Saskatchewan
Agriculture, Food
and Rural
Revitalization

Site Characterization Manual

For the development of Intensive Livestock Operations and Earthen Manure Storage

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Caution:

When printing this document from the PDF on the Internet or from an electronic file, please compare the mathematical formulae in the printed copy against the mathematical formulae in the electronic copy to ensure that symbols have not been altered during the printing process.

Contents

Saskatchewan Agriculture, Food and Rural Revitalization has prepared this manual in accordance with generally accepted engineering principles and practice. Any use of this information, or any decisions based on this information, are the responsibility of the user.

Glossary

- **Aquifer** – a saturated permeable geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients. An aquifer will yield sufficient volumes of water for domestic or commercial use. Hydraulic conductivities in such formations are typically greater than 10^{-7} m/sec.

- **Aquitard** – a geologic formation that does not yield sufficient quantities of water for domestic or commercial use. Such formations generally restrict or confine the flow of water, and typically have hydraulic conductivities of less than 10^{-7} m/sec.

- **Bedrock** – all pre-glacial materials. The tertiary deposits of sand and gravel are considered bedrock aquifers.

- **Contaminant** – a substance capable of degrading the quality of water or of causing water pollution.

- **Drift** – all glacial and post-glacial materials.

- **Earthen Manure Storage** – a structure built primarily from soil, constructed by excavating or forming dikes, to contain liquid manure.

- **Groundwater** – water below the water table.

- **In Situ** – measurements taken of materials in their natural state and location.

- **Intensive Livestock Operation** – an operation where animals are confined and fed and where the accumulated manure is stored prior to use.

- **Pollution of water** – notwithstanding any regulatory definition, for the purpose of this document, means the addition to water of any contaminant which would render the water harmful to public health.

- **Site** – the location where a manure storage facility is proposed.

- **Site Assessment** – the process of gathering information about a potential site and relating site conditions to development decisions.

- **Site Characterization** – allows the comparison of sites based on a scientific method that takes into account the site assessment process, and sets geologic thresholds at which enhanced design criteria are required to minimize risk.

- **Site Investigation** – part of the site assessment process which involves the on site activities of boring holes and collecting data necessary to complete the assessment.

- **Solutes** – dissolved substances in water that may, or may not, be contaminants.

- **Specific Discharge** – rate at which fluid disappears from the surface of a container or structure measured as cubic metres per square metre per unit time (m^3 / m^2 / day).

- **Total Dissolved Solids (TDS)** – the measure of the amount of dissolved material in water. The material may include magnesium, calcium, sodium, iron, manganese, bicarbonate, chloride, sulphate, nitrate, phosphate, potassium and/or carbonate.

- **Water Table** – the top of the zone of saturation where water pressure equals atmospheric pressure. The level of the water table may, or may not, represent a usable water supply.

1.0 Introduction

This document is based on guidelines developed by Manitoba, Saskatchewan and Alberta regulatory agencies to assist in the review, assessment and approval of sites intended for use as intensive livestock operations (ILOs).

As ILOs continue to grow in size and in number, the trend will be to locate production units in relatively undeveloped areas such as the prairie provinces.

In preparation for this shift in production, the governments of Manitoba, Saskatchewan and Alberta have recognized both a need to provide environmental regulations and an opportunity to establish a common environmental approach to the development of ILOs.

Manure is the most significant by-product of livestock production requiring environmental control. Manure management consists of manure storage, which is the basis for this document, and manure use, which is separate from this document.

The site characterization process is important to ensure that proper design considerations are made to prevent groundwater contamination.

The process described in this document will assist producers and professionals to select environmentally sound sites.

2.0 Overview

2.1 Purpose

The purpose of this document is to:

- describe the prairie geologic and hydrogeologic setting and to introduce the reader to the physical systems typically found in the agricultural regions of the Canadian Prairies;
- describe the information required to characterize specific sites for manure storage;
- describe a process which should be followed to collect the required information;
- define **geologically secure** conditions for storing liquid manure; and
- establish geologic thresholds at which enhanced design is necessary for storing liquid manure.

2.2 Scope

This document focuses on the storage of liquid manure. Although many principles of this document may relate to solid manure storage, or even manure application and use, the primary application of this information is for the storage of liquid manure or contaminated runoff. This document concentrates on aspects of environmental protection, rather than on structural engineering criteria.

2.3 Target Audience

The primary audience for this document is consulting or design engineers, along with livestock developers. The document will also assist other parties and agencies, such as municipal governments and local stakeholders, to understand how manure storage design decisions are made.

2.4 Use

Although this document describes a process for characterizing sites, and establishes thresholds requiring enhanced design, this document should not be taken as exhaustive or comprehensive.

Developers, operators, design engineers and regulatory agencies share a responsibility to see that all reasonable steps are taken to ensure the environmental suitability of sites for specific intensive livestock operations.

3.0 Prairie Geologic and Hydrogeologic Framework

3.1 General

The agricultural regions of the three prairie provinces comprise a diverse topography. It ranges from the mountainous regions of the Western Cordillera of Alberta, the rolling mid-continental grassland plains from southeastern Alberta to southwestern Manitoba, to the rugged lowlands of the Canadian Shield of southeastern Manitoba. Topographic elevations range from 1,300 metres (m) in western Alberta to less than 300 m east of the Manitoba Escarpment. Much of the region is flat to rolling; however, relief between major uplands and adjacent plains and lowlands may reach several hundred metres.

Groundwater forms a very important source of water supply throughout this region, with an estimated 20 per cent of the total population and perhaps as much as 80 per cent of the rural population relying on this source of water supply. Groundwater is obtained from both glacial and bedrock aquifers distributed through the three provinces. The following section discusses the major fresh water aquifer units found within the Canadian Prairies.

The prairie drainage system includes the North and South Saskatchewan Rivers, the Red Deer River, the Assiniboine and Souris Rivers, Lake Winnipeg and the Nelson River system, all draining to the Hudson Bay. The Athabasca and Peace Rivers drain part of northern Alberta to the Arctic Ocean by way of the McKenzie River. Small portions of southern Alberta and Saskatchewan drain southward to the Gulf of Mexico through tributaries of the Missouri River.

3.2 Bedrock Geology and Hydrogeology

The Prairie Region is underlain by nearly flat-lying Phanerozoic sedimentary rocks of the Western Canada Sedimentary Basin (WCSB), which lie unconformably upon the crystalline Precambrian basement complex of the Canadian Shield. Bedrock units can be classed as aquifers or aquitards. Bedrock aquifers consist of fractured igneous and metamorphic rocks, carbonates, siliceous shale, sandstone, siltstone and coal, which were deposited in both marine and terrigenous environments. Aquitards consist primarily of shales and evaporates, although some carbonate units may also act as regional aquitards.

Fractured igneous and metamorphic rocks of the Precambrian Shield are used as a source of groundwater supply in parts of southeastern Manitoba. Yields from these rock types tend to be highly variable from location to location as indicated by Betcher *et al.* (1995) who reported well yields to vary from dry holes to more than 14 litres per second (L/s). Groundwater quality from Precambrian rocks was also found to be quite variable in this part of Manitoba. The average total dissolved solids content was slightly greater than 1,000 milligrams per litre (mg/L).

Paleozoic sandstones (the Winnipeg Formation aquifer) and carbonates (the Carbonate Rock aquifer) form major fresh water bedrock aquifers along the eastern and northern edge of the WCSB in Manitoba (Betcher *et al*., 1995). In east-central Saskatchewan, the Paleozoic carbonates are referred to as the Cumberland aquifer (Meneley, 1972). In Manitoba east of the Red River and in the Interlake area of Manitoba, groundwater quality in these aquifers is fresh with a total dissolved solid (TDS) content generally less than 1,000 mg/L. It quickly becomes very saline west of these major topographic divides. The water quality distribution in Saskatchewan is less well known (Pupp *et al*., 1991). Yields from wells completed into sandstones of the Winnipeg Formation aquifer range from 0.2-10 L/s, while yields from fractured and solutioned carbonate rock units range from 0.5 to more than 10 L/s. In areas where dissolution processes have produced very permeable features in the carbonate rocks, well yields can exceed 100 L/s. In Alberta, Paleozoic age carbonates form a fresh water aquifer in parts of the Northern Plains and in the Rocky Mountains and Foothills subdivision where these older rocks have been uplifted and exposed (Pupp *et al*., 1989).

Younger marine and non-marine sediments composed primarily of shale overlie Paleozoic aquifers. However, within the Cretaceous and Tertiary-age sediments there are a number of really extensive sandstone beds, which form significant fresh water aquifers, particularly in Saskatchewan and Alberta. As well, a siliceous member of the upper Cretaceous Pierre Shale forms a widespread aquifer in parts of southwestern Manitoba and southeastern Saskatchewan.

Lower Cretaceous sandstones form potable water aquifers along the northern edge of Mesozoic strata in Manitoba (Swan River Formation), Saskatchewan (the Mannville aquifer) and Alberta (Grand Rapids and Dunvegan Formations). In Manitoba, the Lower Cretaceous Swan River Formation contains fresh water only along the northern and northeastern extensions of the Manitoba Escarpment (Rutulis, 1984). In Saskatchewan, the Mannville Group yields fresh water in a fringe along the southern edge of the Precambrian Shield. Elsewhere in the Prairies, these aquifers contain brackish to saline waters. Production rates are generally sufficient for domestic uses; Pupp *et al*. (1989) report potential production from these sandstones in Alberta to be 0.4 to 2 L/s while Betcher *et al*. (1995) report well yields as high as 7.5 L/s in Manitoba, with a mean of 1.5 L/s.

In southern Alberta, sandstones of the Lower Cretaceous Milk River Formation form a very important local aquifer north of the Montana border. Well yields range from 0.5 to as much as 40 L/s, depending on local lithology. Water quality from this aquifer is generally poor, with TDS ranging from 1,000 mg/L to more than 2,500 mg/L.

Upper Cretaceous and Paleocene non-marine and marine sandstones and coal seams form important and widespread bedrock aquifers in much of southern Saskatchewan and Alberta. The most widespread and productive of these include the aquifers formed by the Judith River (Belly River) and Bearpaw formations that occur in both Alberta and Saskatchewan. Other large scale regional aquifers are formed by sediments of the Paskapoo Formation (east of the Rocky Mountains and Foothills region of Alberta), and the Ravenscrag Formation in southern Saskatchewan. In Manitoba, these sandstone aquifers are generally absent except in the Turtle Mountain area. Well yields are quite variable, but are generally sufficient for individual household or farm use.

The Judith River Formation in Saskatchewan is sufficiently productive to form an important source of municipal and industrial water supply. Many of these formations are capable of yields exceeding one L/s in Alberta and thus form important sources for municipal water supply. Groundwater quality is generally poor with TDS concentrations typically from 1,000-2,000 mg/L or greater, although water quality is generally fresher in the Paskapoo Formation where the TDS is less than 1,000 mg/L in many parts of the aquifer. Wells completed in the Ravenscrag Formation aquifer may yield between 0.06 and six L/s (Meneley, 1983).

In southwestern Manitoba and a small part of southeastern Saskatchewan, fractured siliceous shales of the Odanah Member of the Upper Cretaceous Pierre Shale form an important regional aquifer. Yields are generally less than 0.5 L/s but locally may exceed 10 L/s where the shales are heavily fractured (Betcher *et al*., 1995). Water quality ranges from excellent to brackish, with a general increase in TDS with depth (Betcher, 1997).

Several scattered erosional remnants of undifferentiated layered deposits of Tertiary to Quaternary age form important local aquifers in parts of all three provinces. These deposits are referred to as Wynyard, Cypress Hills and Wood Mountain Formations. These formations may yield up from five to 55 L/s where the thicker coarse-grained remnants are found, although in many areas where these deposits occur, they are too thin to form useful aquifers.

3.3 Geology and Hydrogeology of Unconsolidated Sediments

Throughout most of the prairie region, bedrock is overlain by unconsolidated sediments of Quaternary and Recent age. These sediments consist primarily of glacial tills, outwash deposits of sand and gravel, lacustrine clays, silts and sands deposited in a number of very large lakes which formed at the southern margins of the receding ice sheets, and post-glacial clays, silts and sands deposited in fluvial and lacustrine environments. The thickness of these unconsolidated sediments varies. The sediments are not present in the unglaciated Cypress Hills area, but are up to 300 m or thicker elsewhere (Maathuis, 2000).

Major aquifers are found in Quaternary and Recent sediments within the Prairie Region. They include sands and gravels infilling pre-Quaternary river valleys as well as inter-till or intra-till outwash deposits of sands and gravels and deltaic and lacustrine sands or sands and gravels deposited where major streams entered pro-glacial lakes near the end of the last ice age. Quaternary and Recent lacustrine sands and gravels were laid down in late glacial and modern times in glacial spillways and modern river valleys.

The following discussion will focus on the major aquifers found in Quaternary and Recent unconsolidated sediments; however, there are many parts of the Prairies where these major and aerially extensive surficial or bedrock potable water aquifers are not present.

In these areas, groundwater supplies sufficient for individual farm or household use may be obtained

- from intra-till sands and gravels having only very limited extent or thickness, and
- from thin surficial sands or sands and gravels which often have limited saturated thickness, or
- by the construction of large diameter wells into silts or through silty intervals in tills or clays.

While these local aquifers are generally not able to provide more than individual farm or household needs, they do provide important sources of water. Through parts of the prairie provinces, the buried bedrock surface includes remnants of the pre-glacial drainage system. These features may contain pre-glacial sands and gravels, glacial stratified drift, or outwash and alluvial deposits, which can form important local aquifers. The buried valleys tend to be broad, usually three to 15 kilometres (km) wide, with gently sloping sides. Buried valley aquifers are typically between 30 and 90 m thick and are covered by 30 to 90 m of drift, mainly till. The fill within the valleys is termed Saskatchewan Gravel in Alberta and the Empress Group in Saskatchewan.

In Alberta and Saskatchewan, the pre-glacial buried valley networks or thalwegs of these valleys have been extensively mapped. In Alberta, major buried valley aquifers in the southern part of the province include the Lethbridge Valley aquifer, the Medicine Hat Valley aquifer, and the Calgary, Red Deer and Beverly aquifers and their tributaries. These aquifers are locally capable of yielding from 10 to 50 L/s to a single well. The Hatfield Valley aquifer system is the largest pre-glacial valley aquifer in Saskatchewan. The Hatfield Valley aquifer system enters Saskatchewan at Cold Lake and enters Manitoba east of Yorkton. Through Saskatchewan, the aquifer is approximately 500 km long and up to 30 km wide. The Battleford Valley, Tyner, Estevan Valley, and Swift Current Valley aquifers complete the list of major identified buried valley aquifers in Saskatchewan (Maathuis, 2000).

Individual wells completed into these buried valley aquifers may yield between 30 and 50 L/s. A number of buried valley aquifers have been identified in western Manitoba, including the extension of the Hatfield Valley aquifer of Saskatchewan. However, while these aquifers form important local sources of groundwater supply in some places, their extent has not been well mapped and no formal system of naming these aquifers is in place.

Significant groundwater yields may also be obtained from stratified inter-till or intra-till sand and gravel deposits. In some parts of the Prairies, these aquifers are quite extensive. Since they are typically fully encompassed within low-permeability tills that inhibit recharge, the long-term sustainability of these aquifers must be carefully evaluated. The Regina Aquifer is an example of an intertill sand and gravel aquifer capable of satisfying municipal and industrial water demands. Glacial deposits also occur in valleys that were cut during glaciation. These tend to be narrow and steep, and, where they contain fluvial sands and gravels, are capable of yielding up to 10 to 20 L/s to individual wells.

In some areas, particularly south central and south-western Manitoba, late stage deposition into pro-glacial lakes, which formed along the southern edge of the retreating ice sheets, consisted of silts and sands which form significant local aquifers. The Oak Lake aquifer in southwestern Manitoba is an unconfined sand aquifer, formed by deposition in ancestral Lake Hind. The saturated thickness of the aquifer is locally as much as 25 m with an average sand thickness of approximately 10 m. This aquifer forms the major source of local water supply over an area of approximately 2,000 km^2 (Render, 1987). A number of aquifers were also formed by deposition of sand, where streams flowing into ancestral Lakes Agassiz and Hind formed a series of deltaic aquifers along the margins of these lakes. The largest of these features is the Assiniboine Delta aquifer (Render, 1988) that extends over an area of approximately 4,000 km^2 and provides water for local, municipal, industrial and irrigation uses. Current irrigation withdrawals from this aquifer exceed 6×10^9 litres annually.

Opportunities for the development of groundwater resources also exist in deposits associated with present-day river valleys, where sand and gravel accumulate. In some cases, yields obtained from deposits associated with the Saskatchewan River system are comparable to those obtained from glacial outwash sediments.

3.4 Groundwater Recharge and Quality

Average annual precipitation ranges from about 600 mm in west-central Alberta and southeastern Manitoba to less than 300 mm in southwestern Saskatchewan. Potential evapotranspiration exceeds precipitation by up to 250 mm for much of the May to September growing season, in southeastern Alberta and southwestern Saskatchewan.

Estimates of recharge to groundwater storage on the Prairies range from one per cent to 10 per cent of average annual precipitation, with the lower value being most common. Long-term fluctuations in groundwater levels are due mainly to seasonal variations in water recharge. Changes in water levels can also be generated by pumping from wells, drainage works, irrigation, alteration of lake or reservoir levels through operation of control structures and other non-natural causes. On the Prairies, recharge is greatest in the spring and groundwater levels are at a maximum. These levels generally decline during the summer months and through the winter months, until the onset of a new spring season.

With evaporation exceeding precipitation for much of the year in large parts of Saskatchewan and Alberta, the result is the deposition of salts on or within the soil horizon by evaporation of capillary water. These salts are subsequently flushed into the zone of saturation, increasing the mineralization of groundwater (Maathuis 2000). In western Alberta, groundwater generally contains less than 800 mg/L of total dissolved solids, predominantly of calcium-magnesium bicarbonates. In the semi-arid regions of eastern Alberta and western Saskatchewan, the predominant constituents in groundwater are sodium, calcium, magnesium sulphates and total dissolved solids increase to 2,500 mg/L. In southwestern Manitoba, groundwater TDS averages 2,000 mg/L; in the south central part of the province, groundwater TDS averages 1,100 mg/L and falls to slightly more than 900 mg/L in central and eastern Manitoba. In all cases, calcium and magnesium carbonates predominate and average TDS is generally inversely proportional to the amount of precipitation received annually.

The chemistry of Upper Cretaceous and younger bedrock aquifers reflects interactions between sulphate or bicarbonate drift groundwater and materials in bedrock such as lignite, coal, methane, bentonite and selenite. In Alberta, bedrock aquifers generally can be characterized as sodium bicarbonate. In Saskatchewan, calcium-magnesium or sodium sulphate groundwaters are most common in bedrock aquifers. Bicarbonate waters predominate in the southwest part of the province possibly because of base exchange with bentonitic shales or higher annual precipitation in the Cypress Hills region. Sodium chloride is common in shallow groundwater of the limestone aquifers of Manitoba where influences occur from deeper formations discharging into the Red River Valley.

3.5 Environmental Considerations

There are elements of prairie geology and hydrogeology that lend themselves well to the construction and operation of intensive livestock facilities.

There are also elements that must be avoided, or modified to preclude negative impacts of ILOs on the environment. The engineering and environmental significance of these elements must be known in order to minimize risk and to avoid costly modifications or mitigative measures during the life of the operation.

The evaluation of engineering and environmental information is engineering science based. Groundwater flow characteristics through geologic formations are of primary interest. Darcy's Law is used to relate groundwater flow rates through geological formations to the permeability of the formations and the hydraulic gradient in the area of interest.

The topographic, lithologic and textural characteristics of prairie landforms and their environmental sensitivities are summarized in Table 3-1, General Characteristics and Properties of Earth Materials.

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TABLE 3-1 General Characteristics and Properties of Earth Materials

Table 3 -1 General Characteristics and Properties of Earth Materials

	Geologic Deposit								
	Moraine	**Lacustrine and Fluvial**			**Outwash**	**Aeolian**	**Bedrock**		
Characteristics									
Lithology	**Clay Till**	**Clay**	**Silt**	**Sand**	**Sand-Gravel**	**Silt-Sand**	**Sandstone**	**Shale**	**Carbonate**
Topography	undulating to rolling	flat	flat	flat	flat to rolling	flat to rolling	variable	variable	variable
Bulk Permeabilty	low	low to medium	medium to high	high	high	medium to high	low to high	low to high	medium to high
Shrink-Swell Characteristics	low to medium	high	low	low	low	low	low	low to high	low
Bearing Strength (saturated)	medium to high	low to medium	medium	medium	high	medium	high	medium to high	high
Plasticity	low to medium	medium to high	low	low	low	low	low	medium to high	low
Shear Strength	medium	low to medium	medium	medium	medium to high	medium	high	low to high	high
Ion-Exchange Capacity	high	high	low	low	low	low	low	medium	low
Erodibility	low to medium	medium to high	high	high	low to medtium	high	low to high	low to high	low
Frost Susceptibility	med to high	low	high	low to high	low to medium	medium to high	low	low	low
Potential Degree of Constraint	low	medium	medium to high	high	high	high	medium to high	medium	high

NOTE: descriptions of earth characteristics are not absolute but relative to the range of lithologies

4.0 Site Assessment Process

This section describes the site assessment and decision making process. Site assessment is the process of relating geologic and hydrogeologic conditions to development decisions. The assessment process identifies potential risks and provides a means to mitigate or minimize those risks. An appropriate project design is based on geologic and hydrogeologic conditions as well as social and economic considerations.

4.1 Objectives of Site Assessment

The objective of site assessment is to determine the suitability of the site for the proposed use and the engineering works that may be required for the project.

The assessment process described herein determines the design requirements for the manure storage to ensure environmental safety. The site investigation and the subsequent design requirements are site specific and must consider three-dimensional subsurface conditions to predict performance during construction and operation.

Potential impact on groundwater is a key consideration in the siting and design of earthen manure storages (EMS). An understanding of the physical site conditions is necessary to predict performance of the facility. To determine the level of groundwater protection required, the design engineer must consider:

- pathways available to transport contaminants;
- the rate at which contaminants may move; and
- concentration of the contaminant when it reaches a potential receptor.

4.2 Steps to Complete a Site Assessment

Prior to beginning the site assessment process, the project requirements and constraints must be well understood. Important project requirements and constraints include:

- size;
- potential expansion requirements;
- operational requirements;
- project and site assessment budget;
- utility, water, and transportation requirements; and
- regional limitations or local constraints.

A good site will have many positive social and economic benefits. However, it is difficult to find a site with all the desired features. Sites should be evaluated from both a developer’s and the community’s perspective.

The six steps of a site assessment process are:

- identifying potential sites;
- conducting a preliminary evaluation;
- developing the site investigation plan;
- conducting the site investigation;
- completing the final evaluation; and
- preparing detailed reports.

The process is iterative and interactive. During each step, the client and consultant must decide if the assessment should continue, if previous steps should be repeated or if a new site should be considered.

Figure 4-1 on page 10 illustrates the key decision points of the site assessment process. The process within each step may be more detailed and may vary with the engineering consultant, regional conditions, the specific site conditions, or the specific project objectives.

4.2.1 Identifying Potential Sites

Once the project objectives, requirements and limitations have been defined, potential sites can be identified. Site selection involves consideration of practical, technical and environmental factors, including:

- availability of land for purchase (facility location);
- access to utilities, water, and roads;
- proximity to residences, towns, parks;
- landscape, topography, vegetation;
- proximity to wildlife habitat and the potential presence of rare or endangered species and heritage sites in the area;
- surficial soils;
- proximity to surficial water;
- natural ground and surface water protection;
- suitability of soil for foundations, control works and/or storage liners;
- land area available for manure spreading; and
- local by-laws, licensing and approval requirements.

4.2.2 Conducting the Preliminary Evaluation

The preliminary evaluation begins with the collection of existing background information starting at a broad (provincial) scale then progressing to the regional scale, and finishing at the local or site scale. Use this data to develop maps and cross sections in an effort to identify unsatisfactory sites prior to a costly drilling program. This information can be used to prepare a site investigation and layout plan.

Information available for the preliminary evaluation may include the following:

- National Topographic System (NTS) maps;
- Geology and Groundwater Resources Maps, Saskatchewan Research Council (SRC);
- Soil Survey soil maps and reports;
- Well log records, Saskatchewan Watershed Authority (SWA);
- Potentiometric Surface Maps, SWA;
- land cover satellite imagery, and
- aerial photos – Information Services Corporation (ISC).

The preliminary evaluation will provide information about the regional hydrology, geology and hydrogeology of the site, including:

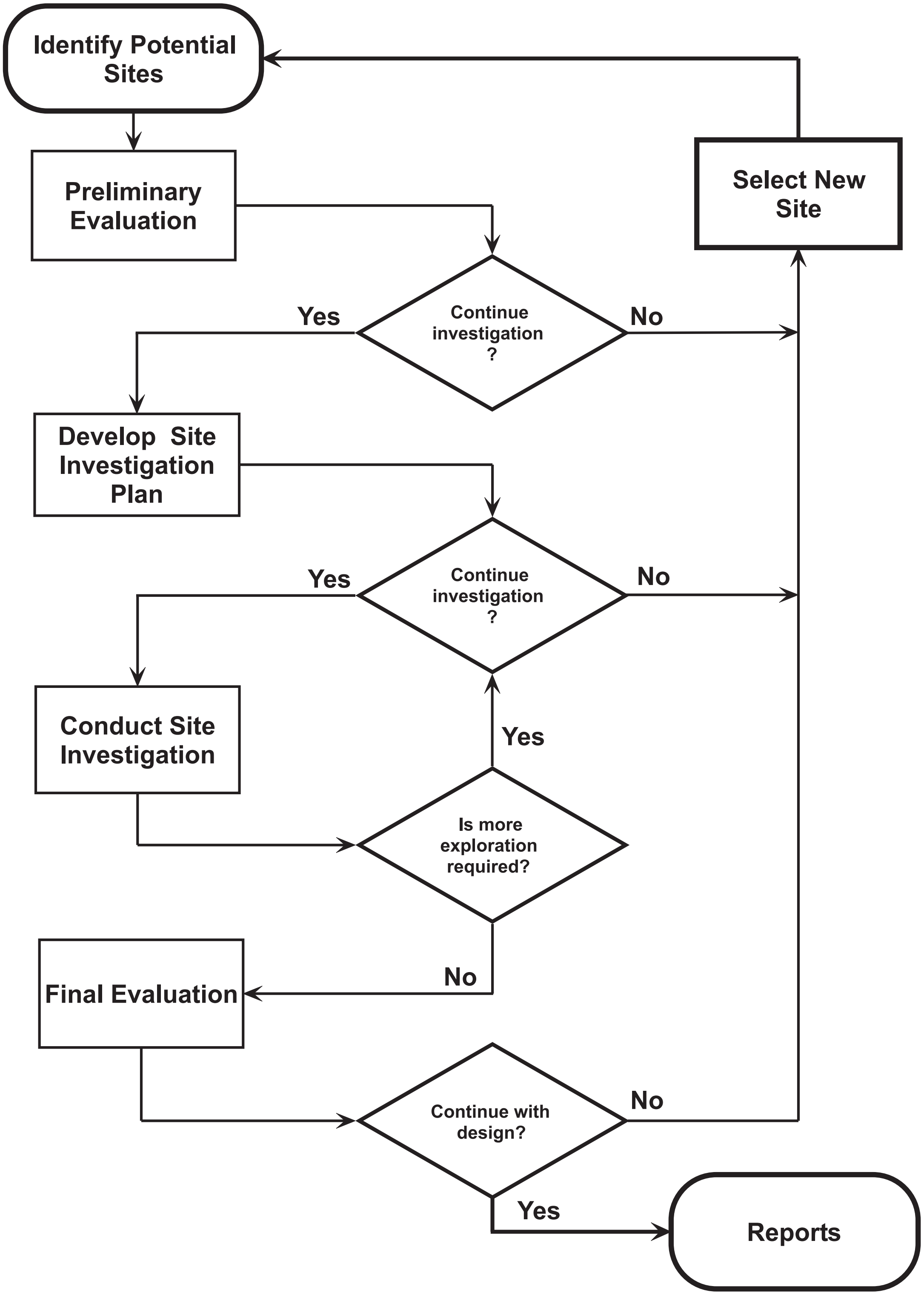
- expected depth to (elevation of) bedrock;
- expected geologic formations that exist in the area;
- probable elevation of the geologic formations;
- depth to usable ground water, both shallow (usually local aquifers) and deep (usually regional aquifers);
- type and texture of soils in the area (agronomic soils classification);
- location of surficial water resources, including rivers, lakes, reservoirs, large sloughs and major water courses;
- regional topography and natural features such as trees, native grass lands;
- proximity to wildlife habitat, heritage resources; and
- potential presence of rare or endangered species.

Other project needs, such as utilities, roads, and proximity, should be considered at this stage.

The information compiled at this stage is used to develop a concept of the expected site conditions, and forms the basis for developing the site investigation plan.

Figure 4-1:

Site Assessment Process



Identifying Potential Sites

Identify potential sites	• availability for purchase • sufficient access to utilities, water, and roads • sufficient land available for manure application (or other utilization processes) • RM maps – proximity of residences
Preliminary evaluation	• preliminary evaluation should begin at provincial scale (bedrock geology) and proceed to local and site specific information • regional information – soil types, watershed, surficial water bodies, watercourses, well records, topography maps, air photos • published studies: water, subsurface exploration • identify potential receptors (aquifers, watercourses) and potential risks • suitability of geology/soils • are there any identifiable unique or costly design requirements? • identify surficial indications of site geology such as outcrops, surficial bedrock, etc.
Continue investigation?	• does the site have sufficient potential to continue investigation?
Develop site investigation plan	• probable site plan • required extent of topographical site survey • probable required extent (depth) of subsurface exploration • probable number of boreholes, including number of locations and/or nests, probable depth of each borehole? • estimate costs of investigation
Continue investigation?	• are the costs for the proposed investigation and the likely design requirements acceptable?
Conduct site investigation	• drill first borehole to proposed required maximum depth of exploration • modify number of boreholes, the proposed depth and/or the proposed locations according to the subsurface conditions encountered (types of subsoil, soil characteristics, soil conditions) • ensure piezometers are properly completed and boreholes that will not be maintained are properly decommissioned • collect required samples and obtain required laboratory analysis • evaluate site investigation data – site geology, soil types and characteristics (Atterberg limits, moisture content)
Is more exploration required?	• is sufficient information available to characterize the site? • are potential receptors and transport pathways characteristics defined?
Final evaluation	• evaluate potential risks should the project proceed at the proposed site (Note site category matrix: **secure, variable, or sensitive**) • based on site conditions and potential risks, determine the level of project design likely required (high factor of safety, detail modelling to determine design requirements, required monitoring requirements) • consult with regulatory agency or agencies
Continue with design?	• are the likely design and construction requirements acceptable?
Reports	• complete investigation and design reports, descriptions of regional and site geology, identify potential risks, identify required (proposed) mitigation, provide justification for design specifications (how/why potential risks are adequately mitigated)

4.2.3 Developing the Site Investigation Plan

The site investigation plan is developed with a view to confirm and enhance the understanding of the geologic and hydrogeologic setting. The plan will contribute to an efficient investigation and assist in collecting adequate and relevant information. A good site investigation will reduce the likelihood of return visits to the site to collect additional field information. The site investigation should be of sufficient extent to describe all relevant site conditions.

The site investigation plan will use information from the preliminary evaluation to:

- establish the aerial extent of investigation required;
- approximate the depth and number of boreholes required;
- establish the collection of soil and water samples and analytical requirements; and
- determine the need for installation of monitoring systems.

Aerial Extent of Investigation

The aerial extent of the site investigation depends on both the physical characteristics of the site and on the physical characteristics of the facilities. Prepare a site plan that allows for placement of all relevant facilities with some flexibility for changes that might be necessitated by the final design. In addition to the physical footprint of the facilities, local features, such as watercourses, ravines, and wells, must be taken into account when determining the aerial extent of the investigation.

Provisions must be made for a topographical survey. A topographical survey helps to establish the relationship of subsurface formations and will assist in the design and location of the manure storage facilities and in the provision of drainage from the site. Accurate elevations are essential for establishing the relationship of water in boreholes.

Depth and Number of Boreholes

The preliminary evaluation provides the project engineer with a concept of the geologic and hydrogeologic conditions. The depth of exploration should extend to an identifiable and known regional formation or to a specific depth that will allow for an evaluation of the sensitivity of the site to be made, or which will meet local or provincial requirements. The borehole should also be of sufficient depth to identify any sand and/or gravel formations expected to exist in the region. Boreholes should always extend through granular (sand and/or gravel) formations.

Estimates of the number, location and depth of borehole explorations can be made based on the site location, orientation of facilities, topography and background geological information. An allowance for additional boreholes should be made if complex conditions are expected.

Collection of Samples

The site investigation plan should include an outline which includes the following:

- the type of samples to be collected (soil and/or water);
- the number of samples to be collected;
- which boreholes are to be sampled;
- which formations are to be sampled;
- the analytical requirements.

Sufficient soil samples should be collected to allow a proper evaluation of the site conditions. Water analyses can provide valuable insight to the relationship of water between boreholes.

Installation of Monitoring Equipment

If complex or sensitive site conditions are expected, or if regulations require, allow for the installation of monitoring facilities during the site investigation. The ability to quantify groundwater conditions such as hydraulic gradient and artesian head are important in the evaluation of the site.

Other Considerations

Development of the site investigation and site plan must also consider:

- regulations (municipal, provincial, federal);
- potential receptors and the potential risk of negative impacts;
- the suitability of geology/soils for the intended project objectives;
- potential design requirements.

The site investigation plan is used to estimate the cost of the site investigation. The proponent will need to establish a budget based on the proposed exploration. Additional costs for known or likely site complexities including any monitoring such as piezometers and/or piezometer nests need to be taken into account.

A decision to proceed or to seek an alternate site will have to be made. If the decision is to proceed, the drilling crew and field engineer or technician must be briefed on what geologic conditions to expect and they should contact the project engineer if unexpected conditions or anomalies are encountered. The number, locations, and depth of boreholes may need to change during field exploration depending on subsurface conditions encountered. Whenever complex hydrogeologic features are suspected, the project engineer should consult with a geologist or hydrogeologist.

4.2.4 Conducting the Site Investigation

The site investigation is the implementation of the site investigation plan. Information collected from the site investigation will confirm or deny the concept developed at the preliminary evaluation. If the site conditions are significantly different than expected, the preliminary plan must be re-evaluated.

The site investigation is a critical part of the site assessment process and provides the major component of the characterization process. Exploration is mainly fieldwork, which includes surveying and mapping, drilling, logging, sampling, instrumentation, and laboratory testing.

The facility design and construction requirements will primarily be based on the information and data collected during the site investigation and exploration. A good field exploration will provide sufficient information to identify any environmental sensitivities or risks for contamination and will provide adequate information to determine design.

The field exploration should determine vertical and horizontal soil profiles and be sufficient to determine the extent, thickness and potential for hydraulic contact between the strata encountered. The field crew and field technician should be familiar with expected subsurface conditions and should contact the project engineer if unexpected conditions or anomalies are encountered.

The soil properties, including moisture content, soil-particle-size distribution, Atterburg limits, hydraulic conductivity and other properties/ parameters, must be measured for each soil formation. Field measurements to estimate the in-situ engineering/ hydrogeologic properties, such as hydraulic conductivity, should be performed.

Soil profiles provide information on the subsurface characteristics so that groundwater flow and potential contaminant movement can be appraised. Exploration must be of sufficient extent to provide groundwater information at the site. Horizontal and vertical hydraulic gradients should be determined. Potential subsurface flow paths through soil fractures and granular soil formations must be identified. When granular formations are encountered the extent and orientation of these layers should be delineated.

Practical field exploration procedures reduce the potential for returning to a site for additional exploration.

- Drill first borings to maximum depth, preferably to a known formation. Subject to the variability of the site and the proximity of resources potentially requiring protection, other boreholes may not need to extend to this depth.
- Do not terminate a borehole within a granular (sand or gravel) formation.
- If granular formations are encountered, ensure other borings extend at least to the elevation the sands and gravels were encountered. Use subsequent borings to delineate the formation.
- Document the location of sample collection sites by surveying or with Geographic Positioning System (GPS) receivers.

Prior to leaving, the field investigation leader should decide if additional exploration is necessary. It may be costly and time consuming to return to a site.

4.2.5 Final Evaluation

Once the site investigation is complete and sample analyses are available, a final evaluation can be made. The final evaluation will determine:

- if the site data confirms the expectations of the preliminary evaluation;
- existing site constraints; and
- preferred options to address site constraints.

Confirmation
The site data should support the basic concept developed at the preliminary evaluation. Scrutinize the data to ensure it compares favourably to what should be expected. An interpretation and reasons for any anomalies or unexpected conditions should be provided.

Constraints
All sites will have constraints, some of which are easier to overcome than others. The physical site conditions and on-site soil properties can be used to determine the site geology and the associated design/mitigation requirements.

Typical site constraints may include:

- availability of suitable soil for the construction of compacted clay liners;
- de-watering requirements for excavation;
- drying or wetting requirements for clay liner installations;
- equipment constraints such as space limitation due to proximity of utility installations;
- proximity to heritage resource sites;
- presence of endangered plant or animal species;
- requirements to maintain or protect natural features such as trees, wetlands, watercourses;
- flood plain elevations; and
- drainage.

The consultant and/or owner must then determine whether the project objectives and design requirements can be met.

Some sites may justify an in-depth review of the risks for impacting groundwater through the use of numerical models which hypothesize anticipated contamination and lag time. The relevance of this approach should be determined in consultation with the regulatory agency.

4.2.6 Developing Specifications and Reporting

At this stage of the site assessment process, it is important to document all the steps carried out, along with the data collected, and the interpretation followed to arrive at the final site classification. That information can then be used to determine design requirements for the site.

The report should outline the concept developed at the preliminary evaluation, and explain how results from the site investigation confirm that concept. The site assessment must clearly identify site sensitivities and constraints so that the design engineer can determine the design requirements to provide a level of protection that meets applicable standards and regulations. Any expected construction limitations should be clearly noted so that contractors can prepare accurate quotes.

Once a decision to proceed with the project has been made, the final design specifications can be completed. This will include specifying the type of facilities and the detailed design drawings, the required material specifications, and construction specifications.

For an earthen manure storage, the design specifications include the material type (such as clay or synthetic material), liner thickness, liner material properties such as clay content and moisture content, and completed liner performance requirements such as target density and hydraulic conductivity.

Construction specifications include the equipment requirements, potential wetting requirements for clay liner installation, lift thickness, scarification requirements, and base preparation requirements.

Final design specifications must include documentation of the site constraints and clearly identify site features that must be avoided, left undisturbed, and/or protected. The quality control and quality assurance requirements should be clearly documented. This can include the construction testing requirements such as moisture content and compaction density for clay liner installations, and seam testing for synthetic liner installations.

A final report should detail the site investigation information and data, and describe the geologic and hydrogeologic setting. The final report outlines the evaluation and design specifications. The resources that could potentially be negatively impacted should be identified. The design specifications that eliminate or minimize the potential for these impacts should be described and a clear statement made of the potential risks.

The site assessment process is the application of systematic scientific approach. The goal is to develop and present a clear understanding of the site. In favourable settings, the process may be completed in one pass. It may take considerable time to complete a comprehensive assessment of complex or variable sites.

4.3 References

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5.0 Geologic Basis for Site Classification

Section 4 of this document explains the process necessary to collect and compile sufficient information about a site so the engineer can proceed with design of the manure storage.

The purpose of Section 5 is to describe the geotechnical/geological information that regulatory agencies will require to evaluate proposed manure storages and to ensure that water resources will be adequately protected. Storage design requirements are site specific. It is nearly impossible to set a single standard that would be appropriate for all conditions. However, proponents, engineering consultants and the public need to know what the regulatory approach is. To balance the need for site specific design, and to provide predictability in regulatory requirements, three categories were defined to broadly define manure storage requirements appropriate to site conditions.

The three categories were defined as **geologically secure**, **geologically variable** and **geologically sensitive**.

The first site category selected, **geologically secure**, describes sites where groundwater resources are naturally protected by the geology.

A key issue in defining a **geologically secure** site is the definition of the attributes of the clay aquitard required to ensure adequate protection of an underlying aquifer.

This section will assist the engineer in understanding the design criteria used by regulatory agencies to determine those conditions and parameters which define a **geologically secure** site, beyond which enhanced environmental protection and engineering design is necessary.

5.1 Theory of Fluid Flow Through Soil – Darcy's Law

Soil consists of voids and solids (Figure 5-1). Voids in the soil may be filled with fluid (usually water), or gas (usually air). In saturated soil, the voids are completely filled with water that, depending on specific conditions, may be moving vertically, laterally or both. Both air and water are fluids, and both can flow through the soil mass when a soil is unsaturated. However, only water moves through the soil when the soil is saturated.

The French engineer, Darcy, showed that the rate of flow of a liquid through saturated clean sands is proportional to the hydraulic gradient.

$$q = k \frac{h_1 - h_2}{l} A, \text{ where}$$

q = the **rate** of discharge (m^3/s)
k = hydraulic conductivity (m/s)
h_1 = initial head (m)
h_2 = head after flow through the soil (m)
l = length of travel through the soil (m), and
A = the cross sectional area (m^2)

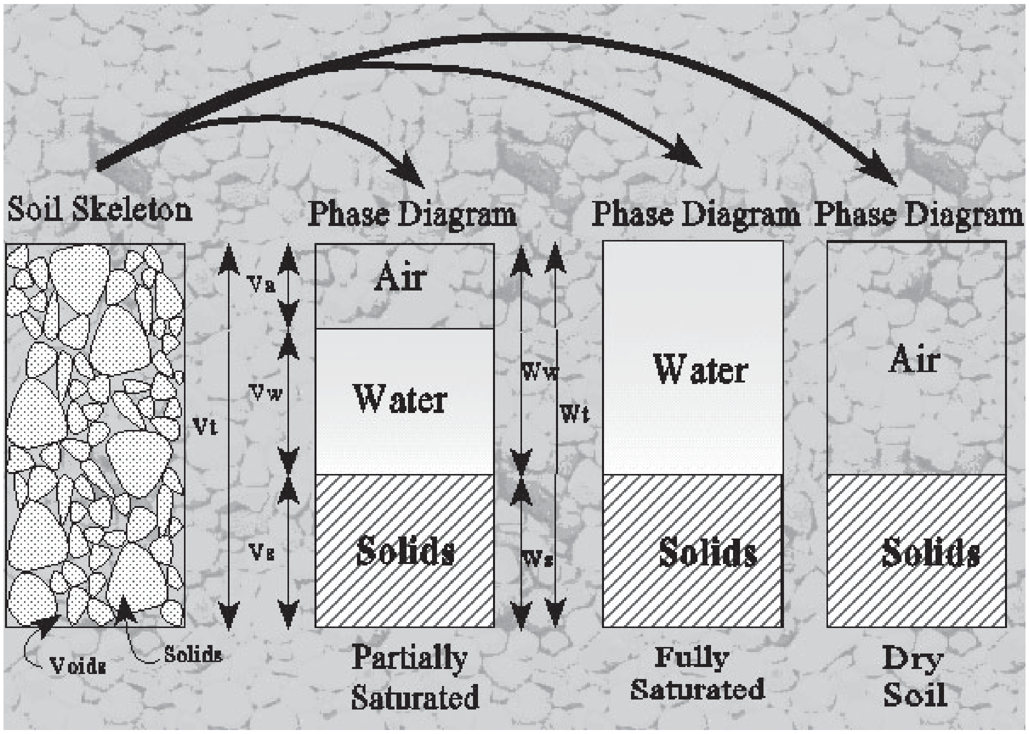
Darcy's Law is commonly expressed as:

q = kiA, where
q = the rate of discharge (m^3/s)
k = hydraulic conductivity (m/s), and
$i = \frac{h_1 - h_2}{l}$ = the hydraulic gradient (m/m)

For Darcy's purpose, and for the purpose of comparing the flow of liquid through soils, the total flow, q, can be divided by the total area, A, and expressed as a specific discharge per unit area (Darcy flux), *v*

v = q/A = ki, where
v = the Darcy flux (velocity) of fluid through the soil ($m^3/m^2/s$ or m/s)

Figure 5-1: TYPICAL SOLID LIQUID VAPOUR DIAGRAM



Although dimensional analysis for v will yield units of velocity (metres per second), this is really a superficial "engineering" velocity. The actual velocity of fluid through a uniform porous soil is expressed as v_s where:

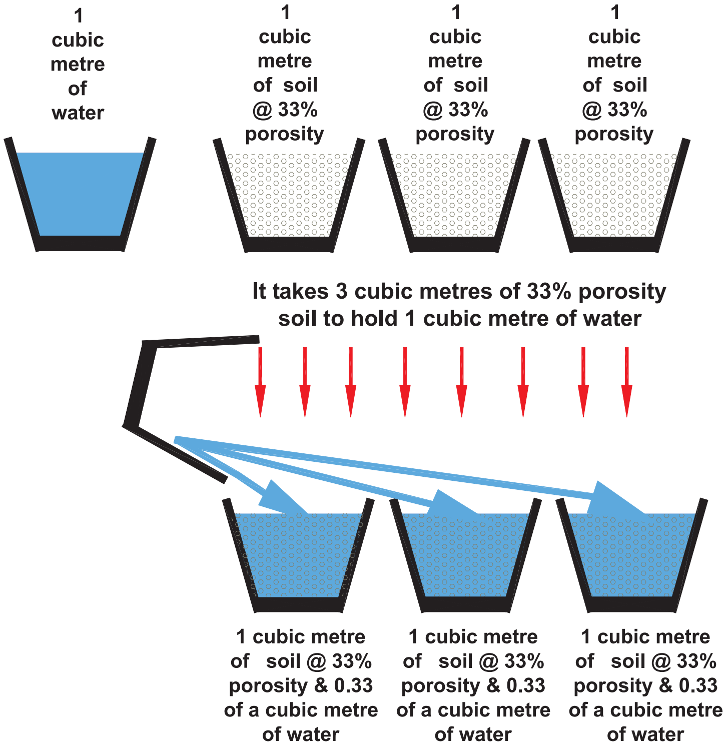
v_s = v / n where
v_s = velocity of fluid (groundwater velocity) through the uniform porous saturated soil (m/s)
v = Darcy flux (velocity) m/s
n = matrix porosity

If one cm of fluid disappears from the surface due to vertical infiltration, that amount of fluid will fill or displace the voids in three cm of soil at 33 per cent porosity (Figure 5-2).

Experiments have shown that Darcy's law is valid for a wide range of soils (Kovacs 1981), and Darcy's law remains the fundamental mathematical expression for describing or measuring the flow of fluid through saturated, porous soils.

This holds true only if the soil is a uniform porous media and *only reflects movement of the actual liquid.* Several other factors need to be taken into account when predicting solute and contaminant migration through soils.

Figure 5-2: ILLUSTRATION OF FLOW THROUGH VOIDS



5.2 Solute and Contaminant Movement through Soil

For the purpose of groundwater protection, consideration must be given to how fluid moves through the soil, as well as to how actual solutes (which could be contaminants) move through the soil profile, with or without the host fluid, usually water.

There are three modes of solute movement in soil:

Advective transport is the movement of solute with the fluid, and can be predicted using Darcy's Law if the soil is a saturated, uniform porous media.

Diffusive transport is the migration of a solute from an area of higher concentration to an area of lower concentration. Diffusive transport can be independent of fluid flow; however, it governs only when fluid flow rates are very low, usually in soils of very low permeability.

Dispersive flow (mixing) occurs when fluid flow rates are high, usually in soils for very high permeability, such as aquifers.

Adsorption is the chemical or physical attachment of solutes to the soil. Some solutes are adsorbed by the soil as they pass through the soil matrix, thus the soil acts as a filtering mechanism that attenuates the movement of solutes. Biological effects are due to naturally occurring organisms in the soil that feed and convert naturally occurring solutes from one form to another.

5.2.1 Fractured and Non-Fractured Soil Conditions

Darcy's Law applies to water flow through saturated uniform porous media, including low permeability materials that confine aquifers (aquitards). Provided aquitards are uniform, they provide natural protection to aquifers.

In Western Canada, fractures in surficial soils are common. Fractures are non-uniformities in the soil that can be interconnected and act as tiny preferential flow paths that allow fluid, and solutes, to move more rapidly through the soil profile than would be expected for a uniform soil. In many cases, the effect of fracturing is sufficiently accounted for by measuring bulk, *in situ*, k values for use in Darcy's equation. In order to rely on natural soil aquitards to provide groundwater protection, the presence and effects of fractures in the soil must be measured, or otherwise taken into account.

5.3 Defining Geologic Categories for Earthen Manure Storages

5.3.1 Predicting Environmental Performance

To accurately predict the environmental performance of an earthen manure storage (EMS) structure, the engineer must consider the existing conditions, and account for the mode of transport mechanisms that most likely govern the seepage of fluids and contaminants from the storage. Although computer programs have made the calculations for such an analysis easier, great care must be taken to ensure that input values used are relevant.

In a study completed by Barbour (2000), the key mechanisms for contaminant release were identified and a sensitivity analysis of the key parameters controlling performance was carried out for a hypothetical EMS located in uniform conditions. The study evaluated vertical flow through a natural clay barrier protecting a lower confined aquifer. The complete report for this is found in "A Study of Solute Transport from Earthen Manure Storage," by GEONET Consulting in March 2000, written as a supporting document for these guidelines.

The key process identified from simple interpretations of EMS performance is transient seepage into a surficial layer followed by vertically downward contaminant transport through the underlying natural clay barrier. Seepage from the EMS will define the extent (geometry) and concentration of the 'source' for subsequent transport through the natural clay barrier. The 'source' is really the 'shadow' of the EMS that develops as a result of infiltration, and lateral flow from the EMS. The geometry and concentration of contaminants within this 'shadow' will vary depending on the nature of the surficial geologic formation (thickness, soil-water characteristic curve, unsaturated hydraulic conductivity, depth to the water table, operation of the EMS, and so on).

Analytic and semi-analytic calculations can predict transport through fractured or non-fractured soils under steady state flow conditions. By assuming the contaminant concentration and geometry of the source, it is relatively easy to compare the key parameters and material properties controlling transport through the clay barrier, namely:

- hydraulic conductivity “k” (m/sec)
- hydraulic gradient “i” (m/m)
- Darcy flux (hydraulic conductivity multiplied by hydraulic gradient) “v” ($m^3/m^2 \bullet$ sec)
- matrix porosity “n”
- coefficient of molecular diffusion “D*” (m^2/yr)
- coefficient of mechanical dispersion “Dm” (m^2/yr)
- dispersivity “α” (m)
- fracture Spacing “S” (m); and
- adsorption of the original contaminant.

The GEONET study reviewed and compiled data from existing studies of Western Canadian soils, geology and hydrogeology. Data was compiled for:

- hydraulic conductivity “k” (m/sec)
- matrix porosity “n”
- coefficient of molecular diffusion “D*” (m^2/yr)
- coefficient of mechanical dispersion “Dm” (m^2/yr)
- fracture spacing “S” (m) and aperture

5.3.2 Analytic Process and Assumptions

Groundwater velocity is calculated as the Darcy flux divided by the matrix porosity. Consequently, porosity is significant in the prediction of velocity. Porosity has little effect on diffusion dominated systems, but is quite significant for advection dominated systems.

The matrix porosity of consolidated clays and tills varies over a relatively small range, 0.2 to 0.4 and is assumed to be the same for both fractured and non-fractured soils. For the purpose of these guidelines, a value of **0.3** is considered suitable.

A reasonable range for the coefficient of molecular diffusion is from 0.003 to 0.01 m^2/y. Sensitivity analysis using values of .003, .01, and .03 m^2/y determined that results are not overly sensitive to this value, and a value of **0.01** is considered representative for Western Canadian conditions.

The coefficient of mechanical dispersion in the direction of groundwater flow is the product of velocity, and a mixing length, referred to as the dispersivity. This parameter is the result of an ‘apparent mixing’ that occurs due to velocity variations within the porous media. Values of dispersivity range from 1/50 to 1/100 of the travel distance (Gelhar *et al*. 1992). A value of dispersivity equal to **0.1 m** is considered appropriate (Woodbury, 1997).

Fracture spacing controls the equivalent hydraulic aperture, and consequently the velocity of flow within the fracture. In general, fracture spacing is small near the surface and increases with depth within the deposit as over burden pressure increases, and the deposit is more isolated from freeze thaw and wet dry cycles.

Numerical simulations used to assist development of these guidelines used chloride as the source. Chloride is not attenuated by adsorption and the results can be considered conservative since most solutes of interest for manure storage would be subject to some degree of adsorption.

5.3.3 Defining Geologic Categories

Fundamental to site characterization guidelines is defining the geologic categories and the storage performance requirements that ensure water resources are protected. Based on the life of manure storage structures, a performance objective of not exceeding a relative concentration of 10 per cent for a conservative species after 50 years is considered adequate. The definition of a **geologically secure** site must, therefore, meet this requirement.

Simulations of contaminant transport from earthen manure storage identify a range of favorable geologic conditions that can be expected to occur in Western Canada. Of key importance to the simulations is the ability to ensure that site conditions meet criteria to conclude that the system will behave as an equivalent porous media (EPM) transport system (GEONET Consulting, 2000).

Under certain conditions (fracture spacing, aperture and bulk k) fractured porous media can be simulated as EPM. This allows the site to be analyzed as advection or diffusion dominated, and several conclusions can be drawn.

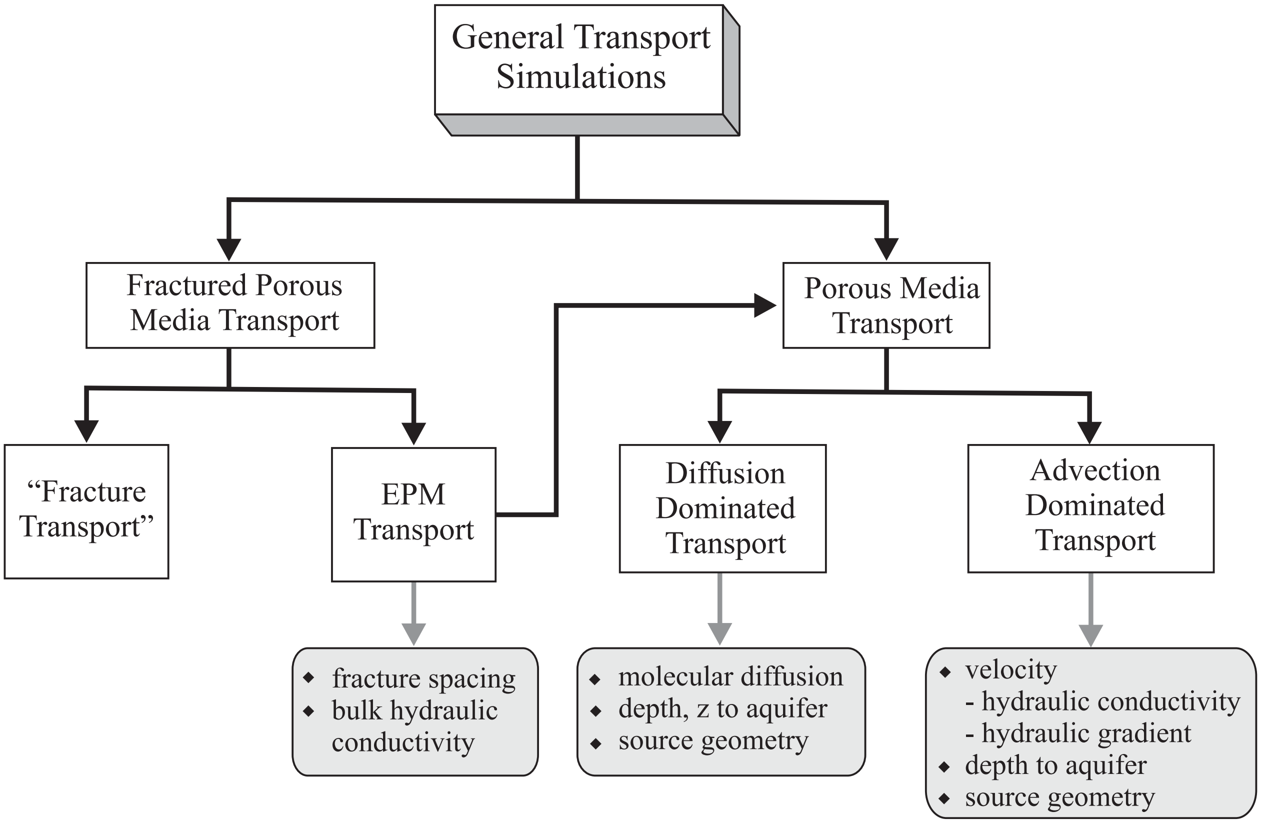
The key issue in advection-dominated systems is the effect of groundwater velocity on transport.

The properties and parameters of particular concern, therefore, are the hydraulic conductivity, hydraulic gradient, and porosity. The minimum necessary depth to an aquifer can then be estimated based on the performance objectives such as time for arrival of a target concentration of solute or contaminant.

The analysis for both diffusion and for advection must be completed and compared in order to determine if the system is advection or diffusion dominated.

Figure 5-3 outlines the steps required to define these requirements.

Figure 5-3: GEONET, March 2000
TRANSPORT SIMULATIONS



The plot in Figure 5-4 illustrates the depth of travel for a 10 per cent target concentration of chloride over time frames of 50, 100 and 200 years. The straight lines illustrate the distance that contaminants travel under advection alone, while the curved lines account for diffusion as well. Given that chloride, a conservative species with respect to movement, was used in the simulation, along with the conservative assumptions for the parameters used in the calculations, a time frame of 50 years is considered an appropriate performance objective.

Figure 5-4 will be used to guide the definition of **geologically secure** sites.

Using a performance objective of not exceeding relative concentration of 10 per cent after an elapsed time of 50 years, then a site with a potential groundwater velocity of 0.15 m/y would require a minimum aquitard depth of 10 m.

Decreasing the groundwater velocity by an order of magnitude does not reduce the minimum depth by an order of magnitude.

If values outside the above parameters exist, or if solute flow though the soil matrix cannot be modeled as equivalent porous media, the engineer must complete detailed engineering calculations and justification for the proposed design.

The interpretative graphs and flow chart provide a means to classify sites. Once sites are classified, guidelines for engineering design and construction can be applied (Table 5-1).

The site categories, **geologically secure**, **geologically variable** and **geologically sensitive**, are defined as follows.

Geologically secure sites have the following minimum characteristics:

- The groundwater velocity (Darcy flux divided by matrix porosity) must not exceed 0.15 cubic metres per square metre per year. This value accounts for hydraulic conductivity of the natural soil aquitard and for the hydraulic gradient of the overall system. For a scenario where the hydraulic gradient equals one, and the porosity equals 0.3, the acceptable soil hydraulic conductivitiy would be equal to, or less than, 10^{-9} m/sec.
- Given these conditions, Figure 5-4 shows that a 10 per cent relative concentration of chloride would take at least 50 years to penetrate 10 m below the manure storage. The engineer must ensure there is sufficient background research (Section 4.0) and site data to reach this conclusion.
- The floor of the storage must be separated from any usable groundwater resource by at least 10 metres of uniform aquitard. Uniformity of the aquitard is crucial to ensure that the actual site conditions meet the conditions of equivalent porous media. Engineers must recognize the precision of actual site data, and provide sufficient factors of safety to protect sensitive receptors.

Geologically variable sites are sites where background data and/or actual site conditions do not meet the minimums of **geologically secure** sites.

Geologically variable sites are often sites with:

- a relatively well defined regional groundwater supply underlying the site;
- variable surficial geologic conditions (often post glacial deposits), such as fractures, layering, sand lenses, or a soil matrix with a high bulk hydraulic conductivity underlain by a natural aquitard; or
- insufficient depth of natural aquitard to provide adequate ground water protection, but sufficient presence of natural aquitard to enhance the safety of engineered groundwater protection systems.

Geologically sensitive sites are sites where:

- a usable groundwater supply is readily identifiable and there is insufficient, or no aquitard separating the floor of the manure storage from the usable groundwater resource, or
- a complex geologic condition, such as fractures, layering, sand lenses, exists and there is no natural aquitard.

Geologically sensitive sites will require advanced design solutions such as positive containment and protection systems.

Figure 5-4: TRANSPORT DEPTHS

Transport depths for a 10 per cent concentration at elapsed times of 50, 100 and 200 years. (Case: D*=0.01 m^2/y, α = 0.1 m and n = 0.3)

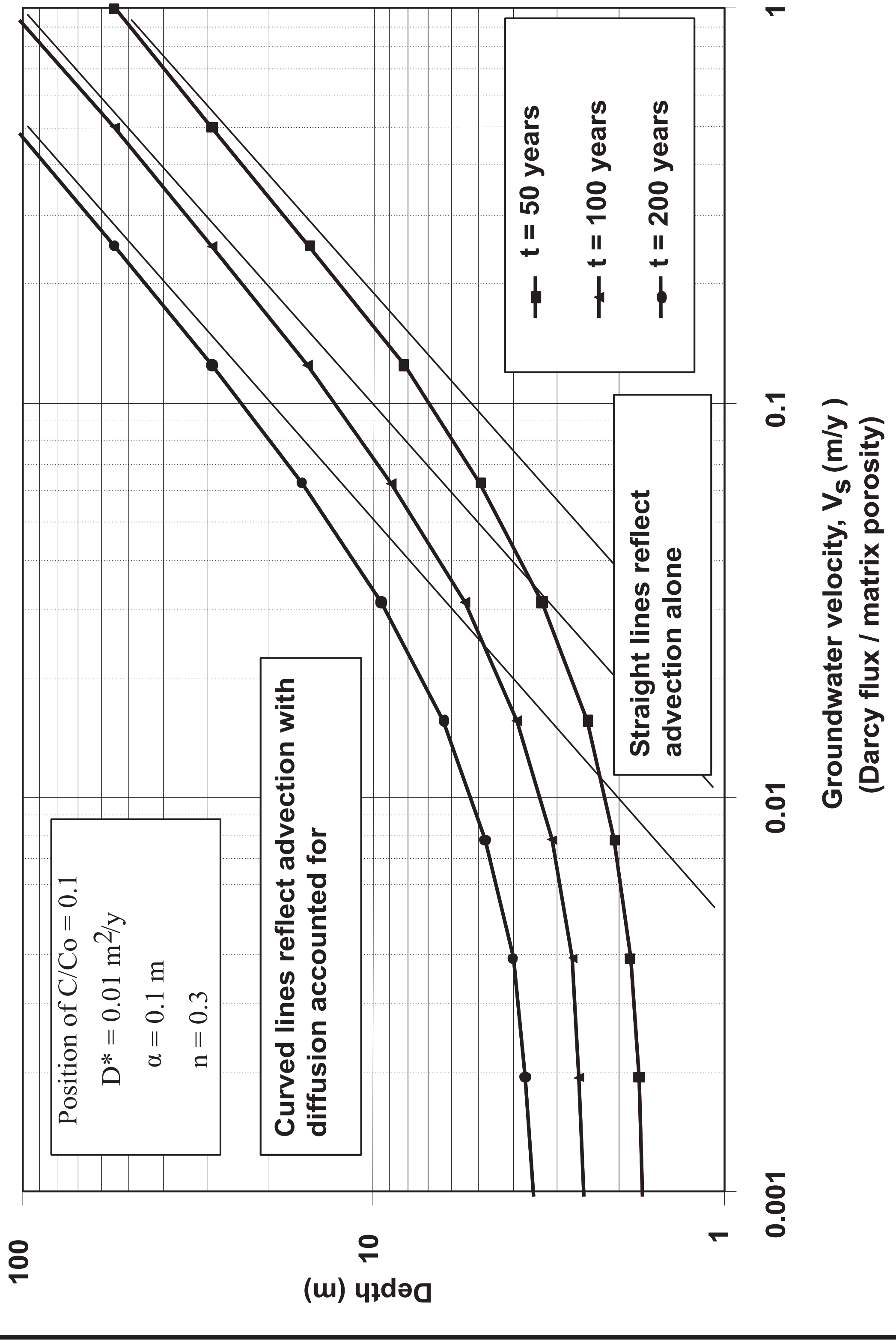


Table 5-1 Geologic Site Categories

CATEGORY	GEOLOGIC & HYDROGEOLOGIC SETTING	MINIMUM DESIGN STANDARDS	MINIMUM CONSTRUCTION CRITERIA	MONITORING PLAN
GEOLOGICALLY SECURE	The floor of the manure storage must be separated from a usable groundwater resource by a uniform aquitard at least 10 metres thick. The Darcy flux divided by matrix porosity through this minimum aquitard shall not exceed 0.15 cubic metres per square metre per year.	Engineering calculations are required to confirm the minimum criteria.	Over excavate any isolated sand lenses encountered and replace with compacted clayey material. Scarify the sub grade to a depth of 15-20 cm and recompact. Provide suitable erosion protection for inlets and agitation.	Usually not required due to soundness of the site, but may be required at the discretion of the regulatory agency.
GEOLOGICALLY VARIABLE	The manure storage will be located in a surficial geologic formation with non-uniform conditions. An aquitard with uniform conditions exists between the surficial geologic formation and any usable groundwater resource.	Control of lateral flow is required. Compacted clay or synthetic liners are suitable design options. Calculations and design drawings prepared by a registered professional engineer must support the design.	Construction is completed according to plans approved by a registered professional engineer. Quality control and inspection during construction by a registered professional engineer is required. As constructed engineering reports may be required by the approving authority	Monitoring facilities may be required. Install wells according to standard engineering practice. The regulator may require a monitoring and reporting plan.
GEOLOGICALLY SENSITIVE	Complex geology with inter bedded clay and sand or gravel strata and there is insufficient or no aquitard separating the floor of the manure storage from a usable groundwater resource.	Engineered steel or concrete storage structures are suitable alternatives. Earthen manure storage options are limited and require advanced design including synthetic or composite liners, collection systems and extensive monitoring. Calculations and design drawings prepared by a registered professional engineer must support the design. Advanced seepage analysis (such as computer modelling) may be required.	Construction is completed according to plans approved by a registered professional engineer. Quality control and inspection during construction by a registered professional engineer is required. As constructed engineering reports, including construction monitoring reports may be required by the approving authority.	Submit a ground water monitoring plan for approval (timing, locations and frequency, reporting and measured analytical parameters) that will address design and site specific criteria.

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