Studies of Seepage Beneath Earthen Manure Storages and Cattle Pens in Manitoba

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Overview

Over the past four years, research has been undertaken in Manitoba by the provincial Department of Conservation and the University of Manitoba to examine the potential for impacts on groundwater quality from seepage beneath earthen manure storages and seasonal cattle pens. In this report we present some of the results of these studies and discuss the potential for groundwater quality impacts from these facilities.

While the paper has been divided into two separate discussions, the theme of each part is very similar – an examination of the rates and concentrations of downward seepage of contaminants beneath areas where manure is concentrated for lengthy periods of time. Both parts of this report also focus on contaminant movement in areas underlain by clays and glacial tills, materials with relatively low permeability that are generally considered to provide good protection for underlying aquifers.

I. Seepage Beneath Earthen Manure Storages

Introduction

There has been a dramatic increase in hog production in North America in recent years. In the last five years the industry has experienced 100% growth in Manitoba, and this trend of rapid expansion is expected to continue. In 1997, over three million hogs were raised in the Province, and sold for an estimated $1.25 billion (Manitoba Pork Council, 2001).

Earthen manure storage structures are commonly used in Manitoba to hold liquid hog manure. The primary advantages of earthen storages are their low cost relative to above-ground facilities and the flexibility to design and construct earthen storages to match the needs of the livestock operation. A potential disadvantage is that earthen storages will “leak” unless they are lined with an impermeable membrane. If a storage is underlain by an aquifer, leakage may result in contamination of groundwater.

In 1998, the Livestock Manure and Mortalities Management Regulation (Manitoba Regulation 42/98) was proclaimed as part of Manitoba’s Environment Act (Rentz and Parsons, 1999), in part to establish design criteria for animal manure storage structures. The regulation recognizes the potential risk that the waste contained in these structures poses to surface and groundwater supplies, and makes provisions to protect these supplies by setting out construction and siting requirements. However, there is currently a lack of case studies regarding the rates of seepage in the clays and tills common to much of Agro-Manitoba. Therefore, it is necessary to investigate current sites so that sound design criteria, based on documented case studies and experience, can be established for the future.

Co-operative studies are currently being undertaken in Manitoba by the Department of Civil and Geological Engineering at the University of Manitoba and the Water Branch of Manitoba

Conservation to examine rates of seepage from earthen storages constructed in glaciolacustrine clays and glacial tills in the province. This program involves the collection of cores from active and abandoned storages, analysis of the cores to define nutrient and dissolved salt contaminant profiles with depth, and modeling the field results to determine rates of fluid and contaminant flux from the storages and the potential for groundwater quality impacts. To date, cores have been collected from nine sites. In this paper we present the results from two sites – one located in glaciolacustrine clays and the other located in glacial tills.

Previous Work

Studies of seepage from earthen manure storages have been extensively reported in the literature. The approaches to these studies have, however, been quite varied. A number of researchers have chosen to examine lateral seepage from earthen storages constructed in sandy materials (Sewell et al., 1975; Ritter et al., 1980; Feng et al., 1992; Westerman et al., 1993). Results from these studies have been varied with some storages showing significant rates of seepage while others appear to have had an initial rapid rate of fluid loss that reduced quickly with time. The reports of "self-sealing" of storages constructed in sandy materials have lead to a number of studies of the self-sealing mechanism and its effectiveness in reducing seepage rates (Lo, 1978; Barrington Thauvette, 1985; Fonstad and Maule, 1995).

Other authors have chosen to examine lateral seepage from earthen storages constructed in clay-rich sediments (MacMillan and Llewellyn, personal communication, 2000) or vertical seepage beneath these facilities (Fonstad and Maule, 1995; McMillan, 2000). In general, lateral seepage rates from earthen storages constructed in clay or clay loam materials have been found to be quite small. Vertical seepage rates, while typically only centimeters to a few tens of centimeters per year in these materials, may however provide a source of concern for those areas where the tills or clays overlie an aquifer at a relatively shallow depth. Modeling studies have recently been undertaken to examine the potential for groundwater impacts due to long-term seepage from earthen storages or continued downward movement of contaminants long after the storage has been abandoned (GEONET Consulting Ltd., 2000)

Methods

At each site, samples of subsurface materials were collected from a single core hole located within the earthen storage and from a background hole located 50-100 m from the storage. The holes within the storages were sited to be inside the side slopes of the berms while the background holes were sited in areas with no history of fertilizer application and far enough removed from the storages to be beyond any seepage influences. Piezometer nests were completed in each background hole to provide information on depth to water table, vertical hydraulic gradient and hydraulic conductivity of sub-soil materials at each site.

Soil sampling was generally performed with a track-mounted auger rig using hollow stem drilling techniques. Continuous cores were collected in split spoons to a final depth. Cores were logged then partitioned into sub-samples, which were individually bagged and stored in a cooler in the field. The core collected from the storage base at the Interlake site was collected by hand with a hand auger. Samples were returned to the University of Manitoba the same day and stored in a refrigerator until submitted to the lab for analysis.

All samples were analyzed for moisture content, and nitrate + nitrite, chloride and ammonium using saturated paste or 1:2 dilutions on dried and ground sub-samples. Most samples were also analyzed for potassium, phosphate and sulphate. Cation exchange capacities and grain size distributions were determined on selected samples representative of the materials encountered in each hole. At several test hole locations a single Shelby tube sample was also collected for hydraulic conductivity analysis in the lab. The results of nitrate + nitrite, chloride, ammonium and phosphate analysis will be discussed.

Results and Discussion

The results for two of the sites where testing has been conducted will be discussed in this section. The first site is located on glacial till in the Interlake area (Interlake) and the second is located on glaciolacustrine clays southeast of Winnipeg (TS).

Interlake

This hog operation is a 4000-sow farrow-only barn that began operating in the spring of 1994. Liquid manure from the barn is stored in an earthen primary cell and two secondary cells. Based on the water well log installed for the barn, the geology at the site consists of 34 m of glacial till overlying a bedrock of limestone and dolostone, which forms a regional aquifer. The piezometric surface in the aquifer was 11 m below ground surface when the water well was drilled. In late October of 1998, a core was collected to a depth of 1.5 m from the northeast corner of the first secondary cell. The core was collected by driving Shelby tubes by hand and removing the tubes with a jack. The background hole was drilled in the fall of 2000. Material descriptions from the background and earthen storage holes drilled at the site indicate a silt till extending to the depth of exploration. The average silt content is 46% by weight and the average clay content 43% by weight. The till transitions abruptly from light yellowish brown to light grey at 6 m below ground surface.

Results for ammonium, nitrate + nitrite, chloride, and phosphate in core samples are shown in Figure 1 for the background hole and in Figure 2 for the hole drilled in the storage. Background ammonium concentrations show a sharp increase at depths above 2 m, from an average of 2 mg/kg to over 7 mg/kg. This change in concentration does not correspond to a change in material type, or oxidation state. The reasons for the apparent change in ammonium concentrations are currently being investigated. Background nitrate + nitrite shows initial concentrations of over 1 mg/kg at the top of the profile, but drops quickly to values of 1 mg/kg or less. The background phosphate profile has an initial value of 15.5 mg/kg, near ground surface, and drops down to 6.2 mg/kg at depths greater than 0.075 m. Background chloride concentrations are scattered along the profile from values under 10 mg/kg to values of 15 mg/kg. One anomalous value of 21 mg/kg occurs at a depth of just over 2.5 m, and corresponds to the discussed increase in ammonium concentration that occurs at this depth. Unlike the ammonium profile, the chloride profile returns to lower values at depths over 2.5 meters.

After approximately 4.7 years of storage operation, ammonium has migrated to a depth of 0.6 m below the base of the storage (Figure 2). There is some evidence of minor nitrification having occurred either in the storage, or at the interface between the stored liquid and the soil surface, as the nitrate + nitrite concentrations are elevated at the top of the profile. Phosphate concentrations vary from 1 to 5 mg/kg below the base of the storage, and are consistent with naturally occurring background concentrations. Chloride concentrations beneath the storage generally decrease down the profile but exceed background values at all depths, indicating that seepage of this contaminant is occurring from the storage structure to depths over 1.5 m below the base of the storage. Lower chloride concentrations occur in the first 0.2 m of the profile, and may indicate a variable-in-time source loading into the system.

TS

In March 2000, a core was collected from the secondary cell of the earthen storage for this barn, established in 1980. Based on the water well log for the barn, the geology at the site consists of 10 m of glaciolacustrine clay overlying 20 m of interbedded glacial till and sand. A bedrock of limestone and dolostone forms a regional aquifer throughout the area. The piezometric surface in the aquifer was 3 m below ground surface when the water well was drilled. Cores from the background and earthen storage boreholes drilled at the site show a glaciolacustrine clay transitioning to glacial till at 10 m below ground surface. Based on laboratory analyses, the clay unit consists of an average of 56% clay by weight, and 31% silt by weight. The sand fraction was found to be 9% by weight. The clay transitions from brown to grey at 5 m below ground surface.

Results for ammonium, nitrate + nitrite, chloride, and phosphate in core samples are shown in Figure 3 for the background hole and in Figure 4 for the hole drilled in the storage. Background chloride ion concentrations increase in a linear fashion with depth along the 10 m sample core, and values trend from over 30 mg/kg near the top of the profile to over 600 mg/kg near the bottom of the profile. Background ammonium concentrations trend from an average value of under 8 mg/kg at depths of up to 6 m, to values over 16 mg/kg at depths over 6 m. Background nitrate + nitrite concentrations exceed 2 mg/kg in the first 1.5 m of the profile, but decrease to values of 1 mg/kg or less to the final sampling depth. Background phosphate concentrations are 12.4 mg/kg at the top of the profile and generally decrease to values of 3.1 mg/kg at depths greater than 0.8 m below ground surface. A drop in concentrations of chloride and ammonium at depths greater than 10 meters below ground correspond with the transition from clay to till.

The TS observed seepage profiles are the result of 20 years of storage operation. Ammonium concentrations are elevated to a depth of approximately 1 m below the storage, the highest concentration of 600 mg/kg occurring just under the storage base. Nitrate + nitrite concentrations vary from between 1 mg/kg and 4 mg/kg under the storage base. The process of nitrification is not occurring within the soil profile as indicated by the constant nitrate + nitrite profile. Phosphate concentrations beneath the storage appear to represent only background levels, and may indicate that phosphorus movement is inhibited in clay-rich sub-soils. Chloride concentrations beneath the TS storage vary from 130 to 420 mg/kg, with the lowest concentration occurring at the bottom of the profile. At some depths below ground surface, chloride concentrations within the background core actually exceed total chloride concentrations from the storage hole, making it difficult to determine the extent of chloride seepage. As with the background core, there is a decrease in the concentrations of chloride and ammonium at the bottom of the profile, corresponding with a transition from clay to till. Similar to the Interlake total seepage profile, lower chloride concentrations exist in the upper 0.3-0.4 m of the profile, and are likely caused by a variable source loading.

Contaminant transport modeling and potential water quality impacts

Due to the conservative nature of the chloride ion, the seepage of this contaminant can be used to determine a conservative, or worst case, contaminant migration rate. To facilitate modeling, background chloride concentrations were removed from the total chloride profile. In the case of the Interlake site, the average background concentration was subtracted from the total contaminant concentration value for each recorded depth. This approach seemed reasonable in light of the near constant background chloride concentration with depth. For the TS site, a linear trend line was fit to the background chloride concentration data and the background value predicted by this line was subtracted from the total chloride concentration value for the particular recorded depth. Where background concentrations exceeded total concentrations in the TS profiles, the resulting negative value was taken as a zero concentration at that particular depth. The differences between the background hole chloride concentrations and the storage hole chloride concentrations are currently being investigated, and as such, modeling results for the TS site are still considered preliminary. These concentrations were then converted from mg/kg of dry soil to mg/L of pore water. Parameters required for modeling were estimated from literature published values for the tills and clays of Manitoba, GWDrill well logs for the site location, and assumptions regarding site conditions.

The analytical solution to the one-dimensional advection-dispersion equation (Ogata and Banks, 1961) was used to predict vertical chloride seepage beneath the two storages. Model predicted versus actual observed chloride concentrations along the sample core are provided in Figures 5 and 6, for the Interlake and TS sites respectively. A constant source input was used to achieve the best-fit results shown in the figures. For the Interlake site, the input concentration used was 550 mg/L, while a value of 1000 mg/L was used for the TS site. Both values are considered reasonable based on an observed range of 100-1000 mg/L of chloride contained in stored hog wastes. The square correlation coefficient (R^2) was used to evaluate the "fit" obtained between the model predicted and observed chloride concentrations. A perfect fit between predicted and observed would result in an R^2 value of 1. The R^2 value between predicted and observed chloride concentrations at the Interlake site is 0.4. The lower chloride concentrations in the upper 20 cm of the profile contribute to this relatively poor fit, and if these three outlying values are omitted, the resulting R^2 is 0.9, considered to indicate good correlation between the predicted and observed data. The model is considered to be representative of the extent of conservative contaminant movement at the Interlake site. For the TS simulation, the R^2 value between predicted and observed chloride concentrations is 0.82, which is considered to be indicative of good correlation between the two data sets. One outlying value occurs at a depth of just over 7 meters, and if removed the R^2 value is 0.9. Again, the model chosen provides a reasonable representation of the extent of conservative contaminant movement at the TS site. Bulk transport rates estimated from the models are 0.18 meters/year through the underlying till at the Interlake site, and 0.05 meters/year through the underlying clay at the TS site.

Using conservative bulk transport rates, it is possible to estimate the worst-case time for elevated contaminant concentrations to reach underlying aquifers. Based on these bulk transport rates, contaminants would be expected to enter the carbonate aquifer beneath the Interlake site in 183 years, while at the TS site, contaminants would be expected to reach the underlying carbonate aquifer in 600 years.

Conclusions

Seepage of ammonium is occurring at both the Interlake and TS sites, however at the time of sample core removal, the process of nitrification that ultimately converts ammonium to nitrate did not appear to be occurring to any appreciable extent. At both sites, there was no evidence of phosphate transport through the underlying materials. Conservative transport of chloride is evident at both sites, and based on the prelimary modeling results, contaminant transport through the till overburden material is more rapid than that occurring through clay.

II. Seepage Beneath Seasonal Cattle Pens

Introduction

Raising cattle is a major industry in Manitoba, with beef cattle production currently estimated at 550,000 head per year distributed among 12,000 producers (Petra Loro, Manitoba Agriculture and Food, personal communication, 2001). While cattle are raised under feedlot conditions in some parts of the prairies of Canada, in Manitoba much of the beef cattle industry consists of range grazing in the warmer months of the year and confinement of the cattle to pens with shelters during the winter. Over the winter period it is typical that a straw/manure pack will be built up in the confinement area. This manure pack is generally removed during the summer months and stockpiled until it is spread in the fields. Concentration of cattle and manure in these seasonal confinement areas raises a concern of seepage of nutrients and salts, and the potential for impacts on underlying groundwaters.

Studies by Partridge and Racz (1972, 1973) had examined the movement of nitrogen and chloride in the unsaturated and saturated zones beneath a cattle pen located on loamy sands in the Haywood area of Manitoba. However, there has been little work done in the province to examine seepage where pens are located over glacial tills or lacustrine clays. To address this issue, studies have been undertaken by the Manitoba Water Branch in the Interlake and Parklands regions since 1996. In this section of the paper we present results for the Interlake region of the province.

Previous work

Numerous studies of seepage beneath cattle pens and the potential for impacts on underlying groundwater have been reported in the literature. One of the earliest and most extensive studies was by Stewart et al. (1967) who reported on the results of soil sampling beneath 70 corrals in a part of Colorado. They found that the amount of nitrate in the soil beneath corrals varied widely, ranging from near non-detect to more than 5,600 kg/ha to a depth of 6.1 m. The average nitrate concentration with depth beneath corrals was significantly greater than for irrigated fields and cultivated dryland fields in the same area. These authors also reported strong evidence that significant rates of denitrification were occurring beneath cattle pens, both at relatively shallow and at greater depths. In general, little nitrate was thought to reach underlying aquifers found at depths below 6.1 metres.

Partridge and Racz (1972, 1973) also found evidence of significant rates of denitrification in both the saturated and unsaturated zones beneath a confinement area located over loamy sands. They found that seasonal accumulations of nitrates in the shallow sub-soils resulting from mineralization of organic N were rapidly lost through dentrification. Nitrate concentrations in shallow groundwaters were low at distances beyond a few 10’s of metres from the pen.

A number of studies have reported that the development of a compacted organic layer at the interface between the manure pack and underlying soils in active feedlots significantly retards the downward movement of water and contaminants. Sweeten (undated) presented a summary of research on this topic while several Alberta studies have also documented the importance of the development of this “impermeable” layer in minimizing seepage (Bennett, 1975; Kennedy et al., 1995; MacAlpine et al., 1996)

Maule and Fonstad (1999) presented results from test drilling and piezometer installation at four feedlots near Saskatoon. The feedlots were underlain by relatively thin sands and silts overlying clays and tills. Based on modeling of vertical contaminant plumes obtained during the study using an advection-dispersion code, contaminant migration rates were found to be very slow. The rate of movement of chloride plumes was reported to be between 10 and 30 mm/yr with contaminants extending only to 2.2 to 4.9 m depth after 30 years.

Methods

Initial studies in the Interlake area were carried out at a seasonal confinement area near Gunton in 1996. Subsequently, drilling was undertaken at an additional seven sites in 1997 and a further four sites in 2000. Pens ranged in age from about five years to more than 80 years. Drilling was carried out in the late fall or late winter at all sites. Test holes were drilled at one or two locations per site to a depth of 6.1 m or bedrock, whichever occurred first. Drill hole locations were selected to be reasonably representative of general conditions in each pen, although at some sites holes were deliberately located in wet depressional areas. One hole was drilled near Gunton to establish background concentrations for the measured parameters and additional information on background conditions has recently become available from work carried out as part of the earthen manure storage study discussed above.

Soil samples were collected using solid stem augers. The augers were advanced 60 cm then withdrawn from the hole and samples collected from the auger stems at 30 cm intervals. Samples were trimmed, described, sealed in “zip lock” plastic bags and stored in a cooler. The augers were then scraped clean, re-inserted in the hole and advanced a further 60 cm. At most sites a Shelby tube core was collected after completing the solid stem hole. In most cases the sample was collected by advancing the tube below the bottom of the solid stem hole but in some instances a second hole was drilled and the Shelby tube sample collected at a specific horizon of interest based on the initial drilling.

Soil samples were kept cool but not allowed to freeze until submission to the lab, generally within a day or two of collection. All samples were analysed for moisture content, and extractable nitrate, ammonium and chloride using saturated paste or 1:2 soil:liquid methods. Results are reported as mg/kg dry weight except moisture, which is reported as a per cent. All samples from the drilling in 2000 were also analysed for potassium, phosphorus and sulphate throughout their length while samples from other years generally were analysed for phosphorus only through the upper 3 m. Samples at 60 cm intervals collected during the drilling done in 1997 were also submitted to the Isotope Lab at the University of Waterloo for tritium analysis by direct counting on pore waters obtained by toluene extraction.

Shelby tube samples were submitted to the Geotechnical Laboratory at the Department of Civil and Geological Engineering at the University of Manitoba for hydraulic conductivity analysis in a tri-axial cell using ASTM 5084-90. Confining pressures were generally set to match expected confining pressures at the depth of sampling although some experimentation was done to examine the influence of different confining pressures on samples with significant fractures. Samples from each major geological unit in each hole were also analysed for grain size distribution and cation exchange capacity at a commercial laboratory.

Results and Discussion

Glacial tills in the Interlake area are developed over a bedrock of Paleozoic limestones and dolomites with significant input from Precambrian sources to the north and east. Based on grain size analyses, these are silt tills with the silt fraction averaging 40% by weight and the clay fraction 24% by weight. Laboratory hydraulic conductivity values range from 1.2×10^{-6} cm/s to 1.7×10^{-9} cm/s with a mean of approximately 5×10^{-8} cm/s. Examination of undisturbed cores and roadside exposures reveals infrequent visible fracturing. The tills are oxidized to a light brown colour from surface to about 5-6 m then abruptly transition to a light grey.

The two most typical concentration vs depth profiles found during the study are shown in Figures 7 and 8 and will be discussed in detail. Only nitrate, chloride, ammonium, and moisture profiles will be presented in this section of the paper. Chloride and nitrate soils analysis results have been converted to concentrations in mg/L of pore fluid based on reported moisture contents. Since most ammonium is assumed to be sorbed to soil particles, ammonium results are shown as mg/kg dry weight of soil.

Figure 7 shows results from a wintering pen that has been in operation for approximately 21 years. The geology consists of a thin soil zone underlain by till to the depth of drilling. Soil moisture content is very low below the top 60 cm. The profile of chloride concentration with depth is used as an indicator of the depth of penetration of seepage from the overlying cattle pen. Chloride is a conservative contaminant which is found at high concentrations in cattle urine and runoff water from solid manure packs. The chloride profile shows very high chloride concentrations in the shallow subsurface, likely the result of near-surface evaporative concentration, which decline to slightly above the range of background concentrations (approximately 70-100 mg/L) by a depth of 6.1 m, indicating seepage impacts extending to at least this depth in the 21-year history of the site. (It should be mentioned that the apparent very high “background” concentration of chloride in the pore water is much higher than is observed in water samples from piezometers completed into these tills in undeveloped areas. Chloride contents in water samples typically range from 2-20 mg/L. It is suspected that the grinding process during sample preparation may expose fresh surfaces on carbonate fragments in the tills, allowing additional chloride to be brought into solution.)

Ammonium concentrations are elevated above background to a depth of approximately 90 cm then remain near background concentrations to the bottom of the hole. Ammonium is a strongly sorbing cation that will attach to the clay component of the tills, limiting its ability to penetrate deeply into the sub-soils. The sorbed ammonium may undergo seasonal or periodic nitrification when the shallow active layer of the sub-soil dries and becomes aerated. Nitrate concentrations on the other hand are greater than 10 mg/L in the upper 60 cm then decline before increasing again below 2.4 m and remaining relatively constant to the bottom of the hole. The nitrate content of the sub-soils to 6.1 m is approximately 344 kg/ha.

Figure 8 shows the results for a cattle pen that has been used as a wintering area on and off for at least the past 30 years, with annual use since 1986 or 1987. The geology was a uniform silt till overlain by about 30 cm of sand. The till transitioned abruptly to a light grey colour (reduced) at about 5.2 m. Depth to the bedrock aquifer at this site is approximately 9 m. The moisture content of the tills was less than 10% below 90 cm although the depth to water table in piezometers completed into the tills on an adjacent field less than 500 m distance and at a similar elevation was 2.3-3.1 m below ground.

Chloride concentrations are significantly elevated above background throughout the depth of sampling indicating penetration of contaminated seepage waters to at least 6.1 m. The very high readings observed in the upper 1.2 m likely reflect the effects of evaporative concentration. Ammonium concentrations are elevated to approximately 1.2 m then remain near background levels to the bottom of the hole.

The nitrate profile shows some very interesting trends. Nitrate concentrations are initially quite high but collapse to less than 10 mg/L by 1 m. This is followed by an increase in concentration to several hundred milligrams per litre by 2.4 m then a gradual decline to the bottom of the hole. Similar nitrate vs depth trends have been observed at a number of other locations during this study and have also been observed by others (Partridge and Racz, 1972). It is interesting to note that this type of profile was also found beneath a hole drilled in a seasonally flooded depressional area in a pen at a separate site but not in a nearby hole drilled on a better drained part of the pen at this site were a profile similar to Figure 7 was found.

The initial high nitrate concentration in the upper 30-60 cm is likely a result of nitrification of ammonium or organic nitrogen during times when this interval dries out and aerates. At slightly greater depth, where reducing conditions may persist through much of the year due to more stable moisture conditions and the accumulation of organic matter (Partridge and Racz, 1972; McCalla and Elliot, 1971), nitrate in infiltrating soil water will be lost by denitrification. The chloride/nitrate ratio shown on Figure 8 provides support to this assumption, with the ratio increasing significantly through this zone. The subsequent build-up of nitrate from 1.2-2.1 m may reflect a return to oxidizing conditions below the zone of organic accumulation and water retention immediately beneath the pen. Nitrification of ammonium or organic matter that may be seasonally transported through the shallow reduction zone would lead to a gradual increase in nitrate until complete conversion has occurred or the tills become fully saturated. Again, the declining ratio of chloride to nitrate as nitrate increases indicates nitrate gains in the system through this interval, supporting a nitrification explanation for nitrate increase rather than periodic breakthroughs of nitrate from the very shallow subsurface.

The reduction in nitrate concentration below 2.1 m is very interesting. Nitrate concentrations decline rapidly compared to chloride to a depth of about 5.2 m, below which the chloride/nitrate ratio remains constant. This shape of the lower portion of the nitrate plume may result from one or a combination of factors. It may be that the downward mass flux of nitrogen was less in the past. This seems an unlikely explanation however since the shape of this type of nitrate profile with depth is quite similar at many sites of different ages. Alternately, the gradual decline at depth may reflect contaminant transport in a fractured porous medium with advective transport occurring primarily in fractures and diffusion to the matrix. Deeper sampling would show lower concentrations since less time has elapsed for matrix diffusion to occur. The profile of chloride concentration with depth is much more uniform over the interval 2.7-5.2 m however, indicating that this explanation is unlikely.

The most likely explanation for the loss of nitrate below 2.1 m would appear to be that nitrate reduction is occurring in the tills. This is supported by the decline in nitrate concentration beginning at the approximate depth of the water table. Electron donors may include organic matter transported from the surface (although transport depths of more than 4.6 m would seem unlikely in these materials) or sulfides contained in the till matrix (Russell, 1993).

Conclusions and Recommendations

Analysis of nutrient and salt concentrations in soils and pore waters beneath seasonal cattle pens in the Interlake region of Manitoba has shown that significant mass fluxes of nutrients and salts can occur beneath the pens. Vertical fluid transport rates appear to be in the order of a few 10’s of centimetres per year. Where cattle pens are underlain by shallow aquifers, significant local groundwater quality impacts may occur.

Further investigation is warranted to examine a number of issues. Several pens should be studied in greater detail than has been done in this study to determine how micro-topography in the pens affects seepage rates and concentrations of contaminants in seepage fluids. There are some indications from this study that a significant percentage of contaminant flux may occur in wet or ponded areas of the pens. As well, additional field studies should be undertaken to develop a better understanding of the volumetric fluid flux occurring beneath these pens. Isotopic and modelling studies should also be carried out to develop a better understanding of contaminant transport processes and, in particular, processes that either increase or decrease nitrate concentrations. The issue of whether nitrate concentrations decline due to loss through denitrification is fundamental to understanding the potential for impacts on groundwater quality in underlying aquifers.

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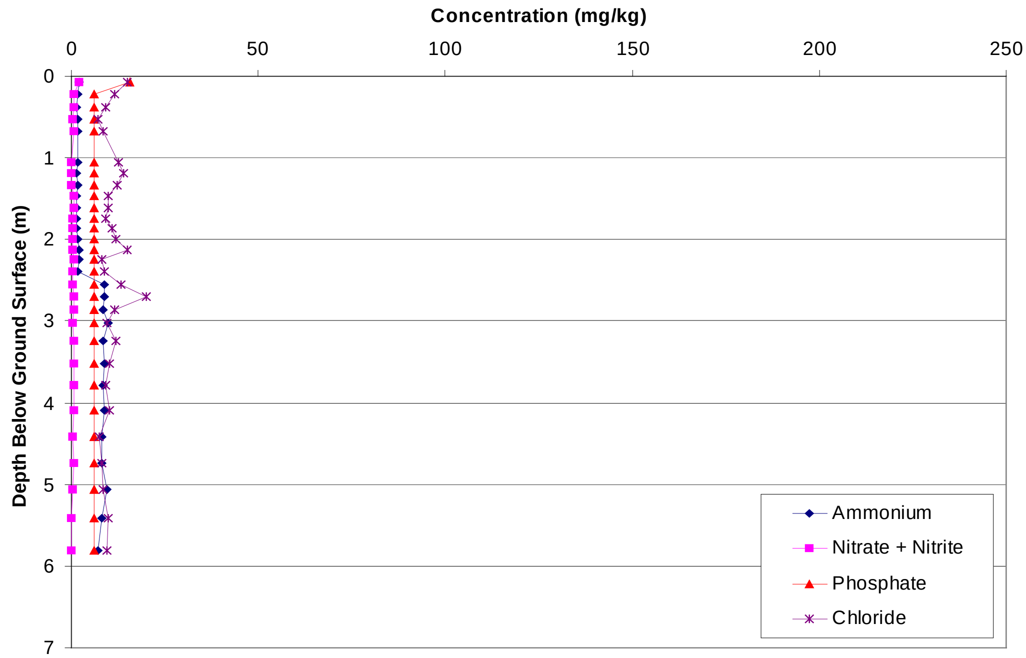

Figure 1. Interlake Background Concentration Profile of Ammonium, Nitrate + Nitrite, Phosphate, and Chloride

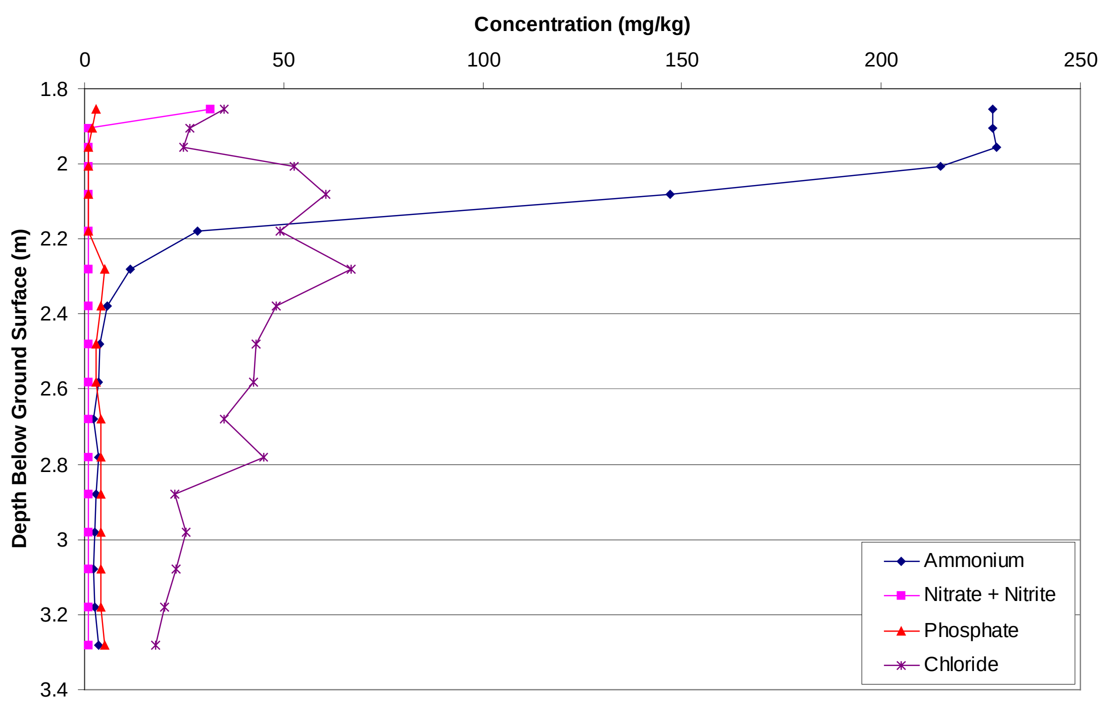

Figure 2. Interlake Total Concentration Profile of Ammonium, Nitrate + Nitrite, Phosphate, and Chloride

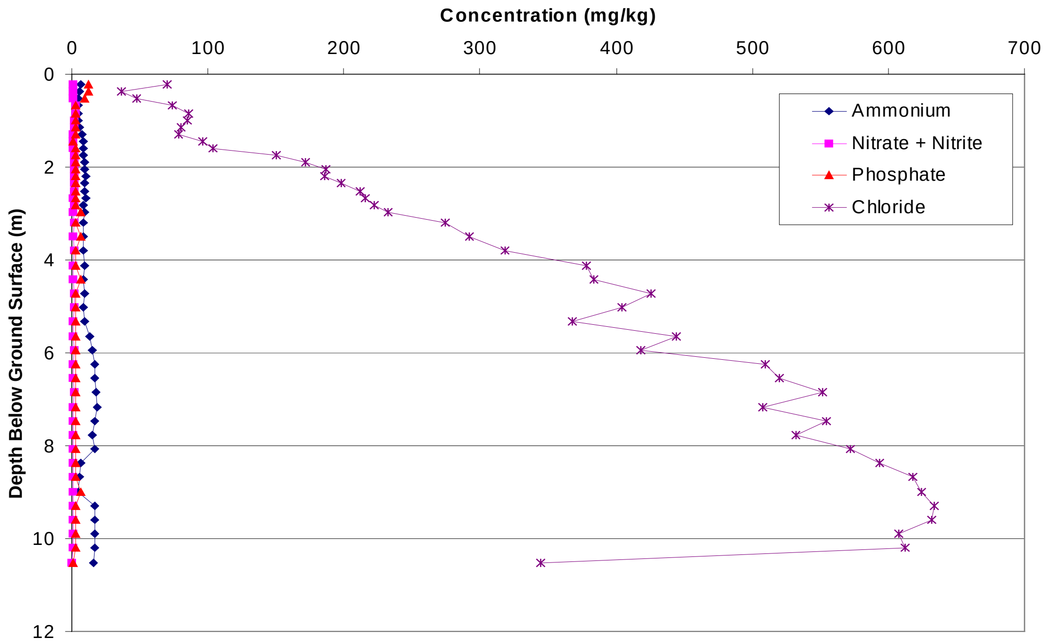

Figure 3. TS Background Concentration Profile of Ammonium, Nitrate + Nitrite, Phosphate, and Chloride

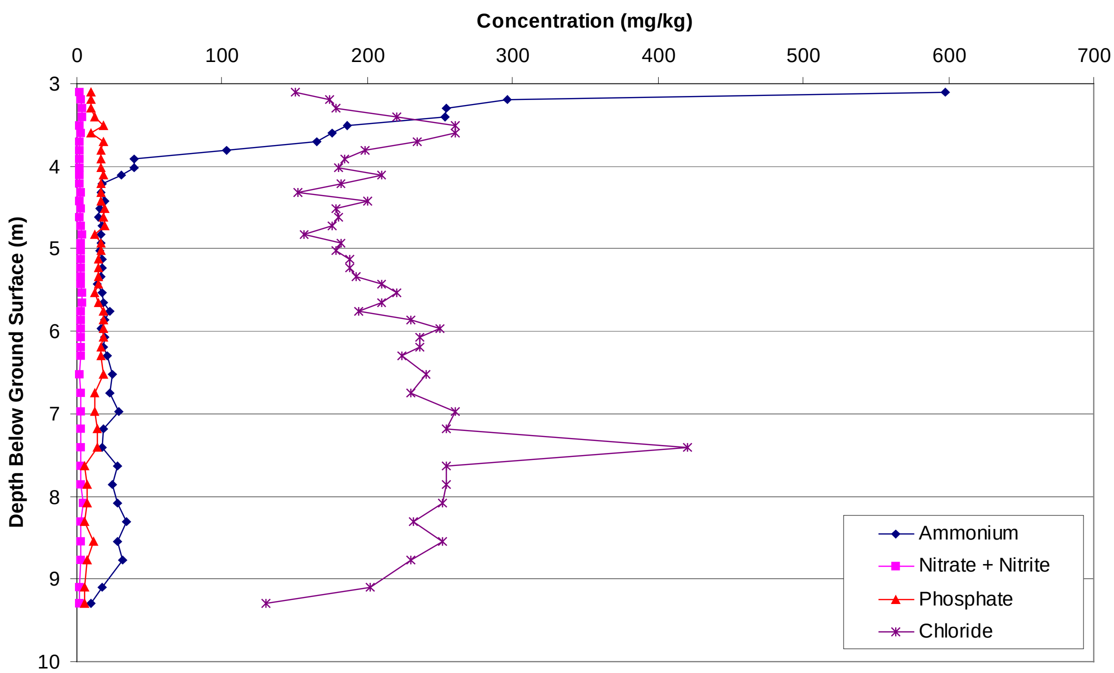

Figure 4. TS Total Concentration Profile for Ammonium, Nitrate + Nitrite, Phosphate, and Chloride

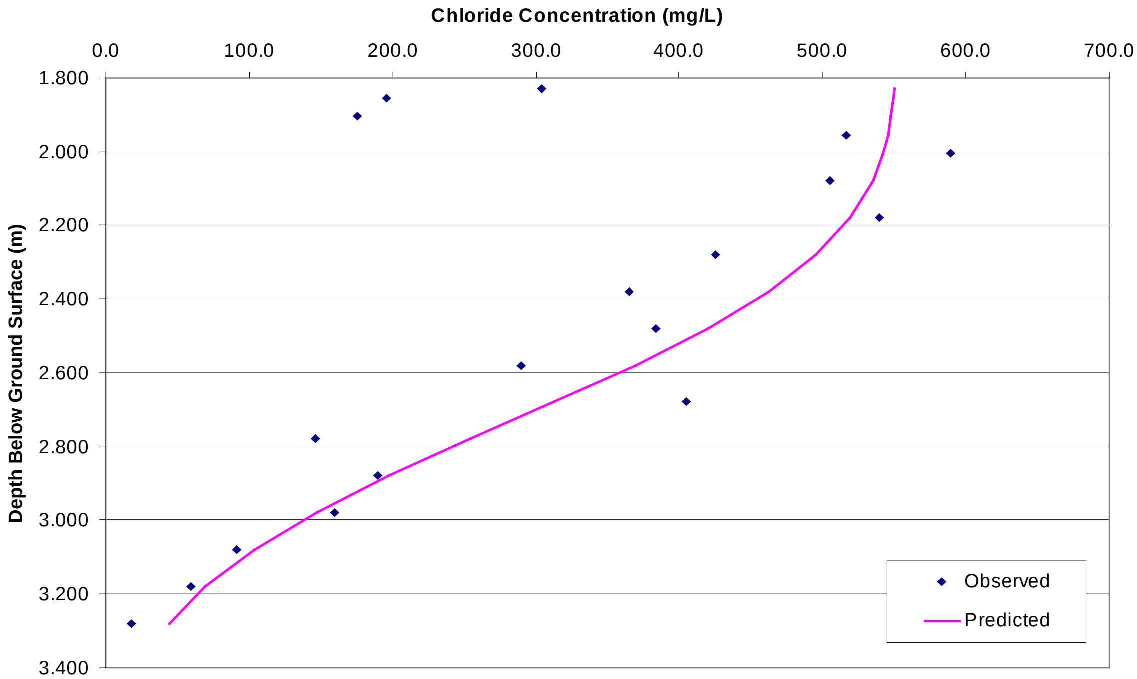

Figure 5. Interlake - Model Predicted vs. Actual Observed Chloride Concentration

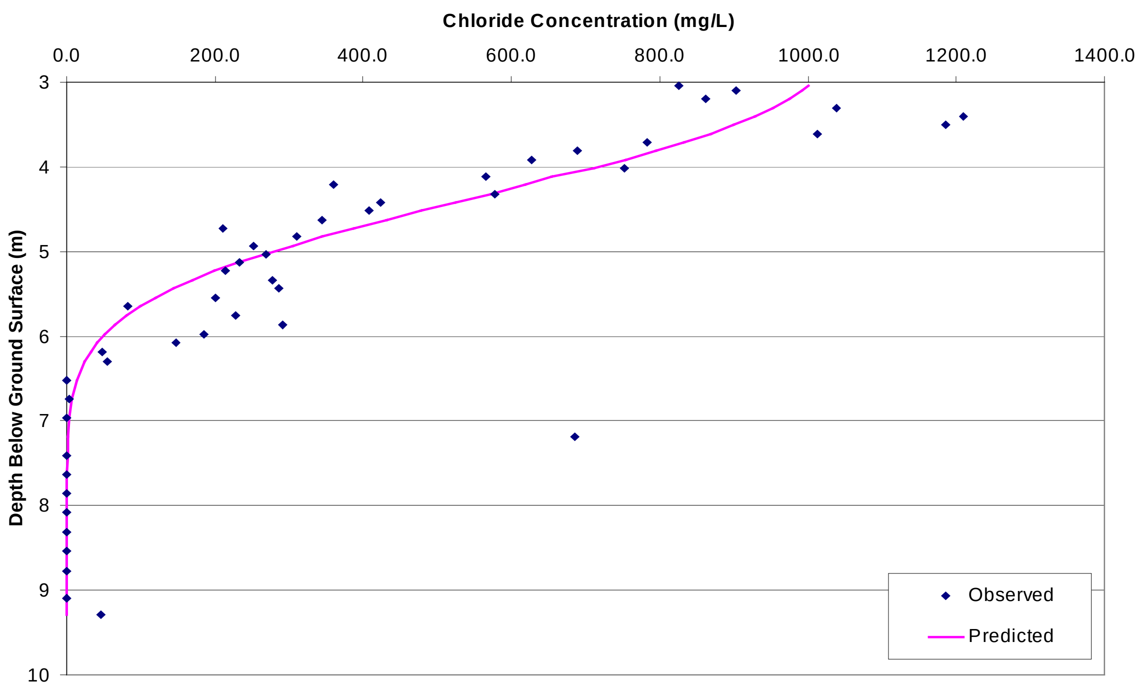

Figure 6. TS - Model Predicted vs. Actual Observed Chloride Concentration

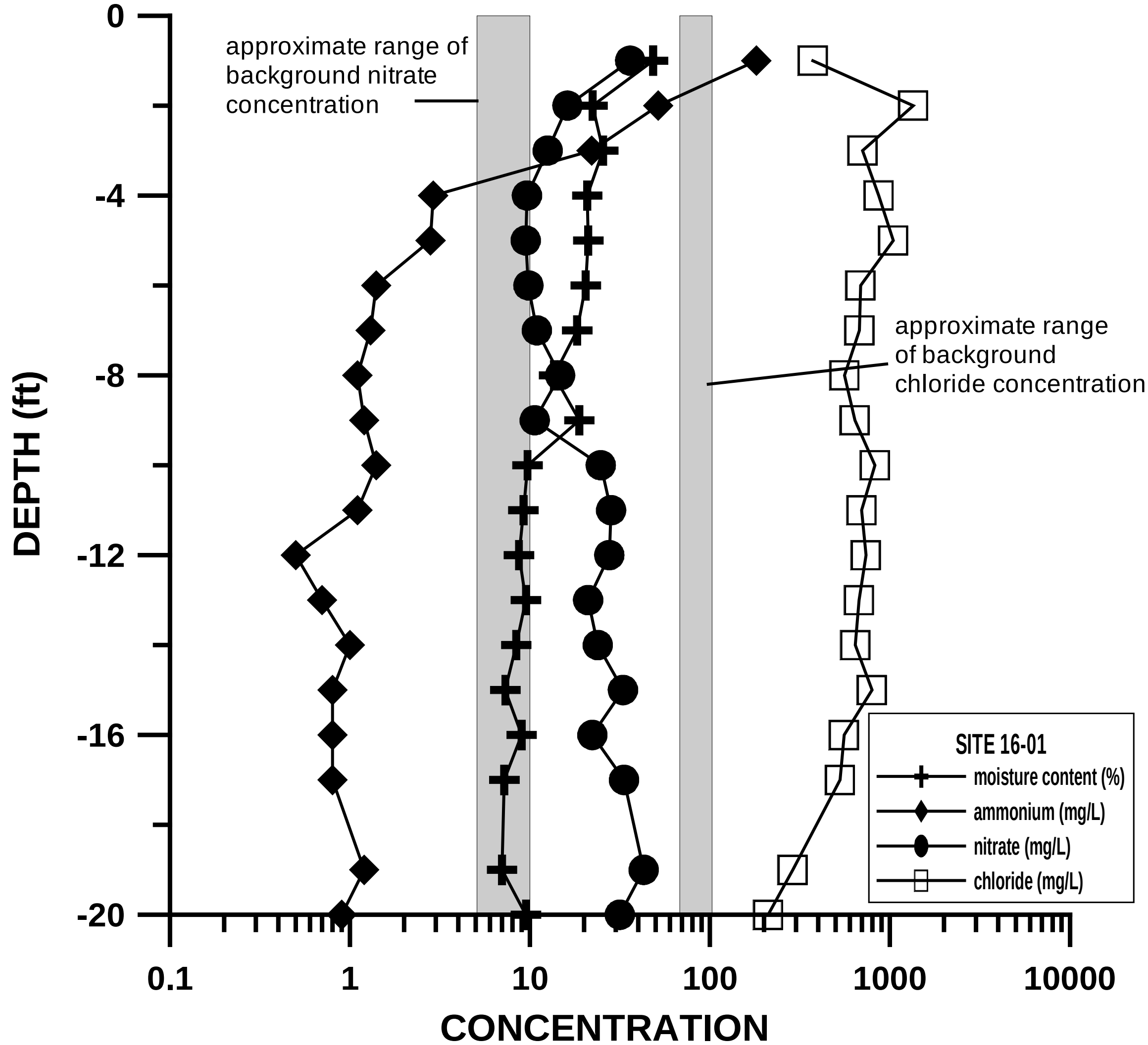

Figure 7 Soil and pore water ammonium, nitrate, chloride and moisture profiles beneath site Interlake 16-01.

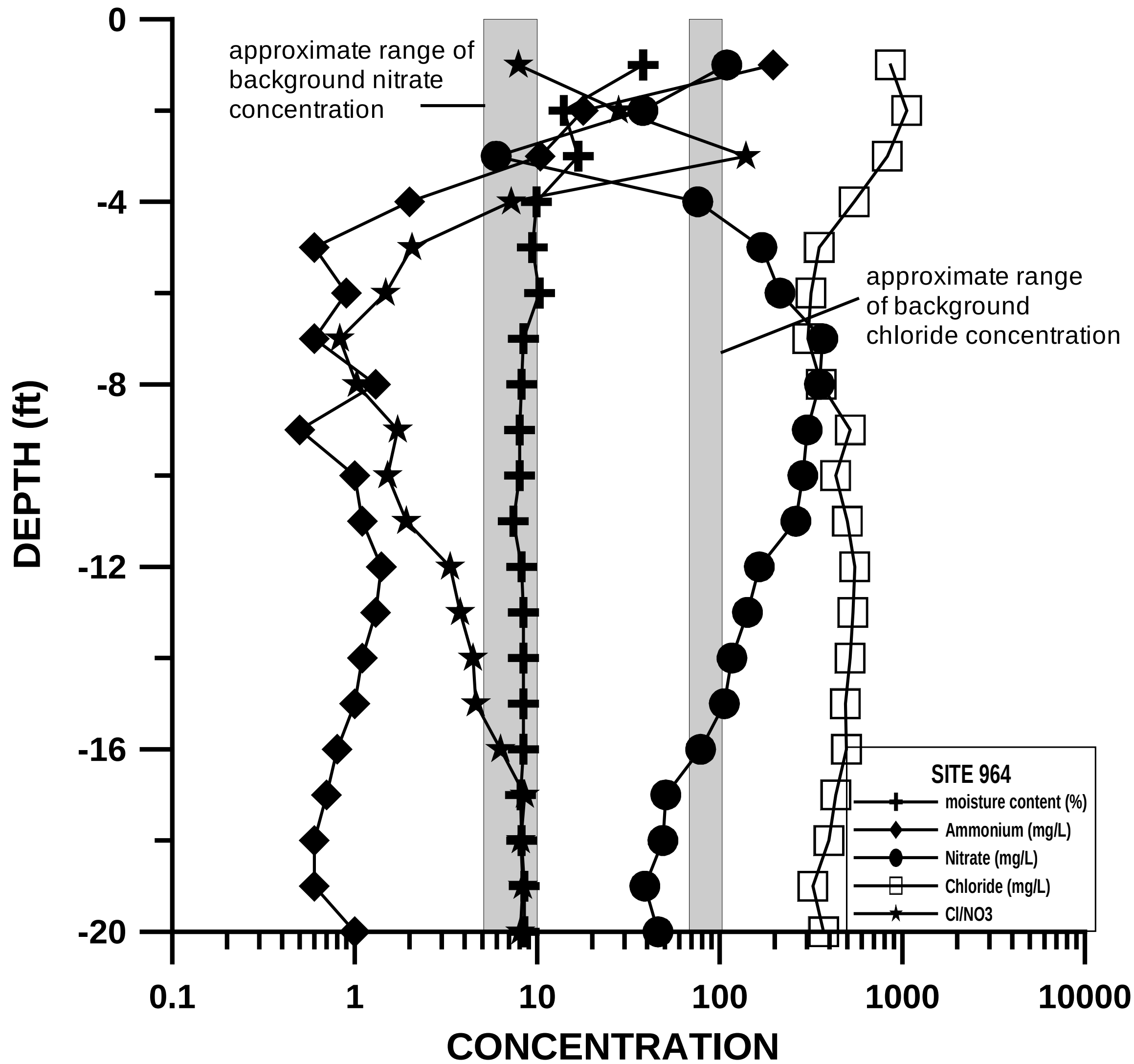

Figure 8 Soil and pore water ammonium, nitrate, chloride and moisture profiles beneath site Interlake 964.