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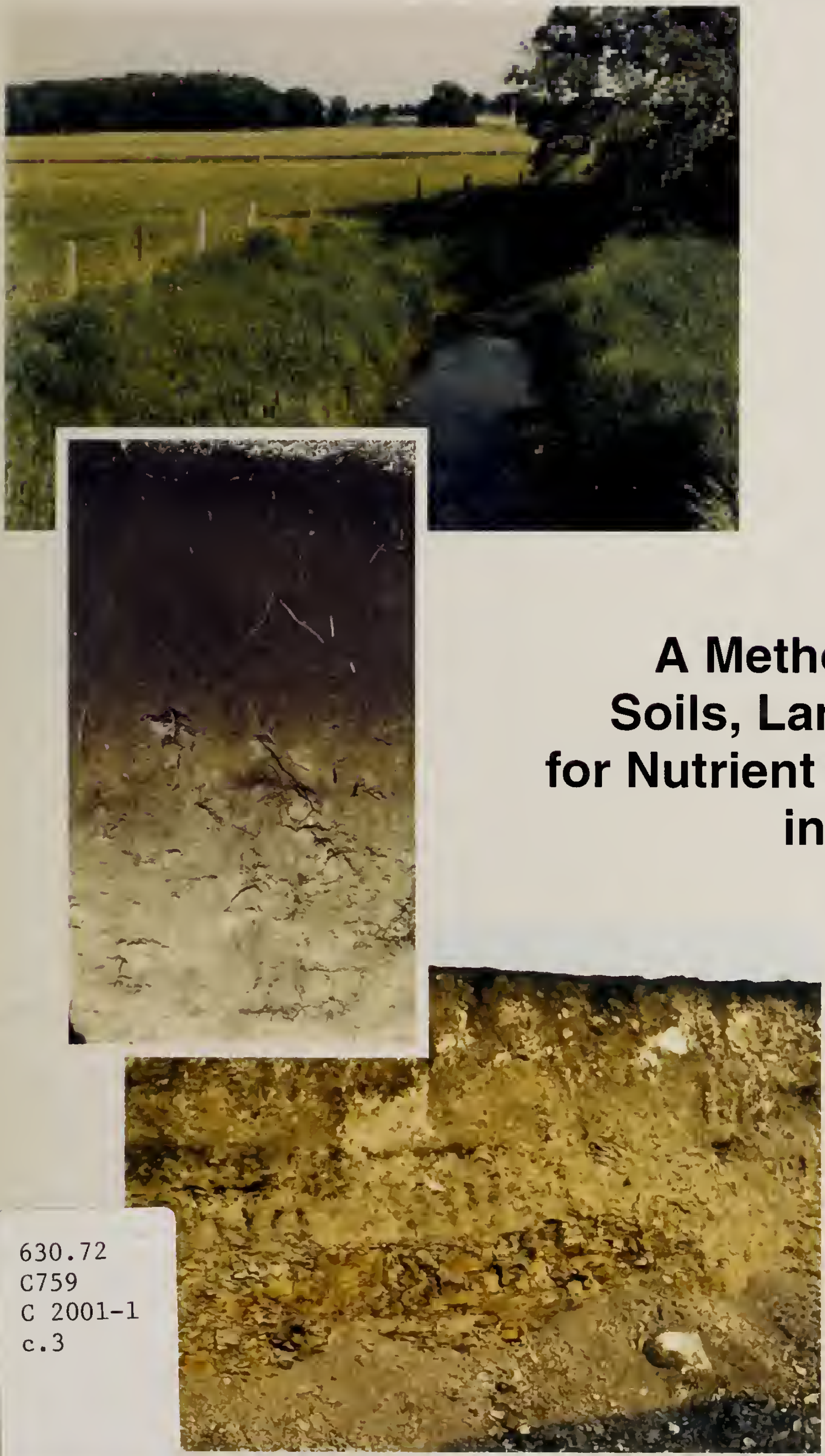

A Methodology for Evaluating Soils, Landscapes and Geology for Nutrient Management Planning in the Prairie Landscape

R.G.Eilers and K.E. Buckley (eds)
Agriculture and Agri-Food Canada

Canada

Research Branch
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A systematic approach to land based decision-making with standardized resource data bases, digital map information, manure management research and farm practices guidelines using GIS as a decision support tool.

A project supported by the Hog Environmental Management Strategy (HEMS)

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Canada

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EXECUTIVE SUMMARY

This bulletin describes the development of a standard methodology for evaluating soil suitability for nutrient management in the prairie landscape, specifically related to the application of swine manure. The procedure involves the integration of soil, landscape and geological information to define environmental sensitivities and thus highlight management requirements to sustain soil and water quality. Resource information for both soil and geology has been standardized and integrated to define a series of nine soil management groups (SMGs). Example maps depicting the various components and the resultant soil management groups have been developed for three test areas encompassing rural municipalities or portions of counties in Alberta, Saskatchewan and Manitoba.

The main functions of this methodology are firstly, to provide a standard description of the land resource base in terms of environmental limitations, and secondly to serve as a decision support mechanism to link users directly to management information such as provincial farm practice guidelines through a menu-driven interactive process. The methodology will be used by resource specialists and land use planners at the provincial and local municipal level and will be applied at a broad level in the planning process. This decision support system is intended to assist resource specialists and planners in making environmentally sound decisions for the purpose of siting swine production units and in making recommendations for application of swine manure to the land base in an environmentally sustainable manner. The Research Branch in collaboration with the Prairie Farm Rehabilitation Administration (PFRA), Natural Resources Canada (NRCan), and provincial resource specialists, developed this evaluation methodology using expertise in pedology, geology, hydrology, meteorology, soil chemistry, land use and manure management.

The methodology is based on the premise that more and better use can be made of existing albeit limited technical resource information for land use planning purposes. By applying standard scientific principles and concepts to resource database information, a rational, systematic description of land units has been developed for land use planning. However, it is not intended that site specific approval and development be by-passed in this process.

This bulletin fulfills the initial objectives of the original study, namely:

i) to develop standardized structure for:
- soils data base and maps at 1:100 000 scale
- geological (drill log and water well) data base and surficial geology maps at 1:250 000 scale
- climatic risk maps for the prairie region

ii) to develop a standard protocol for integrating resource data to define the environmental sensitivities of soil landscapes, and

iii) to propose a user-friendly method of linking resource constraints to relevant management information using geographic information system technology.

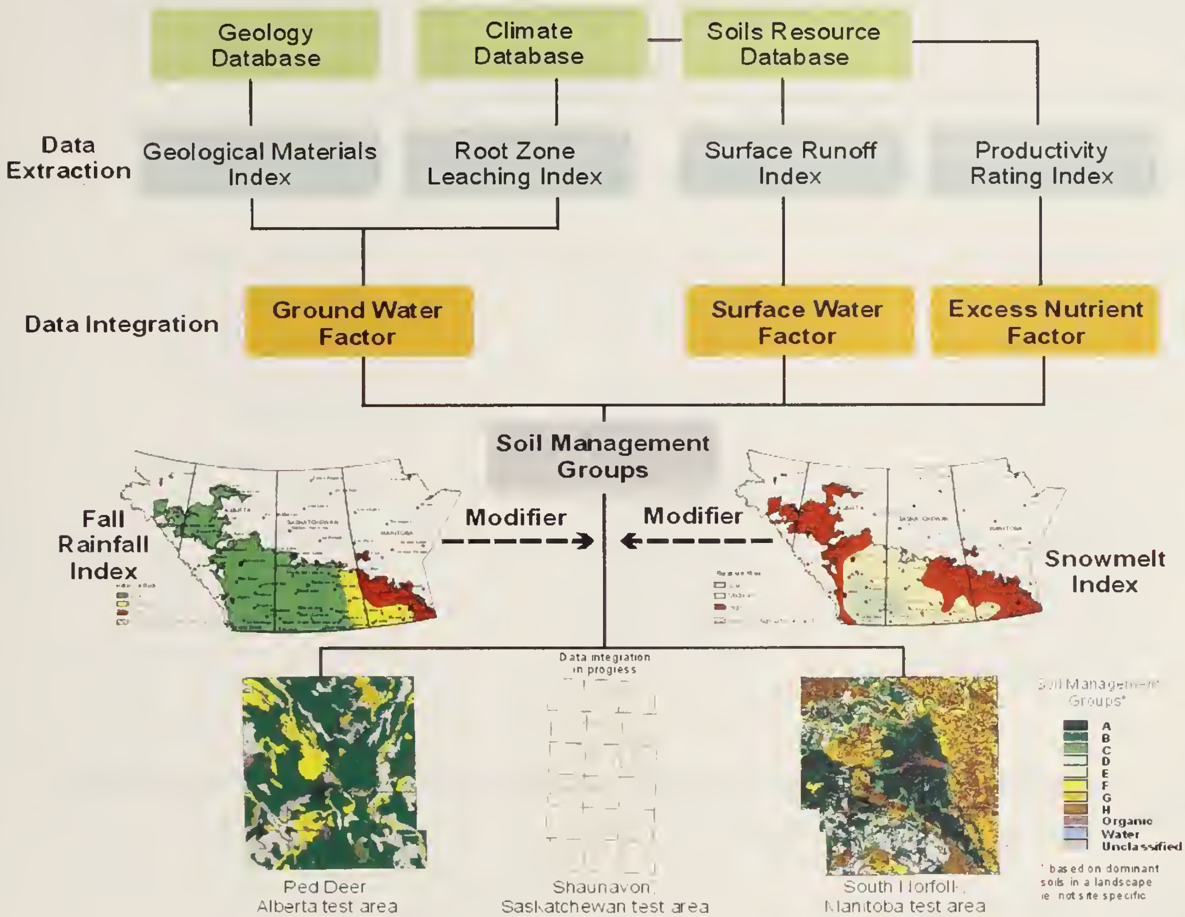
This project has resulted in the development of a system to rate soils and landscapes in terms of the three major factors which influence risk to the environment. These are the soil nutrient factor, the surface water factor and the groundwater factor. These three resource factors are combined in a matrix fashion and subsequently grouped into a nine soil management groups (SMGs) based on similar kinds and seriousness of limitations. The final groupings can be presented in map or report format. The derivation of SMGs is based on intrinsic properties of the soils, landscapes and surficial geology which are available in electronic and geographic information system databases. Data integration is based on the assumption that the physical environment can be described in terms of sensitivity factors for soil and water quality.

Nutrient Factor - based on the assumption that highly productive soils will have the best capacity to store and supply nitrogen (N) to planted crops, and thus, minimize the potential to have N in excess of crop requirements in the soil profile. This factor uses a sub-component of a soil productivity rating system to assess land suitability for spring seeded small grains. The soil information is derived from detailed databases for soil series in each province.

Surface Water Factor - based on the geomorphic characteristics of the land surface, incorporates an index for risk of surface runoff derived from the soil and landscape database (including properties such as the soil erodibility, slope length and slope steepness).

Groundwater Factor - based on geologic drill logs, water well data and surficial geology, incorporates a Soil Leaching Index derived from the soil database (soil profile - 0 to 1 m), combined with a Geologic Materials Index derived from a standardized drill log database (describing the type, thickness and permeability of geologic materials).

Each SMG can be treated as requiring unique management considerations. The user will be able to work through the methodology by interacting with menu-driven linkages to the appropriate databases describing the resource limitations, and the management considerations. Management guidelines and regulations will be those as provided in farm practices fact sheets and publications, and include information such as provincial set-back and manure application guidelines. The menu links to maps which indicate likelihood of adverse seasonal weather conditions, tables describing manure type and quality, methods of manure applications, rates of applications, timing of application, and example cropping systems that would optimize nutrient uptake and biomass production.



Summary of resource based analysis and data integration to derive Soil Management Group maps.

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I. INTRODUCTION *(R.G. Eilers, K.E. Buckley, K.W. Thompson)*

There is an urgent need for environmentally sound planning for the expansion of the swine industry on the Prairies. This has raised many questions about the adequacy and use of available resource information and expertise in providing answers to questions of appropriate land use.

Land use regulation is the responsibility of the rural municipalities in Saskatchewan and Manitoba. Alberta has recently transferred that responsibility to Natural Resource Conservation Board. Often the expertise required to assess environmental concerns is not readily available to municipalities. Frequently, there are too few, or no guidelines at all, for interpreting available resource information such as soils and geology.

The Hog Environmental Management Strategy (HEMS) project was undertaken to provide a first level evaluation of soils and other resource information for use by land use planners. It provides a systematic approach for interpreting and displaying available information about the characteristics of the soils and geologic materials in municipal districts and counties. The methodology will facilitate initial screening of potential areas for locating intensive livestock operations. However, individual site approvals will still require detailed site investigations.

A. Background

The Canadian swine industry generates more than $3 billion in farm income and contributes significantly to employment of primary producers and in the pork processing industry. Pork and swine exports currently represent $1.5 billion, or eight percent, of all agri-food exports in Canada (AAFC, Hog Environmental Management Strategy, February 1998). The swine and pork industries also demonstrate growth potential in the agri-food sector. This expansion is an important component of the agricultural economic diversification taking place on the Prairies. It has lead to a significant shift in the size and management of the traditional swine operation as well as rapid growth in associated technology.

Because of this rapid increase in production, there is an urgent need to develop tools to assist in decisions regarding the siting of operations and the suitability of the land base for manure management and application. Manure is a by-product and therefore a cost to production. On the other hand, manure represents a potential source of nutrients for annual crop and forage producers, as well as a source of organic material for soil amendments. Animal manure management is both an agricultural and environmental issue. It's an agricultural issue because of the recent, and projected rapid, increase in swine, cattle and poultry production on the Prairies. It is an environmental issue because intensive livestock operations (ILOs) produce large quantities of manure in a very small space. This manure must be moved and managed in some economical and environmentally acceptable way. Large volumes of manure realistically and practically can only be managed by returning it back to the land in some form at both economical and environmentally acceptable rates.

Inappropriate rates, timing and methods of manure application to any soil and landscape may result in concerns for surface water and groundwater quality. In addition, nitrogen losses through volatilization represent an economic loss to the producer and a deleterious addition to the atmosphere. It should be acknowledged that although this study recognizes the importance of greenhouse gas emissions as well as odour from both barns and fields during and after application, it does not deal directly with these issues. However, some mitigation may be provided through management activities for processing and application such as composting and injection.

In view of the rapid increase in the number of ILOs, the timing is critical for the development of a systematic and standardized approach to resource evaluation so planners will have access to the best available pedological, geological and hydrological information. This information will greatly assist decision-makers in evaluating proposed ILOs by providing geo-referenced information about regions of the Canadian Prairies in which soil management and agricultural practices can be designed for safe applications of manure.

B. Scope of the Project

How do we return animal manure "resources" to the field in a manner which will protect and sustain the long term quality of our soil and water, while at the same time enhance land productivity? The timing and rate of application, and quantity of manure applied to the soil must be based on the nutrient demand of the crop and the ability of the soil to store and retain nutrients (specifically nitrogen and phosphorus). The current issue of sustainable manure management, specifically swine manure, will be addressed from the points of view of nutrient management and crop requirement, surface water protection and groundwater protection.

Most of the soil information for the Prairie Ecozone is now in digital format at 1:100 000 scale and available for addressing agricultural and environmental issues using geographic information systems (GIS). Relevant resource information can be generated as printout reports or as generalized maps, to aid land managers in siting ILOs. The land resources will be defined by soil management groups (SMGs) which will be the basis for making recommendations for swine manure application to the soil landscapes.

It must be made clear that the maps will ***not*** be sufficiently detailed for individual site selection. However, the maps will be useful by indicating local environmental conditions to be considered while conducting on-site evaluations.

1. Partnerships

Implementation of the HEMS project required the formation of partnerships, not only among Agriculture and Agri-Food Canada's Research Branch, Policy Branch and Prairie Farm Rehabilitation Administration (PFRA), but also with Natural Resources Canada (NRCan), the three Prairie provinces and the Canadian pork industry. The terms of reference and various responsibilities are outlined below.

- **Research Branch and PFRA:** responsible for project coordination with the three Prairie provinces, industry and Policy Branch to ensure that consistent approaches and methods were adopted. PFRA also assisted with site selection, gathered groundwater and climate information, and contracted for in-house preparation of maps, etc. The Land Resource Group of Research Branch assembled the soil survey data, reconciled inconsistences and provided recommendations on data handling procedures. All relevant data sets were merged to provide interpretations useful to land use planners and industry.

- **Provinces:** participated to varying degrees in all phases of the project, including test area selection and development of communications strategies. The provinces also participated in the standardization of the soils and geological resource data sets for the project.

- **Industry:** involved throughout the program to ensure that the end results would be useful for its requirements. Industry also participated fully in the development of the communications strategies.

2. Anticipated Benefits

Developing the swine industry to its full potential depends largely upon sustainable and environmentally sensitive growth. Achieving this systematic development relies on planning to identify appropriate manure management practices. Planning requires an understanding of environmental conditions and their interactions. Standardizing this information across the Prairie region would make the assessment of potential growth areas for the swine industry much easier. Adopting a consistent measure of determining environmental risk for all regions of the Prairies will improve public awareness of the issues facing the swine industry as a whole.

Demonstrating the use of a consistent, methodical approach to swine development across the Prairie region delivers a very positive message. Responsible producers and governments working together to provide rational land use plans which address environmental issues will facilitate sustainable development, and protect the Prairie public as well as foreign interests. The increasing importance of an exporter's production reputation to foreign consumers reveals an additional need to be on solid footing environmentally. In addition, the work and partnering with provincial governments and agencies in gathering applicable data will be useful to many sectors within the agriculture and agri-food industry by facilitating consistent approaches to agricultural development and providing information for all levels of governments, industry, producers, non-government organizations (NGOs) and investors.

3. Project Outputs

Information disseminated from this study has been assembled in a highly co-ordinated manner involving the federal and provincial governments and industry. Numerous activities have been undertaken to promote awareness and transfer of this technology (Appendix A). This function was an integral part of this project, intended to optimize the understanding of the procedure and minimize the potential for misinterpretation of the data.

The following messages must be clear.

- The data as presented represents an indication of the levels of management that may be required for soils in a specific area.
- The data should not be used to evaluate a specific site. Specific sites will require a detailed investigation using the same methodology.

- The baseline soils and geologic data are suitable for generalized, wide applications for all types of land use planning and development - not just manure management.
- This bulletin describes a standardized methodology based on current knowledge and the rationale used to define the soil management groups and develop appropriate management options for each group.
- Standardized structures for soils and geology from water well drill log data bases across the Prairies will facilitate and enhance data sharing.
- Examples of standard maps and report products showing the integrated data variables are provided for three test areas.

C. Objectives

The main objective of this project was to develop a standard methodology (a decision support tool) for assessing soil suitability for swine manure application on prairie soils and landscapes. Five sub-objectives were established.

1. To complete and standardize databases for digital soils maps at 1:100 000 scale for the test areas in a manner that can be applied across the Prairie Ecozone.
2. To standardize the geological and hydrological database for application of a Geological Materials Index (GMI) appropriate to a scale of 1:100 000 for the Prairie Ecozone.
3. Organize climate data for probability analysis of extreme events for the early, middle and end of growing season in the Prairie Ecozone.
4. Develop a standard protocol for integrating each of these data sets to define soil management groups (SMGs). Each group is to be defined by dominant environmental factors requiring appropriate management practices and considerations for environmentally sustainable application of swine manure to both agricultural and non-agricultural prairie soils and landscapes.
5. To propose a user-friendly decision support mechanism for linking resource constraints to management research and farm practices guidelines.

1. Conceptual Framework

In the broadest sense, the issue of sustainable manure application to land is dependant on:

- the capacity of the soil to accept, retain and supply soil nutrients for crop growth,
- the topographic conditions that affect surface water runoff to depressions or surface water bodies, and
- the properties of the soils and geologic materials which will restrict leaching to groundwater aquifers (Figure 1.1).

The type of manure, method of application, type of crops to be grown, properties of the landscape and soils and proximity to surface and groundwater are important considerations in protecting the environment. The issues of odour and greenhouse gas emissions are not addressed directly but rather indirectly through the management options for manure.

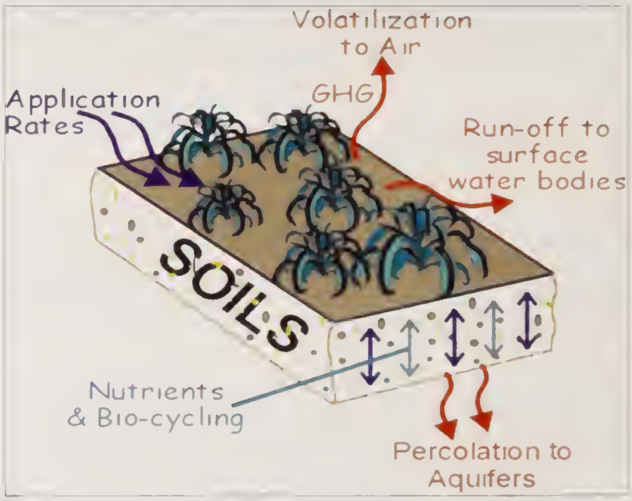

Figure 1.1 Fate of manure nutrients applied to the landscape.

The key concepts can be summarized by the following function:

$$\textbf{Land Use Considerations} = \int (\textbf{soils} + \textbf{geology/hydrology} + \textbf{climate} + \textbf{manure management})$$

For this equation, the elements are defined below.

Soils - includes the identified soil types and their spatial distribution in the landscape, their physical and chemical characteristics that determine leaching potential (textures), runoff potential (slope steepness and length), and nutrient retention capacity (organic matter, salinity, pH, etc.). Highly pervious soils, sloping soil landscapes, soil drainage/moisture regimes, productivity, etc., need to be considered.

Geology/Hydrology - includes characteristics of geologic materials, surface water bodies and groundwater aquifers. Type, texture, depth and permeability of surficial deposits, from drill log databases, combined with presence, persistence and proximity to surface water bodies, depth to groundwater tables, etc.

Climate - includes temperature and precipitation, probabilities of extreme events during spring, mid-season and post harvest. Precipitation intensity exceeding infiltration influences the risk surface runoff and precipitation amount exceeding available soil storage capacity adds to the risk of deep leaching.

Management - includes generally accepted practices of manure production, storage and handling, nutrient status, rates and times of applications, crop types and rotations. Crop types will determine methods of application and amount of nutrients required. For example, pastures, woodlots and forage crops would not be considered suitable for injection systems. Vegetable crops and forages may not be suitable for irrigation systems. Stage of crop growth and soil temperatures (e.g. frozen surfaces), need to be considered in calculating rates and timing of application respectively.

Application of manure should be based on considerations for surface water and groundwater factors and on the plant/crop nutrient demand, minus the inherent or residual soil nutrient status, and the nutrient content of the manure.

Manure Nutrient application = crop demand - available soil nitrogen supply

Although this treatment deals specifically with nitrogen (N), inferences can be made to other nutrients such as phosphorus (P) and potassium (K). The management of P for example, is a major issue for sustaining water quality (Sharpley et al. 1999). The potential build-up of any nutrient in, or added to, the soil varies with soil type and conditions. A risk rating procedure for P, developed in the United States (McFarland et al. 1998), is briefly described in the management section of this bulletin.

2. Framework application

The application of this framework is directed toward optimizing the use of swine manure to enhance crop production while minimizing the risk to surface water and groundwater quality. It should be applicable at all scales for the Prairies and may well be adaptable to other regions of Canada. The weighting factors for individual components may vary from place to place in relation to the scale of the resource information databases including climate and the type of cropping systems and animal production units. However, it should be recognized that most animal manure will return to the land in some form, whether raw or processed.

The prime consideration in this framework is to make the best possible use of existing information in a geographic information system (GIS), and link it to relevant provincial management guidelines. The technology is available in many locations, but the information must be presented in a manageable form. GIS analysis will aid in developing manure management plans for producers (Quade et al. 1998). The issues to be addressed by this decision support methodology include: protection for surface water and groundwater, estimation of the nutrient capacity of soils, and management options for manure. A schematic showing the conceptual integration of these components and the link to management is shown in Figure 1.2

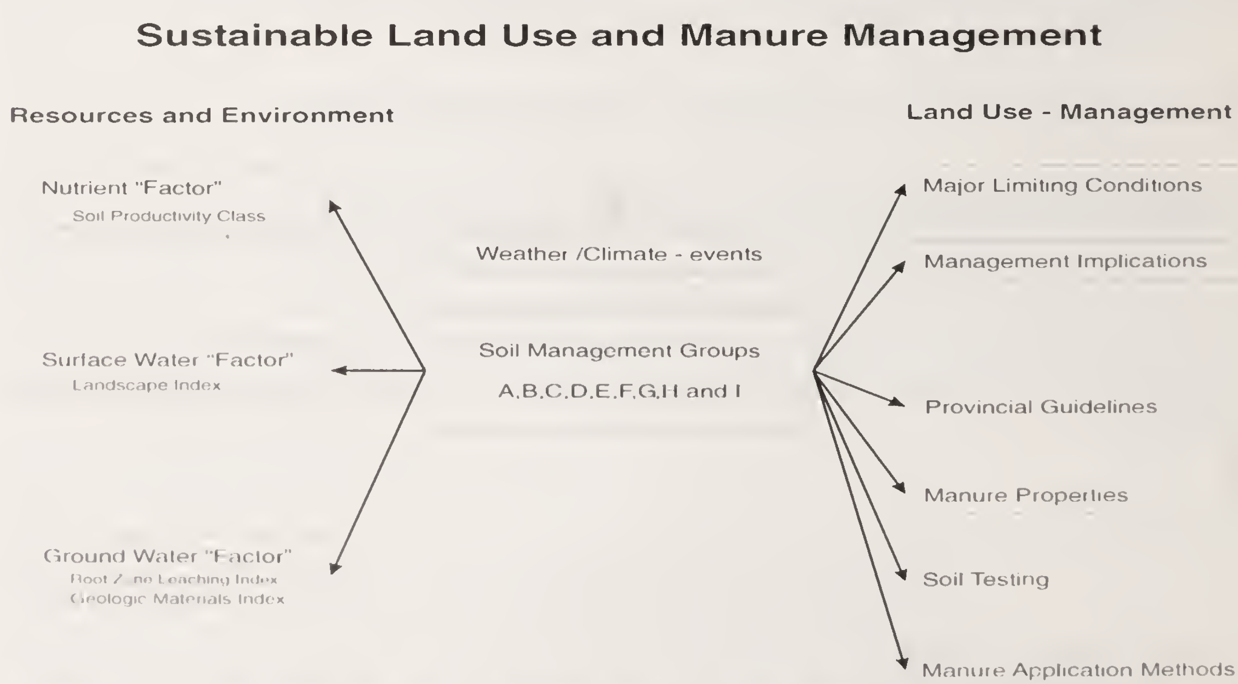

Figure 1.2 **Conceptual model for a decision support mechanism, integrating resource information, to define soil management groups according to their environmental susceptibility and linkage to land use and farm practices guidelines.**

D. Methodology

For the past 60 to 80 years, information on soils, geology, hydrology and climate has been collected for the agricultural region of the three Prairie provinces. Numerous agencies and government departments have been involved in the collection, cataloguing, storage and publication of this data. The data was collected by a wide range of expertise, and for widely differing reasons, applications and uses. The rationale for collecting the data ranged from the need for characterization of broad land areas to highly detailed, site-specific purposes. Consequently, a wide range of systems, definitions and publications resulted.

The original objectives and applications for the majority of this data was related to agricultural development for crop and livestock production potentials. For the most part, the data has been used as separate databases for specific applications. However, in more recent times there has been the need to evaluate land capability, not only for the sustainability of crop and livestock production, but also to assess the sustainability or impact of various agricultural practices on the natural resources themselves. With the advent of computer technologies "high tech tools", such as simulation modeling and geographic information systems, there is an opportunity to improve land use decision-making by interpreting these electronic data sets to assess and minimize the risk to the natural resources.

1. Selection of Study Areas

One of the first activities of the steering committee was to select several localities from the Prairie region for development and testing of this decision support framework. Selection criteria was that there be a range of soils, geology and climate conditions and that these areas have some interest in using computerized resource databases for ILO planning. With the cooperation and support of provincial agriculture and resource staff, three sites were selected (Fig. 1.3).

Alberta

The County of Red Deer, west and south of the city of Red Deer, was selected. The 20-township area includes Townships 34 to 38, Ranges 28 West of 4^{th} to 3 West of 5^{th} meridian. The area is primarily in the Thick Black soil zone, grading to Dark Gray along the western edge.

Saskatchewan

The study area consists of two rural municipalities (RMs) in the Shaunavon area, in the southwestern part of the province. It includes RM 78 Grassy Creek, Townships 6, 7, & 8, Ranges 16, 17, & 18 West of 3rd meridian, and RM 108 Bone Creek, Townships 9,10 & 11, Ranges 16, 17, & 18 West of 3rd meridian. The project is within a slightly more arid portion of the Brown soil zone.

Manitoba

The selected area was the Rural Municipality of South Norfolk, which includes Townships 7, 8, and 9 and Ranges 8, 9 and part of 10, west of the prime meridian. This site is in the more humid portion of the Black Soil Zone.

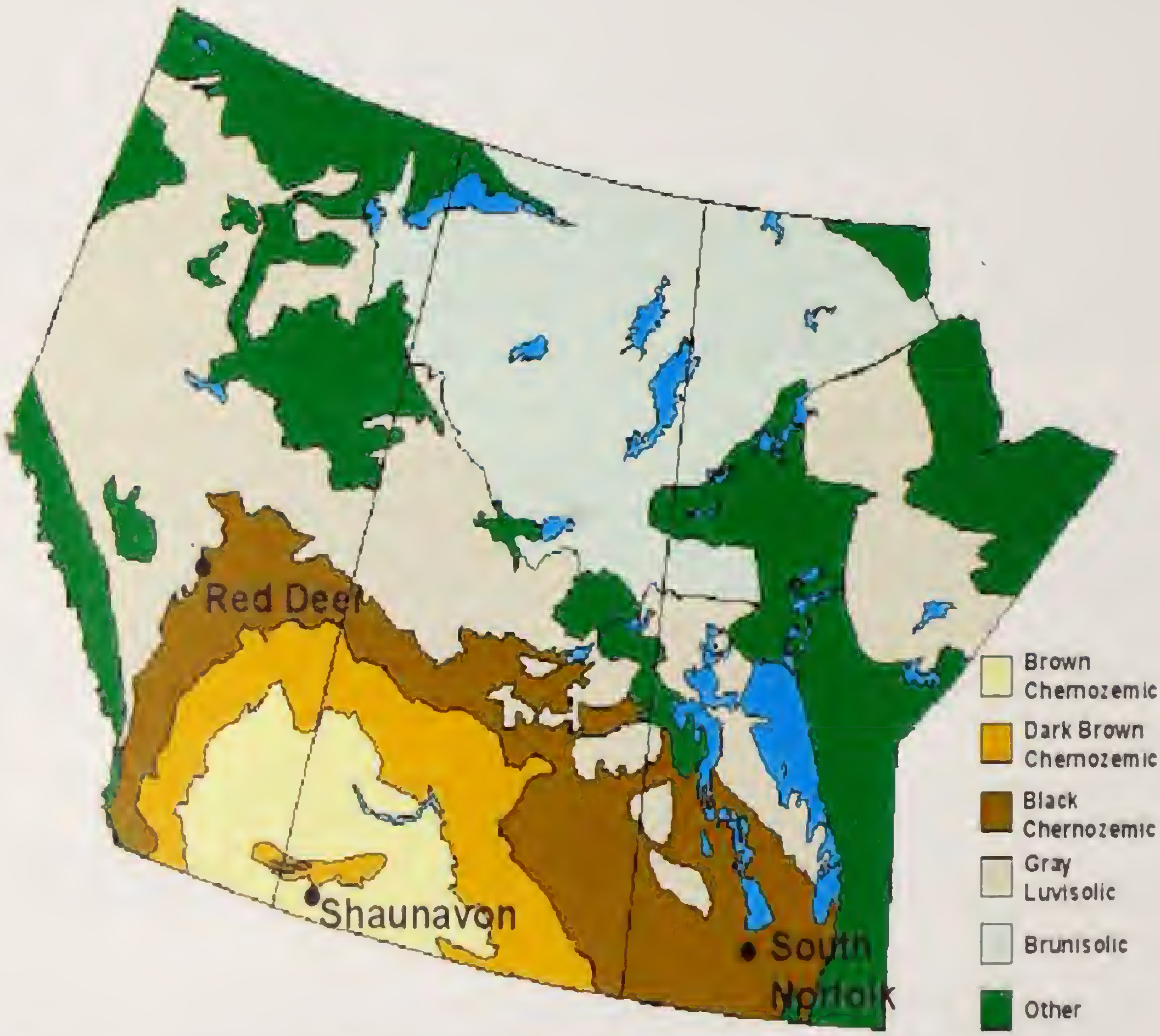

Figure 1.3 Location of the study sites in Alberta, Saskatchewan and Manitoba.

2. An Overview of Available Resource Information

Soil maps provide the most detailed database for portraying the spatial variability of soil and landscape conditions for Prairie agricultural lands. Map scales vary somewhat from area to area, but the most widely available and commonly used soil maps in the Prairie Ecozone are the reconnaissance maps at 1:100 000 scale.

The areas (polygons) on soil maps delineate intrinsic differences in the spatial distribution of soil and landscape conditions. Each polygon is defined by soil features such as soil types, and their proportional distributions, texture, thickness and drainage. Polygons are also defined by terrain features such as slope steepness and length, and the presence and degree of stoniness, salinity and surface erosion. All of these factors combine to determine the capability or capacity of the soil to produce crops.

Surficial geology maps, hydrology (groundwater and surface water) maps and climatic maps are typically available for this same area but at smaller, more generalized scales (1: 250 000). Typically, these databases have been used to supplement and complement the information portrayed on the soils maps for agricultural uses.

To protect the environment, the impact agricultural practices may have on the inherent quality of the soils, groundwater, surface waters and the air must be determined. These resources can be affected by the nature of the inputs and outputs and the degree of disturbance related to agricultural use.

3. Geographic Information System - Database components

Base Map

All digital soils maps have been registered to the 1:50 000 national topographic base maps available through Natural Resources Canada.

Soils Database

The soils database components include the most recent digital soils information for the agricultural portion of each of the three Prairie provinces. The most common scale is 1:100 000, the typical scale for reconnaissance soil maps in the Prairie Ecozone. Some areas have more detailed soil maps (1:50 000, and 1:20 000), but for the first approximation of this technology, the 1:100 000 base has been chosen.

The soils database, although derived and digitized under different programs in each province, is now available for all rural municipalities and counties within the agricultural portion of the Prairie Ecozone. This data set is available from the land resource units or provincial departments of agriculture in each province. Currently, it is not universally available through the Internet, or local federal or provincial websites. It is typically available on individual rural municipality or county boundary bases.

Geological/Hydrological Database

The geology database consists of water well drill log information recorded, collated, maintained and archived by the respective provincial groundwater agencies. This archive is primarily used for evaluating the hydrogeological environment and for assessing quantity and quality of domestic water supplies. It is also used to evaluate the potential impact of agricultural practices.

Climate Database

The climate analysis for this project was based on PFRA hydrology (stream runoff) records. The objective was to calculate the likelihood of extreme events which would affect the risk for surface runoff and the potential for soil leaching. There are typically three critical periods for manure application to agricultural lands - preseeding for annual crops, mid-growing season (for forage and pasture lands where manure applications could occur after the first harvest), and the fall season after harvest but before freeze-up. The aridity values (P-PE) for the soil leaching calculations were derived from the Ecostrat database from CanSIS.

4. Development of Indices from Database Components

The use of resource databases for ILO planning requires that the data be transformed into information useful to planners and expressed in useful terms. For this project, the technical data was used to calculate four indices to address the potential fate of applied nutrients: a) soil productivity index (Nutrient Factor), b) soil landscape index (Surface Water Factor), c) root-zone leaching index, and d) a geological materials index (GroundWater Factor). The values for each index were then grouped into three, more manageable information classes of High, Medium and Low for each factor. Subsequently, these three major factors - Nutrients, Surface Water and Groundwater - were combined in a 3 x 3 x 3 matrix to define the environmental conditions for each soil in the landscape according to more generalized Soil Management Groups (SMGs). The SMGs typically encompass the significant environmental conditions that should be considered in developing manure management plans. At the field level, however, a relatively large range of local variations may be included in any particular SMG description. Therefore, more specific field inspections or knowledge should be incorporated into the planning process. The rationale for the use and development of specific indices for each database is discussed in the following section. A list of resource information databases available for the Prairie region is provided in Appendix B.

References

(Related to framework concept and application)

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Sharpley, A.N., T. Daniel., T. Sims, J. Lemunyon, R. Stevens, And R. Parry. 1999. Agricultural Phosphorus and Eutrophication. U.S. Department of Agriculture, Agricultural Research Service, ARS-149, 42 pp.

McFarland, A., L.Hauck, J. White, W. Donham, J. Lemunuon, and S. Jones. 1998. Nutrient management using a phosphorus risk index for manure application fields. Proceedings of the Manure Management Conference February 10-12, Ames, Iowa.

II. NUTRIENT FACTOR *(J. A. Brierley)*

One of the key factors in this HEMS methodology is to evaluate the environmental sustainability of supplying nutrients to soil landscapes through manure application. Although the initial objective was to consider only nitrogen for this broad scale evaluation, the concept of a Nutrient Factor was adopted. It represents a more holistic concept to the soil productivity capacity and was defined as "the soil's capability to support nutrient uptake by crops". This decision was based on the assumption that highly productive soils are the most efficient "nutrient-managers". Conversely, it was assumed that low productivity soils were less efficient, and in fact would likely be prone to nutrient (such as nitrogen) loss through volatilization/denitrification, leaching or runoff. After considering several options, the soil component of a published Land Suitability Rating System (Agronomic Interpretations Working Group, 1995) was selected as the surrogate indicator for the Nutrient Factor in this project.

Since one of the main premises of this project was to optimize the use of existing technologies and data, the Land Suitability Rating System (LSRS) methodology appeared to be an attractive model. First of all, it was component-based. Secondly, it used a number of individual databases. Thirdly, each database was evaluated separately, and finally, each of the components was integrated to yield a rating and class of suitability. In addition, the LSRS approach already exists in an automated form, allowing the rating of all soil series in any digital GIS map in Canadian Soil Information System (CanSIS) format. Thus, it is easily modified to assess the inherent productivity potential of all prairie soils. This potential productivity rating could be used as a proxy for nutrient capacity. Soils with high productivity potential can be expected to retain and supply more nutrients and thus would be suitable for higher application rates of swine manure.

It was also assumed that the LSRS logic and program is available and can readily be modified or "relaxed" so as to reflect the link between productivity and nutrient uptake considering the following:

- the soils component of LSRS can be used as a "proxy" for predicting the inherent productivity of a soil landscape,
- productivity relates to total dry matter yield, and
- yield equates to nutrient uptake.

A. Background

In 1995, the Agronomic Interpretations Working Group published the technical bulletin "Land Suitability Rating System (LSRS) for Agricultural Crops" which described the rating system. The initial intent was to develop the system for spring-seeded small grains, with the understanding that it could eventually be universally adopted and adapted for any crop. To date, only the document for spring-seeded small grains has been published.

The framework and logic described in this manual has since been translated and programmed into a software program and algorithm which uses soils, climate and land resource information contained in the National Soil Database (CanSIS). The final values generated by the LSRS algorithms are categorized into seven classes which are similar to the seven classes for agricultural capability described by the Canada Land Inventory (1965).

In summary, LSRS is a seven-class system where climate, soils and landscape are rated separately. The underlying premise for rating each of these three components is:

- climate identifies what crops may be grown,
- soils indicate how much may be produced, and
- landscape identifies the management constraints associated with agricultural activities.

The limiting factors and the method of integration of each component are documented in the LSRS manual. The component with the lowest rating determines the overall class of the interpreted soil landscape. For example, a soil in a specific location/area may have a climate component rating of Class 2, a soil component rating of Class 2, but an associated landscape component rating of Class 6 due to steep slopes. Therefore, the overall LSRS rating for this soil landscape is Class 6T with "T" designating severe topographic limitations for spring-seeded small grains.

For this application, the landscape portion of LSRS was not used because other crops, such as forages and pastures which have less stringent landscape constraints, can also benefit from manure application. Instead, a separate landscape index was developed that more closely describes the potential for runoff and surface water contamination.

Following this rational, if the soils component of LSRS reflects the inherent productivity of soils across the Prairies, then the potential nutrient uptake may be inferred from the seven LSRS classes. For example, if the soil component productivity rating is Class 1, its inherent productivity and potential nutrient uptake should be proportionately greater than that of Class 2, 3 or 4. Therefore, theoretically, more swine manure could be applied annually to Class 1 soil than to Class 2, 3 or 4 soils.

However, for the application of swine manure to Prairie landscapes to be environmentally sustainable, the amount of applied nutrients plus those provided by the soil should be equal to the nutrients used by the crop. The greater the total dry matter yield, the greater the amount of nutrients (specifically nitrogen N) absorbed within the vegetation. If the total amount of available N equals the amount used by the crop during the growing season, the likelihood of nitrate contamination of the surface water and groundwater is reduced. Since N demand is crop-dependent, nutrient balance calculations are assumed to be a management consideration.

B. Modifications to LSRS

The soil component within the LSRS approach can be used to determine and compare the inherent productivity of one soil to another.

The soil component of LSRS considers:

- water supplying factors,
- surface factors,
- subsurface factors, and
- drainage factors.

Values for each of these factors are calculated from a group of sub-factors by means of a series of deduction tables which are described in Chapter 4 of the LSRS manual. A summary of the surface and subsurface properties which determine their inherent productivity capacity are presented in Table 2.1. These attributes are described for each soil in the soils database for the Prairie Ecozone. These factors determine the inherent soil productivity, and thus a rating for the nutrient balance capacity of soils.

Table 2.1 **Attributes of the four primary factors in the LSRS Soil Component used to estimate the potential inherent productivity of individual mineral soils.**

Water Supplying Factors	Surface Factors	Subsurface Factors	Drainage Factors
Aridity (P - PE)	Structure/consistence	Impeding layer	Drainage class
AWHC - surface texture	Organic Carbon content	Bulk density	Depth to water table
Subsurface texture	Depth of topsoil	Contrasting layer	
Depth to water table	Reaction (pH)	Reaction (pH)	
	Salinity (EC)	Salinity (EC)	
	Sodicity (SAR)	Sodicity (SAR)	
	Thickness of peat		

The following examples illustrate the sensitivity of the soil component of the LSRS methodology. These examples are somewhat simplified because not all of the factors within this component are incorporated here. The deduction points are determined from look-up tables in LSRS manual which have since been converted to formulas for computerized automatic calculation. Note that all soils start with 100 points and deductions are determined by individual factors.

Example 1

Consider a Black Chernozem developed on medium textured till in the Edmonton area versus a Brown Chernozem developed on medium textured till in the Medicine Hat area.

Black soil – granular structured, loam textured surface, 20 cm thick, (no other limitations)

P-PE = -200 Deduction - 10 pts. (Table 4.2 in LSRS manual).

Final Soil Rating = 90 points, Class 1. (basically no limitations)

Brown soil – granular structured loam textured surface, 15 cm thick, (no other limitations)

P-PE = -350 Deduction - 50 pts. (Table 4.2 in LSRS manual).

Surface organic C content (Brown soil) Deduction - 5 pts. (Table 4.6 in LSRS manual)

Final Soil Rating = 45 points, Class 3M (water supplying limitation)

Example 2.

A Brown Chernozem developed on coarse textured glaciofluvial material versus a Brown Chernozem developed on medium textured till.

Coarse textured Brown soil – granular structured sandy loam textured surface, 15cm thick

P-PE = -350	Deduction - 60 pts. (Table 4.2 in LSRS manual)
Surface OC content (Brown soil)	Deduction - 5 pts. (Table 4.6 in LSRS manual)

Final Soil Rating = 35 points, Class 4M (water supplying limitation)

Medium textured Brown soil – granular structured loam textured surface, 15 cm thick

P-PE = -350	Deductions - 50 pts (Table 4.2 in LSRS manual).
Surface OC content (Brown soil)	Deductions - 5 pts. (Table 4.6 in LSRS manual)

Final Soil Rating = 45 points, Class 3M (water supplying limitation)

Since the aridity (P-PE) value is the same for each soil, it is apparent that the system reasonably differentiates soils based on the intrinsic chemical and physical properties which have been used to describe, classify, characterize and map soils in the landscape. The data define and differentiate soils in the digital files linked by GIS to soils maps.

Notes of clarification for adapting and modifying LSRS

1. As it presently exists, the LSRS program may be used to calculate soil productivity ratings. By inserting "0" values for the climate and landscape factors, these components can be ignored in this calculation.

2. In the assessment of the inherent productivity of Prairie soils using the soils component of the LSRS methodology, the potential benefits of adding organic matter (manure) is **not** taken into account. For soils where the initial organic C values are less than 2% (i.e. Luvisols), it is conceivable that addition of manure will improve (increase) the soil component rating by 10 points.

3. It is to be assumed that this procedure for assessing the inherent productivity of Prairie soils will only be applied in areas already deemed suitable for growing agricultural crops. For example, in northern areas where the agro-climate is unsuitable (5-6H), this soil productivity methodology would not be applicable. Since these soils cannot effectively use manure nutrients for annual crop production, any manure applied would ultimately be lost through leaching, runoff or volatilization.

C. Nutrient Factor Classification

The LSRS automated procedure calculates discount points for each soil series on the soils maps. However, for this application, an attempt was made to simplify the final rating using classifications of High, Medium and Low to describe the capability of soils to accept, retain and supply nutrients (specifically nitrogen) to climatically adapted crops. To do this, three class intervals for the index values were adopted (Table 2.2).

Following the LSRS procedure, soil productivity classes 1, 2 and 3, (numeric index values > 60), represent highly productive soils and thus intuitively have a high nutrient management capacity. Therefore, soils with index values greater than 60 were classified as High for the Nutrient Factor. Soils with index values between 20 and 60 (LSRS classes 4 and 5) were considered to have an intermediate productivity potential for regionally adapted crops and were therefore classified as Moderate for the Nutrient Factor. Similarly, soils with numeric index values < 20 (LSRS classes 6 and 7, annual cultivation not recommended even on an occasional basis) were considered to have very low productivity capability and thus were given a Low classification for the Nutrient Factor.

In the case of determining the risk of having excess nitrogen in the root zone, it is intuitive that if soils have a low capacity for nutrient retention and supply to crops, that the nitrogen would be at risk of loss to deep leaching. Conversely, if soils have a high capacity to retain and supply nitrogen to crops, the risk of having excess nitrogen build up in the profile will be low (Table 2.2). This reasoning was adopted for the Nutrient Factor integration procedure to define soil management groups, discussed in Section VI.

Table 2.2 Classification of Nutrient Factor

Numeric Index Value	Nutrient Factor Classification	Risk of Excess Nitrogen in Profile
< 20	Low (L)	High (H)
20 - 60	Moderate (M)	Moderate (M)
> 60	High (H)	Low (L)

1. Nutrient Factor Classification for a Soil Polygon

Each soil series in a soil polygon is given an index rating according to the above criteria. A polygon rating is developed by summing the extent of each soil component having the same productivity index rating. Table 2.3 shows the extent and productivity index ratings for a soil polygon containing five soil components. In this example, the sum of the extent of soil components with a Low productivity index is 55%, High is 35%, Moderate is 10% and could be represented by a polygon rating of L(55)H(35)M(10). For consistency, the dominant Nutrient Factor (L) is used for integration with other derived indices of this methodology.

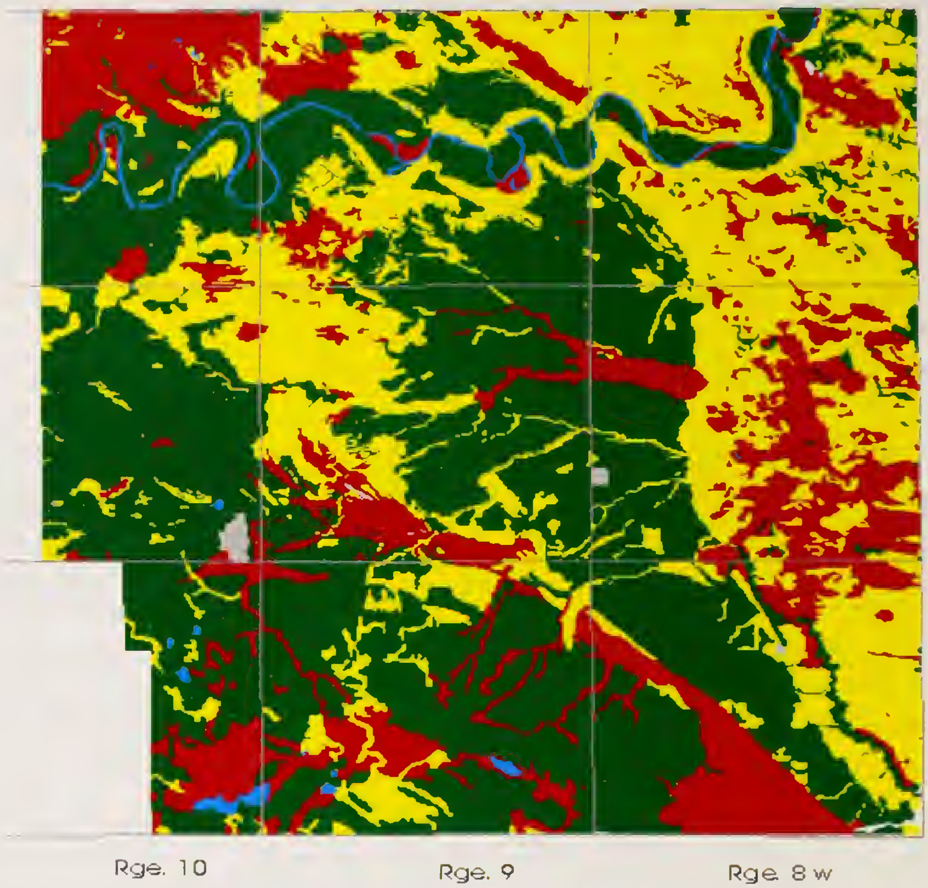
Table 2.3 Areal Extent and Productivity Index for five soil components representing a polygon.

Component (Soil Series)	Soil Series Extent (%)	Numeric Index Value (from the LSRS Soil Component)	Nutrient Factor Classification
1	40	10	L
2	20	60	H
3	15	10	L
4	15	75	H
5	10	25	M

Assumptions

It is assumed that for the generic application of this procedure, only the numeric index value for each soil component is used. The identification of the limiting conditions such as wetness (W), excess salts (N) etc, although available in the database, will not be apparent in the final Nutrient Factor classification.

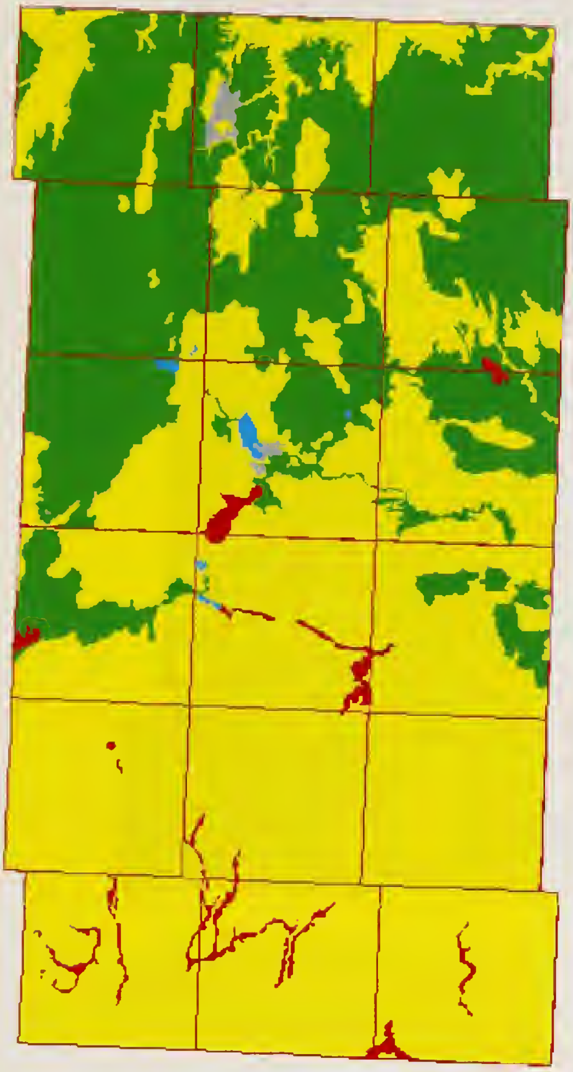
Example maps of the Nutrient Factor calculated using the LSRS productivity component for soils in each of the test areas are shown in Figures 2.1, 2.2 and 2.3 respectively.



The relative risk of manure nitrogen applied to soils to be fully utilized for crop production. High productivity soils will have a greater ability to supply and retain periodic manure N applications for crop growth and represent a lower risk for potential manure N losses.

	Low	Highly productive soils with good water and nutrient retention capacities, organic matter content and natural fertility
	Moderate	Moderately productive soils with significant limitations for annual field crop production. Soil limitations may be due to excess wetness, droughtiness, salinity, shallow depth to restricting layers, or other factors
	High	Low productivity soils unsuitable for annual crop production. Manure N applications present a high risk of migration to surface or groundwater sources. Severe soil limitations can include very coarse texture, extreme wetness or salinity, bedrock, or other factors
	Water	
	Unclassified	

Figure 2.1 Nutrient Factor classes for soils in the Rural Municipality of South Norfolk, Manitoba.



The relative risk of manure nitrogen applied to soils to be fully utilized for crop production
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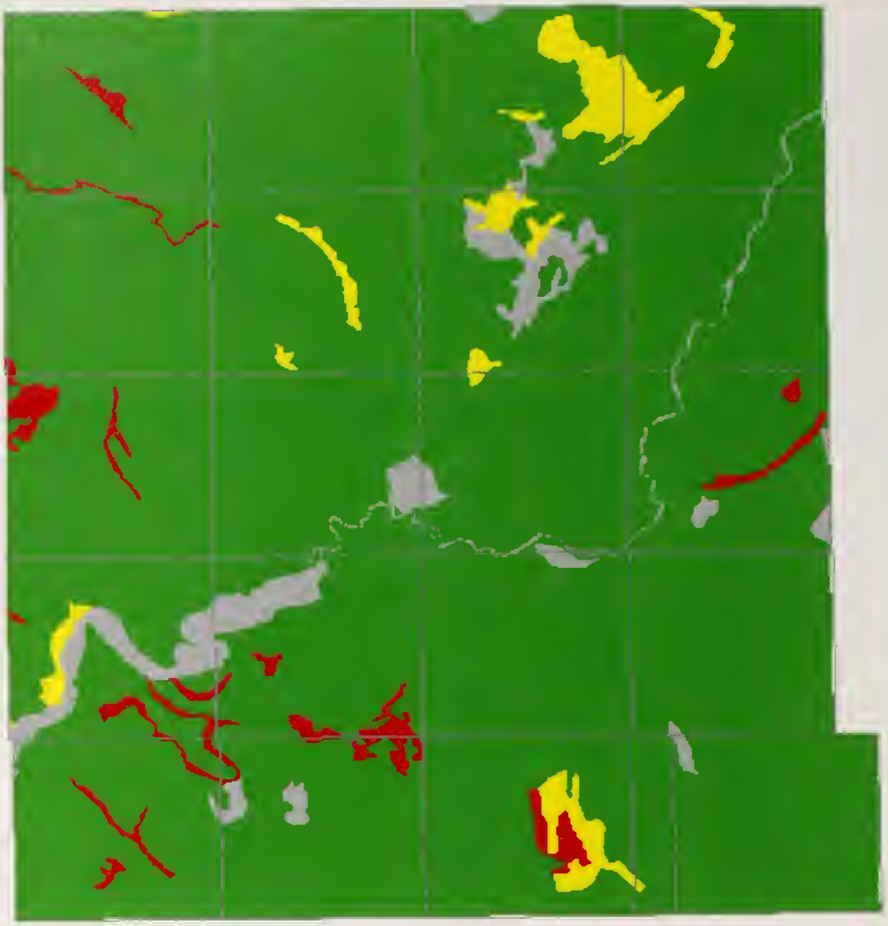
	High	Low productivity soils unsuitable for annual crop production. Manure N applications present a high risk of migration to surface or groundwater sources. Severe soil limitations can include very coarse texture, extreme wetness or salinity, bedrock, or other factors.
	Water	
	Unclassified	

Figure 2.2 **Nutrient Factor classes for soils in Rural Municipalities 108 and 78, Saskatchewan.**



The relative risk of manure nitrogen applied to soils to be fully utilized for crop production. High productivity soils will have a greater ablility to supply and retain periodic manure N applications for crop growth and represent a lower risk for potential manure N losses.

(green)	Low	Highly productive soils with good water and nutrient retention capacities, organic matter content and natural fertility
(yellow)	Moderate	Moderately productive soils with significant limitations for annual field crop production. Soil limitations may be due to excess wetness, droughtiness, salinity, shallow depth to restricting layers, or other factors
(red)	High	Low productivity soils unsuitable for annual crop production. Manure N applications present a high risk of migration to surface or groundwater sources. Severe soil limitations can include very coarse texture, extreme wetness or salinity, bedrock, or other factors
(blue)	Water	
(grey)	Unclassified	

Figure 2.3 **Nutrient Factor classes for soils in a portion of Red Deer County, Alberta.**

References

Canada Land Inventory. 1965. Soil Capability Classification for Agriculture. Canada Land Inventory Report No. 2. ARDA, Dept. of Forestry Canada, Ottawa.

Agronomic Interpretations Working Group. 1995. Land Suitability Rating System for Agricultural Crops: 1. Spring-seeded small grains. Edited by W.W. Pettapiece. Tech. Bull. 1995-6E. Centre for Land and Biological Resources Research, Agriculture and Agri-Food Canada, Ottawa. 90 pages, 2 maps.

III. SURFACE WATER FACTOR *(R.G. Eilers, R. Woodvine)*

The surface water factor (SWF) was adopted as an indicator of the potential for surface runoff. SWF incorporates attributes of the physical conditions of the soil surface (erodibility) and topographic characteristics such as slope length and steepness which influence runoff velocity. As well as being carried in solution, nutrients in manures such as nitrogen, phosphorus and potassium, along with trace elements and salts, are frequently associated with eroded particulate materials and sediments.

An important aspect of the SWF is that it conceptually addresses the potential for transfer of phosphorus (P) in sediments moving from slopes to depressions or water bodies because it includes a soil erodibility factor. A brief description of management factors affecting the risk of P loss in surface runoff is provided in Section VII of this bulletin.

A. Landscape Index (LI)

A second major objective of this project was to assess the inherent risk to surface water bodies from runoff and manure loss from sloping landscapes. Most Prairie landscapes have complex surface morphologies due to their glacial and fluvial origin. A technique was needed to characterize and describe this variability in simple terms that would be useful for making management decisions for manure applications. A landscape index (LI) was developed that could be calculated from attributes of each soil and associated topography. The LI was adopted as a means of defining and differentiating the sensitivity and complexity of the land surface.

Three main factors were used in the landscape index: slope length (L), slope steepness (S), and soil erodibility (K). These factors were adopted from the Universal Soil Loss Equation (USLE), (Wischmeier et al. 1965) because:

- relevant information is presently included in, or can be easily calculated from, the new digital soils database for the Prairie Ecozone,
- the potential for surface water runoff is a direct function of slope length and steepness, (runoff increases with increasing slope steepness) (Wang et al. 2000), and
- removal of particulate materials which include nutrients in the sediment is a function of the soil erodibility factor (K).

These factors can be considered spatially stable landscape characteristics for planning purposes.

The other elements in the USLE relate to factors that are spatially and temporally very dynamic such as rainfall and land use management practices. Because land use and management can be tailored to some extent to consider variable rainfall conditions (probabilities), these factors were not considered inherent attributes of the landscape. For example, two landscapes with similar surface textures and similar topography may be in different regions under different land use and significantly different probabilities of extreme rainfall and snowmelt events. Recommendations and management practices must be specific to these conditions. Planners using this methodology must consult appropriately-scaled probability maps to assess the actual risk of surface runoff and consider relevant management strategies accordingly.

The landscape index is determined from: LI = KLS

The LI was calculated for each soil polygon within the designated test areas. The K factor was used for each of the indicated soil components and the median value of the indicated slope length and steepness class assigned to each soil. The values for each soil were rated High, Medium or Low to describe the relative sensitivity of soil landscapes for surface runoff (Table 3.1). This procedure will only provide an approximate indication of the LI.

Table 3.1 Classification of Surface Water Factor (SWF).

Numeric Landscape Index (LI) Values	SWF Classification
< 0.006	Low (L)
0.006 to 0.033	Moderate (M)
> 0.033	High (H)

The low SWF class will be characterized by very low and gentle slopes, and will not specifically highlight the importance of micro-relief at the field scale. Very flat land with clay textured soils typically has micro-relief which results in frequent shallow surface ponding. During agricultural development, much of this land has been improved by the construction of artificial drains. These drains provide a high potential for rapid loss of manure nutrients directly into larger networks of provincial drains and natural waterways. Therfore, a low SWF rating may require additional considerations for manure management planning.

1. Surface Water Factor Classification for a Soil Polygon

Each soil series in a map polygon is given an index rating according to the above criteria. A polygon rating is developed by summing the extent of each soil component having the same landscape index. Table 3.2 shows the extent and landscape index ratings for a soil polygon containing five soil components. In this example, the sum of the extent of soil components with a Low landscape index is 55%, High is 35%, Moderate is 10% and could be represented by a polygon rating of L(55)H(35)M(10).

For consistency, the dominant SWF rating (L) for this polygon will be used for integration with the other two factors.

Table 3.2 Areal Extent and Landscape Index for five soil components representing a soil polygon.

Component (Soil Series)	Soil Series Extent (%)	Landscape Index Values	Surface Water Factor Classification
1	40	0.001	L
2	20	0.6	H
3	15	0.002	L
4	15	0.75	H
5	10	0.025	M

Example of a level landscape with a low (LI) surface water factor

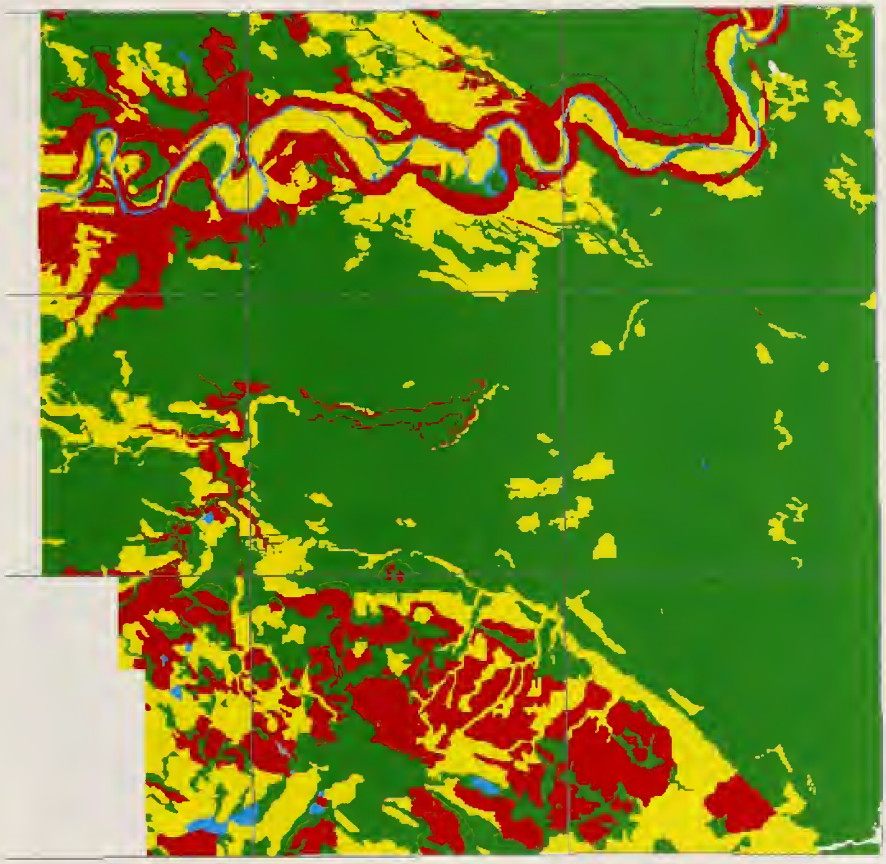
Assumptions

It is assumed that the generic application of this procedure will reflect the most typical management considerations in a given landscape. However, there is a significant (35%) portion of the polygon for which surface runoff is a strong possibility. This condition will be noted in the description of the soil management groups. The identification of the limiting conditions, although available in the database, will not be specifically indicated in the final SMG map designation.

It is also assumed that this index applies to "bare soil" landscapes. Therefore, landscapes with moderate and high SWF classes indicate that management and land use practices must be developed for specific fields to mitigate the risk to runoff.

Example maps of the Surface Water Factor calculated using the Landscape Index for each soil in the test areas and thus reflecting the soil landscape susceptibility to runoff, are shown in Figures 3.1, 3.2 and 3.3.

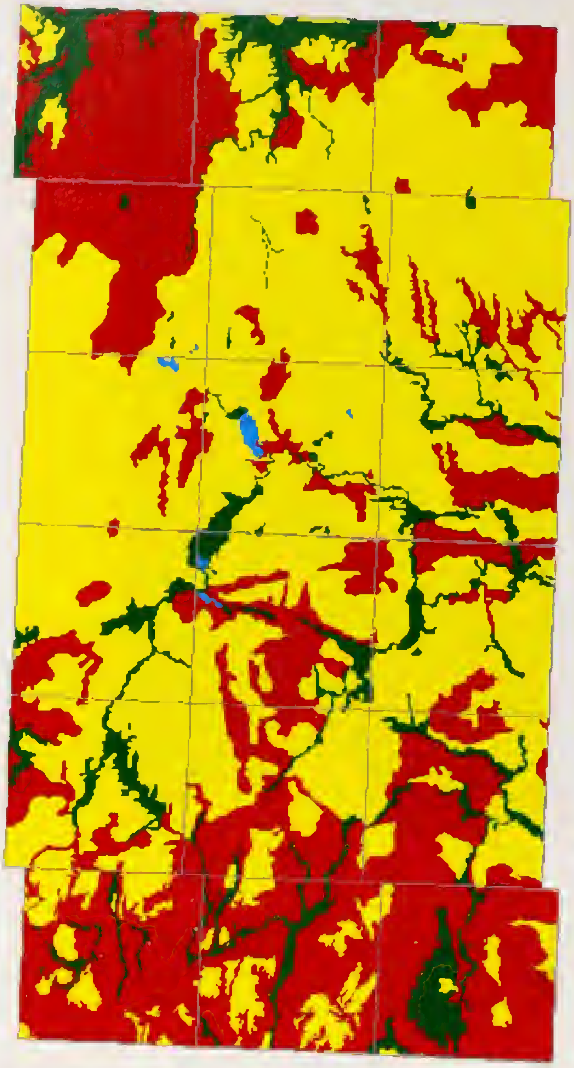
Example of a soil landscape with a high (LI) Surface Water Factor



The relative risk of surface runoff and potential for manure nutrient (N) transport down slope to surface streams or water bodies. It is based on a surface soil erodibility factor, as well a slope length and slope steepness.

	Low	Soils with a low run off and erosion risk, a low to high water infiltration capacity, and level to gentle slopes.
	Moderate	Soils with a moderate run off risk due to low to moderate soil infiltration capacities and either long low slopes or shorter moderate slopes.
	High	Soils with a high run off risk, with have low to moderate infiltration capacities. Slopes are typically short and steep but can also be moderate with long slope lengths.
	Water	
	Unclassified	

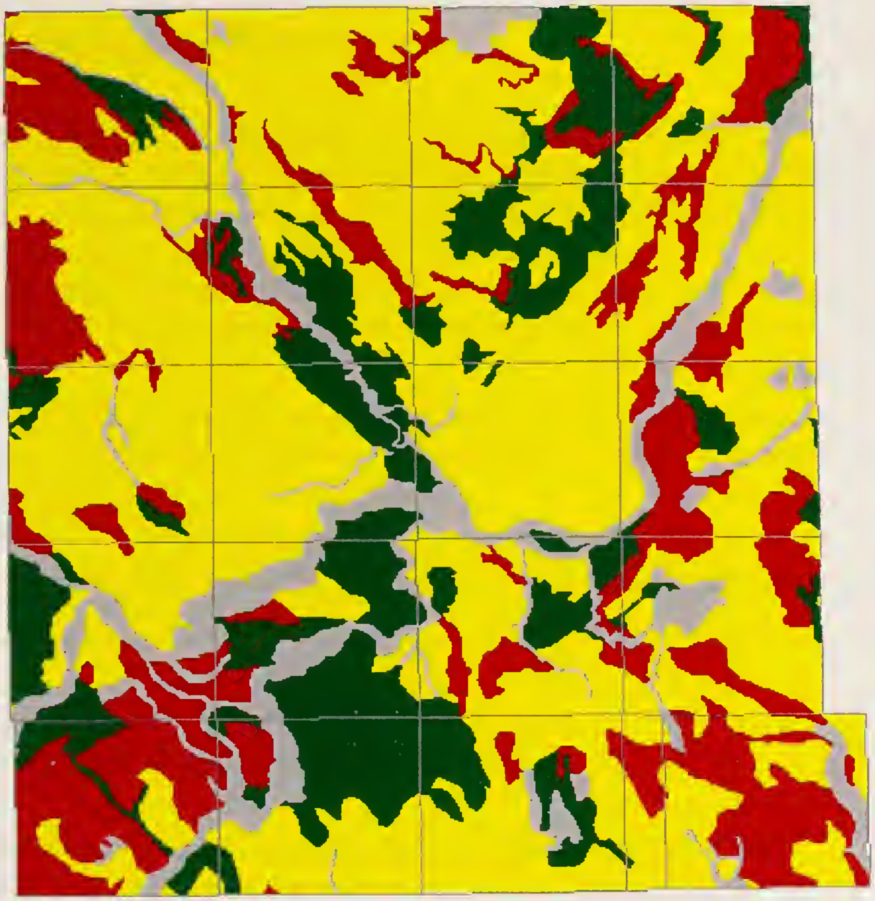
Figure 3.1 Soil landscape index (LI) classes for the Rural Municipality of South Norfolk, Manitoba.



The relative risk of surface runoff and potential for manure nutrient (N) transport down slope to surface streams or water bodies. It is based on a surface soil erodibility factor, as well a slope length and slope steepness.

(dark green)	Low	Soils with a low run off and erosion risk, a low to high water infiltration capacity, and level to gentle slopes.
(yellow)	Moderate	Soils with a moderate run off risk due to low to moderate soil infiltration capacities and either long low slopes or shorter moderate slopes.
(red)	High	Soils with a high run off risk, with have low to moderate infiltration capacities. Slopes are typically short and steep but can also be moderate with long slope lengths.
(light blue)	Water	
(grey)	Unclassified	

Figure 3.2 Soil landscape index (LI) classes for Rural Municipalities 108 and 78, Saskatchewan.



The relative risk of surface runoff and potential for manure nutrient (N) transport down slope to surface streams or water bodies. It is based on a surface soil erodibility factor, as well a slope length and slope steepness.

Low	Soils with a low run off and erosion risk, a low to high water infiltration capacity, and level to gentle slopes.
Moderate	Soils with a moderate run off risk due to low to moderate soil infiltration capacities and either long low slopes or shorter moderate slopes.
High	Soils with a high run off risk, with have low to moderate infiltration capacities. Slopes are typically short and steep but can also be moderate with long slope lengths.
Water	
Unclassified	

Figure 3.3 Soil landscape index (LI) classes for a portion of Red Deer County, Alberta.

References

Wischmeier, W. H. and D.D. Smith. 1965. Predicting Rainfall-erosion Loss from Cropland East of the Rocky Mountains. U.S. Department of Agriculture, Agriculture Handbook No. 282, U.S. Government Printing Office, Washington, D.C.

Wang, G., G. Gertner, P. Parysow, A.B. Anderson. 2000. Spatial prediction and uncertainly analysis of topographic factors for the revised Universal Soil Loss Equation (RUSLE). Journal of Soil and Water Conservation 55:374-384.

IV. GROUNDWATER FACTOR

The groundwater factor (GWF) addresses the relative potential for soluble constituents (nutrients in this case) to leach through the soils, move through the underlying materials and enter the nearest-to-surface aquifer. Soils are the first line of defense in protecting groundwater since all crop production inputs enter the soils first. In defining the capacity of the soil to retain these nutrients, the capacity of the soils to hold water was taken into consideration and expressed in terms of a *root zone leaching index (RZLI).*

Next, the capacity for the underlying materials to transmit soluble constituents from below the root zone to the closest underlying aquifer was examined. This capacity was expressed in terms of a *geologic material index (GMI).*

The final rating for the groundwater factor was derived from a matrix integration of the RZLI and GMI.

A. Soil Roct Zone Leaching Index (RZLI) *(W.D. Eilers)*

One of the major environmental concerns with applying manure to the land is the possibility of nutrients leaching below the rooting zone of crops and entering the groundwater. The immediate economic concern to the farm manager is losing the benefit of these nutrients to his crop. If he recognizes the potential for nutrient leaching, he can apply appropriate manure management practices to mitigate these losses and subsequently protect the environment and his profitability. The RZLI was developed to provide a method that could be applied throughout the Prairie Ecozone to evaluate the potential for water and nutrient movement below the normal rooting zone of common crops. The index uses soil data contained in the 1:100 000 scale National Soil Database files of each province and the 30-year normal climatic data linked to Canadian ecodistricts (Bootsma and Ballard 1997). The index can be applied at both broader and finer scales provided appropriate data are obtained.

The methodology adopted for this project is similar to a procedure used by the nitrogen water risk component of the Agri-Environmental Indicators (AEI) project (MacDonald and Gleig 1996.) The methodology is derived from a partial water balance technique whereby estimates of the water available for leaching, based on precipitation minus potential evapotranspiration (P-PE) data, are compared to the available water-holding capacity (AWHC) of the soil. Where the amount of water available for leaching (P-PE) exceeds the available water-holding capacity of the soil, there is heightened risk for nutrient movement below the crop rooting zone.

In the Prairies, soil polygons on 1:100 000 scale maps may be represented by up to six soil components (soil series) identified in the map unit. The available water-holding capacity (AWHC) of each series can be calculated using soil layer thickness and volumetric moisture contents at one-third and 15 atmospheres moisture tension. The AWHC thus calculated is summed for each layer to a depth of 100 cm.

The Canadian Ecodistrict Climate Normals GIS database contains 30-year (1961-1990) monthly climatic normals for 1021 ecodistricts in Canada. Climatic normal data was interpreted for the ecodistricts from point-based weather station data. Among other information, this database provides monthly P-PE data calculated using the Penman (1948) and the Thornthwaite (1957) methods. The data based on the Penman method were used in calculating the Root Zone Leaching Index.

On the Canadian Prairies, most groundwater recharge normally occurs with snowmelt. During the summer growing period, P-PE values normally indicate a moisture deficit. By September, the potential evapotranspiration has decreased substantially due to cool temperatures, annual crops having matured, and other plants entering their dormant winter stage. After this time, precipitation largely goes into soil storage (before freeze-up) or remains frozen until spring. Therefore the greatest potential for leaching of nutrients below the rooting zone occurs when the overwinter accumulation of precipitation melts in the spring. The sum of the September to March P-PE values is used by this index as an indication of the water available for leaching. The index does not provide an estimate of the amount of leaching that occurs, but rather provides a means of ranking the potential for leaching among different soils and areas. This is also a critical period for leaching as manure is often spread or applied in the fall season and some of the nutrients are available to leach with the spring snowmelt.

The root zone leaching index (RZLI) for a soil component is calculated as follows:

RZLI = P-PE (Sum September to March) – AWHC (to 100cm)

A negative RZLI indicates insufficient moisture to satisfy the water-holding capacity of the soil, while a positive RZLI indicates moisture in excess of water-holding capacity and an increased leaching potential. These numeric RZLI values were classified into low, moderate and high categories (Table 4.1)

Table 4.1 Classification of Root Zone Leaching Index.(RZLI)

Numeric Index Value	RZLI Classification
< -25 mm	Low (L)
-25 - 100 mm	Moderate (M)
>100 mm	High (H)

As the drainage class of a soil is an indication of its long term moisture status, adjustments were made to ratings for individual soil components according to soil drainage class, regardless of RZLI value.

- It was felt that imperfectly drained and poorly or very poorly drained soils should be rated as moderate (M) and high (H) respectively.
- An exception was made for poorly drained soils with >60% clay in the first C horizon. It was felt that due to the very low permeability of these soils, a moderate (M) rating was adequate.
- Very poorly drained soils with >60% clay in the first C horizon remained in the high (H) class.
- All organic soils were rated as high (H) leaching potential.
- For soils having a residual (bedrock) substrate, only the layers above the residual material were used in the calculation of the available water-holding capacity.
- Non-soil components were given a rating of U and water bodies were rated W. It is expected that no manure would be applied on these components.

1. Application of RZLI to a Soil Polygon

Each soil series in a soil polygon is given an index rating according to the previously described criteria. A polygon rating is developed by summing the extent of each soil component having the same leaching index rating. Table 4.2 shows the extent and leaching index ratings for a soil polygon containing five soil components. In this example, the sum of the extents of soil components with a low leaching index is 55%, high is 35%, moderate is 10% and could be represented by a polygon rating of L(55)H(35)M(10). For consistency, the dominant leaching component in this example (L) is used for integration with other project indices.

Assumptions

In developing this index several assumptions were made.

All of the water-holding capacity of the soil is available in September, that is, cropped land has used all available water from the soil. This assumption may not be valid in any particular year depending on the rainfall received. In addition, the assumption is not correct for land that has been summer-fallowed as these lands should have very little of the water-holding capacity available in the spring.

The amount of moisture received, as calculated by the Penman method, (P-PE summed from September to March) is available at spring melt. It is assumed that this water is either held in the soil before freeze up or remains frozen until spring. No allowance is made in this index for runoff losses. Since the purpose of the index is to rate soils based on their physical properties and the long-term normal climatic conditions, only an estimate of the amount of water potentially available for infiltration - leaching is required. Other estimates of the amount of available moisture could be used if appropriate adjustments to the index were made.

Land use practices such as summerfallow or fall irrigation which result in high soil moisture status in the fall potentially increase the risk of leaching from snowmelt.

Table 4.2 Areal Extent and Root Zone Leaching Index for five soil components representing a soil polygon.

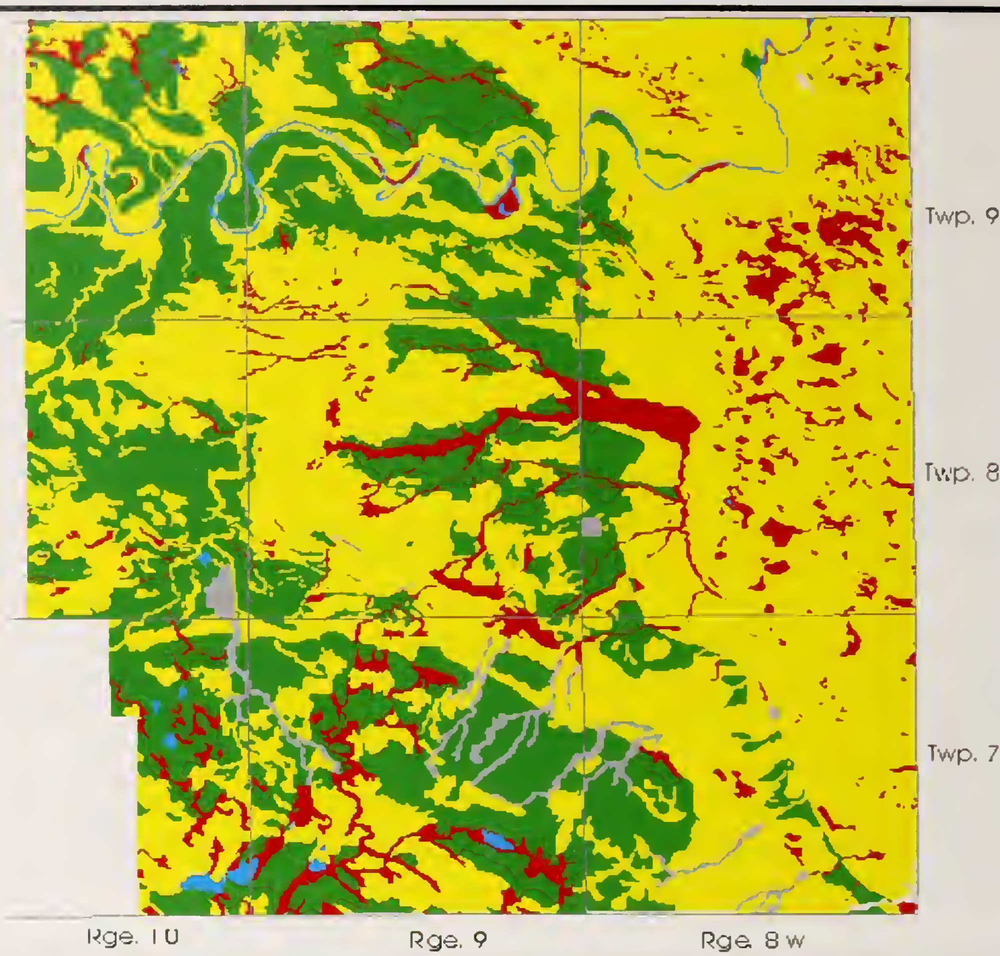
Component (Soil Series)	Soil Series Extent (%)	Numeric Root Zone Leaching Index	RZLI Classification
1	40	-50	L
2	20	120	H
3	15	-50	L
4	15	120	H
5	10	25	M

2. Information Products

The RZLI is suitable for use with 1:100 000 scale soil maps and databases. It could be readily applied to field scale or to site-specific information. The basic requirements for the index are a reliable estimate of the available water-holding capacity of the soil and an estimate of moisture available for leaching. The available water-holding capacity can usually be estimated adequately based on the soil's physical properties including texture, organic matter content and soil bulk density. The amount of moisture available for leaching can be estimated by measurements of precipitation over the winter period. Indeed, improvements to the index of the field or site-specific scale could be made by measuring fall soil moisture conditions before freeze-up and actual overwinter measurements of precipitation. These measurements could be used to adjust manure management plans to mitigate conditions which would lead to a higher potential for leaching.

The temporal variability of RZLI can be taken into consideration for local field conditions by recording crop type and yield related to the amount of after-harvest precipitation. This index could be developed and programmed for real time soil moisture calculations to assist in planning for time and rates of manure applications. For example, applying manure on dry soils is not likely to result in leaching. On the other hand, applications on moist or saturated soils may result in increasing the risk for surface runoff, leaching and denitrification losses.

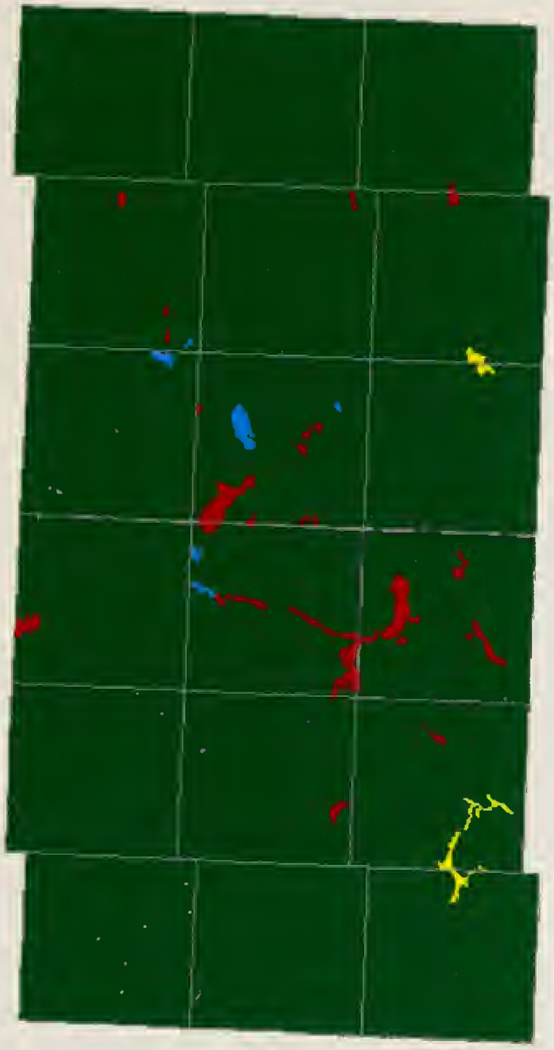
Example maps of the Root Zone Leaching Index for the three test areas, reflecting the long term status of available water in the root zone at spring melt, are shown in Figures 4.1, 4.2, and 4.3 respectively.



The relative potential to leach nutrients out of the soil rooting zone prior to the crop growing season. For the Canadian prairies, RZLI is based on net precipitation during the non growing season (P-PE for September to March), in comparison to the soil water holding capacity of the soil rooting zone. Water holding capacity is calculated for all the soil layers of the dominant soil to a depth of 100cm, with further adjustments for soils with high water tables and heavy clay soils with slow permeability. Soils with a high water holding capacity and low precipitation can more effecitively retain spring melt water within the soil root zone, and are considered to have a lower risk of nutrient leaching.

Low	Spring soil moisture levels are typically less than the soil water holding capacity
Moderate	Spring moisture levels typically meet or slightly exceed the soil water holding capacity
High	Spring moisture levels typically exceed the total available soil water holding capacity
Water	
Unclassified	

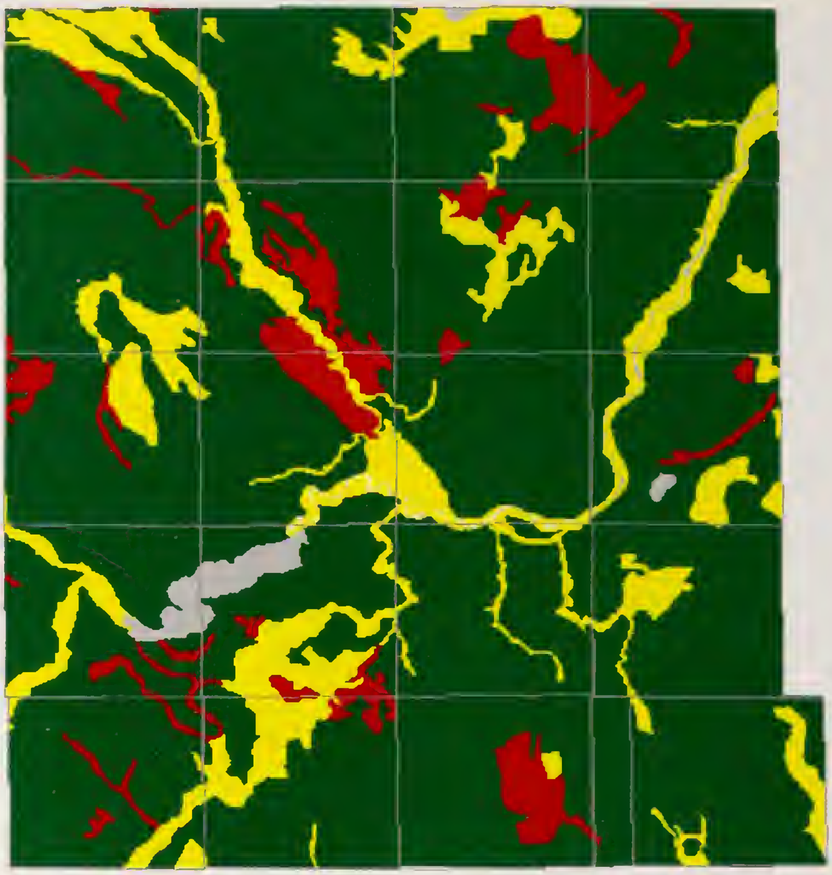
Figure 4.1 Root zone leaching index (RZLI) for the Rural Municipality of South Norfolk, Manitoba.



The relative potential to leach nutrients out of the soil rooting zone prior to the crop growing season. For the Canadian prairies, RZLI is based on net precipitation during the non growing season (P-PE for September to March), in comparison to the soil water holding capacity of the soil rooting zone. Water holding capacity is calculated for all the soil layers of the dominant soil to a depth of 100cm, with further adjustments for soils with high water tables and heavy clay soils with slow permeability. Soils with a high water holding capacity and low precipitation can more effecitively retain spring melt water within the soil root zone, and are considered to have a lower risk of nutrient leaching.

	Low	Spring soil moisture levels are typically less than the soil water holding capacity.
	Moderate	Spring moisture levels typically meet or slightly exceed the soil water holding capacity
	High	Spring moisture levels typically exceed the total available soil water holding capacity.
	Water	
	Unclassified	

Figure 4.2 Root zone leaching index (RZLI) for the Rural Municipalities 108 and 78, Saskatchewan.



The relative potential to leach nutrients out of the soil rooting zone prior to the crop growing season. For the Canadian prairies, RZLI is based on net precipitation during the non growing season (P-PE for September to March), in comparison to the soil water holding capacity of the soil rooting zone. Water holding capacity is calculated for all the soil layers of the dominant soil to a depth of 100cm, with further adjustments for soils with high water tables and heavy clay soils with slow permeability. Soils with a high water holding capacity and low precipitation can more effecitively retain spring melt water within the soil root zone, and are considered to have a lower risk of nutrient leaching.

(green)	Low	Spring soil moisture levels are typically less than the soil water holding capacity
(yellow)	Moderate	Spring moisture levels typically meet or slightly exceed the soil water holding capacity
(red)	High	Spring moisture levels typically exceed the total available soil water holding capacity
(blue)	Water	
(grey)	Unclassified	

Figure 4.3 Root zone leaching index (RZLI) for a portion of Red Deer County, Alberta.

B. Geological Materials Index (GMI) *(T. Dash, J. Rodvang, J. Lebedin, B. Jones)*

Groundwater is all water below the saturated soil zone or water table. It occurs in all geologic formations including those referred to as aquifers and aquitards. Aquifers are geologic formations permeable enough to yield economic quantities of water to wells. Aquitards describe geologic formations that are not permeable enough to transmit water at quantities sufficient to support viable water wells (Freeze and Cherry 1979). Seasonally saturated near-surface deposits may form aquifers for several months or years but may not be reliable in severe drought conditions.

For most agricultural soils, the depth to water table and the nature of the soil at the ground surface are important considerations for assessing their productive capacity and potential. The proximity of the water table to ground level is somewhat inferred by the soil drainage classification. This section will discuss the use of available geologic information to complement the soil ratings and provide a more comprehensive assessment of the relative security of groundwater aquifer quality in the Prairie ecosystem. Most of the following information has been derived and excerpted from a report on the Oldman project in Alberta (Dash and Rodvang, 2000) which was undertaken to assess aquifer vulnerability.

The objectives of both the Oldman and this HEMS project were to provide a regional overview of the relative vulnerability of groundwater related to geological materials across selected study areas without specifically identifying aquifers. Locations with shallow pervious materials (or potential aquifers) are much more vulnerable than those with pervious materials covered by thick layers of impervious materials (aquitards). Livestock developments in areas with relatively high sediment permeability should expect greater costs associated with investigative, engineering and agronomic requirements to mitigate potential problems.

For both projects, it was recognized that because of scale and data limitations, detailed site-specific investigations will be required to confirm the actual groundwater vulnerability at any specific site. It was also recognized that maps of this type can be misused or misunderstood. Therefore, the groundwater vulnerability inferred by maps of the type proposed for these two projects are to be used only as guides and cannot replace expert judgement based on site-specific data or investigations, where actual aquifer conditions can be determined.

For both projects, the target audience is rural provincial specialists and municipalities as it is recognized that these levels of government are most closely concerned with day-to-day decisions concerning a variety of land use zoning issues, in this particular case, livestock enterprises. Components of this study were incorporated into the Oldman River Basin study.

1. Rationale AVI vs GMI

Dash and Rodvang (2000) provide an in-depth discussion of various methods of assessing the hydraulic properties of near-surface geologic deposits. They specifically focus on the Van Stempvoort et al. (1992 and 1993) "Aquifer Vulnerability Index" (AVI) method for mapping the vulnerability of the nearest-to-surface aquifer to surface contaminants, since these are inferred to be the most vulnerable to contamination. In the AVI method, vulnerability is based on the thickness and estimated hydraulic conductivity of individual geologic layers overlying the shallowest aquifer.

The degree of protection over the shallowest aquifer is indicated by hydraulic resistance to vertical flow (c) as calculated for each well or test hole log (Eq. 1).

$c = \sum d_i / K_i$ for identified layers on well logs, 1 to i, [1]

where

d = thickness of each geological layer logged above the uppermost aquifer surface, (distance unit) and

K = estimated vertical hydraulic conductivity of each geologic layer (distance/time).

Conversion factors are used to convert "c" into time units of years, and indicates the approximate time for water to move downward through the layers above the uppermost aquifer. The resulting vulnerability categories were defined as very high "c" (less than 10 years) to very low "c" (greater than 10,000 years), as summarized in Table 4.3.

Table 4.3 **Vulnerability ratings for ranges of hydraulic resistance (adapted from Dash and Rodvang 2000).**

Vulnerability Rating	Hydraulic Resistance (c) [years] from Van Stempvoort et al. (1992 and 1993).	Examples of equivalent lithological thicknesses, when c is calculated using K_v values suggested in Appendix C
Very High	≤10	• < 4.5 m of till • < 3 m of shale • < 8 m of sandstone
High	>10 to ≤100	• 4.5 to 8 m of till • 3 to 5 m of shale • 8 to 19 m of sandstone
Moderate	>100 to ≤1000	• 8 to 13 m of till • 5 to 8 m of shale
Low	>1,000 to ≤10,000	• 8 to 17 m of till • 8 to 21 m of shale
Very Low	>10,000	• >17 m of till • >21 m of shale

The HEMS steering committee chose this procedure as a practical approach for incorporating a geologic component into the overall assessment of soil landscape suitability for manure application. With respect to calculations of index values based on travel time, and recognizing it would be applied at specific data points (ie. appropriate at any scale), it was decided to refer to it simply as a geological material index (GMI) to avoid any direct inference to users that somehow the information was accurate for delineating aquifer boundaries. Rather, it should be viewed simply as a glacial drift cover characterization tool.

The GMI component, like AVI, takes advantage of existing provincial water well data. Provincial drill logs were converted to standard lithological descriptions using standardized lithology equivalency tables prepared by respective geo-technical experts in both provincial and federal agencies. Then, through a process of sorting and ranking, each lithological unit was assigned the "most likely" relative hydraulic properties using available test data as well as available hydrological and geological expertise. The location of each classified drill log was plotted to the centroid of the respective legal subdivisions or quarter sections (Figure 4.4: example map of drill log distribution in the South Norfolk test area, Manitoba).

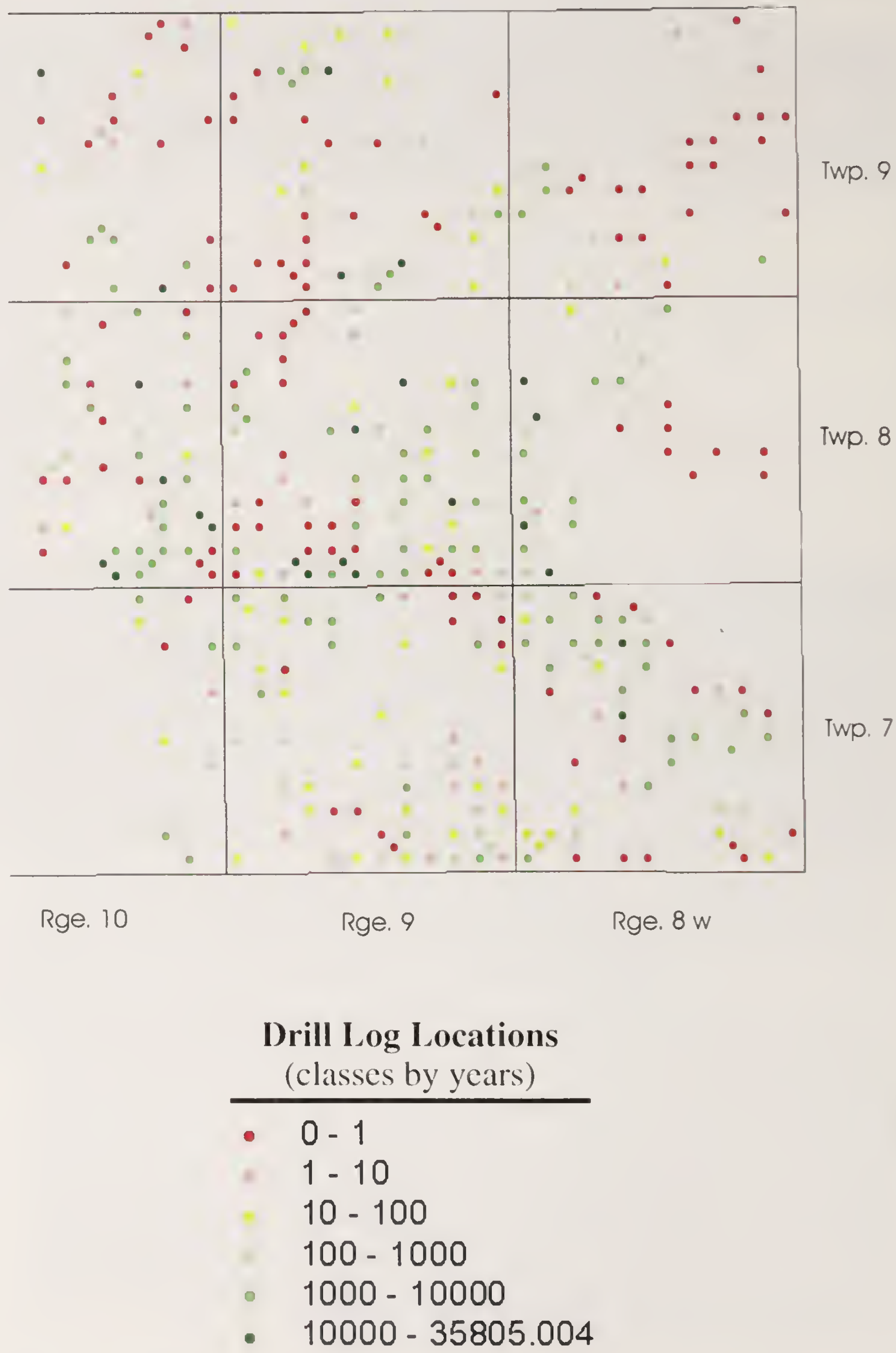


Figure 4.4 **Distribution of classified drill logs in the Rural Municipality of South Norfolk, Manitoba.**

This plot map was then overlayed in a GIS on the surficial geology map (Figure 4.5). The GMI for each polygon on the surficial geology map was then approximated from the dominant or most frequent "c" value for each water well and drill log contained within the polygon.

This approach (see Appendix C) varies slightly from the technique developed and used in Alberta (Dash and Rodvang, 2000). However, the result is a map depicting GMI classes for each surficial geology polygon and not individual " c" values for each well. The "c" value represents the approximate time in years it would take for a contaminant to reach the nearest-to-surface potential aquifer. The resultant GMI map (Figure 4.6) being of smaller scale than the soils map, was used to obtain a GMI rating for individual soil polygons for the final derivation of the Groundwater Factor Map.

2. Deriving the GroundWater Factor (GWF)

The GMI values are combined with calculated estimates of soil leaching potential to describe the Groundwater Factor in this methodology. This information is then used in conjunction with soils and cropping information to determine the level of management required to protect groundwater from surface contaminants.

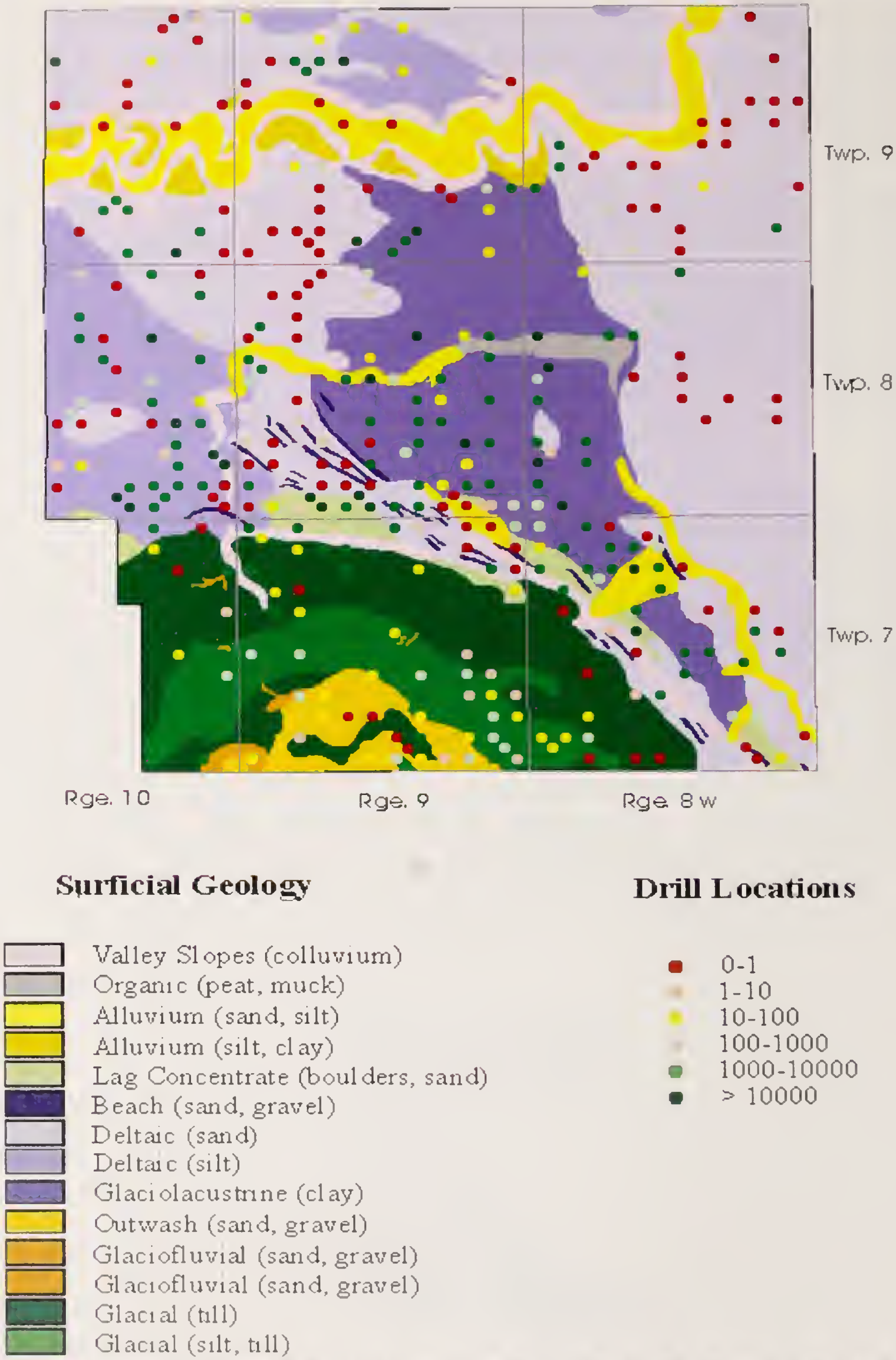


Figure 4.5 Distribution of classified drill logs overlain on surficial geology map in the Rural Municipality of South Norfolk, Manitoba.

3. Application

For Prairie-wide application of this GMI, there is a need for standard translations and conversions of geologic data for each provincial database. Presently, these databases consist of three differently formatted water well databases and differing geological nomenclature. Standard color schemes, legends, scales and production methods for map presentation are lacking. Standards are required to ensure map continuity and that map interpretation is consistent across diverse regions. The database and maps are suitable for regular routine updates as the primary water well database continues to expand. Attention is required to ensure that existing geological and physiographic information is also taken into account. Final GMI maps will be compiled at a 1:100 000 scale.

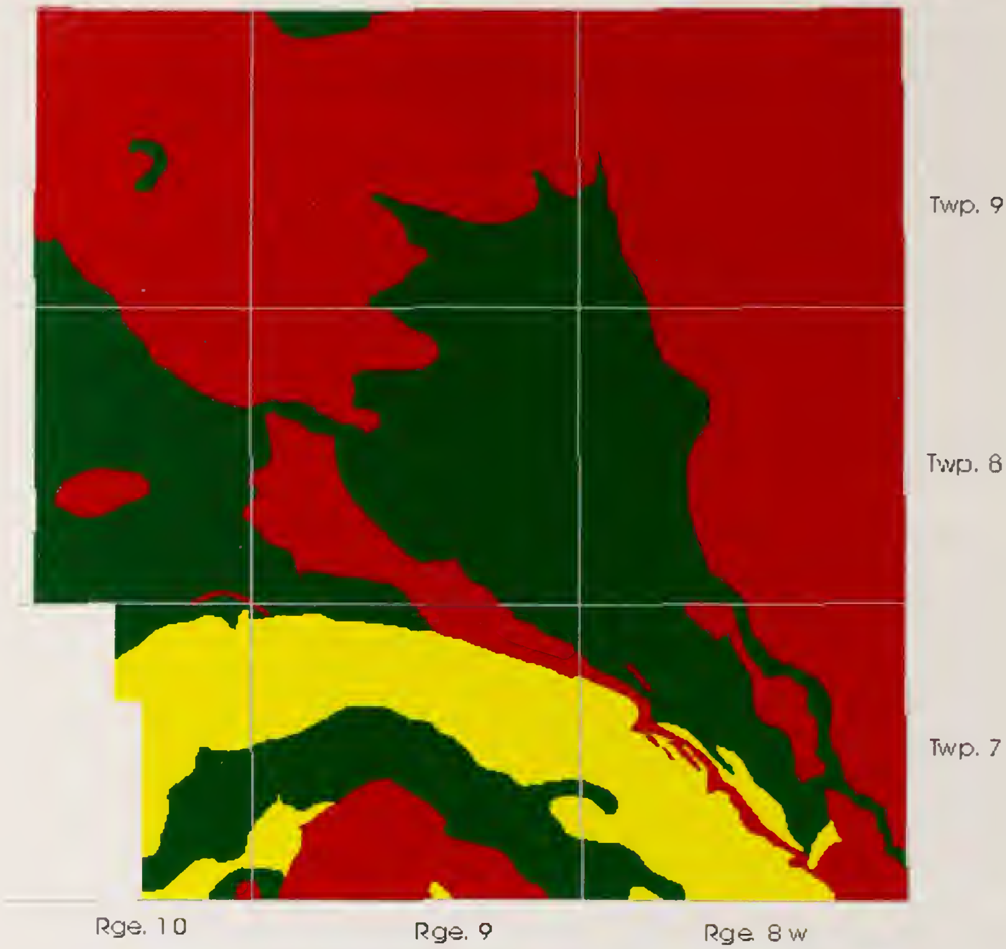
A more detailed description of the drill log standardization, transformation and interpretation for the Alberta context is provided by Dash and Rodvang (2000). An analogous detailed description of the standardization procedure for a similar conversion requirement for the lithologies in the Manitoba "GWDRILL" database has been described by Thorleifson et al. (2000). These standard descriptions were used in an "expert-opinion" conversion procedure to develop a geological materials index (GMI) map for a portion of the Red Deer County in Alberta and the South Norfolk test area in Manitoba. It is anticipated that a similar treatment for the Saskatchewan well and test hole database would be possible in the future.

Example maps of GMI for the Rural Municipality of South Norfolk in Manitoba and the County of Red Deer Alberta are shown in Figures 4.6 and 4.7 respectively.

Two types of information are shown on each map:

- surficial geology polygons with estimated GMI rating (as determined by provincial groundwater specialists), and
- water well point data with symbols to reflect the "c" value for individual water well locations.

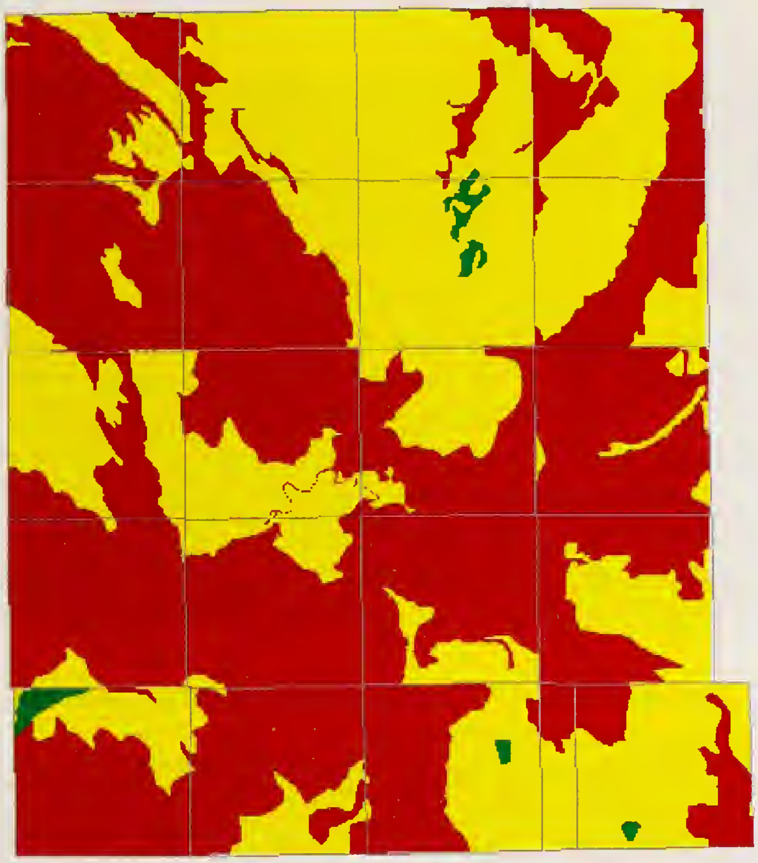
In some cases, multiple "c" values are available for one location such as where there is more than one well in an LSD or quarter section. This data is retained in the database to provide the user with some sense of variability in GMI ratings within an LSD or quarter section, or for that matter, within a surficial geology unit.



The approximate travel time in years that it would take for a water soluble contaminant to reach the nearset-to-surface potential aquifer.

	Low	Estimated travel time > 100 years.
	Moderate	Estimated travel time 10 to 100 years.
	High	Estimated travel time < 10 years.
	Water	
	Unclassified	

Figure 4.6 **GMI map for Rural Municipality of South Norfolk, Manitoba.**



The approximate travel time in years that it would take for a water soluble contaminant to reach the nearset-to-surface potential aquifer.

(green)	**Low**	Estimated travel time > 100 years.
(yellow)	**Moderate**	Estimated travel time 10 to 100 years.
(red)	**High**	Estimated travel time < 10 years.
(light blue)	**Water**	
(grey)	**Unclassified**	

Figure 4.7 GMI map for Red Deer County, Alberta.

4. Integration of Index Components

Since most agricultural inputs are applied to the soil surface, the RZLI represents the first management consideration.. Any highly soluble inputs in excess of crop requirements that can freely to move below the root zone may represent potential risks to groundwater quality.

Therefore, since soils and geological materials exist in a continuum, (soils representing only the upper 100 cm) a single ranking was developed to define the Groundwater Factor (GWF). This ranking was derived by integrating the RZLI with the GMI in a three-by-three matrix and assigning a simplified High, Moderate and Low ranking to describe the various combinations as shown in Table 4.4. Note that in this matrix, the moderate to very low AVI categories from Table 4.3 were combined and treated as low (L) GMI in Table 4.4. Similarly, the high category (Table 4.3) was treated as moderate (M) and the very high (Table 4.3) was treated has high (H) in Table 4.4.

Table 4.4 Groundwater Factors derived from combinations of the soil Root Zone Leaching Index and the Geologic Materials Index.

Vulnerability (Table 4.3)	RZLI / GMI	Low	Moderate	High
Very Low (>10,000 years) Low (1000 ≤ 10,000 years) Moderate (100 ≤ 1000 years)	Low (>100 yrs)	L	L	M
High (10-100 yrs)	Moderate (10-100 yrs)	L	M	H
Very High (< 10 years)	High (< 10 yrs)	M	H	H

Groundwater Factor classes:

Low - soils in this category generally have adequate capacity to retain fall precipitation and normal snowmelt water, and overly drift materials with a low to moderate potential for solutes to adversely influence underlying aquifers.

Moderate - soils in this category sometimes have inadequate capacities to retain fall precipitation and snowmelt water, and overly drift materials with variable thicknesses and potentials for solutes to adversely influence underlying aquifers.

High - soils in this category typically have inadequate capacities to retain fall precipitation and snowmelt water, and overly drift materials with relatively short downward travel times and thus a high potential for solutes to adversely influence underlying aquifers. Unconfined aquifers typically fall into this category.

The GWF describes the relative long-term expected capacity of the soil root zone to hold moisture at snowmelt with the estimated travel times for water (or a soluble non-reactive substance) to move downward through the underlying drift materials. Note that the level of the water table or saturated soil zone is not specifically highlighted in this scenario, only the travel time required to reach a defined underlying potential aquifer. Lithological materials that may form an aquifer, regardless of the current state of saturation, are included as they are thought to represent pathways along which soluble contaminants could easily move should they become saturated.

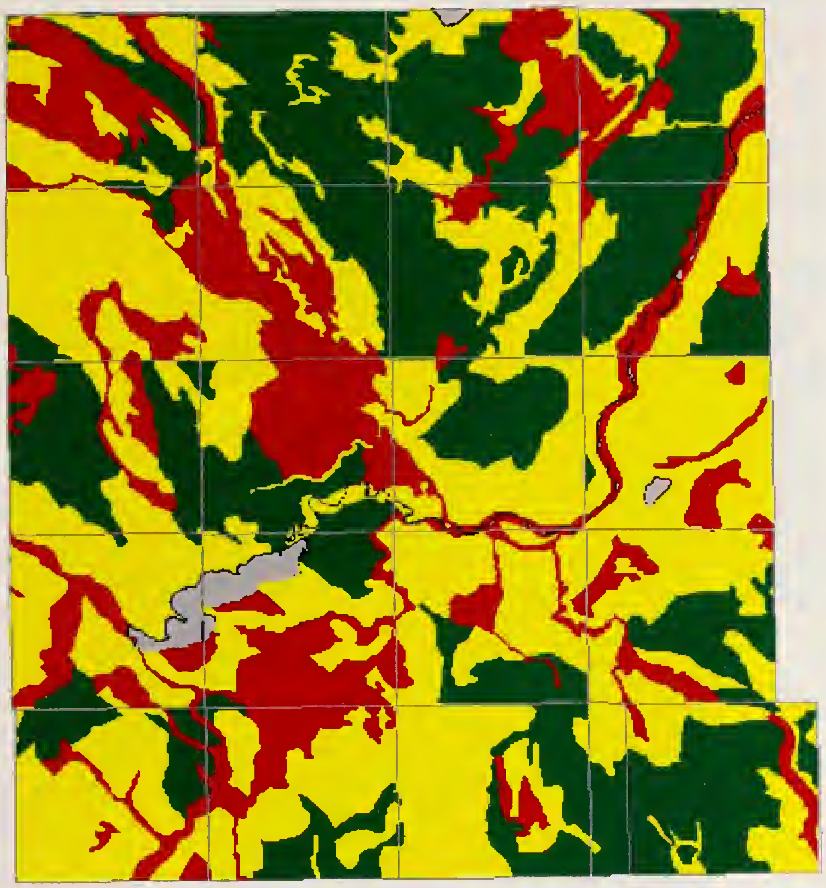
The combination of RZLI with the GMI facilitates the recognition of the value and function of soil in the leaching process. Leaching is a natural and necessary landscape process by which groundwater aquifers become replenished. Leaching only becomes a concern when the quality of the soil water being recharged is compromised by alien constituents which may impair the quality of the water in the aquifer or the health of the aquifer itself. The chemical, physical and biological characteristics of soils are determined largely by the quantity and quality of the water available in the profile. Only the excess water that cannot be used by plants or retained in the profile leaches through and is potential groundwater recharge. The quality of this leachate is of utmost importance in determining the long term risk to the underlying aquifer. Thus, there is an intimate relationship between soil quality and water quality.

The RZLI recognizes the physical role of soils in groundwater recharge and hence, aquifer protection. However, because of the broad generalizations that have been considered in this methodology, only soils with a low RZLI actually modify the GWF rating as noted in Table 4.4. This modification can result from two potential circumstances. Soils in more arid areas would have less risk to GWF because of lower precipitation and less available water, therefore a lower RZLI. Secondly, because clay textured soils in any environment are assumed to have a relatively lower risk of leaching and hence a lower GWF because of their great water retention capability.

The Groundwater Factor considers only the physical environment of the soils and geological materials. It does not consider degree of saturation, cation exchange capacities, or any potential oxidation/reduction functions related to mitigating or attenuating the movement of soluble substances.

Example maps of the GWF for the County of Red Deer Alberta and the Rural Municipality of South Norfolk in Manitoba are shown in Figures 4.8 and 4.9 respectively.

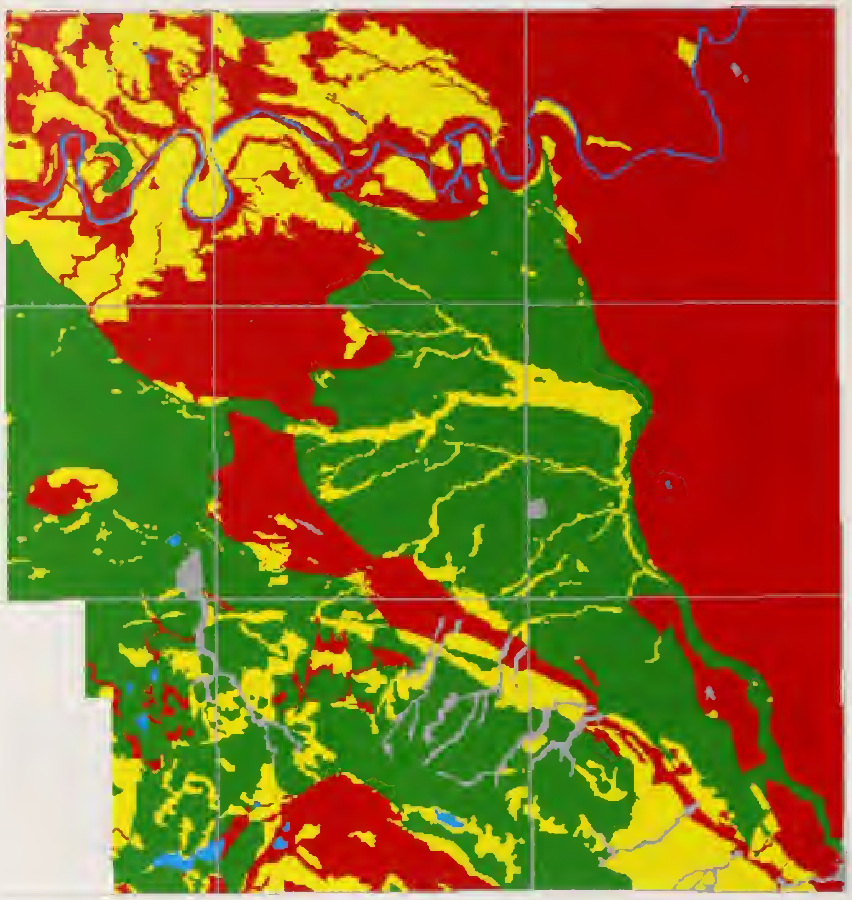
Example: A shallow sandy loam soil (RZLI = M) overlying a highly pervious aquifer (GMI = H) results in a high groundwater factor rating.



The relative likelihood of excess residual N leaching downward throught the soil and subsoil materials to an aquifer. It is derived from the combination of the Root Zone Leaching Index and the Geological Materials Index.

(dark green)	**Low**	Soils typically have an adequate capacity to retain normal fall precipitation and spring snow melt, and overlay thick deposits of slowly permeable, glacial drift materials with low potentials for solutes to affect underlying aquifers.
(yellow)	**Moderate**	Soils sometimes have an inadequate capacity to retain fall precipitation and normal snow melt water, and overlay glacial drift materials of variable thicknesses and potentials to protect underlying aquifers.
(red)	**High**	Soils typically have an inadequate capacity to retain fall precipitation and normal snow melt water, and overlay glacial drift materials with relatively short downward travel times for transport of solutes to potential underlying aquifers. Unconfined aquifers typically fall into this category.
(light blue)	**Water**	
(grey)	**Unclassified**	

Figure 4.8 Ground Water Factor (RZL/GMI) map for Red Deer County, Alberta



The relative likelihood of excess residual N leaching downward throught the soil and subsoil materials to an aquifer. It is derived from the combination of the Root Zone Leaching Index and the Geological Materials Index.

(green)	Low	Soils typically have an adequate capacity to retain normal fall precipitation and spring snow melt, and overlay thick deposits of slowly permeable, glacial drift materials with low potentials for solutes to affect underlying aquifers.
(yellow)	Moderate	Soils sometimes have an inadequate capacity to retain fall precipitation and normal snow melt water, and overlay glacial drift materials of variable thicknesses and potentials to protect underlying aquifers.
(red)	High	Soils typically have an inadequate capacity to retain fall precipitation and normal snow melt water, and overlay glacial drift materials with relatively short downward travel times for transport of solutes to potential underlying aquifers. Unconfined aquifers typically fall into this category.
(blue)	Water	
(grey)	Unclassified	

Figure 4.9 Ground Water Factor (RZL/GMI) map for the Rural Municipality of South Norfolk, Manitoba.

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V. CLIMATE FACTOR *(R. Woodvine)*

Information about the long-term climatic conditions in the Prairie Ecozone has been used to characterize the sustainability of soil quality as affected by the annual risk of wind and water erosion on agricultural lands (McRae et al, 2000). It has also been used in this project to calculate a root zone leaching index which reflects the annual potential for excess water in the root zone at snowmelt and thus the potential for deep leaching of nutrients. In addition, the working group felt that climatic information is an important factor for seasonal land use planning. Practices such as the timing and application rates of manures to soil landscapes should be done during periods when risks to the environmental integrity of soils, surface waters and groundwater are minimal.

Specifically, it is important to consider seasonal weather conditions such as the probability of extreme events. The probability or risk of snowmelt runoff, combined with the probability of rainfall events increases the risk of surface runoff and subsequent erosion of sediments containing nutrients and particulate organic materials derived from manures. Any potential for excess soil moisture which increases the risk of root zone leaching should be considered.

A. Risk of surface runoff

The risk for surface runoff into adjacent water bodies or low lying areas is dependent on precipitation patterns and the probability of extreme events. Extreme events refer to conditions such as rainfall with intensities that produce significant runoff, soil erosion and surface ponding. When combined with the Surface Water Factor, the probability of extreme events can have a significant influence on land use and management planning to minimize environmental impacts. In reality, this represents a major challenge for manure management.

Snowmelt or intense rainstorms following land application of hog manure can cause surface runoff and/or leaching, potentially contaminating off-site surface or subsurface water sources. The risk depends on both climate and landscape.

Two Climate Indices were developed and mapped, based on data from existing sources. Runoff magnitude and variability are both important factors in assessing the relative risk of adverse impacts from snowmelt runoff. Regions with normally low, but occasionally extreme, snowmelt runoff may require similar management practices as regions with consistently high snowmelt runoff but little annual variability.

1. Snowmelt Index

The snowmelt index was calculated using the following expression:

Snowmelt Index = *f*(Runoff Magnitude Factor x Runoff Variability Factor)

where:

Runoff Magnitude Factor = Median (50%) Annual Unit Runoff (mm)

Runoff Variability Factor = Ratio of 25% to 70% Annual Unit Runoff

In most years, runoff on the Canadian Prairies consists almost entirely of snowmelt runoff. Isopleths of annual unit runoff have been developed and mapped by PFRA for probabilities of exceedence ranging from 90% to 10%, and are presented in PFRA Hydrology Report #135, "Annual Unit Runoff on the Canadian Prairies", February 1994. Values for the 70%, 50% and 25% probabilities of axceedence were extracted for selected stations and used to calculate Snowmelt Indices. These indices were then mapped to illustrate the distribution of the relative risk for agricultural areas of the Prairies as shown in Figure 5.1

Snowmelt Runoff Index

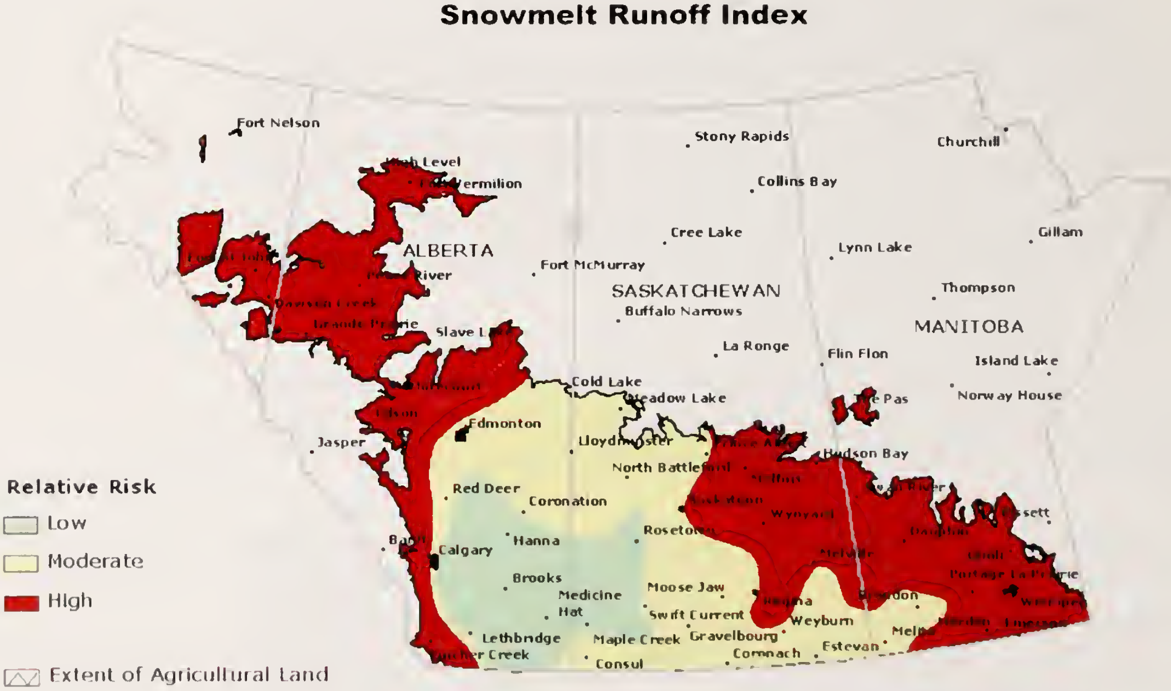

Figure 5.1 Index map depicting the long term risk of snowmelt runoff.

2. Rainstorm Index

There are three important factors to consider in assessing the relative risk of leaching and/or runoff from rainstorm events. Antecedent moisture conditions and rainstorm intensity both indicate the relative consequence (leaching and/or runoff) of rainstorm events. Rainstorm frequency indicates the relative occurrence of such events. Rainstorm Indices were developed and mapped for three distinct seasons to accommodate operational requirements in the field respectively:

April 1 to May 31,	(Figure 5.2)
June 1 to August 15,	(Figure 5.3)
August 16 to October 31.	(Figure 5.4)

For each time period, a Rainstorm Index was calculated according to:

Rainstorm Index = *f*(Antecedent Moisture x Rainstorm Intensity x Rainstorm Frequency)

where:

Antecedent Moisture = 30-year normal soil moisture
Rainstorm Intensity = 1:10 24-hour rainfall (mm)
Rainstorm Frequency = Average number of days per year with >25 mm rainfall

The Antecedent Moisture was determined for each station location and season as the 30-year soil moisture, based on Versatile Soil Moisture Budget Modelling for the predominant soil texture and land cover at that location.

The Rainstorm Intensity was determined for each season at selected stations as the 1:10 24-hour rainfall. (i.e., the highest intensity rainfall within 24 hours occurring one year in 10). These were estimated from frequency curves developed from published daily precipitation data at Environment Canada meteorological stations.

The Rainstorm Frequency was determined for each season as the number of days with greater than 25 mm rainfall, divided by the number of years of data (30).

Rainstorm Indices were calculated on a seasonal basis from published daily data for the 30-year normal period 1961-90 at select locations in the Canadian Prairies.

Climatic Indices have been calculated for most of the Prairie Ecozone at a very broad scale (1:5 000 000). Application of these values to individual soil polygons which are at a scale of 1:100 000 or larger, was not considered appropriate for this project. However, the calculations of the various indices and the maps are intended to serve as an awareness to planners and managers that seasonal weather conditions need to be considered in the development of sustainable, long-term manure application plans. Specifically, consideration should be given to soil moisture conditions at the time of application and the likelihood of extreme events which could lead to runoff and/or leaching.

Rainstorm Runoff Index

Spring: April 1 to May 31

Figure 5.2 **Rainstorm runoff index map depicting the long term risk during April 1 to May 31.**

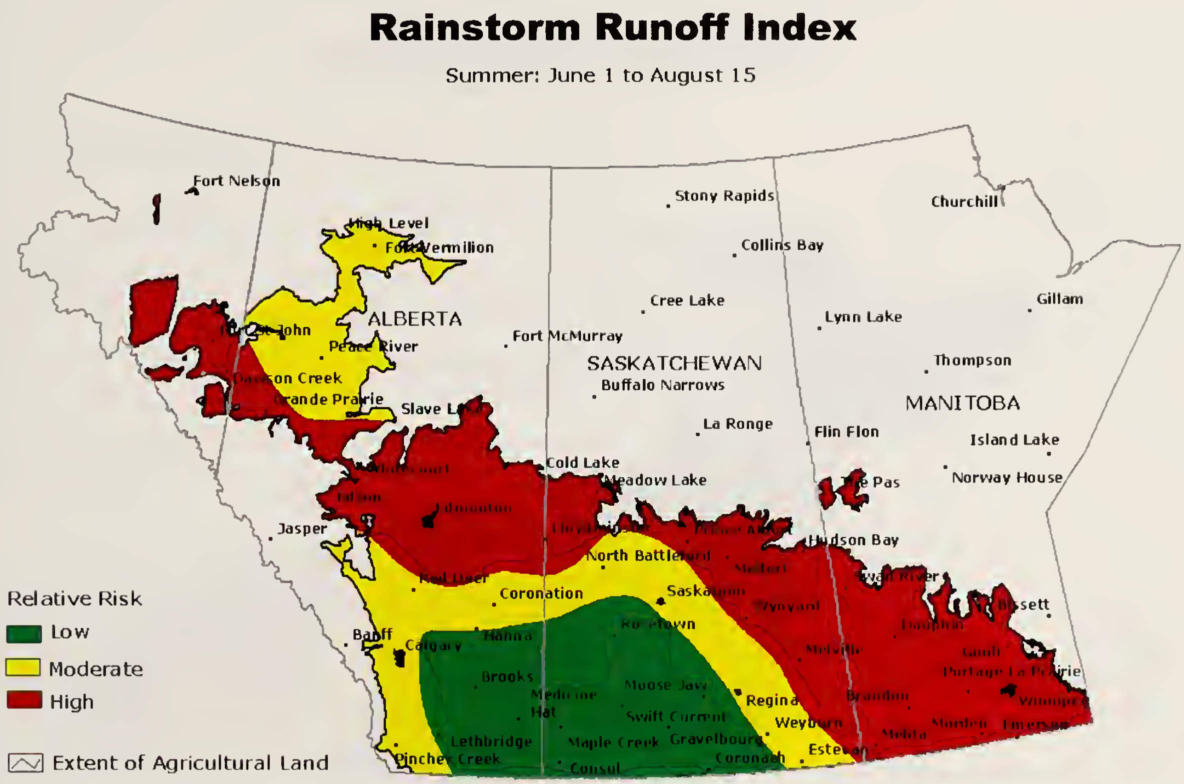

Figure 5.3 Rainstorm runoff index map depicting the long term risk during June 1 to August 15.

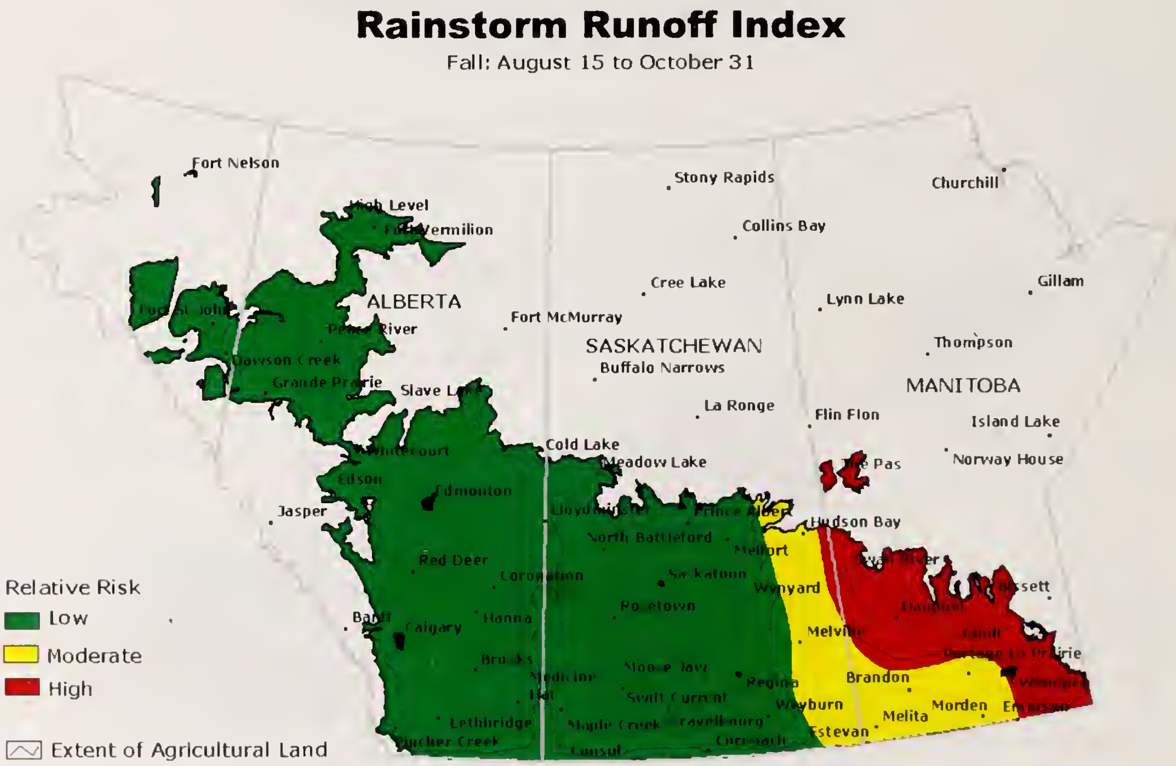

Figure 5.4 Rainstorm runoff index map depicting the long term risk during August 16 to October 31.

B. Information Products

The Snowmelt Index analysis has been completed and a preliminary map for the Canadian Prairies has been prepared. Preliminary seasonal Rainstorm Indices have been developed and mapped using the indicated methodology, but with the Antecedent Moisture based on accumulated seasonal rainfall and gross evaporation rather than on modeled soil moisture normals data. These climatic index maps depict the probability of extreme events and can be used to modify the range of recommendations for the SMGs in specific areas. They will form part of the menu of linked data sets.

C. Application

It is intuitive that climate/weather circumstances strongly influence decision-making in nearly every aspect of land use and manure management planning. Because climate/weather is temporally and spatially variable even at the local level, its influence and impact on land use will also vary spatially and temporally apparent. The methodology described in this report focuses on the spatially variable, but significantly more stable, physical aspects of the resource environment, that is, the soils and geology.

The influence of weather conditions on management decisions is much more important at the local level. Users and planners are therefore expected to apply the best local climate/weather information available when specific land suitability assessments are undertaken. The climate information presented here is designed to create an awareness of the importance of developing management plans for specific soil management groups in concert with local environmental circumstances. These will relate primarily to the timing, rates and methods of application, types and quality of manures, and cropping system selections. Local environmental circumstances related to management are also discussed in the current provincial farm practices guidelines for swine producers in each of the Prairie provinces.

The climatic indices were calculated to give a regional environmental perspective and are not intended for application to specific soil polygons.

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VI. FACTOR INTEGRATION *(W.R. Fraser)*

The Nutrient, Surface Water and Groundwater factors previously discussed represent individual pathways for potential manure nutrient loss from agro-ecosystems. Although each factor can be evaluated independently for any soil landscape area, it was considered more practical to integrate the ratings into a smaller number of significant Soil Management Groups (SMGs) for land management decision-making. Each Soil Management Group defines soil landscapes that have a relatively similar combination of risk factors and manure nutrient use characteristics. Management practices can then be selected to address the environmental sensitivities for each SMG, facilitating optimum sustainable manure nutrient use while minimizing the potential for nutrient losses due to leaching or surface runoff. A discussion of research information and agricultural policies that may be consulted in the development of manure management options for Soil Management Groups is provided in Section VII.

A brief overview of the factors and classes is provided here, followed by a discussion of the integration technique used to define Soil Management Groups. This methodology is designed to be generic so that it may be tailored for specific nutrient issues (such as N, P, etc.). Further, the SMG definitions in this section are expressed in terms of potential risk of manure nitrogen particular losses.

A. Nutrient Factor

The Nutrient Factor expresses the risk that manure N (nitrogen) applied to soil landscapes will not be fully utilized for crop production. This can be considered as the inverse of soil productivity. The assumption is that soils with a higher suitability for crop production represent a lower risk for N losses. That is, highly productive soils produce high yield crops more consistently, and thus can more effectively use relatively large annual inputs of manure N (up to crop requirements). Soils with a low capability for crop production cannot consistently use large periodic applications of manure N for crop growth, and thus the excess N would result in a higher risk of surface water or groundwater contamination.

Many soil properties affect land suitability for crop production. The soils component of the Land Suitability Rating System (LSRS) for Agricultural Crops (Table 4.2 in Agronomic Interpretations Working Group, 1995), was selected as a suitable and comprehensive method to evaluate and integrate these various soil properties.

The LSRS recognizes seven soil suitability classes for crop production which are combined into the following three groups describing their relative risks for excess nutrient loss (see Section II).

Ln **Low N risk.** These soils have a high productivity potential (LSRS classes 1, 2, and 3), enabling them to use large amounts of manure N for annual crop production. They have a low risk of excess residual N after harvest. Soil limitations for production are slight to moderate.

Mn **Moderate N risk.** These soils have a moderate productivity potential (LSRS classes 4 or 5) and typically have a high proportion of improved forages and pastures which could benefit from manure nutrients. To minimize the risk of excess N, manure should be applied according to target yield guidelines. Significant soil limitations, such as excess wetness, droughtiness or stoniness may require additional management considerations and may limit the range of cropping practices and target yields.

Hn **High N risk.** These soils and non-soils have a low productivity potential (LSRS classes 6, and 7) and severe limitations that make them unsuitable for annual crop production. Soil limitations may include very coarse texture, extreme wetness or salinity, or unsuitable soil climate for crop production. Land use on these soil landscapes is typically native forages and pastures and although manure application may be physically feasible in some locations, the soils would have a high risk for N loss to either groundwater or surface water runoff.

B. Surface Water Factor

The Surface Water Factor expresses the likelihood of manure N being moved downslope to contaminate surface streams and water bodies (Section III). This factor is a combination of soil landscape properties for slope steepness and length, which determine the velocity and volume of runoff , and the soil erodibility factor which determines the likelihood of soil particulate matter moving downslope with the water. These parameters are recognized and measured in the field and used in the Universal Soil Loss Equation (Wischmeier and Smith 1965). They also represent landscape parameters available in the 1:100 000 scale digital soil databases for the Prairie provinces.

Three classes of potential runoff risk have been identified for the Surface Water Factor.

Lr **Low surface water risk**. Landscapes with level to gently sloping topography and soils may have low to high infiltration capacities.

Mr **Moderate surface runoff risk**. Landscapes with either long, low, slopes, or shorter moderate slopes, and low to moderate soil infiltration capacities.

Hr **High surface runoff risk**. Landscapes with moderately steep, long slopes, or steep, short slopes with low to moderate soil infiltration capacities.

C. Groundwater Factor

The Groundwater Factor describes the likelihood of manure N leaching downward through the soil and subsoil materials to an aquifer. This is a combination of the soil Root Zone Leaching Index (RZLI) and the Geologic Materials Index (GMI), as previously defined in Section IV.

Both indices are defined in terms of three classes and subsequently combined in a matrix to define three classes of potential risk to groundwater.

Lg **Low groundwater risk.** These soils generally have adequate capacity to retain normal snowmelt water, and overlay drift materials with a low to moderate potential to adversely influence underlying aquifers. They are well to imperfectly drained, with loamy to clayey textures and high water-holding capacities. The permeability of the surface soil and subsurface materials is slow, and there are typically several metres of the slowly permeable materials above the regional aquifer.

Mg **Moderate groundwater risk.** These soils sometimes have inadequate capacities to retain snowmelt waters, and overlay drift materials with variable thicknesses and potentials to protect underlying aquifers. They are moderately well to imperfectly drained, with loamy to coarse loamy surface textures. The permeability of the soil material is high to moderate. The subsurface materials may have either a shallow depth of slowly permeable materials, or a deeper thickness of moderately permeable material overlaying potential aquifers.

Hg **High groundwater risk.** These soils typically have inadequate capacities to retain snowmelt waters, and overlay drift materials with relatively short downward travel times and thus have a high potential to adversely influence underlying aquifers. They typically have variable soil drainage associated with very coarse textures, generally high permeabilities and low moisture-holding capacities. The subsurface materials have high GMI values indicating that either the underlying aquifer is close to the surface, or that the overlying materials are moderately to rapidly permeable.

D. Soil Management Groups

Soil Management Groups (SMGs) have been developed from the integration of the Nutrient, Surface Water and Groundwater factors, with three classes each (Low, Medium, High), resulting in a matrix of 27 (3x3x3) unique combinations.. Although each factor can be evaluated independently for any soil landscape area, it was considered more practical to group the ratings into a smaller number of significant groups for land management decision-making. SMGs define soil landscape areas with relatively similar risks for crop production, manure application and environmental protection. Each SMG represents one or more of the 27 unique risk factor combinations, and each can be associated with a specific combination or set of recommended manure and land management practices.

SMGs can be portrayed graphically, with Groundwater, Surface Water, and Nutrient factors representing the x, y and z axis. As each factor has three possible values (Low, Medium, High), the result is a 3-D matrix or "feature space" with the 27 unique "xyz" combinations (3x3x3) representing specific cell positions (Figure 6.1). Closely related combinations, with adjoining positions, define each SMG. This can also be portrayed in two dimensions using a set of three, 2-dimensional 3x3 matrix tables. Tables 6.1a, b, and c show the SMG classes assigned to specific combinations of Surface Water, and Groundwater factors, for Low, Moderate, and High N risk classes respectively.

It is important to note that during the systematic analysis of the three resource factors, and the use of a standard 3-dimensional mathematical matrix approach for integration, certain combinations of soil, landscape and geological conditions are allowed for, which in reality, may not physically exist For example, it is unlikely that soil landscapes have both a high risk of surface runoff and a high risk of leaching to groundwater. The SMG categories and definitions are considered first approximations and further evaluation and validation is required.

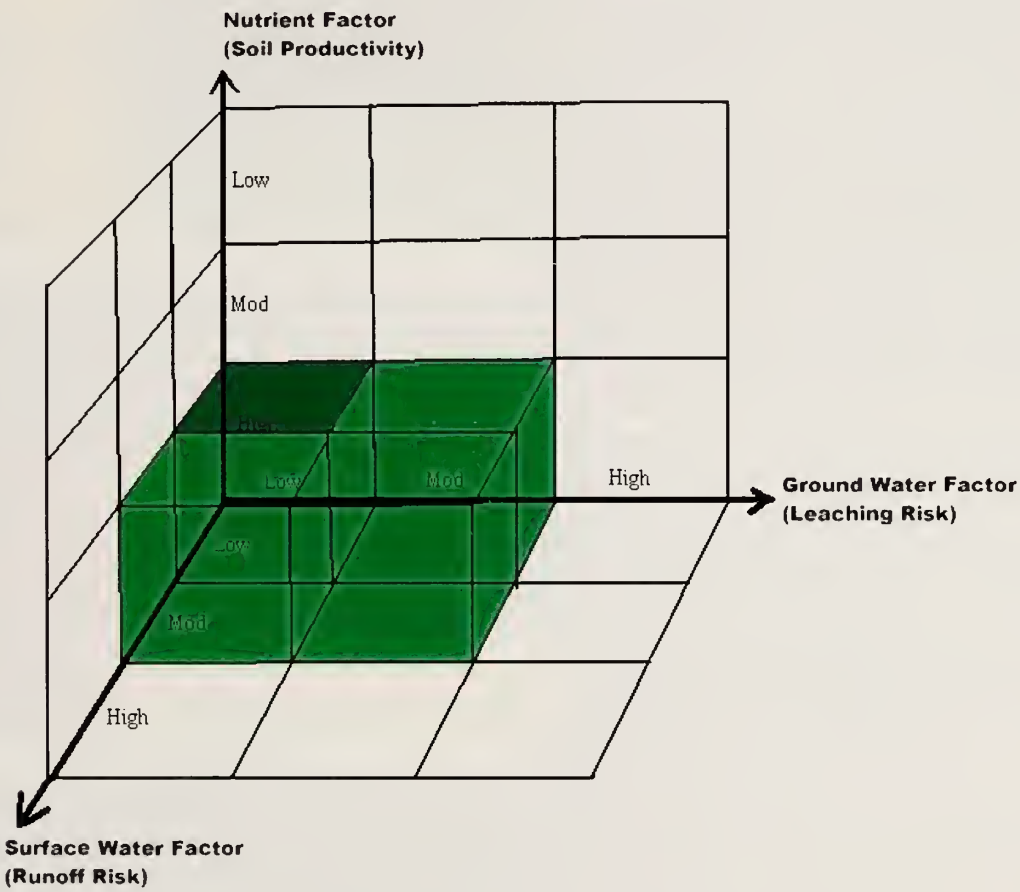


Figure 6.1 **A schematic 3-D matrix graphical integration of the three factors to derive the Soil Management Groups.**

Table 6.1a, b, and c **Soil Management Groups (SMGs) for soil landscapes where the N Risk is Low, Moderate, and High, respectively.**

Low N Risk (Ln) (High productivity)	**Groundwater Risk Low (Lg)**	**Groundwater Risk Moderate (Mg)**	**Groundwater Risk High (Hg)**
Surface Runoff Risk Low (Lr)	(Ln, Lr, Lg) **SMG A**	(Ln, Lr, Mg) **SMG B**	(Ln, Lr, Hg) **SMG F**
Surface Runoff Risk Moderate (Mr)	(Ln, Mr, Lg) **SMG B**	(Ln, Mr, Mg) **SMG B**	(Ln, Mr, Hg) **SMG F**
Surface Runoff Risk High (Hr)	(Ln, Hr, Lg) **SMG D**	(Ln, Hr, Mg) **SMG D**	(Ln, Hr, Hg) **SMG F**

Moderate N Risk (Mn) (Mod. productivity)	**Groundwater Risk Low (Lg)**	**Groundwater Risk Moderate (Mg)**	**Groundwater Risk High (Hg)**
Surface Runoff Risk Low (Lr)	(Mn, Lr, Lg) **SMG C**	(Mn, Lr, Mg) **SMG C**	(Mn, Lr, Hg) **SMG G**
Surface Runoff Risk Moderate (Mr)	(Mn, Mr, Lg) **SMG C**	(Mn, Mr, Mg) **SMG C**	(Mn, Mr, Hg) **SMG G**
Surface Runoff Risk High (Hr)	(Mn, Hr, Lg) **SMG E**	(Mn, Hr, Mg) **SMG E**	(Mn, Hr, Hg) **SMG G**

High N Risk (Hn) (Low productivity)	**Groundwater Risk Low (Lg)**	**Groundwater Risk Moderate (Mg)**	**Groundwater Risk High (Hg)**
Surface Runoff Risk Low (Lr)	(Hn, Lr, Lg) **SMG H**	(Hn, Lr, Mg) **SMG H**	(Hn, Lr, Hg) **SMG H** (Organic) **SMG I**
Surface Runoff Risk Moderate (Mr)	(Hn, Mr, Lg) **SMG H**	(Hn, Mr, Mg) **SMG H**	(Hn, Mr, Hg) **SMG H**
Surface Runoff Risk High (Hr)	(Hn, Hr, Lg) **SMG H**	(Hn, Hr, Mg) **SMG H**	(Hn, Hr, Hg) **SMG H**

Definitions

Soil Management Group - A

SMG "A"

Highly productive soils with low risk of nutrient loss to surface water runoff or leaching to groundwater.

Management options are unrestricted, within provincial guidelines. Soils in this group are typically deep, medium to fine texture and have a generally flat topography.

SMG "A", is defined by a single combination of factors:

Ln, Lr, Lg **(Low N, Low runoff, and Low groundwater risk)**

Soil Management Group - B

SMG "B"

Highly productive soils with low to moderate risk of surface water runoff and/or leaching to groundwater.

Many soils in this group with a moderate runoff risk have loam to clay textures and moderate slopes (2 to 9%). Soils with a moderate groundwater risk typically have medium to moderately coarse soil textures with moderate permeability. Some management considerations to minimize the leaching risk of the soil and geological materials overlying potential groundwater aquifers are required.

Management options for SMG "B" are generally broad, although more restrictive than for SMG"A". Since productivity is high, applications of manure N could supply annual crop requirements. Incorporation of manure, rather than surface application, should be encouraged on sloping lands where the risk of surface water runoff is moderate (Mr). Sensitivity to timing and rates of manure application are more critical on coarse textured soils with moderate risks for leaching to groundwater (Mg).

Three combinations of factors define the soils in SMG "B":

Ln, Lr, Mg (Low N risk, Low runoff and Moderate groundwater risk), or
Ln, Mr, Lg (Low N risk, Moderate runoff and Low groundwater risk), or
Ln, Mr, Mg (Low N risk, Moderate runoff and Moderate groundwater risk)

Soil Management Group - C

SMG "C" Marginally productive soils with low to moderate risk of nutrient loss to surface water runoff and/or leaching to groundwater.

Manure management options for SMG "C" soils are more restrictive than for SMG "A" or "B", due to a lower (moderate) productivity potential. The relatively severe limitations for annual crop production (LSRS classes 4 or 5) may be due to excess wetness, droughtiness, stoniness, salinity, or a combination of factors that require additional land management considerations. Cropping options and potential yields are more limited than for highly productive soils, limiting the amount and timing of manure N applications that can be safely applied. Moderate limitations due to either surface water runoff risk or groundwater risk may further restrict the options for manure management. Nutrient management plans should be developed for these soils. For example, incorporation of manure, rather than surface application, should be encouraged on sloping lands where the surface water risk is moderate (Mr). Timing and rate of application may be more sensitive on coarser textured soils where the risk of groundwater leaching is moderate (Mg).

Four combinations of factors define the soils in SMG "C":

Mn, Lr, Lg (Moderate N risk, Low runoff and Low groundwater risk), or
Mn, Lr, Mg (Moderate N risk, Low runoff and Moderate groundwater risk), or
Mn, Mr, Lg (Moderate N risk, Moderate runoff and Low groundwater risk), or
Mn, Mr, Mg (Moderate N risk, Moderate runoff and Moderate groundwater risk)

Soil Management Group - D

SMG "D" Highly productive soils with a high risk of nutrient loss to surface water runoff, and a low to moderate risk of leaching to groundwater.

The soils in SMG "D" have productivity potential (LSRS classes 1 to 3, a slight to moderate limitation for annual crop production) and are therefore considered to have a low N risk. The groundwater factor is low to moderate. Many soils in this group have loam to clay textures and steep slopes (5 to 9% or greater). Some soil landscapes with lesser slopes, but longer slope lengths, or with lower surface soil infiltration rates can also result in a high runoff risk.

Manure management options for SMG "D" soils are primarily concerned with practices to limit the risk of surface water contamination from runoff. Soils in this group have significant topography. Manure should be directly injected rather than surface applied.
Two combinations of factors define soils in SMG "D":

Ln, Hr, Lg **(low N risk, High runoff and Low groundwater risk), or**

Ln, Hr, Mg **(low N risk, High runoff and Moderate groundwater risk)**

Soil Management Group - E

SMG "E" Marginally productive soils with a high risk of nutrient loss to surface water runoff, and a low to moderate risk of leaching to groundwater.

The soils have severe to very severe limitations for annual crop production (LSRS soil ratings of class 4 or 5), and are therefore considered to have a moderate N risk. The groundwater risk is low to moderate, the moderate risk being associated with shallow depressional areas where runoff collects. Many soils in this group have loam to clay textures and steep slopes (5 to 9 % or greater). Some soil landscapes with lesser slopes, but longer slope lengths, or with lower surface soil infiltration rates can also result in a high runoff risk.

Manure management options for SMG "E" soils are primarily concerned with practices to limit the risk of surface water contamination from runoff. Soils in this group have significant topography. Manure should be incorporated by injection, rather than surface applied. The amount and timing of manure applications is limited by the moderate N risk (Mn) as the soils have significant limitations for annual crop production. This may be due to a variety of factors, such as excess wetness, droughtiness, stoniness, or salinity which require additional land management considerations. These soils are marginal for annual crop production, but may typically have a high proportion of improved forages and pasture which may benefit from manure nutrients. Nutrient management plans are required.

Two combinations of factors define the soils in SMG "E":

Mn, Hr, Lg **(Moderate N risk, High runoff and Low groundwater risk), or**
Mn, Hr, Mg **(Moderate N risk, High runoff and moderate groundwater risk)**

Soil Management Group - F

SMG "F" Highly productive soils with a low to high risk of nutrient loss to surface water runoff, and a high risk of leaching to groundwater.

The soils have slight to moderate limitations for crop production (and a low N risk). The runoff risk for surface waters is typically low to moderate. One of the three combinations in SMG "F" (Ln, Hr, Hg) has both a high surface runoff risk and a high groundwater risk. These are considered to be relatively rare, and are included within SMG "F" to emphasize the risk for groundwater. SMG "F" soils generally have coarse textures, and a limited water holding capacity. The drift materials (GMI values) may be relatively shallow in depth and slowly permeable, or have moderate thickness but with higher permeability overlying a potential aquifer.

Manure management options for SMG F soils are primarily concerned with practices to limit the risk of leaching. The soils ability to hold nutrients for use by crops is typically limited, so that the amount and timing of manure N applications should be closely matched to meet crop uptake requirements. SMG "F" soil landscapes have low to moderate limitations for annual crop production (LSRS classes 1 to 3). Since these soils have a high potential productivity, the amount of manure N that can be safely applied to meet annual crop requirements is more a function of the landscape and leaching factors.

Three combinations of factors define the soils in SMG F:

Ln, Lr, Hg **(Low N risk, Low runoff and High groundwater risk), or**

Ln, Mr, Hg **(Low N risk, Moderate runoff and High groundwater risk) ,or**

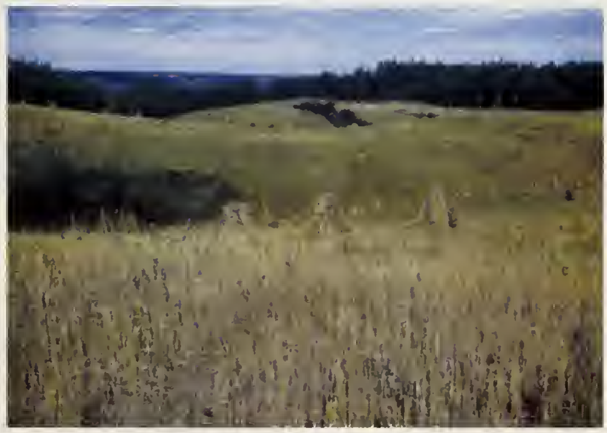
Ln, Hr, Hg* **(Low N risk, High runoff and High groundwater risk)**

** this combination rarely occurs within current test areas.*

Soil Management Group - G

SMG "G" Marginally productive soils with a low to high risk of nutrient loss to surface water runoff, and a high risk of leaching to groundwater.

These soils have severe to very severe limitations for annual crop production (LSRS class 4 and 5) and therefore a moderate N risk. The runoff risk for surface waters is typically low to moderate. One of the three theoretical combinations in SMG "G" (Mn, Hr, Hg) has both a high surface runoff risk and a high leaching risk for groundwater contamination. Very few soil landscapes matching these combinations were found within the test areas, and their inclusion within SMG "G" emphasizes the risk to groundwater. SMG "G" soils generally have coarse textures, and a limited water-holding capacity. The GMI values indicate a relatively shallow depth of slowly permeable material, or a moderate thickness of more permeable materials overlying a potential aquifer. Manure management options for SMG "G" soils are primarily concerned with practices to limit the risk to groundwater. The soils ability to hold nutrients for use by crops is typically limited, so that the amount and timing of manure N applications should be closely matched to meet crop uptake requirements.



SMG "G" soil landscapes have significant limitations for annual crop production (LSRS classes 4 or 5). These may be due to a variety of factors such as droughtiness and stoniness or a combination of factors. These require additional land management considerations. Since potential annual crop yields on moderately productive soils are lower, the amount of manure N that can be safely applied to meet annual crop requirements is also lower than for SMG "F". These soil landscapes typically have high proportions of land use devoted to forages and native pasture which may benefit from judicial and timely applications of manure, providing appropriate methods of application are available.

Three combinations of factors define the soils in SMG "G":

Mn, Lr, Hg (Moderate N risk, Low runoff and High groundwater risk). or
Mn, Mr, Hg (Moderate N risk, Moderate runoff and High groundwater risk), or
Mn, Hr, Hg* (Moderate N risk, High runoff and High groundwater risk)
** this combination rarely occurs within current test areas.*

Soil Management Group - H

SMG "H"

Low productivity soils. Surface and groundwater risk factors range form low to high. Land areas maybe natural habitat for grazing animals (wild and domestic), wetlands, woodlands and recreation.

Soil landscapes in this group have suitability soil ratings of 6 and 7 with a low potential for agriculture. Limitations may be due to climate, extremely shallow soils or other severe soil conditions. Risk to groundwater and surface water runoff can vary from low to high. Land use is typically native forages and pasture. Improvements to the land must be made before implementing a sustainable nutrient management plan. As a general rule however, no manure N application methods can be recommended.

Nine combinations of factors define the soils in SMG H:

Hn, Lr, Lg, (High N risk, Low runoff and Low groundwater risk), or
Hn, Mr, Lg (High N risk, Moderate runoff and Low groundwater risk), or
Hn, Hr, Lg (High N risk, High runoff and Low groundwater risk), or
Hn, Lr, Mg (High N risk, Low runoff and Moderate groundwater risk), or
Hn, Mr, Mg (High N risk, Moderate runoff and Moderate groundwater risk), or
Hn, Hr, Mg (High N risk, High runoff and Moderate groundwater risk), or
Hn, Lr, Hg* (High N risk, Low runoff and High groundwater risk), or
Hn, Mr, Hg (High N risk, Moderate runoff and High groundwater risk), or
Hn, Hg, Hr (High N risk, High runoff, and High groundwater risk)
**(except peaty Gleysols and Organic soils, in SMG I)*

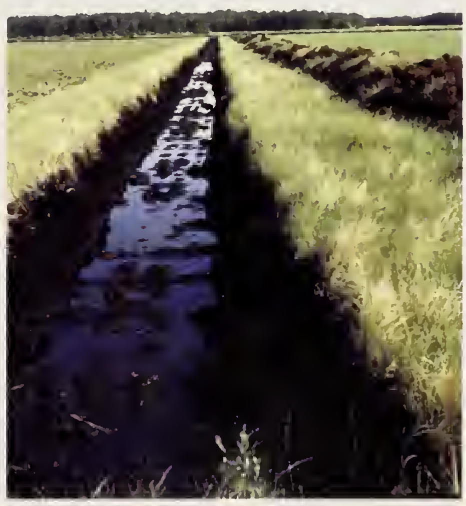
Soil Management Group - I

SMG "I" Organic (peat) soils and very poorly drained mineral (Gleysolic) soils with peaty surface layers, having severe to very severe limitations for annual crop production and high risk to groundwater.

These soils have very high water tables, organic soil textures and colder soil temperatures than surrounding mineral soils. If used for annual crop production, these soils require special management to regulate water table depths, for seed bed preparation and to overcome soil nutrient deficiencies. Risk of groundwater contamination from manure N applications is high due to the nearness of the water table to the soil surface and the permeability of the organic soil materials.

In the Prairie provinces, most organic and peaty Gleysolic soils remain in their native state and are not used for annual crop production. Most are too wet, or have adverse soil pH or wood contents, or have alternative value as wetlands that make annual crop production impractical.

Some organic or peaty Gleysolic soils, particularly level, non-woody, fen peat deposits with enhanced drainage, have been used but remain marginal for crop production. Nutrient management intensity levels for organic soils is very high.



Soils in SMG "I" are typically identified as a high N risk, low risk for runoff, and high risk for groundwater (Hn, Lr, Hg). Better drained mineral soils with a similar risk combination have a different set of very severe soil management conditions, and are defined in SMG "H". Organic and peaty Gleysol soils in SMG "I" are distinguished from the mineral soils in SMG "H" on the basis of soil taxonomy and drainage (Very poorly drained Gleysolic or Organic soil orders). One combination of risk factors defines the soils in SMG "I":

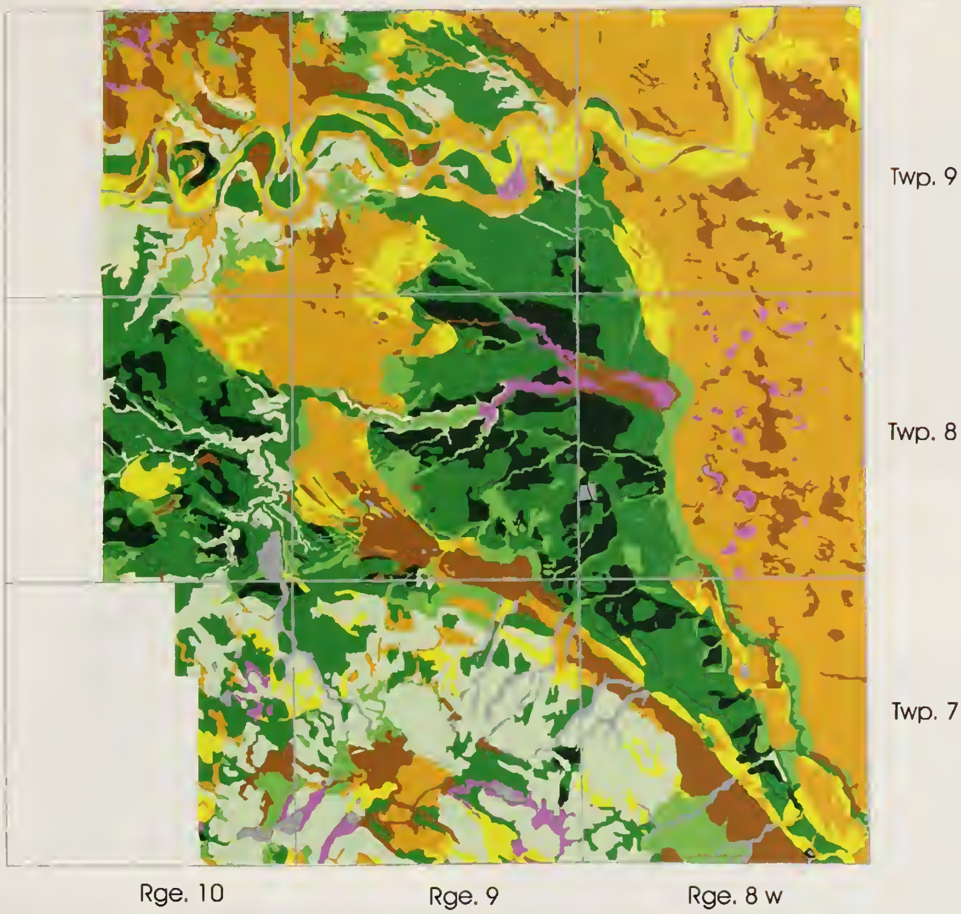
Hn, Lr, Hg **(peaty Gleysols and Organic soils - with High N risk, Low runoff and High groundwater risk)**

E. Considerations for using Soil Management Groups

SMGs can be mapped for any geographic location for which standardized soils and geological databases are available. To illustrate this land suitability rating methodology, three test areas were selected at locations across the prairies. The standardized soil database was completed for all three areas. However, the standardized geological database was completed only for the Manitoba and Alberta test areas. Individual maps of the various component indices were produced for each test area, with the exception of the GMI for geologic material for Saskatchewan. Therefore, using the three key factors previously defined, only the SMG maps for the Manitoba and Alberta test areas are provided here (Figure 6.2 and 6.3 respectively).

Each SMG identifies important environmental circumstances that must be addressed when developing manure management plans and selecting options. The current available research information about manure type, quality, handling, and application is summarized in the following section. The link between the attributes or limitations of the SMGs to the appropriate management information will be the focus for development of an interactive decision support package at a later date when the current methodology concepts have been reviewed, validated and tested in other areas, and the logic for the programing has been established. The latter will involve input from planners and researchers as well as the public sector.

At this time, manure management recommendations are somewhat generic, as each SMG can occur in many geographic areas, with a range of possible soil and climatic conditions. Additional points to note at this stage in the development of this strategy are listed below.



A Highly productive soils with low risk of nutrient loss due to surface water runoff or ground water leaching.

B Highly productive soils with a moderate risk of nutrient loss from surface water runoff and/or from ground water leaching.

C Marginally productive soils with low to moderate risk of nutrient loss from surface water runoff or ground water leaching.

D Highly productive soils with a high risk of nutrient loss from surface water runoff and a low to moderate risk of ground water leaching.

E Marginally productive soils with a high risk of nutrient loss from surface water runoff and a low to moderate risk of ground water leaching.

F Highly productive soils with a low to high risk of nutrient loss from surface water runoff and a high risk of ground water leaching.

G Marginally productive soils with a low to high risk of nutrient loss from surface water runoff and a high risk of ground water leaching.

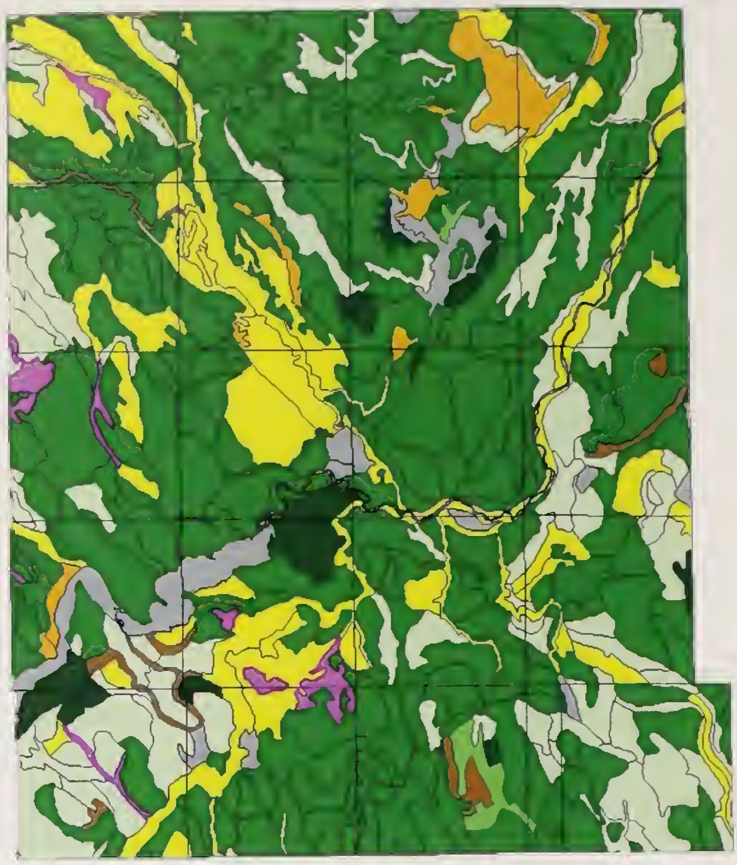
H Low productivity soils. Surface water and groundwater risk factors can range from low to high.

I Organic soils and very poorly drained mineral soils.

Water

Unclassified

Figure 6.2 **Soil Management Groups for the Rural Municipality of South Norfolk, Manitoba.**



- **A** Highly productive soils with low risk of nutrient loss due to surface water runoff or ground water leaching.
- **B** Highly productive soils with a moderate risk of nutrient loss from surface water runoff and/or from ground water leaching.
- **C** Marginally productive soils with low to moderate risk of nutrient loss from surface water runoff or ground water leaching.
- **D** Highly productive soils with a high risk of nutrient loss from surface water runoff and a low to moderate risk of ground water leaching.
- **E** Marginally productive soils with a high risk of nutrient loss from surface water runoff and a low to moderate risk of ground water leaching.
- **F** Highly productive soils with a low to high risk of nutrient loss from surface water runoff and a high risk of ground water leaching.
- **G** Marginally productive soils with a low to high risk of nutrient loss from surface water runoff and a high risk of ground water leaching.
- **H** Low productivity soils. Surface water and groundwater risk factors can range from low to high.
- **I** Organic soils and very poorly drained mineral soils.
- **Water**
- **Unclassified**

Figure 6.3 Soil Management Groups for a portion of Red Deer County, Alberta.

Specific crop management requirements.

The specific type of crop to be grown, the crop rotation sequence, irrigation, use of inorganic fertilizers, existing soil properties and fertility, etc. may all modify the potential crop requirements for manure N. This will affect the amount or timing of manure N applications that can be safely applied.

Micro-relief on frozen coarse textured soils causes ponding and surface runoff in man-made drains.

Specific soil types, and their limitations and management.

Although soils within the same SMG have similar productivity ranges, they may differ significantly in terms of their specific limitations to crop growth. Some soils may have severe moisture deficiencies, while others may have problems due to moisture excess, stoniness or other specific soil factors. These may restrict or modify the recommended range of manure management options.

Micro-relief on flat clay textured soils results in ponding after heavy rains and runoff in man-made drains.

Climatic factors.

A number of overall climatic parameters, such as the growing season length, heat units and precipitation can affect crop and soil management options. Several additional climatic parameters, such as probability of snowmelt and intense rainfall events in specific time intervals (spring, summer and fall) have been devised for the Prairie provinces specifically for this project. These maps should be consulted to assess regional change in risk of runoff or leaching from certain manure management application or timing options. However, for more specific local risk assessment, users will have to consult the most appropriate local climate station databases. Areas with higher risk of intense rainfall or snowmelt events in specific time periods may further restrict the manure application methods and timing recommendations for a particular SMG.

Multiple soil landscape components.

Some soil landscapes have multiple components, with different SMG ratings and management options. These may hinder or modify field scale management operations.

Specific provincial or local regulations.

Each province or local administration (rural municipalities) may have different regulations regarding manure application on steep slopes and specific setbacks from residences, streams, or wells etc. These considerations are not part of the overall SMG recommendations and maps developed under this project. The reader is referred to their respective provincial guidelines.

Future management and cropping options.

SMG groups are based on physical soil and subsoil properties that are spatially variable although relatively stable over time. Management and cropping options are much more flexible and typically can be expected to change over time as additional technological advances and research knowledge becomes available. The current descriptions and discussion of manure management information in the following section will need to be reviewed periodically, to incorporate future advances in knowledge and research information.

Prairie agricultural landscape.
In the foreground - highly productive with low environmental impact.
Non-productive, non-agricultural steep lands in the background.

References

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Wischmeier, W. H. and D.D. Smith. 1965. Predicting Rainfall-erosion Loss from Cropland East of the Rocky Mountains. U.S. Department of Agriculture, Agriculture Handbook No. 282, U.S. Government Printing Office, Washington, D.C.

VII. MANURE MANAGEMENT PRACTICES AND MITIGATING FACTORS *(K.E. Buckley)*

Typically, a complete manure management system includes land for livestock feed production, animals that produce manure and associated waste-waters, manure storage and handling facilities, manure application equipment and sufficient land for recycling excreted animal nutrients. Modern specialized and concentrated animal production systems present challenges in managing the balance among animal production, crop production and the environment.

Because of the intrinsic properties of manure such as the highly variable nutrient content and variable rate of nutrient release, determining the appropriate manure application rate can be a problem. The use of highly sophisticated equipment can aid in achieving even distribution of nutrients and avoiding over-application. When "contracting out" manure application, the livestock operator can gain some assurance of the proper delivery of nutrients to the land by employing reputable and responsible contractors.

Finding enough land to apply manure at proper rates can be difficult. Few large livestock operations have land near enough to their barns to allow optimum rates of manure application. Reaching agreements with neighbours for manure spreading on their fields is an option, although many are not willing to pay full value for the nutrient value of manure (Eric Rempel - personal communication).

The following is a summary of common manure management practices on the Prairies, an indication of potential losses, recommended nutrient fertilization levels, pertinent information from the provincial guidelines and management considerations for manure application.

A. Swine Manure Handling Alternatives

Swine manure can be handled as a solid, semi-solid or liquid (Fig. 7.1). Alternative handling systems for swine manure are shown in Figure 7.2. Liquid manure handling is by far the most common system. For composting, manure solids need to be separated from the liquid. Adding flocculants, such as polyelectrolytes and organic polymers, to manure slurries before separation can significantly improve the separation but flocculants are expensive.

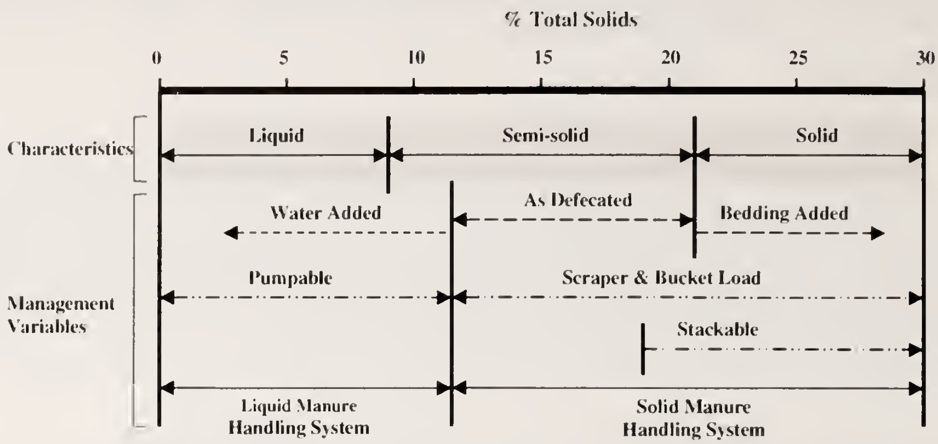

Figure 7.1 Physical manure characteristics and handling requirements. (Adapted from Ohio State University Bulletin 1992).

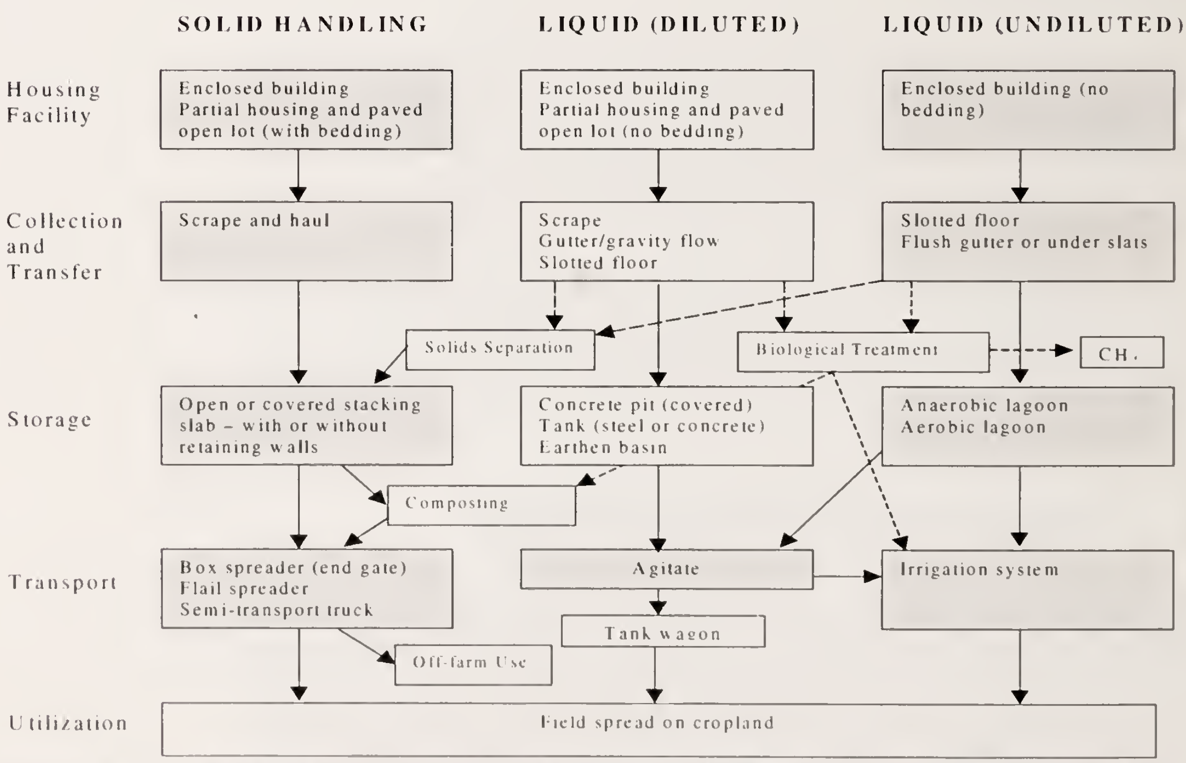

Figure 7.2 Handling alternatives for swine manure (Adapted from Ohio State University Bulletin 1992).

B. Hog Manure Production and Nutrient Characteristics

Approximately 70-89% of feed N is excreted as feces. The nutrient concentration and organic matter content of stored or treated waste may vary depending on time of year (Kachanoski, G. et al 1997). Nitrogen as the ammonium ion and about three-quarters of the potassium are found in the liquid portion. Nearly all of the organic nitrogen and phosphorus are contained in the solids. Table 7.1 indicates the variability in nutrient content of stored liquid swine manure. The characteristics of manure vary greatly from operation to operation depending on animal size, animal numbers, ration and amount of water or bedding added to the manure (Table 7.2).

Table 7.1 Variability in nutrient content of liquid swine manure in earthen storages[a]

Statistics	TKN	Ammonia	Organic Nitrogen	P_2O_5	K_2O	Na	EC mS/cm	Moisture %
	lbs/1000 Imperial gallons							
# samples	90	78	78	89	89	89	89	89
Low 95%	23.9	16.5	7.4	14	13.9	4	13.4	96.8
Mean	27.3	19.2	8.1	18.6	15.6	4.5	14.8	97.3
Upper 95%	30.7	21.9	8.8	23.5	17.3	5.1	16.1	97.9

[a] Manitoba Dept. of Agriculture (1997)

Table 7.2 **Approximate swine manure production and nutrient content.**[a]

Animal Type	Animal Weight	Total Manure Production		Nutrient Content		
				N	P_2O_5	K_2O
	kg	kg/day	Mg/yr	kg/day		
Nursery	16	1	0.36	0.007	0.005	0.005
Grower	41	2.7	0.99	0.019	0.014	0.015
Finisher	79	5.2	1.9	0.036	0.027	0.028
	102	6.6	2.41	0.046	0.034	0.036
	113	7.4	2.7	0.052	0.039	0.04
Gestating Sow	125	6.3	2.3	0.028	0.022	0.022
	148	7.6	2.77	0.033	0.026	0.026
	181	9.1	3.32	0.041	0.032	0.032
Sow & Litter	136	12.9	4.71	0.083	0.063	0.066
	181	15.9	5.8	0.111	0.084	0.086
Boar	159	7.9	2.88	0.035	0.027	0.028

[a] Adapted from Midwest Plan Service 1985, and American Society of Agricultural Engineers Standard D384. The nutrient contents of manure can be 20% or more above or below table values. N = total N, Elemental P = 0.44 x P_2O_5, Elemental K = 0.83 x K_2O

1. Nutrient Losses from Manure during Storage, Handling and Application

Kachanoski et al (1997) found that volatilization of N as ammonia (NH_3-N) in the barn was the major pathway of N loss. Approximately 23% of excreted N was lost as gaseous NH_3-N in the barn storage areas before pumping to outside storage lagoons and tanks. The manure N in the barn storage areas accounted for 57% of feed N, 60% of which was in the ammonium ion (NH_4^+) form. The gaseous N loss in the barn was calculated to be 17.4% of feed N. The carbon (C) in the manure pumped to the outside lagoons and tanks accounted for only 9% of feed input C and contained significant amounts of volatile fatty acids. Losses of C during storage in uncovered lagoons and tanks was approximately 44% and as a result, only 5% of feed C remained in the manure at time of spreading.

Agitation and irrigation of the liquid manure resulted in a further 33% loss of the manure N as NH_3. Kachanoski et al. (1997) observed that losses from agitation were much greater in the summer compared to fall when losses were somewhat greater than spring. The rate of ammonia loss was attributed to manure temperature. Approximate losses of nitrogen as ammonia during handling and storage in a number of management systems are given in Table 7.3.

Table 7.3 Nitrogen (NH_3) losses during handling and storage.[a,b]

System	% Loss of Excreted Nitrogen
Solid	
Manure pack	20-40
Open lot	40-60
Scrape and haul	15-35
Liquid	
Below-ground storage tank (covered)	15-30
Above-ground storage tank	1-5
Earthen storage (Short-term)	20-40
Anaerobic storage [c]	70-80
Aerobic storage	80-97

[a] Typical losses due to storage and handling between excretion and land application. Values adjusted for dilution. Any losses that occur during land application are in addition to these values.

[b] Adapted from Johnson and Eckert (1995).

[c] Losses are likely higher than those experienced in earthen storage under Canadian Prairie climatic conditions.

Surface spreading and subsurface injection are two of the most common land application methods. The equipment used for delivery of liquid manure to the field are tanks, dragline hoses and irrigation lines. However, because of concerns about odour and ammonia loss, irrigation with stationary or travelling big guns is rapidly losing favour. There is a variety of tools available for injection or immediate incorporation. These tools include knife, coulter and sweep injectors. Incorporation tools and methods involve the use of discs, shallow tillage and minimum tillage. On many parts of the Prairies, the practice of low disturbance seeding is being adopted in order to reduce soil erosion and conserve soil moisture. Presently, most of the commercially available openers create an unacceptable level of soil disturbance during liquid manure application even at low ground speeds (PAMI 1999). The lack of availability of appropriate low disturbance equipment limits potential manure nitrogen conservation during application to grassland. However, surface banding with the "sleighfoot" or "drag-shoe" manure applicator has been shown to improve N recovery from manure by 18-30% compared to splash plate application (Bittman et al 1999).

Relative N losses that may occur during application are shown in Table 7.4. There is some disagreement on the amount of nitrogen lost during irrigation. Kachanoski et al. (1997) found that a small amount of the loss (3-5% of manure N) occurs during effluent irrigation. Their findings are similar to those published by Midwest Plan Service (1985).

Table 7.4 Estimated nitrogen losses from liquid swine manure during application.[a]

System	% Nitrogen Lost
Solid	
Broadcast	15-30
Broadcast, incorporate within 24 h	1-5
Liquid	
Broadcast, no incorporation on established forage	35
Broadcast, incorporation within 24 h	1-5
Broadcast, incorporation within 2 days	15-25
Broadcast, incorporation within 3 days	25-35
Broadcast, incorporation after 3 days	40-60
Injection	0
Irrigation, no incorporation	60-80
Irrigation, incorporation within 3 days	25-35
Irrigation, sprinkler	15-35*

[a] Farm Practices Guidelines for Hog Producers in Manitoba". (1998)

*Midwest Plan Service (1985)

2. Fertilizer Value of Swine Manure

The two main management strategies for manure application are management for maximum nutrient efficiency and management for maximum application of manure nutrients. If efficiency is the goal, the application rate must be based on the nutrient present at the highest level in terms of crop needs. In most cases, this is phosphorus (P). Manure should then be applied to meet crop requirement for P. The second strategy is to determine the rate of application that will satisfy crop requirements for N without causing environmental problems. This maximizes the rate of application of N, while making less efficient use of P and K (Johnson et al 1995).

Most existing regulations and guidelines require that all manure applications be within agronomic rates for N to prevent a build up of this nutrient in the soil. Phosphorus is a concern in situations where large amounts of manure are broadcast without incorporation deliberately to promote nitrogen volatilization.

Handling and storage systems are factors in the amount of nutrient available for land application (Table 7.5, Figure 7.3).

Table 7.5 Approximate fertilizer nutrient value at time of application to land.[a]

Handling System		Nutrients available to the plant			
	Dry Matter %	**Total N**	**NH^+_4**	**P_2O_5**	**K_2O**
Solid		**kg/tonne** *(x2 = lb/ton)*			
With bedding	15-20 (18)	4.0-4.9 (4.5)	2.7-4.0 (3.1)	1.4-2.6 (1.8)	2.2-3.7 (3.0)
Without bedding[b]	17-20 (18)	3.1-4.5 (3.6)	2.2-3.6 (2.7)	1.0-2.0 (1.4)	2.2-2.3 (2.6)
Liquid		**kg/1000 Liter** *(x10 = lb/1000 imperial gal.)*			
Liquid Pit	2-7 (4)	3.4-6.6 (4.3)	2.5-3.7 (3.1)	0.7-1.6 (1.4)	1.2-3.0 (2.2)
Earthen Storage	0.3-2.0 (1)	0.4-0.7 (0.5)	0.2-0.6 (0.5)	0.05-0.2 (0.1)	0.2-0.6 (0.4)

[a] adapted from Sutton et al 1983 (means in parentheses)

[b] Open feedlot systems

In most systems, P and K losses are usually negligible but nitrogen losses in storage can be significant (Sutton et al 1999). The P and K available from swine manure application is considered to be equivalent to that available from fertilizer grade P and K. All of the ammonia N is available to crops in the year of application.
With modern feeding systems, manure particle size is small and mineralization rates approaching 50% of the organic N in the first year may be expected (Hatfield et al 1998). Little additional N contribution is expected from liquid swine manure three years after application. In contrast, work by Diez and Krauss (1997) indicated that long-term application of manure composts results in increasing nitrogen mineralization rates over time. In loamy soil, 16 % of the applied compost N was found in the yield of the first rotation, but in the second year this percentage rose to 40 % of applied compost N.

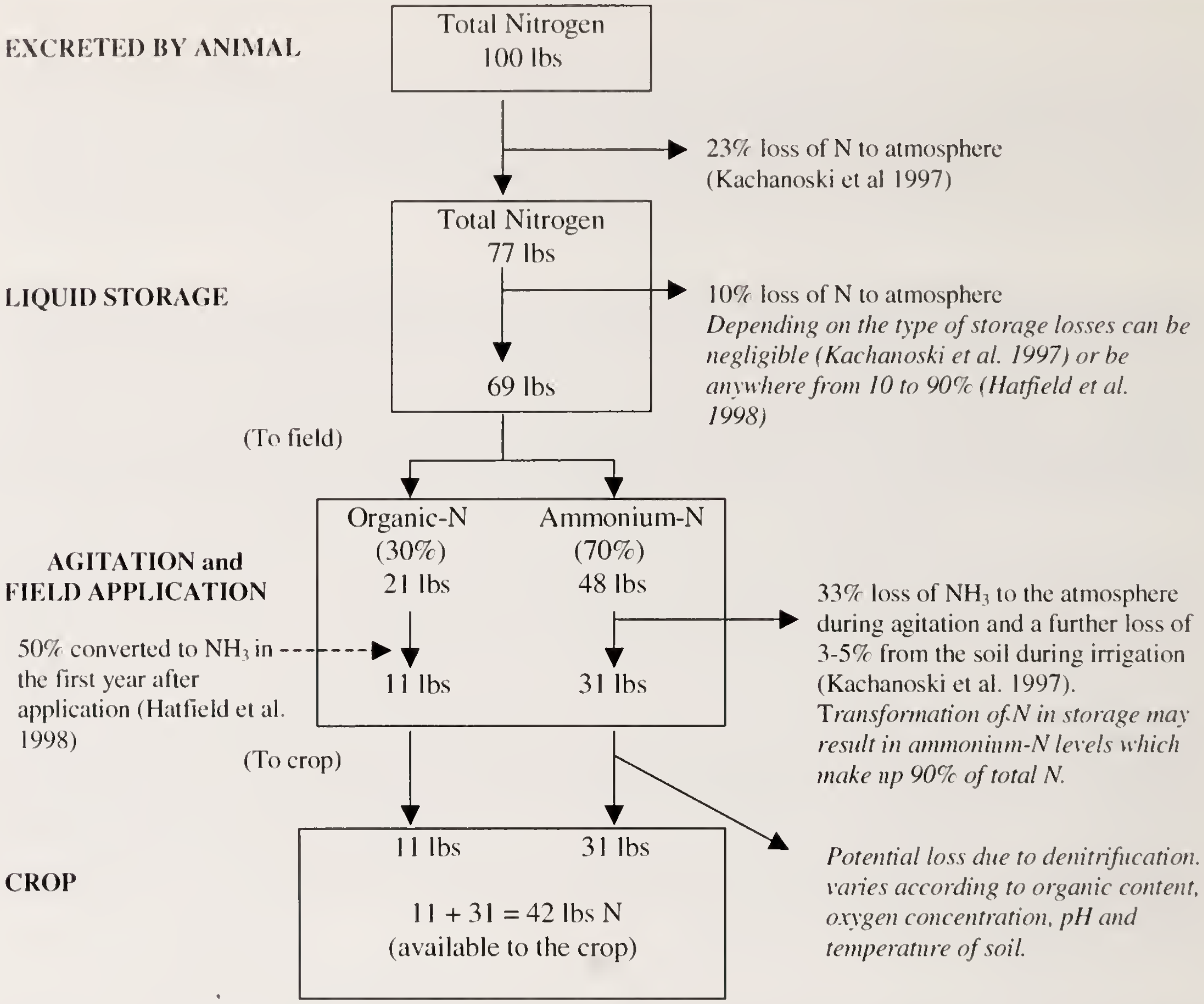

Figure 7.3 **Estimated proportions of liquid manure N lost though volatilization, and resulting crop-available N from the organic N and ammonium-N fractions (the proportions of ammonia and organic N in manure are highly variable depending on type and duration of storage as well as animal type and climatic factors).**

Nitrogen transformations in soil follow the same principles regardless of the source of N. But the rate or extent of mineralization, immobilization and other soil biological processes (i.e. volatilization, nitrification and denitrification) will be functions of the composition (e.g. organic compounds, trace elements, soluble salts) of the N source applied and the environmental conditions (i.e. soil properties, microclimate effects) under which the soil organisms operate (Evanylo 2000).

Generally, composted or solid manures are decomposed more rapidly on coarse textured soils than on fine textured soils, and more rapidly under warm moist conditions than under cold, dry conditions. Time of application plays an important role in effect on available nitrogen (Beauchamp et al 1997), and any delay before incorporation will have an effect on available nitrogen. To maximize nutrient use efficiency, applying manure close to seeding time is recommended especially in areas of high rainfall and highly permeable soils. Fall application of liquid swine manure can result in initial N losses of 15-50% through denitrification or leaching and is not generally recommended on coarse textured soils. On the other hand, spring application increases soil compaction, delays fieldwork and seeding. Application after soil temperatures have fallen below 10°C on non-saturated soils will limit denitrification losses. Table 7.6 compares the equivalent amount of manure required to provide the same nutrient values as commercial fertilizer on Ontario soils.

Table 7.6 Effect of type of fertilizer and timing of application on equivalent nutrient value.[a]

Type and Method of Fertilizer Application	Amount of material (kg) required to give one kg of nutrient		
	Nitrogen	Phosphate	Potash
Anhydrous ammonia	1.2	-	-
Urea	2.5	-	-
Blended fertilizer (20-20-20)	5	5	5
Liquid swine manure (Spring/Incorporate)	526	1430	714
Liquid swine manure (Fall/Incorporate)	1250	1430	714

[a] Adapted from Hilborn (1992)

To ensure high nutrient efficiency from added manure in soils with adequate to high range of P and K, growers should apply manure at rates that would satisfy only the crop phosphorus and /or potassium needs. Manure contains much more potassium than magnesium or calcium and after many years of continued manure application in some areas of the Prairies, the ratio of K to Mg and Ca may be too high for optimum crop growth and subsequently, efficient manure nutrient utilization (Marschner 1986). When the K+ supply is abundant, luxury consumption of K often occurs in forage crops. Even in the presence of adequate plant tissue Mg, the presence of excess K can depress blood magnesium in lactating cattle causing grass tetany (Maynard and Loosli 1969).

C. Considerations to Reduce Impacts of Manure Application

Reduction of environmental impacts from intensive livestock operations require solutions to an array of operational system problems such as:

- excessive feeding of nutrients,
- poor manure handling, storage and application techniques,
- inadequate land base and inappropriate cropping systems to properly recycle manure nutrients, and
- the inability or unwillingness to adopt improved practices.

Some of the considerations other than manure nutrient content and crop nutrient needs are:

- existing soil fertility levels,
- site limitations,
- tillage type, and
- soil moisture content.

Consult your local provincial manure management guidelines and regulations for more specific information for setbacks from water sources and property lines (See Manitoba examples, Tables 7.7 and 7.8).

Table 7.7 Distances from watercourses, sinkholes, springs, wells and residential property lines for manure spreading (m).swine manure.[a]

Slope	Application Method		
	Surface Applied and Irrigation		Injection
	No Incorporation	Incorporation	
less than 4%	30	20	5
4-6%	60	40	10
6-12%	90	60	15

[a] Manitoba Agriculture (1998)

Table 7.8 **Distance from watercourses, sinkholes, springs, well and residential property lines for manure spreading between November 10 and April 15 (m).[a,b]**

Slope	Application Method		
	Surface Applied and Irrigation		Injection
	No Incorporation	Incorporation	
less than 4%	150	N/A	N/A
4-6%	300	N/A	N/A
6-12%	450	N/A	N/A
>12%	prohibited	prohibited	prohibited

[a] Manitoba Agriculture (1998)

[b] From Manitoba Livestock Manure and Mortalities Management Regulation (42/98). 1998. Manitoba Conservation.

1. Management Factors Affecting Runoff Potential

Runoff potential is affected by numerous factors, some of which are fixed by the nature and location of the field and others that can be altered through management. Quantitative evaluation of these factors can be difficult because the factors either have not been quantified, or they interact with each other in field conditions.

Naturally occurring factors that affect runoff potential include:

- location of surface water – proximity to manured fields,
- slope steepness and complexity – the presence of depressional areas between manured area and surface water lower the potential for surface water contamination,
- soil and weather conditions – frozen, saturated or compacted soils and periods when rainfall exceeds evapotranspiration increases the potential for runoff, and
- soil type – soils with low infiltration rates or high moisture status are more likely to promote runoff.

McFarland et al. (1998) investigated the causes of unacceptable P risk in identified fields to help in the selection of ways to lower that risk. During the course of this work, a Phosphorus Risk Index was developed using a number of parameters.

Each of the following parameters is assigned an interpretive rating:

- increase risk as rate of applied P (lb P2O5/acre/yr) increases: 0-20 (very low risk), 20-60 (low risk), 60-100 (medium risk), 100-140 (high risk), >140 (very high risk).

- increase risk as soil test P (available P) increases: <20 ppm (very low risk), 20-60 ppm (low risk), 60-100 ppm (medium risk), 100-140 ppm (high risk), >140 (very high risk).

- increase risk as distance to water body decreases: >1000 ft (very low risk), 500-1000 ft (low risk), 200-500 (medium risk), 30-200 ft (high risk), <30 ft (very high risk).

- risk associated with application method: surface application with no incorporation (high risk), surface application with incorporation (low risk), stationary big gun (high risk).

- risk associated with timing of application: considered the rainfall intensity associated with each month in which organic or inorganic P was applied using 30-minute rainfall intensity data for 30 years.

- risk associated with vegetation management: presence of crop residue and cover during non-growing season (low risk), annual crop with no cover during winter (high risk).

- risk associated with grazing intensity: low grazing intensity (low risk), high grazing intensity (high risk)

Easily-used field rating systems like that described by Leytem et al. (2000) were developed for use by extensionists, crop consultants and farmers in order to rate relative potential for P loss to surface waters.

Management factors that can alter the potential for manure nutrient runoff include:

- buffer strips – preferably multi-storey planting with roots at various depths. Where manure has been broadcast on the surface and not incorporated, simulated rainfall studies have indicated that a 0.75 m. wide switch-grass hedge planted on the contour along a hill slope reduced runoff of P and N as well as reducing soil erosion (Beegle 1998).

- manure characteristics, application rate and application method. Liquid manure applied at rates greater than soil infiltration rate can promote runoff. Injection or incorporation of applied manure reduces chances of runoff.

- pre-existing soil nutrient status. More nutrients are likely to move off fields when soils have a high crop-nutrient or soil-test level rather than lower crop-nutrient test levels.

- timing. Fall application carries a potentially higher risk of loss due to leaching or runoff either in the fall or following spring compared to manure application just prior to seeding (Goss & Smith 1995).

- management of grazing intensity. Higher grazing intensity promotes runoff potential.

- use of cover crops. Cover crops reduce erosion and removal of excess nutrients
.

- crop rotation strategy affects soil moisture levels and nutrient release.

- soil moisture status at time of application.

- soil surface condition. A rough or covered soil surface reduces runoff compared with soil surfaces that are smooth or have little residue cover.

Conservation tillage systems preclude deep incorporation of manure and cause high nutrient levels to develop near the soil surface. Runoff water that is in intimate contact with highly nutrient-enriched soil results in potentially high soluble phosphorus concentrations in runoff water (Beegle 1998). Beauchamp et al. (1997) and Kachanoski et al. (1997) have suggested that conservation tillage should work well with manure injection systems to conserve ammonia and reduce nutrient runoff. Tillage effects on runoff need to be evaluated on a field or small watershed scale rather than on small plots to better reflect tillage and manure effects on a landscape basis (Moncrief et al. 1998).

2. Management Factors Affecting Leaching Potential

The role of macro-pores in the transport of surface-applied nutrients is not yet well understood and is of particular concern where long-term no-till is practiced. The lack of disturbance or disruption by tillage has been shown to increase earthworm activity which can contribute significantly to macro-pore formation. The phenomenon of preferential flow by macro-pores acts to conduct water and solutes quickly to significant soil depths without saturating the soil matrix. This is of particular concern on tile-drained porous soils. In certain conditions, liquid manure can flow to significant depths through natural cracks in the soil (Figure 7.4). Movement of manure through soil cracks to tile drains has been identified as an environmental concern in Ontario. The current thinking is that cultivation of the soil prior to manure application may destroy the cracks and stop this accelerated flow.

Surface cracks in dry heavy clay soils (Vertisols) enable rapid water movement deep into the subsoils.

Management factors that can alter the potential for manure nutrient leaching include:

- timing – spring versus fall application,
- use of a cover crop,
- use of nitrification inhibitors in liquid manure (although efficacy of use is questionable),
- application rate,
- management of grazing intensity – poor stand management can increase leaching potential,
- pre-existing soil nutrient status,
- crop rotation, and
- manure treatment to stabilize the nitrogen – eg. composting.

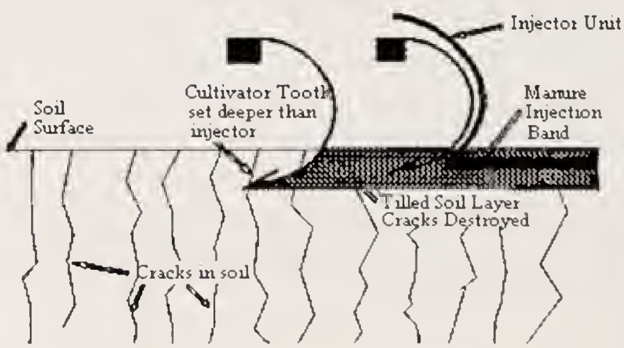

Figure 7.4 Effect of cultivation on movement of liquid manure through soil cracks.

3. Soil disturbance and residue cover

Manure incorporation represents a conflict among best management practices for soil erosion control, conservation of soil moisture and manure management. Liquid manure should be incorporated into the soil for odour control, maximum availability and conservation of nutrients, and control of potential manure runoff. But, for maximum soil erosion control, the soil and crop residue should remain undisturbed. The amount of soil disturbance and residue cover are affected by the type of injection equipment and the ground speed. Most openers, spaced 30 inches (76 cm.) apart, cause full disturbance when travelling at ground speeds of five miles per hour or more and may result in residue cover reduction of 29 to 89% depending on the type of annual crop (Shelton 1999). Composted manure can be surface-applied without incorporation on most landscapes. Surface-applied compost may reduce soil erosion induced by slaking of soil aggregates by heavy precipitation.

Composting is an important manure management option

4. Accumulation of salts and heavy metals

North Carolina researchers estimate that as a percentage of the total mineral content of the diet, excreted swine manure contains 86%, 110%, 79%, 59%, and 66% of the Cu, Zn, Mn, Ca, Mg, K, and Na, respectively, offered to the pig in the diet. Zinc is routinely added at 50-100 ppm, copper at 5-10 ppm and selenium at 0.3 ppm to prevent deficiency symptoms.

Copper

In nursery and some grower-finisher diets, copper is added to diets at 125-250 ppm (1-2 pounds of copper sulfate per ton) to enhance growth and feed efficiency. Purdue researchers have concluded that this level of dietary addition results in a reduction in biological activity in manure pits and anaerobic lagoons and potentially in localized areas in the soil. Incidences of chronic copper poisoning have occurred in sheep grazing swine-manured pastures (Kerr et al 1991).

Zinc

Although University of Nebraska swine nutritionists do not routinely recommend the practice, many swine producers have begun to add 3000 ppm zinc (as zinc oxide) to weaned pig diets as a growth promotant and as an aid in reducing scours. No research is available, as yet, on the amounts of zinc that accumulates in manure as a result of this nutritional practice.

Chromium

For growing-finishing pigs, additions of 100-800 ppb chromium as chromium picolinate reportedly enhance carcass lean and reduce carcass fat. Similar to zinc, there are no reports in the literature as to the amount or chemical form of chromium in manure from pigs fed supplemental chromium.

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VIII. SUMMARY AND INTERPRETATIONS FOR SOIL MANAGEMENT GROUPS *(R.G. Eilers, K.E. Buckley)*

A. Linking Soil Management Groups to Resource and Manure Information

The development of standardized databases for basic resource information on soils, landscapes and surficial geology was one of the initial objectives of this project. Classifying, categorizing and grouping these data sets in meaningful ways for use by soil specialists and agronomists was a second major objective.

Each of the resource databases contains hundreds of thousands of individual pieces of information specifically identifying important properties and characteristics of complex materials. The first step was to standardize the data content and structure to facilitate automated accessibility using geographic information system technology. Key attributes from these data sets were selected and used to calculate numeric indices for each of the principle components. Each of these indices was then further simplified into three classes of high, medium and low. Finally, the three major factors were integrated into soil management groups (SMGs). Each SMG represents specific combinations of soil landscape conditions which have similar issues for manure management. This procedure is summarized in Figure 8.1.

A third objective was to illustrate how current information about manure characteristics and management information could be compiled and organized for ease of access for development of manure management plans. **It is important to note that throughout this methodology, the goal has been to be descriptive rather than prescriptive, thus leaving the responsibility for developing land use and manure management plans at the local level in the hands of resource specialists and planners**. A generalized interpretation of each SMG according to their nutrient management intensity levels along with cautionary notes and reminders is presented in Table 8.1.

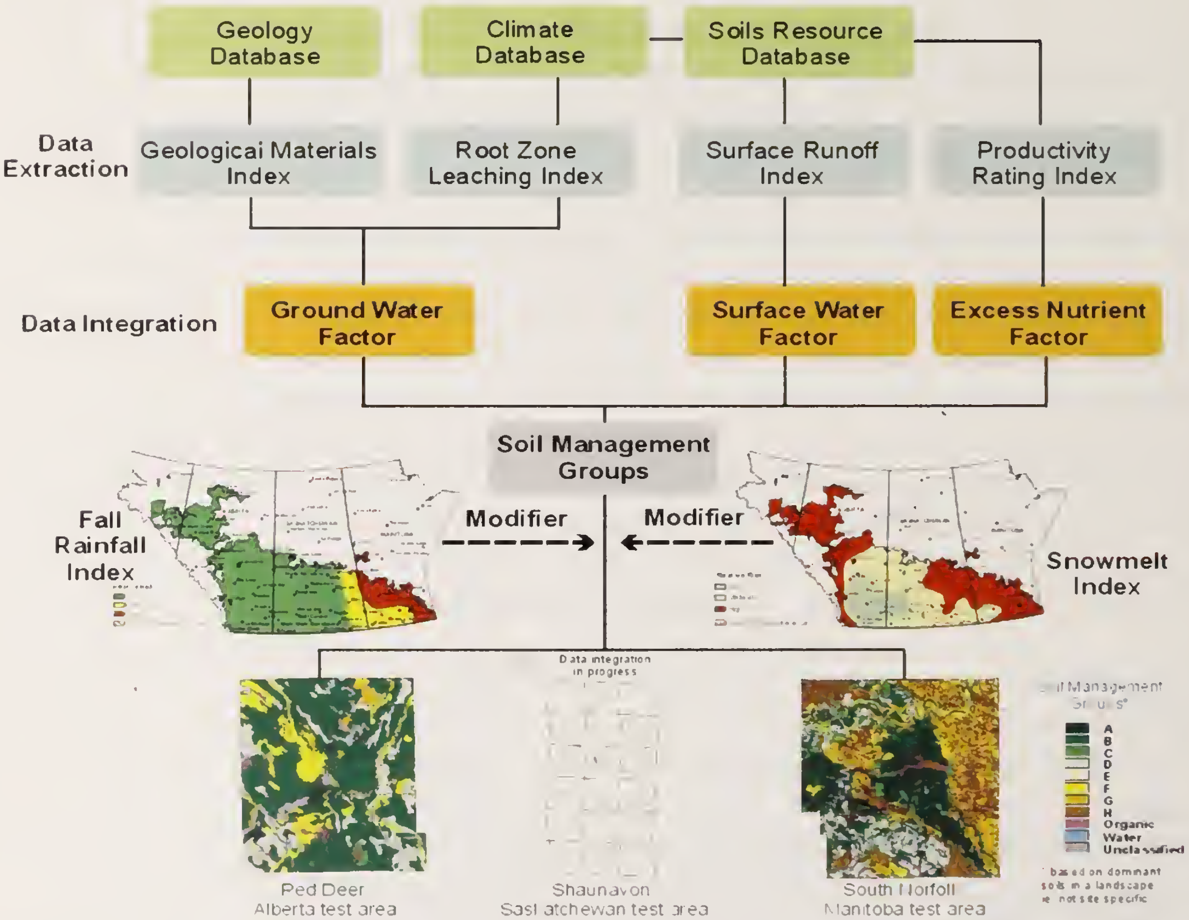


Figure 8.1 **Summary if resource based analysis and data integration to derive Soil Management Group maps.**

The following definitions relate to the Interpretations for Soil Management Groups Table 8.1

General Description of Nutrient Management Intensity Levels:

NORMAL - As per provincial recommendations, guidelines and regulations

- **Manitoba** - Manitoba Soil Fertility Guide; Farm Practices Guidelines for Hog Producers; Manitoba Livestock Manure and Mortalities Regulation MR42/98

- **Saskatchewan** - Establishing and Managing Livestock Operations. Published by Saskatchewan Agriculture and Food, Inspection and Regulatory Management, Regina, SK. 20 pp.
  - Manual for Developing a Manure and Dead Animal Management Plan. Published by Saskatchewan Agriculture and Food, Agricultural Operations Section, Regina, SK 11 pp.

- **Alberta** - Under the Agricultural Operation and Practices Act (revised statutes of Alberta 2000, Chapter A-7), the Standards and Administration Regulation (Alberta Regulation 267/2001) governs manure storage, nutrient management and minimum distance separation. Available on-line at http://www.qp.gov.ab.ca/documents/regs/2001_267.cfm Published by Alberta Queen's Printer, Edmonton, AB. 81 pp.

MODERATE
- Annual nutrient management planning to estimate and adjust nutrient inputs and outputs

HIGH
- Annual nutrient management planning to estimate and adjust nutrient inputs and outputs
- Periodic soil sampling to four feet to monitor nutrient movement in soil profile
- Collection of detailed crop nutrient and yield measurements to verify nutrient removal

VERY HIGH
- Improvements to the land must be made before implementing a sustainable nutrient management plan
- Annual nutrient management planning to estimate and adjust nutrient inputs and outputs
- Periodic soil sampling to four feet to monitor nutrient movement in soil profile
- Collection of detailed crop nutrient and yield measurements to verify nutrient removal

FOOTNOTE • On-site, in-field soil survey data of greater detail will enable refinement of Nutrient Management Intensity Level originally based on reconnaissance level investigation.

Table 8.1 **Interpretations for Soil Management Groups.**

	Soil Management Groups	Nutrient Management Intensity Level	Additional Management Considerations
	A - Highly productive soils with low risk of nutrient loss to surface water runoff or leaching to groundwater.	Normal	•No additional considerations
	B - Highly productive soils with low to moderate risk of surface water runoff and/or leaching to groundwater.	Normal	•No additional considerations
	C - Marginally productive soils with low to moderate risk of nutrient loss to surface water runoff and/or leaching to groundwater.	Moderate	•Implementation of a nutrient management plan recommended
	D - Highly productive soils with a high risk of nutrient loss to surface water runoff, and a low to moderate risk of leaching to groundwater.	Normal	•Winter application not recommended •Fall broadcast application should be followed by rapid incorporation •Low-disturbance direct injection of liquid manure recommended •Vegetated buffers along waterways recommended
	E - Marginally productive soils with a high risk of nutrient loss to surface water runoff, and a low to moderate risk of leaching to groundwater.	Moderate	•Implementation of a nutrient management plan recommended •Winter application not recommended •Fall broadcast application must be followed by rapid incorporation •Low-disturbance direct injection of liquid manure recommended •Vegetated buffers along waterways recommended

	F - Highly productive soils with a low to high risk of nutrient loss to surface water runoff, and a high risk of leaching to groundwater.	Moderate	•Winter and fall application not recommended •Low-disturbance direct injection of liquid manure recommended •Vegetated buffers along waterways recommended •Periodic soil sampling to four feet necessary to monitor nutrient movement in soil profile – results may indicate need for adjustment of nutrient management plan
	G - Marginally productive soils with a low to high risk of nutrient loss to surface water runoff, and a high risk of leaching to groundwater.	High	•Implementation of a nutrient management plan recommended •No winter spreading •Fall application not recommended •Spring or split applications recommended •Periodic soil sampling to four feet necessary to monitor nutrient movement in soil profile – results may indicate need for adjustment of nutrient management plan •Detailed crop nutrient and yield measurements required to verify nutrient removal
	H - Low productivity soils. Surface and groundwater risk factors range form low to high. Land areas maybe natural habitat for grazing animals (wild and domestic), wetlands, woodlands and recreation.	Very High	•Improvements to the land must be made before implementing a sustainable nutrient management plan
	I - Organic (peat) soils and very poorly drained mineral (Gleysolic) soils with peaty surface layers, having severe to very severe limitations for annual crop production and high risk to groundwater.	Very High	•Improvements which enable reclassification of soil to a higher SMG must be made before implementing a sustainable nutrient management plan •Manure application not recommended

*Compiled by Manitoba Advisory Group.

B. Interactive Manure Management Tools.

Future implementation of this methodology will involve the development of interactive GIS tools, that is, creating software to automate procedures for linking map information (eg. SMG's) to appropriate data bases. A simple example for accessing relevant research information is to use the 'hot' internet addresses provided as supplements to the references in section VII. Although this activity is beyond the scope of the original project, development of more sophisticated interactive GIS software tools remains a high priority. A description of a proposed prototype for a menu driven GIS decision support program is provided as follows.

1. Menu Approach to Resource and Management Information

A menu approach for accessing relevant resource and management information is proposed. It will enable users to quickly link digital map information (SMG's) to appropriate management information. Using GIS maps (Figure 8.2) and on-screen "point-and-click" procedures, users will be able to select a particular area on the map and link to sets of resource and management information such as descriptive resource tables (eg. Table 8.1) and/or manure information tables (Section VII).

The menu will consist of two themes, a resource limitations/attributes theme (stylized soil block) and a manure management theme (swine symbol, Figure 8.2). The menus will have a hierarchal structure going from the very general to the very detailed and technical. Following this menu system, users will be able to select resource information for each land area or SMG and identify the major factors influencing or limiting the potential for manure application (Figure 8.3). An example of the proposed content of the resource theme is provided in Table 8.2.

Figure 8.2 Example map of soil management groups, a selected polygon and a pop-up menu showing two themes: management or resources.

Figure 8.3 Selecting resource theme - provides general description of resource limitations for the selected polygon in the SMG map.

Table 8.2 **Example of resource menu information content.**

SMG Class - Generalized description	Factors	Indices	Data
SMG : A, B, C, D, E, F, G, H, I. For example: using SMG "D" Highly productive soils capable of high nutrient uptake by crops with slight risk for excess N. High surface water risk and low to moderate groundwater risk	Nutrient Factor	Soil limitation (s) to productivity	- Soil Map Unit - texture - drainage - salinity - stoniness
	Surface Water Factor	Landscape index	- slope steepness class - slope length class - soil erodibility
	Groundwater Factor	Rootzone Leaching Index	- AWHC - P-PE (Sept-Mar.)
		Geologic Materials Index	- general lithology - permeability class - drill log available

AWHC - available water-holding capacity; P-PE - precipitation minus potential evapotranspiration.

Next, users will consult the management theme in the menu and select the appropriate box indicating the various information categories such as general limitation/mitigation information (Figure 8.4), provincial and municipal guidelines/regulations for setbacks (Figure 8.5), manure application methods, (Figure 8.6) etc. An example of the information content for the management theme is presented in Table 8.3.

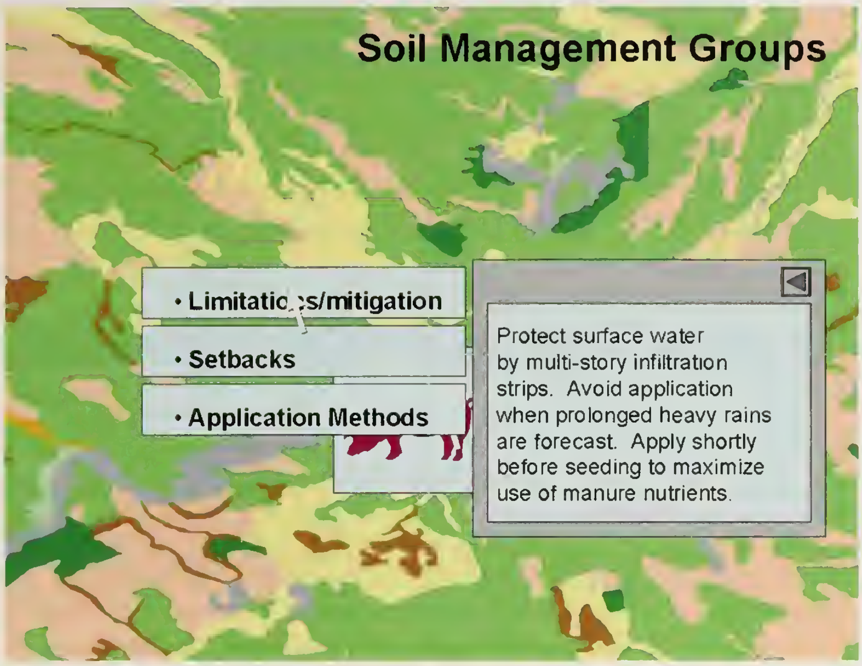
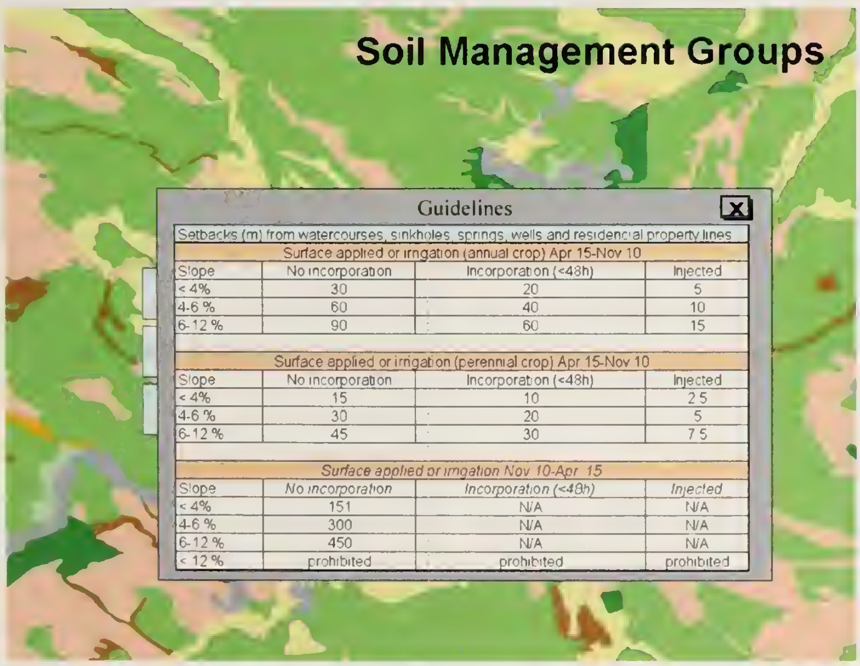


Figure 8.4 **Selecting the management theme - provides general indications of mitigation considerations for manure application in the selected polygon in the SMG map.**



Setbacks (m) from watercourses, sinkholes, springs, wells and residencial property lines			
Surface applied or irrigation (annual crop) Apr 15-Nov 10			
Slope	No incorporation	Incorporation (<48h)	Injected
< 4%	30	20	5
4-6 %	60	40	10
6-12 %	90	60	15
Surface applied or irrigation (perennial crop) Apr 15-Nov 10			
Slope	No incorporation	Incorporation (<48h)	Injected
< 4%	15	10	2 5
4-6 %	30	20	5
6-12 %	45	30	7 5
Surface applied or irrigation Nov 10-Apr 15			
Slope	*No incorporation*	*Incorporation (<48h)*	*Injected*
< 4%	151	N/A	N/A
4-6 %	300	N/A	N/A
6-12 %	450	N/A	N/A
< 12 %	prohibited	prohibited	prohibited

Figure 8.5 **Example of provincial setback guidelines for the selected polygon in the SMG map.**

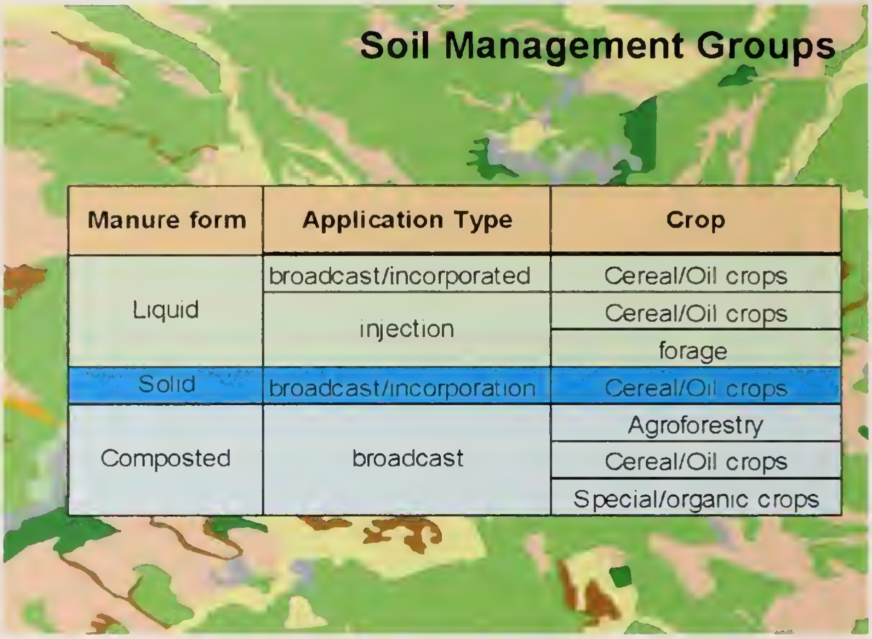


Figure 8.6 **Example menu for selecting application methods for manure in the selected polygon on the SMG map.**

Table 8.3 **Example of management menu information content.**

SMG - generalized mitigation options	Guidelines Provincial/municipal	Specific criteria	Cropping System - land use practices.
For example using - **SMG " D" -** Protect surface water by multi-story infiltration strips. Avoid application when prolonged heavy rains are forecast. Apply shortly before seeding to maximize use of manure nutrients.	Application Methods	- broadcast/incorporation - injection	- Cereal/oil seed - forages/cereals - forages/pasture - permanent pasture
	Set back regulations	- table for farm practice guidelines	- recommendations for surface water protection
	Manure type	- liquid - solid - compost	- nutrient requirement
	Manure handling and storage	- nitrogen loss - N:P ratio	- application timing
	Soil Test	- N, P, K, field levels	- target yield requirements

Table 8.3 is presented as an example menu which could be developed for all SMGs.

The information will be accessible through GIS linkages between map and menu. The use of GIS in daily activities is increasing at a very rapid rate. As a tool in a decision support system, GIS will allow users to interact "click and capture" information as they work through the system. At the end of their search, users will have compiled a preliminary report of the information related to the suitability of their particular field or land area for manure applications. An example of a work sheet that users can fill in to describe the specific field conditions is provided in Appendix D.

C. Next Steps

The next steps in the development and adaptation of this methodology will be to undertake field testing to validate and refine the procedure. This will include application to additional databases for many more rural municipalities combined with field evaluations and discussions with local councilors and resource specialists. This will provide an opportunity to gage the utility and acceptability of this approach by provincial specialists in each province. To ensure a truly user-friendly approach, this phase will consider close collaboration with local resource specialists, land planners and municipal leaders.

As a reminder, this technology ***does NOT replace the need for on-site ratings and evaluation***. The resource information that is currently available is not sufficiently detailed or adequate for siting ILO facilities such as barns or earthen manure storage units. Rather, it is simply a tool and a systematic approach to be used for screening or assessing the suitability of soils in the Prairie landscapes for the application of swine manure taking into consideration the protection of soil, surface water and groundwater quality. The generic nature of the methodology however, means that this technology should greatly facilitate generalized all-purpose planning for various land use issues involving all inputs to the environment.

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Appendix A: Technology Transfer Activities: Meetings, Seminars and Posters

The following is a documentation of the awareness and promotional activities undertaken during the course of this HEMS project. Publicity, awareness and technical presentations were made by members of the working groups and advisory committee. Feedback and support for the project from these events has been extremely useful in the development and formulation of much of the rationale.

Date	Place	Event	Audience	Presentation Format
April 15, '98	Carman, MB	Swine Manure Management Workshop	MDA, AAFC, Univ. of MB, Industry	Overheads - Presentation of original concept
Sept. 9-10, '98	Manitoba	Field Tour	PFRA	Informal discussion of environmental implications of siting swine production units
Sept. 23, '98	Winnipeg	Interview - AAFC Media Relations Unit	Public release	Interview (overview of the project)
Oct. 1, '98	Selkirk, MB	Manure Expo, '98	Industry, Producers, Univ. of Manitoba, government	Poster (overview and outline of project)
Oct. 6, '98	Brandon	AAFC Regional Directors' Meeting	Directors from Western Region	Overheads (overview and outline of project)
Oct., '98		Informational Meeting	Manitoba Agriculture Soils Staff	Informal with overheads
Nov., '98	Brandon	Informational Meeting	Manitoba Agriculture Western Region	Slide presentation
	Winnipeg	MRAC Meeting	PFRA, MRAC Board	Slide presentation
Jan. 26, '99	Mitchell, MB	Livestock and the Environment Open House	Producers, University, Industry, government	Poster (overview and outline of the project)

Feb. 2-3, '99	Winnipeg	Manitoba Society of Soil Science Meeting	Academics, Manitoba Agriculture	1. Slides (overview) 2. Slides, paper (soils database) 3. Poster (summary and progress)
Feb. 11-12, '99	Ottawa	CLRN Meeting		1. Slide presentation 2. Poster
Feb. 16-18, '99	Calgary	Alberta Soil Science Workshop	Academics, government	Poster (summary and progress)
Feb. 17-18, '99	Saskatoon	Saskatchewan Soil Conservation Society Annual Meeting	Industry, producers, academics, government	Poster (summary and progress)
June 22-25, '99	Saskatoon	Tri-Provincial Conference on Manure Management	International, academics, government, producers, consultants	1. Slide presentation 2. Poster
Aug. 5, '99	Selkirk, MB	Manure Expo '99	Producers, dealers, MB Gov't, university	Poster
Oct. 13, '99	Gimli, MB	Meeting of the Tri-Provincial Committee on Livestock Development and Manure Management	Committee members and Manitoba Agriculture	Presentation - overheads
Dec. 10-11/99	Ottawa	CPC Symposium	Industry, government	Poster
Jan. 10-11/00	Winnipeg	17th Annual Red River Basin Land and Water International Summit Conference - sponsored by The International Coalition (TIC).	Water managers, urban and rural councilors, mayors, reeves, private industry, university and government.	Presentation - overheads, Poster, and Abstract (published)
Jan. 25-26/00	Winnipeg	Manitoba Soil Science Society Annual Meeting	Industry, government, university	Poster
Feb 9-10/00	Regina	Saskatchewan Soil Conservation Association	Industry, government, university	Poster

Feb 22-24/00	Medicine Hat	Alberta Soil Science Society Annual Meeting	Industry, government, university	Poster
June, 26/00	Calgary	Manure 2000	Industry, government, university	Poster
Oct. 2/00	Regina	Informational Meeting	PRFA - NRCan, Sask Ag.	Presentation - ppt
Oct. 5/00	Swift Current	SPARC/WLRG - From bench-top to landscape workshop	WLRG and SPARC scientists, university	Presentation - ppt
Oct. 28/00	Winnipeg	Informational Meeting	Manitoba Agriculture	Presentation - ppt
Nov. 21/00	Winnipeg	Informational Meeting	Industry, Trade and Mining, (Matile, Betcher)	Overhead presentation
Nov . 24/00	Winnipeg	Seminar	Dept. Soil Science, U of M seminar series	Presentation - ppt
Nov. 28/00	Winnipeg	Informational Meeting	MB prov., Axys Consulting	Overheads
Nov. 30/00	Winnipeg	Informational Meeting	Prov. Gov. - Agric, Envir. Water Res, Surficial Geology, Ind. Trade and Mining, ADM, directors	Presentation - ppt
Nov. 24/00	Winnipeg	Department of Soil Science - (U of M) Seminar series	Prof. Dept. Soil Science, grad students, provincial government.	Presentation - ppt
Dec. 4/00	Winnipeg	Informational meeting - soils suitability methodology	Soils group - MDA	Discussion
Jan. 24/01	Winnipeg	Manitoba Soil Science Society Annual Meeting	Industry, govt., university	Presentation - ppt
Feb. 22-23/01	Saskatoon	Soils and Crops Workshop	Industry, govt., university	Presentation - ppt

Appendix B: Resource information databases available for the Prairie region and the attributes utilized for soil management groups

Databases Available (source)	Attributes	Indices	Factors - for Soil Mgmt. Groups (calculated)	Rationale for use of database
1. Soils - AB,SK,MB (1:100 000)	Physical -AWHC - K, L, S, Chemical - O.C., pH, etc.	- Root Zone Leaching (RZL) - Surface Runoff Risk - Nutrient Retention	Groundwater Surface Water Nutrient Factors	Soil maps provide the most detailed spatial data base for describing resource limitations for agricultural land use
2. Climate (AES)	Canadian Ecodistrict Climate Normals (1961 - 1990)	Aridity (P-PE) RZL potential	Groundwater Surface Water	Prairie Regional data applied at the ecodistrict level for soil moisture values
3. Climate (PFRA regional hydrology)	Runoff magnitude, and variability, antecedent moisture, rainstorm intensity and frequency	Snowmelt Rain storm	Surface Water	Stream data provides support for runoff risk and thus surface water quality risk
4.Geology/Hydrology. AB- Environment SK- Water Corp MB- Conservation	(digital files) Drill logs-wells,test holes Drill logs-wells,test holes GWDRILL	Geological Materials Index	Groundwater	Time scenarios for contaminants to move downward to shallowest aquifer
5. Surficial Geology Maps (1:250 000)	Composition, spatial variability and distribution	Geological Materials Index	Groundwater	Spatial extent for extrapolating GMI.
6. Manure Management practices (compiled here)	Nutrient Quantity	NA	Nutrient	Literature data for manure quality and quantity.

Appendix C: Steps used to derive the Geologic Materials Index and Groundwater Factors for South Norfolk in Manitoba

(Note: The steps outlined here generally follow a much more detailed description of the approach developed and applied in Alberta - Rodvang and Dash 2000)

1. Standardize lithology of all well logs in GWDRILL (Thorleifson et al. 2000).

2. Sort logs and delete those with missing data

3. Describe each layer in standardized logs in terms of aquifer (> 0.6 m sand and/or gravels) yes or no.

4. Assign appropriate hydraulic conductivity value to each of the standardized layer lithologies.

5. Determine resistance to flow between the ground surface and the nearest-to-surface aquifer for each drill log, (equation 1 - thickness of lithological layer times Ks). Express results in years according to Table 4.3. In this methodology this value is referred to as the Geologic Materials Index (GMI).

6. Each well log was labeled according to the appropriate resistance class (Table 4.3).

7. Well logs are referenced to the nearest quarter section, and in some locations more than one drill log occurs. As a result, a range of GMI values can occur at one LSD. Examine the LSD where multiple wells occur and determine the average hydraulic conductivity of the wells to represent that LSD. The results are displayed geographically by the centroid of each LSD and/or quarter section (Figure 4.4).

8. The map of spatially distributed well logs or averages for multiple well occurrences are labeled according to hydraulic resistance GMI classes and is then overlain on the surficial geology map at 1:250 000 scale (Figure 4.5).

9. The number of wells in each GMI class was determined for each surficial geology polygon on the surficial geology map. The dominant GMI class (represented by the largest number of wells in each GMI class) was used to categorize the hydraulic characteristics of that polygon (H,M,L). If the surficial geology polygon had equal numbers of well logs in two or three classes, the GMI class was determined by considering the GMI rating of adjacent well logs in neighbouring surficial geology polygons (Figure 4.6).

10. The Groundwater Factor map was then derived by overlying the RZLI map on the GMI map (Figure 4.9) by intersecting the RZLI map polygons and the GMI map polygons in ArcView. The resultant values are classified according to the matrix shown in Table 4.4.

Additional Notes:

1. This analysis and interpretation of drill and well log data combined with surficial geology and soil water-holding capacities recognizes the relative importance of the near surface soil profile properties which are only coarsely defined by the geologic logs. The available water retention capacity of the soil profile (1 m thick) coupled with the permeability of the underlying geologic materials more typically defines the ability of the various materials to transmit water downward.

2. This generic interpretation incorporates two important components of the geo-ecosystem; pedology and hydrogeology. It therefore has application for many land quality questions. In reality, these factors define the capacity for groundwater recharge. All groundwater recharge to aquifers happens as a result of leaching through the soil zone. However, the process or rate of leaching only becomes a risk factor when there is some potential for undesirable soluble materials to move through the soil and downward with water to the aquifer. Under these circumstances, the process could be described as a risk of contamination.

3. It should be noted that the Groundwater Factor considers only the physical soils and geological environment. It does not consider degree of saturation, cation exchange capacities, oxidation/reduction or any potential mitigating or attenuating functions related to the soluble substances. These are circumstances which need to be addressed on a case-by-case basis for specifically defined issues. However, this concept of a groundwater factor, in combination with other pedological, biological and geochemical processes (data) may have some applications for other broad level environmental evaluations.