may mitigate from this EMS pond, it is clear that unlined EMS ponds should not be located in areas of coarse soils. Furthermore, where an EMS pond is planned in such vulnerable areas, a complete engineering investigation and design must be carried out. A seepage analysis designed to predict seepage travel times and potential hydrogeologic impacts of the EMS pond should also be conducted as part of the design calculations. Finally, quality control at the construction stage is imperative to ensure that the facility functions as designed and the EMS pond must be vigilantly maintained to guarantee its continued performance.

Most of the seepage at the other sites was occurring through preferential soil flow paths. Preferential flow paths discovered in this study were:

- horizontal sand fissures and lenses within layered glacial tills,

- vertical and horizontal weathering fractures in the upper till zones,
- pathways caused by the growth of tree roots into the berm and sidewalls of an EMS pond or
- a till-bedrock interface layer where the EMS pond was placed directly on top of the bedrock.

However, seepage into these preferential flow pathways appeared to remain localized due to confinement within the more general soil matrix.

All the seepage problems could have been prevented with the use of better siting, design and construction methods and would most likely have been identified under the site characterization protocols used today. The combined use of background resource data with a minimal site-specific investigation appears adequate to characterize and determine the potential problems presented by a proposed EMS site. The required intensity of a site investigation should be determined by the designer (engineer), the approval authority and the owner. Realistic expectations regarding environmental protection need to be developed on a site-by-site basis. The investigation and design requirements at any site should be tempered by consideration of the degree of natural seepage protection provided by natural site conditions and the value of the resource being protected. A team effort to develop the engineering requirements for the manure storage structure and level of protection required to conserve local natural resources will ensure the development of a safe and effective manure storage facility.

10.1.1 Manure Seals

The literature review suggested that ponded manure causes soils to clog and seal to reduce seepage and contaminant transport from EMS ponds. The lack of evidence of seepage from these EMS ponds investigated in this study indicates that there is likely some mechanism at work here that is mitigating contaminant movement. Perhaps manure seals are forming on the bottoms and sides of these EMS ponds. The literature shows that manure seals can deteriorate from many causes including drying and freeze-thaw desiccation and bursting due to air bubble entrapment and release. The evidence that some seepage is occurring from the EMS ponds investigated in this study suggests that manure seals are not 100% reliable to prevent seepage from EMS ponds. Therefore, It is recommended that manure seals be accepted as secondary seepage protection that provides extra insurance against seepage-related groundwater contamination. This is consistent with the conclusions of others who have studied and reviewed the literature on animal manure EMS pond and lagoon seepage (Dye et al., 1984, Fonstad, 1996a, 2000).

10.1.2 Summary

The following points summarize the conclusions of this study:

- Unlined EMS ponds should not be constructed into sandy soils or other high permeability materials.
- Sand lenses and soil fractures and other subsurface anomalies appear to provide vectors for limited amounts of seepage and contaminant movement from EMS ponds, especially in glacial till soils.
- Because of the inability to completely characterize the subsurface environment and the unknown nature (i.e. thickness, consistency, continuity) of subsurface soil anomalies, EMS ponds in clay tills require an artificial liner to protect against seepage into the fractures and fissures common to these soils.
- Trees should not be grown on berms or in the close proximity of EMS ponds as they can create .
- NH_4 is mobile into sand lenses and other preferential flow pathways where they exist in the soils at the sidewalls of an EMS pond.
- NO_3 contamination of shallow groundwater due to EMS pond seepage appears to be a problem only where the EMS ponds are sited into coarse soil materials.
- NH_4 is attenuated near the perimeter of the floor and sides of the EMS pond by most soils.
- Attenuated NH_4 beneath the floors and sides of EMS ponds may become a problem at the abandonment stage where aerobic conditions are allowed to develop within these soils.

- Movement of pathogenic microorganisms via seepage from EMS ponds in rare but can occur into coarse, highly fractured or layered soils where coarse material lenses are present.
- Site investigation methods have improved, and will continue to improve, the siting of EMS ponds.
- Better site investigations will also improve EMS pond design practices.
- Professional supervision should be required during construction of these facilities to ensure quality control and ensure performance to the designed protection standard.
- Manure seals should not be relied upon to prevent seepage from EMS ponds in Alberta.

10.2 Usefulness of the EM 31 Results

The EM 31 could not reliably detect seepage from EMS ponds. The failure was attributed to the intermittent nature and spatial variability of seepage related to flow through coarse textured lenses and fissures and fractures in the glacial till soils and to vertical seepage patterns at the coarse textured soil site (Site 1). The instrument is also unable to detect salinity with depth, as seepage was found to occur into layered soils with horizontal lenses of coarse material.

The three sites where EM 31 survey results were used to design the investigation program was also where the least amount of seepage was found. Using the guidance of the EM surface contours to design the physical investigation program at one of these sites led to less effective monitoring network than would have been designed using traditional techniques. Therefore, EM 31 surveys are not recommended as a tool for designing traditional soil and water investigation programs for EMS seepage studies.

10.3 Recommendations

10.3.1 Siting, Design and Construction of EMS Ponds

- Background resource data should be used to assist with the site characterization study. These data are useful to identify the physical characteristics of a site and its surroundings and their use can reduce the overall cost of the site investigation.

- A site-specific investigation is necessary to confirm actual site conditions as indicated by the resource data review and to identify subsurface anomalies that would not be evident from the resource data review. The designer and approval authority should determine the intensity of the site investigation required.
- All EMS ponds should be designed by a professional engineer and the level of protection required at a particular site should be addressed within that design. Most EMS ponds, regardless of site characteristics, will require some level of artificial seepage protection.
- A system should be developed to evaluate the vulnerability and value of groundwater resources in Alberta. This information should be used to assess the level of seepage protection required on a project basis.
- The evidence suggests that poor quality construction can result seepage from EMS ponds. Therefore, construction supervision should be mandatory ensure quality construction control and that EMS performance standards are met.
- Evidence of seepage due to tree root pathways in the berm at one study site illustrates the importance of proper maintenance of these structures. Therefore it is recommended that EMS ponds be inspected and maintained regularly.

10.4.2 Recommendations for Further Study

- Continued monitoring of the water quality parameters at these sites over several years would allow observation and evaluation of EMS seepage on long-term water quality trends near EMS ponds. This is highly recommended as the piezometer network is already in place to conduct such a study.
- In additional to continued water quality monitoring of existing sites, it is recommended that additional sites of different size, age and site characteristics be investigated in the future. In conducting these investigations the following is recommended:
    - Limit the number of soil chemistry parameter analysis to the main indicators reviewed in this study.

    - Soil analysis should be expanded to include microbiological indicators to see if manure-related bacteria are moving into the soils near and below EMS ponds.
    - Two to three soil samples should be collected for analysis from each sample interval to allow statistical analysis of soil chemistry data.
    - Samples from below the berms and bottoms of EMS pond should be collected to evaluate downward movement of manure-related solutes.
    - Cores should be collected from the side walls and bottoms of the EMS pond to evaluate the reliability, consistency and permeability of natural field scale manure seals.
- Though cation movement was not discussed to any degree of detail in this report, soil cation concentrations were measured and tabulated. A cursory analysis indicated that some evidence of unusual soil cation movement was occurring at some of the study sites. This seemed to suggest that cation movement might be useful as an early indicator of seepage plume development. Fonstad (2000)[1] observed similar trends in the data he collected and he is now developing a theory that suggests that high concentrations of NH_4 in the soils in the near subsurface soils below and adjacent to an EMS may be displacing Ca, Na, Mg and K ions from the exchange sites within those soils. The theory has a solid analytical basis since ammonium acetate is used to displace cations from soils to analyze for soil cation exchange capacities (CEC) (McKeague, 1978). Further research is recommended to test this theory. If it is shown to be true, soil or water cation flushes may be useful as an early warning detection indicator for seepage from EMS ponds.

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[1] Fonstad, March 2000. Personal Communication, University of Saskatchewan, Saskatoon, SK

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