Assessment of Environmental Sustainability in Alberta's Agricultural Watersheds

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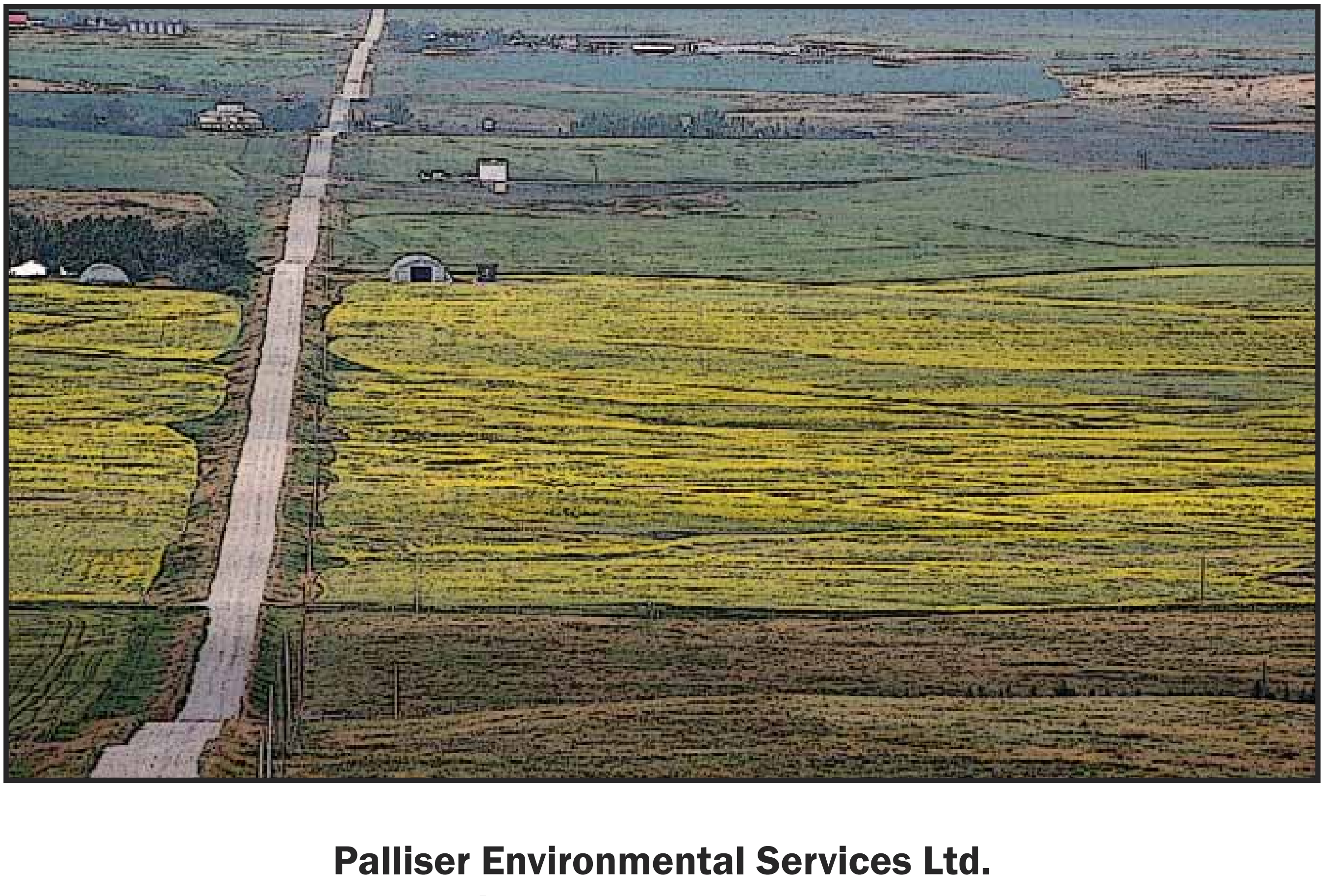
Assessment of Environmental Sustainability in Alberta's Agricultural Watersheds

Volume 1:

Summary and Recommendations



Palliser Environmental Services Ltd.
Alberta Agriculture and Rural Development
2008

Steering Committee

This document was commissioned and lead by a steering committee from Alberta Agriculture and Rural Development.

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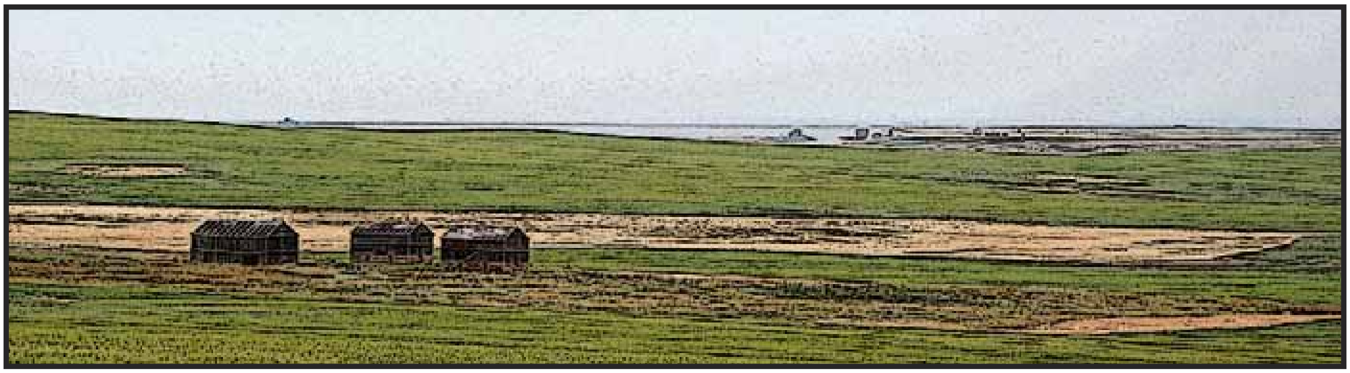

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Executive Summary

Introduction

Environmental sustainability is essential for the survival, growth and prosperity of the agricultural industry in Alberta. It is defined as maintaining a balance among economic viability and environmental assets (soil, water, air, and biodiversity) such that ecosystem integrity is upheld for future generations. In order for the agricultural industry to best plan for the future, an understanding of the current state of environment and the impacts of agriculture on the environment are required.

Alberta Agriculture and Rural Development has led several long-term projects to assess soil and surface water quality and the impact of agriculture on these natural resources. The Assessment of Environmental Sustainability in Alberta's Agricultural Watersheds (AESAAW) project was initiated in 2007 to consolidate project information from three provincial initiatives:

- Alberta Environmentally Sustainable Agriculture (AESA) Water Quality Monitoring Project;
- AESA Soil Quality Monitoring Project; and the
- Alberta Soil Phosphorus Limits Project.

These initiatives monitored and assessed soil and water quality within representative agricultural areas of Alberta (Figure 1). The AESAAW project summarizes the results from these projects to:

i) Provide a provincial synopsis on the current impacts of agriculture on environmental sustainability in Alberta with a focus on soil and water quality;

ii) Provide recommendations that address the future sustainability of agricultural watersheds in Alberta; and

iii) Identify information gaps in current research and future directions.

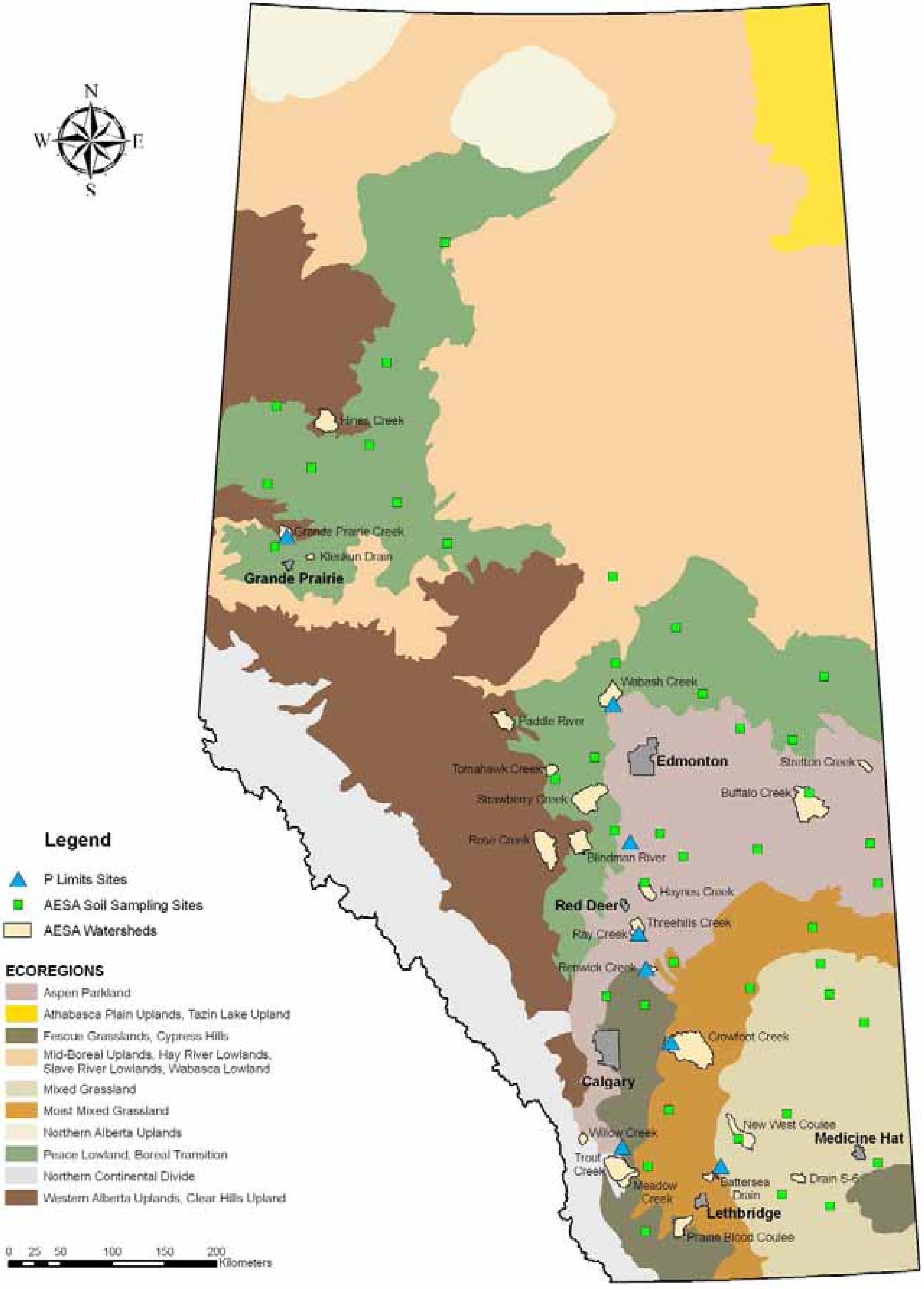
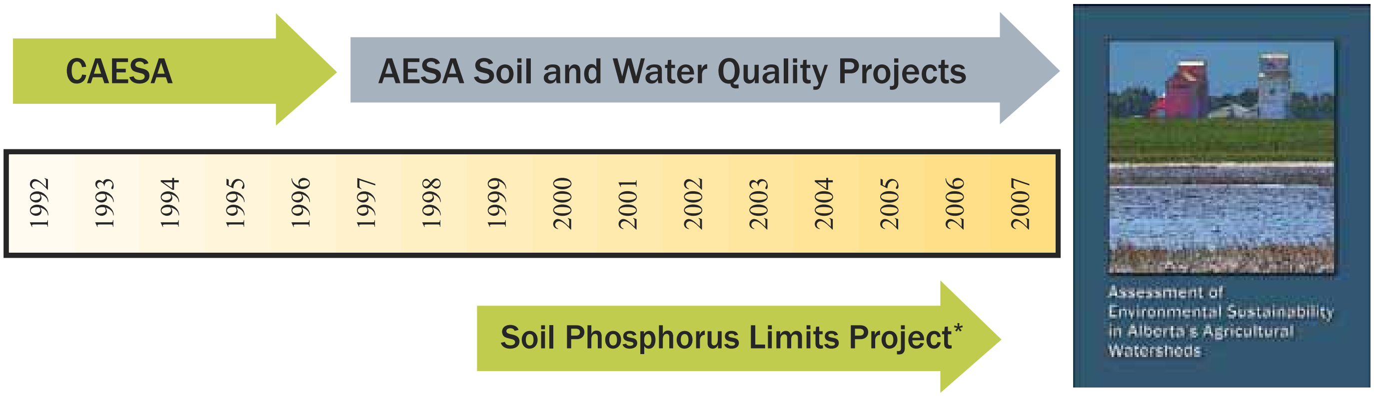


Figure 1. Location of the eight Soil Phosphorus Limits microwatershed sites, forty-two AESA soil sampling sites, and outlines of the twenty-three AESA watersheds. Soil sampling and P Limits symbols are not drawn to scale.

The AESA Soil and Water Quality Monitoring Projects were developed to address recommendations from the Canada-Alberta Environmentally Sustainable Agriculture (CAESA) Agreement (Figure 2). Under the CAESA Agreement, scientific and producer-led studies were undertaken to broadly assess the impact of agriculture on the environment. It included the first comprehensive assessment of the industry's impact on water quality in Alberta.

CAESA recognized that management of key nutrients, such as phosphorus, within the agricultural industry was required in order to improve sustainability of Alberta's agricultural watersheds. Recognizing that little scientific information was available, the Alberta Soil Phosphorus Limits Project was initiated in 1999. The project determined soil phosphorus limits for agricultural lands that would protect surface water quality in Alberta from degrading.



*includes microwatershed study and collection of nitrogen data (2002 to 2005)

Figure 2. The AESSAW project summarizes the AESA Soil and Water Quality Projects as well as the Soil Phosphorus Limits Project, which were built on information from the CAESA Agreement.

AESAAW Project Reports

The AESAAW project is comprised of 5 volumes:

Volume 1: AESAAW Summary and Recommendations;
Volume 2: AESA Soil Quality Monitoring Project;
Volume 3: AESA Water Quality Monitoring Project;
Volume 4: Nitrogen Loss in Surface Runoff; and
Volume 5: Predicting Phosphorus Losses from Agricultural Areas.

Volume 1: AESAAW Summary and Recommendations

This volume provides an overview of the key findings of the AESA Soil and Water Quality Monitoring Projects and the Soil Phosphorus Limits Project. Prior to the AESAAW project, the analyses of the multi-year AESA datasets were not published. The Soil Phosphorus Limits Project was published in 2006 (available at: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag11864). The AESAAW report summarizes the results of nitrogen loss analyses that were not included in the Soil Phosphorus Limits Project volumes and also highlights additional work identifying phosphorus risk areas which was initiated as a result of the AESAAW project.

Volume 2: AESA Soil Quality Monitoring Project

This volume summarizes the long-term soil quality data collected under AESA. The AESA Soil Quality Monitoring Project was implemented to assess the state of soil quality throughout Alberta and the risk of change in soil quality resulting from farm management practices. Forty-two, non-manured soil benchmark sites were selected to assess trends in soil quality in seven ecoregions. The sites represented a range of agricultural practices.

Volume 3: AESA Water Quality Monitoring Project

This report summarizes the long-term water quality data collected under AESA and CAESA. The AESA Water Quality Monitoring Project was designed to track changes in water quality in agricultural streams in Alberta with time to examine the relationship between agricultural intensity and stream water quality. The study focused on monitoring water quality in 23 small agricultural watersheds with different levels of farming intensity (low, moderate, high, and irrigation) across a representative range of climatic conditions.

Volume 4: Nitrogen Loss in Surface Runoff

The primary focus of the Soil Phosphorus Limits Project was to determine environmental soil phosphorus limits for agricultural lands in Alberta that would protect surface water quality; however, soil and water nitrogen data were also collected. As part of the AESAAW initiative, the nitrogen data from 8 provincial microwatersheds were summarized in 2008 to determine the relationship between soil nitrogen and nitrogen in runoff from agricultural land.

Volume 5: Predicting Phosphorus Losses from Agricultural Areas

Watershed modeling is recognized as a valuable tool for predicting the effect of land management on surface water quality and can be used to make recommendations that may reduce agriculture's impact on water quality. Modeling is dependent upon field data such as that collected in the AESA and Soil Phosphorus Limits projects. This volume summarizes the AESAAW modeling project. The objectives were to evaluate the performance of the Alberta derived soil-runoff phosphorus relationships at the watershed scale and develop phosphorus export risk categories for selected AESA watersheds. This information can be used to develop watershed scale phosphorus export risk maps, which allows agricultural producers and planners to determine the optimum locations for intensive livestock facilities.

Conclusions and Recommendations

Based on the technical information that was collected and assessed within the three provincial initiatives and the AESAAW project, the following key conclusions and recommendations were developed.

Conclusions

1. **A comprehensive soil and surface water quality database is now available for Alberta's agricultural areas.**

    - Data were collected through the Alberta Environmentally Sustainable Agriculture (AESA) soil (1998 to 2006) and water quality (1997 to 2006) projects for representative agricultural regions of Alberta.
    - Soil quality data from 42 sites were representative of cropland managed under progressive practices in Alberta.
    - Water quality data from 23 small watersheds represented the varying degrees of agricultural intensity (low, moderate, and high) and agricultural management (dryland and irrigated).

2. **Provincial scale soil and surface water quality have remained relatively constant during the last decade.**

    - Most key measures of soil quality were unchanged during the monitoring period, with the exception of agronomic soil test phosphorus (STP) levels and bulk density. Although the STP levels slightly increased, levels remained below the agronomic threshold of 120 kilograms/hectare in the top 15 cm of soil.
    - Soil bulk density tended to decrease with time as practices improved to include more reduced tillage and use of forages in rotation.
    - Overall, nitrogen and phosphorus concentrations in surface water did not change in agricultural watersheds during the monitoring period.

3. **A field-scale relationship exists between phosphorus concentrations in the soil and surface water; however, a relationship between nitrogen in the soil and surface water was not apparent.**

    - Non-manured benchmark AESA soils averaged less than 70 kilograms/hectare of STP. Soils with long histories of heavy manure application could have STP values in excess of 1000 kilograms/hectare.
    - The risk of phosphorus loss to runoff water increased with increasing STP concentrations.
    - Soils that were amended with manure and had STP concentrations above the agronomic threshold lost more phosphorus to surface waters.

4. **Surface water quality guidelines for nutrients were generally exceeded in Alberta's agricultural watersheds.**

   - Water quality guidelines were exceeded more frequently as agricultural intensity increased.

   - In the high agricultural intensity watersheds, water quality guidelines for total phosphorus (TP) and total nitrogen (TN) were most often exceeded. Total phosphorus met the protection of aquatic life guideline <12% of the time and TN met the guideline <16%.

   - Low agricultural intensity watersheds met TP and TN guidelines <59 and <85% of the time, respectively.

5. **Surface water quality will deteriorate if agricultural intensity increases using current management practices.**

   - The AESA data support previous studies that show as agricultural intensity increases, water quality decreases.

   - Nutrient and pesticide concentrations and detection frequencies increase with agricultural intensity; however, bacteria data do not follow the same trend with agricultural intensity.

   - The presence of fecal bacteria in agricultural streams appears to be more closely related to ecoregion characteristics, which reflect differences in livestock management and wildlife communities.

6. **Low level concentrations of a variety of pesticides were commonly found in agricultural watersheds.**

   - Thirty-seven of 68 pesticides analyzed in the water quality monitoring program were detected at least once from 1999 through 2006.

   - Most of the pesticides detected were herbicides. The eight most common herbicides detected were 2,4-D, MCPA, dicamba, clopyralid, triclopyr, MCPP, picloram, and imazamethabenz-methyl.

   - The types of herbicides detected in each watershed tended to be associated with agricultural intensity and management.

7. **There are concerns about possible cumulative impacts of the various herbicides found in the water.**

   - Of these eight most commonly detected herbicides, only four have water quality guidelines. The four that do not have guidelines are clopyralid, triclopyr, MCPP, and imazamethabenz-methyl.

   - Only 30 of the 68 pesticides that were analysed have water quality guidelines.

   - Current guidelines do not account for possible synergistic effects of herbicides with the same mode of action or possible chemical interactions.

8. **The Alberta derived soil-runoff phosphorus relationships were able to predict TP and TDP concentrations at a sub-watershed scale.**

   - The Haynes Creek M1 sub-basin watershed soil-runoff data suggested that about 80% of TP and 50% of TDP measured in the stream can be directly related to STP values from the top 15 cm soil depth.

   - Detailed data sets are required to assess the relationships for larger watersheds.

9. **Critical source areas, or areas with high nutrient levels and risk of runoff, are likely responsible for the majority of phosphorus losses from agricultural land.**

    - A modeling study showed that while the critical source areas with high STP levels represented approximately 35 to 45% of the watershed, these areas accounted for 64 to 70% of the TP export.

    - Other areas within the watershed will also contribute over time and with multiple runoff events.

Recommendations

1. **Alberta's agriculture industry must focus efforts on reducing nutrient loads from agricultural lands into watersheds through improved on-farm and critical source area management.**

    - Continue to develop science-based, practical, and economical mitigation solutions (Beneficial Management Practices) that producers can implement to reduce nutrient loading to surface waters.

    - Implement appropriate on-farm and critical source area management practices in Alberta's watersheds through producer-led watershed stewardship groups.

2. **Develop surface water quality targets for nutrients in agricultural watersheds that are achievable, protective, and allow for sustainability in the long term given best agri-environmental management practices.**

    - Current water quality guidelines may restrict agricultural production, particularly livestock development, even with current technology and best management practices.

    - Establish nitrogen and phosphorus water quality targets for agricultural streams based on
        - ambient nutrient concentrations in watersheds with minimal human disturbance;
        - protection of water quality for aquatic ecosystem health; and,
        - livestock development with the best environmentally sustainable management practices.

3. **Assess the impacts of low levels of multiple pesticide residues in surface waters on aquatic ecosystem health.**

    - Low levels of pesticides commonly co-occur in Alberta's surface waters.

    - There are increasing concerns about the cumulative impact of pesticides on the health of aquatic ecosystems.

    - Without water quality guidelines, it is difficult to determine whether pesticides pose a threat to aquatic ecosystems, human drinking water, irrigated crops, or agricultural livestock.
        - support the development of surface water quality guidelines by the Canadian Council of Ministers of the Environment (CCME) for the four most frequently detected pesticides in Alberta surface waters (imazamethabenz-methyl, MCPP, clopyralid, and triclopyr).

    - Support implementation and further development of Alberta Environment's Pesticide Risk Assessment tool to evaluate the potential impacts of multiple pesticides on aquatic ecosystem health.

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- AESA Water Quality Committee and ARD and AENV sampling staff involved in the AESA Water Quality program.
- GIS and data analysis support for Assessing the Performance of the Phosphorus Limits Equations and Defining Critical Source Areas within Selected Small Agricultural Watersheds.

Appreciation is expressed to the many agricultural producers throughout Alberta for their support in allowing project staff to set up and operate monitoring stations on their land.

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List of Abbreviations

AESA	Alberta Environmentally Sustainable Agriculture
AESAAW	Assessment of Environmental Sustainability in Alberta's Agriculture Watersheds
AGRASID	Agricultural Region of Alberta Soil Inventory Database
AOPA	*Agricultural Operation Practices Act*
ASWQG	Alberta Surface Water Quality Guidelines
BMP	Beneficial Management Practices
$CaCl_2$-P	calcium chloride extractable phosphorus
CAESA	Canada-Alberta Environmentally Sustainable Agriculture
CEC	cation exchange capacity
DPS	degree of phosphorus saturation
DRP	dissolved reactive phosphorus
EC	electrical conductivity
FWMC	flow-weighted mean concentration
K	potassium
NH_3-N	ammonia nitrogen
NO_2 + NO_3-N	nitrite and nitrate-nitrogen
PSI	phosphorus sorption index
SO_4^-S	sulphate
STP	soil test phosphorus
TDP	total dissolved phosphorus
TKN	total Kjeldähl nitrogen
TN	total nitrogen
TP	total phosphorus
WEP	water-extractable phosphorus

1.0 Introduction

Environmental sustainability is essential to a viable agricultural industry in Alberta. Environmental sustainability allows agriculture producers to meet their needs without compromising the ability of future generations to do the same. Generally, environmentally sustainable agriculture will maintain valued qualities of the environment, such as clean water and productive soils, while agricultural producers enjoy social and economic benefits.

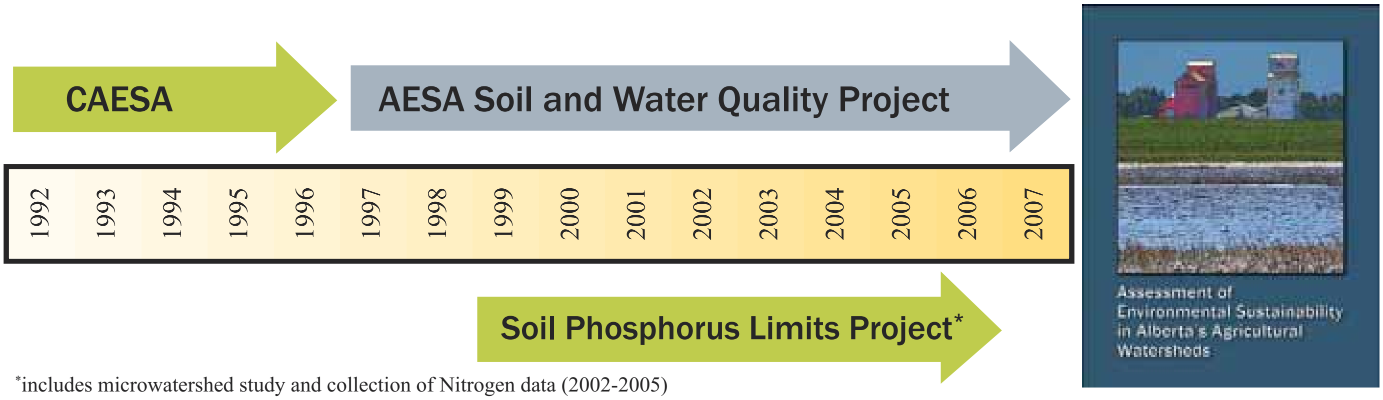
Environmental sustainability can be measured using a variety of indicators that reflect the pressure the agricultural industry places on the environment. Common agri-environmental indicators are air, soil and water quality, and biodiversity. Monitoring these indicators helps measure the impact of the agricultural industry on the environment through time.

Alberta Agriculture and Rural Development monitored environmental indicators to assess environmental sustainability in agricultural watersheds for more than a decade. A series of soil and water quality studies were initiated in the early 1990s by the Canada-Alberta Environmentally Sustainable Agriculture (CAESA) agreement (Figure 1.1). This program aimed to improve resource management as the agri-food industry grew, by promoting environmentally sustainable practices in agricultural production and processing (CAESA 1998 - Water Quality Committee). CAESA identified soil and water quality as the two most important indicators related to agricultural sustainability in the province.

Sustainable agriculture: *An integrated farming system that will, over the long term, satisfy food and fibre needs, enhance environmental quality, make the most efficient use of resources, sustain the economic viability of farm operations.*

The Alberta Environmentally Sustainable Agriculture (AESA) project evolved from CAESA. The AESA project also supported research, monitoring and extension activities focused on soil and water quality.

The Assessment of Environmental Sustainability in Alberta's Agricultural Watersheds (AESSAW) report summarizes the AESA Soil and Water Quality Projects as well as the Soil Phosphorus Limits Project, completed to better understand nutrient transport and loss from agricultural land. The first half of this report provides background information related to agriculture in Alberta, an overview of soil and water as natural resources and a review of nutrient transport processes in the environment. The second half summarizes the results of the agri-environmental research projects.



*includes microwatershed study and collection of Nitrogen data (2002-2005)

Figure 1.1. Timeline for the CAESA, AESA and Soil Phosphorus Limits projects.

1.1 Agriculture in Alberta

About one third of the land in Alberta (21 million hectares) is in agricultural production (Statistics Canada 2007). Although the total amount of agricultural land has remained stable since the last census in 2001 (Figure 1.2), there is an overall trend toward a reduction in farm numbers and an increase in farm size in the province (Figure 1.3). Since 2001, consolidation of small farms has decreased the total number of farms by almost 8%, to 49,431 farms. At the same time, the average farm size has increased by 8.8%, from 393 hectares to 427 hectares (Figure 1.3). With the reduction in farm numbers, the number of farm operators has decreased by 6%, from 76,195 in 2001 to 71,660 (Statistics Canada 2007). These changes in farm size and number will likely influence the future of agricultural production in the province.

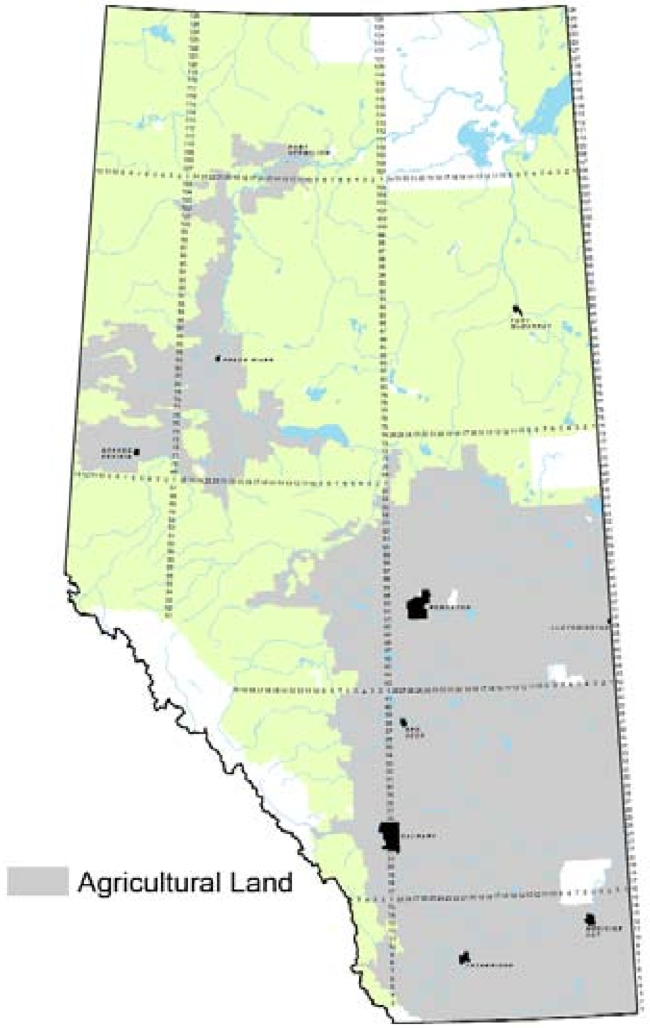


Figure 1.2. Agricultural land in Alberta.

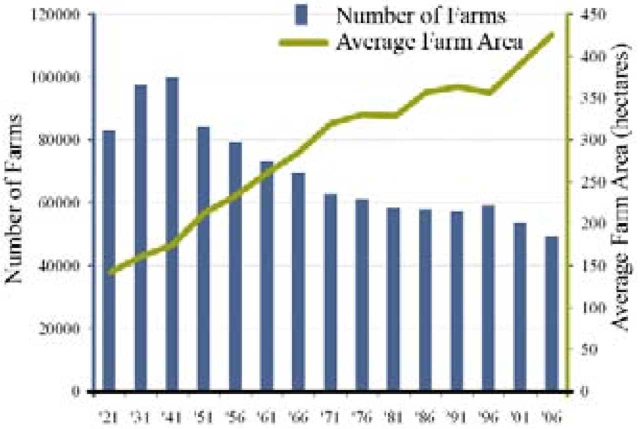


Figure 1.3. Number of farms and average farm size in Alberta, 1921 to 2006.

The area in crops, native pasture and other agricultural land uses in the province has remained relatively stable since 1996 (Figure 1.4). Approximately 9.5 million hectares are seeded to crops, with grain and oilseed representing 25.2% of the agricultural land area. An additional 9 million hectares are in pasture and 1.5 million hectares are used for other primary production, such as woodlots or Christmas tree production (Statistics Canada 2007).

The remaining land area is where summerfallow is used as part of crop rotations. Land in summer fallow has decreased from 1,437,000 hectares in 1996 to 907,000 hectares in 2006 (Figure 1.4). This downward trend is expected to continue as producers realize the benefits of continuous cropping and soil conservation. There is an increasing trend in the amount of area seeded to tame pasture, from 1,915,000 hectares in 1996 to 2,484,000 hectares in 2006 (Figure 1.4). Approximately 5.4% of the cultivated area in Alberta is irrigated, mostly in the southern part of the province (Irrigation Water Management Study Committee 2002).

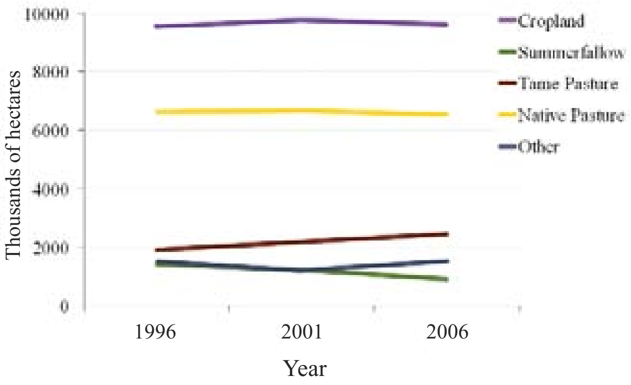


Figure 1.4. Alberta farms classified by land use.

Beef cattle operations account for 41.5% of the farm operations in the province. These operations manage approximately 6.6 million cattle and calves annually, representing 39.4% of all beef raised in Canada. Southern Alberta raises the greatest number of cattle and the numbers decrease northward (Figure 1.5).

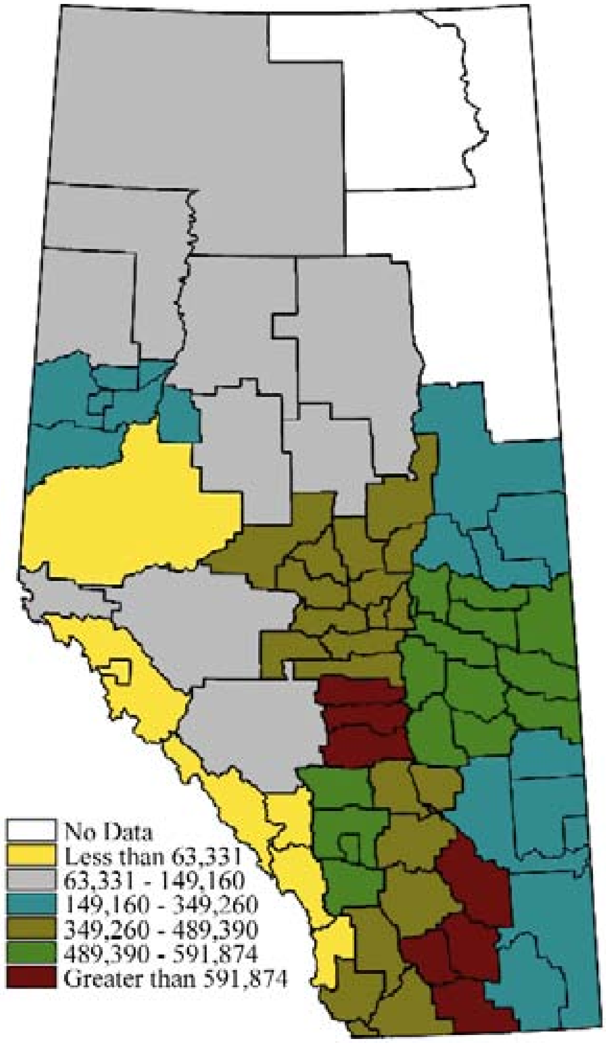


Figure 1.5. Density of cattle and calves by municipality in 2001.

The agricultural industry contributes about 2% of Alberta's gross domestic product. In 2006, crops and livestock (plus livestock products) each accounted for approximately 50% of the total gross value of agricultural production, at roughly $3.4 to 3.8 million. Including market receipts, program payments and custom work, the province's gross farm receipts totaled $9.9 billion in 2006, almost unchanged since 2001.

As Alberta's finite land base is increasingly pressured by the activities and competing interests of agriculture, oil and gas, forestry, industrial development, housing, recreation, and conservation, there is a growing concern regarding economic growth and the long-term management of natural resources. In relation to population, Alberta has grown faster than any other province in nine of the last ten years (Government of Alberta 2007). With the population increasing, cities and towns have expanded onto lands that were often used for agricultural activities and are now being used for acreages and other urban developments. This causes fragmentation of agricultural lands, as well as tension and pressures on Alberta's sensitive areas and natural habitats. Environmental sustainability will be a key factor in the viability of Alberta's agricultural industry.

1.2 Soil and Water Quality Issues in Alberta

There are competing interests for the finite land base in Alberta among multiple land uses. With wide spread growth in the provincial population and economy, tremendous pressure is put on the land to provide resources for everyone. Within the agricultural sector, the pressure to increase production in a more intensive and efficient manner has led to the growth of larger scale farms and increased use of such inputs as energy, fertilizers, manures, pesticides and herbicides. These inputs increase productivity, but if improperly managed they have negative impacts on soil and water resources.

Soil

Soil plays an important role in our natural environment and is the most common medium for plant growth. It is made up of four components: mineral material, organic material, air, and water. Soil quality affects the degree to which the soil supports and sustains crops, range and woodland production, nutrient cycling, the buffering and filtering of toxic substances, and the quality of water flow, water storage and other water-related functions (Daily et al. 1997; Bolinder et al. 1999; Brejda et al. 2000a, b; Carter 2002; Wander et al. 2002).

Soil also provides habitat for a variety of organisms that are critical in facilitating processes that support plant growth. Soil quality can be degraded due to problems related to erosion, loss of organic matter, compaction, and contamination (Winder 2003).

Soils are classified and grouped according to their similar properties and the factors that contributed to their formation, including landscape characteristics, time, biology and climatic influences on the parent materials (Soil Classification Working Group 1998). Agriculture takes place largely within areas with four types of soil: the Brown, Dark Brown and Black Chernozems, and the Dark Gray Chernozems/Dark Gray-Gray Luvisols (Figure 1.6).

Chernozemic soils are associated with native grassland vegetation and are high in organic matter, and are well to imperfectly drained (Soil Classification Working Group 1998). The soil groups within the Chernozemic order are further classified by surface soil colour, which reflects the range in soil organic matter content of the group. Darker surface colour is a reflection of greater organic matter content. For example, the organic content of Brown Chernozem soils ranges from 3 to 4%; organic matter in Black Chernozem soils ranges from 6 to 10%.

Luvisolic soils are associated with mixed forest vegetation. They have a sandy loam to clay texture and are well to imperfectly drained (Soil Classification Working Group 1998). Under native conditions, decomposing litter overlays the surface layer of Luvisolic soils. Luvisolic soils generally are light-coloured, and have a surface layer composed of residual deposits of soil, dust, and rock particles produced by the action of the wind (eluviation) and a subsurface layer where clay particles have accumulated. Luvisolic soils contain more than 30% organic matter, which has accumulated under moist conditions.

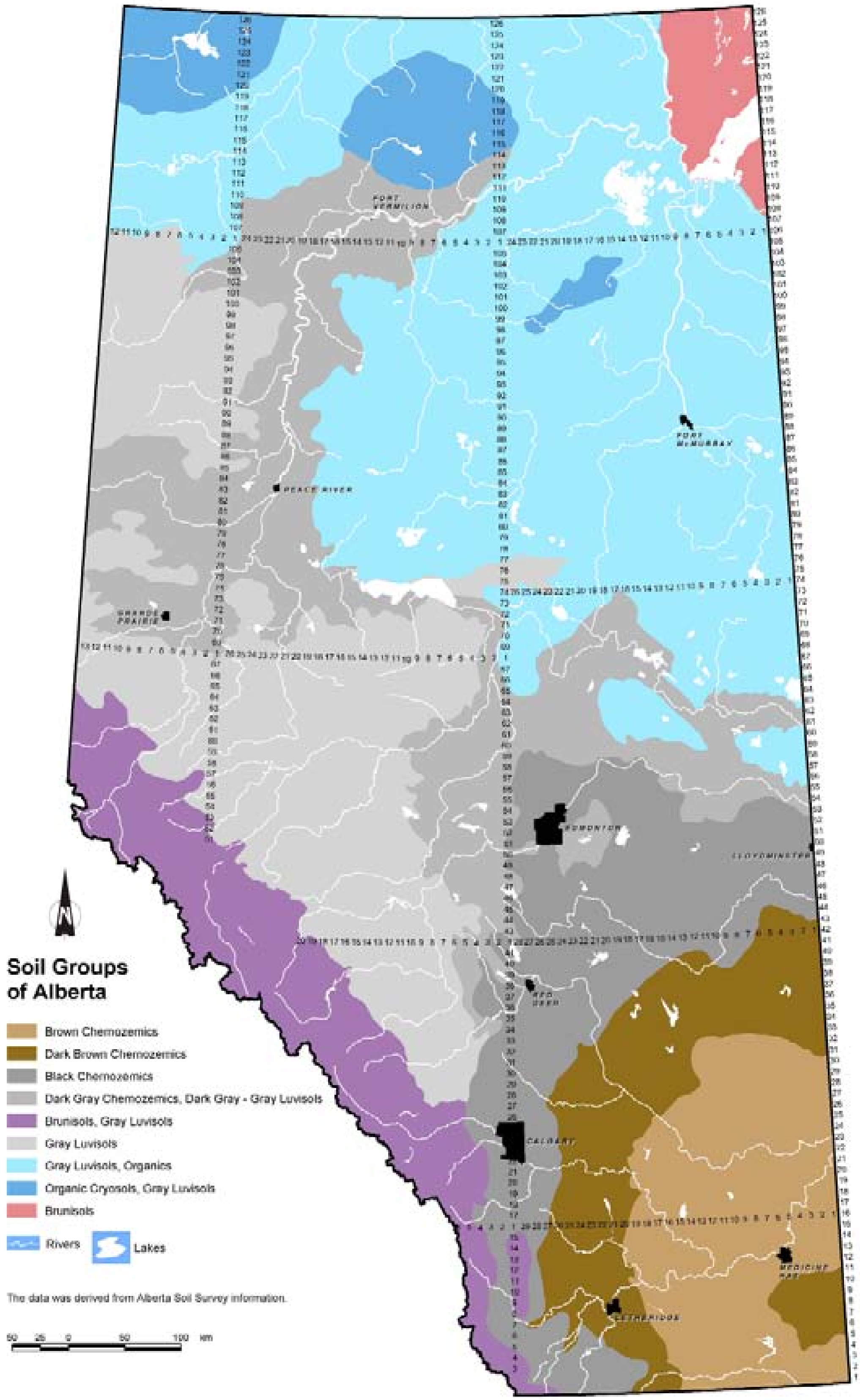


Figure 1.6. Soil groups of Alberta.

Soils can be divided vertically into layers or horizons defined by how each were formed (Figure 1.7). The major mineral soil horizons are labeled as A, B and C. The mineral horizon that forms at or near the surface is called the A horizon. It is the zone where leaching and eluviation of materials occurs and where most of the soil organic matter accumulates. The B horizon is a subsurface mineral horizon that is characterized by an enrichment of organic matter or clay, by the development of soil structure, or by a colour change that indicates mineral reactions. The C horizon is a subsurface soil mineral layer that is less affected by soil processes than the A and B horizons and contains the parent material.

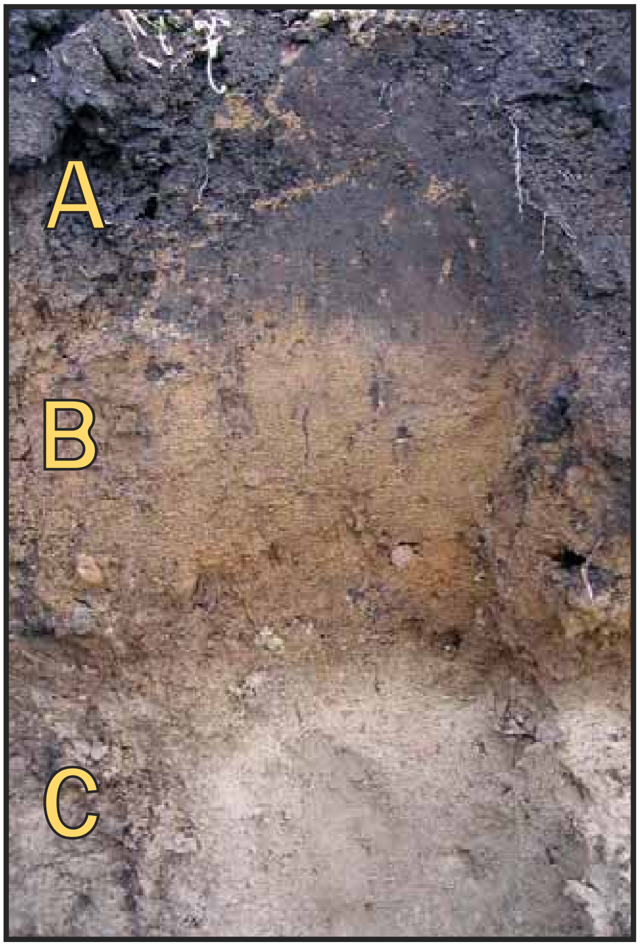


Figure 1.7. Soil profile showing the A, B and C horizons.

Soil texture is a property used to describe the relative proportion of different mineral particle sizes in a soil. Clay particles are very small (fine textured), silt particles are slightly larger (medium textured) and sand particles are relatively large (coarse textured). The majority of the agricultural soils in Alberta are loamy, that is, a roughly equal mixture of sand, silt, and clay-sized mineral particles (Figure 1.8). These soils generally have higher water holding capacities than coarse (sand) or fine (clay) textured soils. However, once the maximum water holding capacity has been reached, runoff and erosion of particulate and dissolved forms of nutrients and pesticides can occur. Management practices that reduce water erosion include crop rotations, cover cropping, conservation tillage, contour cropping, vegetated buffer strips, and grassed waterways (Hilliard and Reedyk 2000).

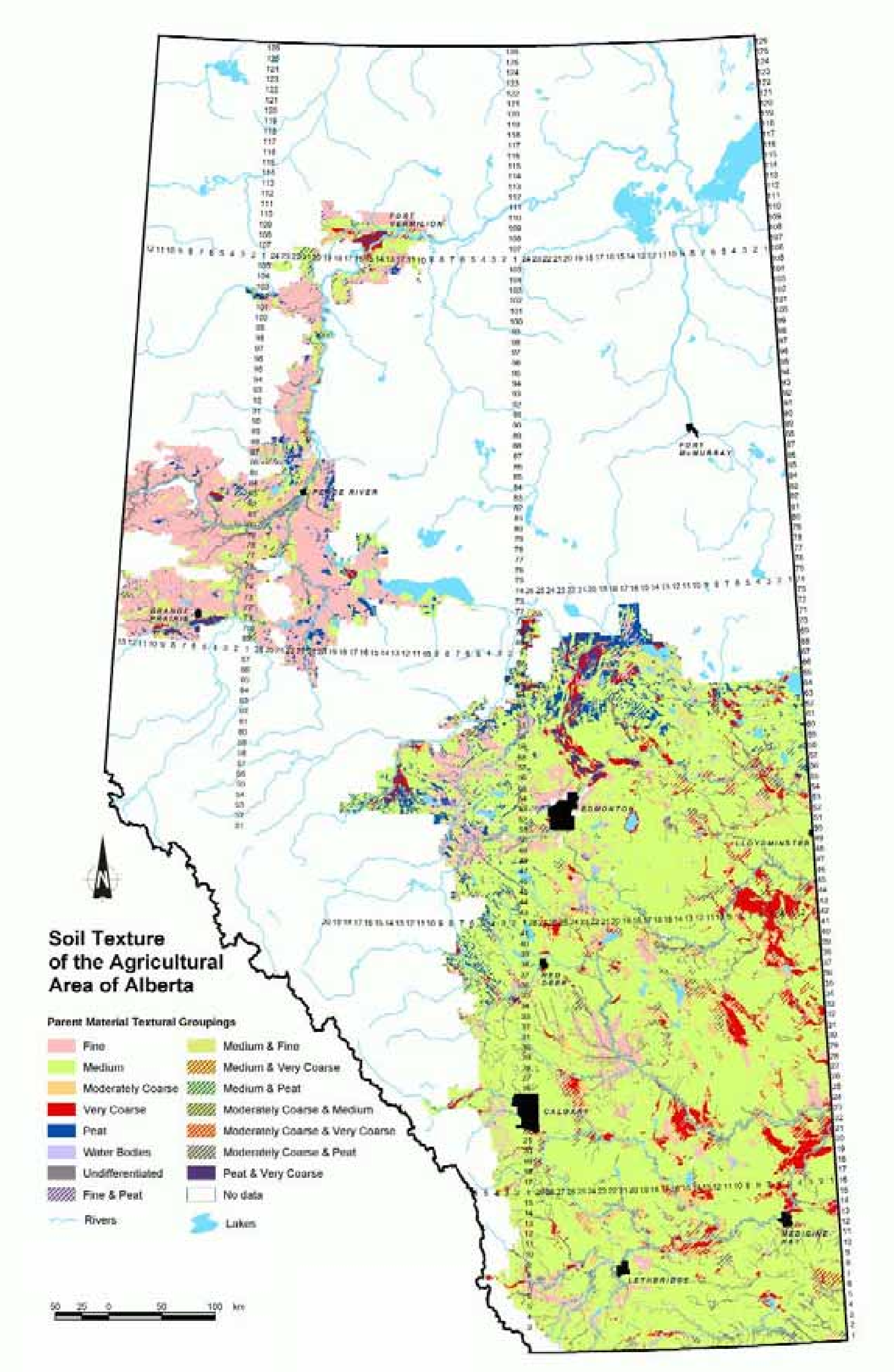


Figure 1.8. Soil textures in the agricultural areas of Alberta.

Water

Alberta has a seeming abundance of water, however, variations in geography, climate, and human demand create regions of relative scarcity. In regard to agriculture, the least amounts of surface water and precipitation occur in the parts of the province with the greatest amounts of agricultural activity.

Of the five main withdrawal or consumptive uses of water in Alberta, agricultural use is the largest (thermal power, municipal use, industrial use, and water injection for crude oil extraction are the other four). Though water quantity is critical, concern over water quality becomes an equally important factor in water management issues, especially in regard to sustainable agriculture.

Water Quality

Water quality is an important factor contributing to the sustainability of the agricultural industry in Alberta. It is determined by measuring many of the physical, chemical and biological constituents found in water and comparing these findings to provincial and federal water quality guidelines, such as the Surface Water Quality Guidelines for Use in Alberta (AENV 1999). Separate water quality guidelines exist for agricultural use (i.e., irrigation water and livestock water), recreation, aesthetics, and for the protection of freshwater aquatic life.

Good quality water protects human health and aquatic ecosytems. Maintaining good water quality is essential to minimizing impacts on downstream water users and aquatic life and reduces the costs associated with municipal water treatment. It also leads to higher crop yields, the prevention of salt accumulation in the soil and improved weight gain in livestock. Willms (2002) found that yearling heifers provided with good quality water gained, on average, 23% more weight than cattle exposed to poor quality water sources. Cattle that had access to clean water spent more time grazing and less time resting than those offered pond water.

Water quality is influenced by a variety of natural and human-made factors, including the volume of stream flow, local geology, climatic conditions, the degree of development along streams, lakes and other surface waters, non-point sources of runoff, and point sources of effluent that discharge into surface water bodies (Figure 1.9). Examples of agricultural point sources include pesticides from farmyards (e.g., from leaking tanks or rinse water), runoff from intensive livestock operations or cow-calf wintering sites, and contamination at animal watering locations. Non-point sources of runoff include pesticide, manure and fertilizer applications on cultivated land, grassland and irrigated land (Riemersma et al. 2006; Soil Phosphorus Committee and LandWise Inc. 2006) (Figure 1.9).

In the United States, agricultural activities are one of the leading causes of impairment to water quality in streams and lakes (USEPA 2007). The addition of nutrients into surface water, in particular phosphorus and nitrogen, has also been documented as a concern in Alberta (CAESA 1998 - Water Quality Committee). Agricultural sources of water contamination include runoff of sediments, nutrients and bacteria from fields and livestock operations, pesticides, the runoff of salts and trace elements from irrigation residues, and to a lesser degree, subsurface flow and leaching of pesticides and nutrients into the groundwater (Sharpley and Syers 1979; Daniel et al. 1998).

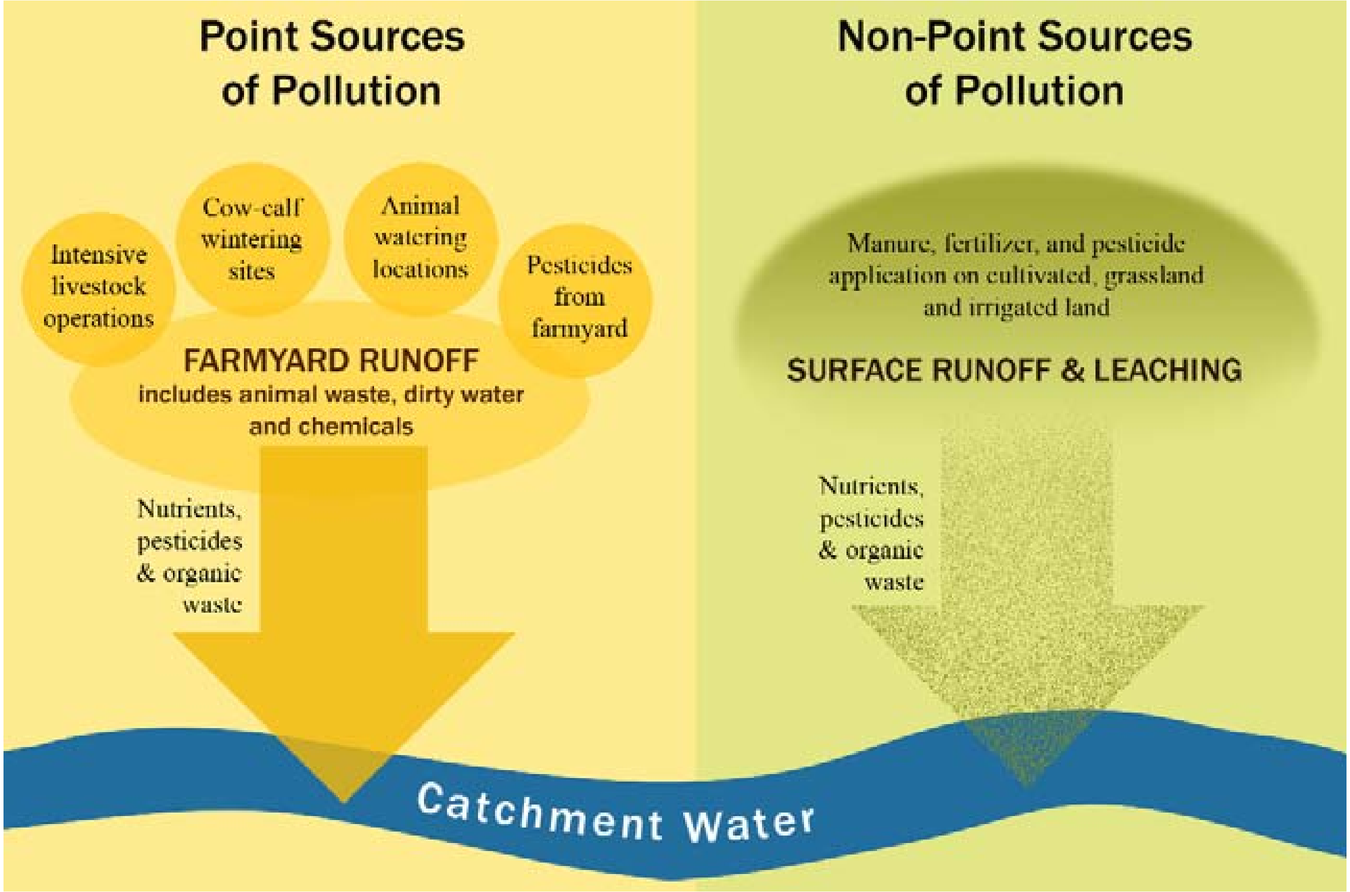


Figure 1.9. Point and non-point sources of agricultural pollution.

One of the main influences on water quality is flow volume, or the amount of water in a stream at a given time. High flows can benefit water quality by reducing contaminant concentrations through dilution; however, high flows that result when surface runoff enters a river, following a precipitation or snowmelt event, may also increase concentrations of contaminants coming off land surfaces. Flow volumes and concentrations are used to calculate load, that is, the total amount of a substance in a stream. The loads can then be used to assess the impact on receiving water bodies. Streams with large flow volumes often have greater loads and a larger potential impact on receiving water bodies than smaller streams.

Soil and Water Interactions

In order to impact water quality, contaminants must be transported from land to water. The most important transport mechanisms in Alberta are spring snowmelt and precipitation. Snowmelt and rainfall can produce runoff events, causing water to flow over the ground surface. In the same way, irrigation water can be a mechanism for the transportation of contaminants to water bodies. Runoff may be greater in areas where soil is compacted, where

***Adsorption** is the accumulation of gases, liquids, or dissolved matter on the surface of a solid or on particles within a liquid.*

***Absorption** is the assimilation of one substance into another.*

***Desorption** is the removal of an absorbed or adsorbed substance.*

vegetation cover is limited and where soil is bare or frozen. The intensity, frequency and duration of precipitation events and soil type will influence runoff volumes and cause variation among regions. Contaminants are transported by adsorbing onto sediments that are then eroded from a site or they may be transported in a dissolved form and carried in runoff water to surface and groundwater (Cross and Cooke 2002).

Phosphorus

Phosphorus is an important macronutrient needed for the growth and health of plants and animals. Plants take up this nutrient from the soil as inorganic phosphorus (H_2PO_4- and HPO_4^{-2}). Phosphorus in the soil is replenished by desorption and dissolution of inorganic phosphorus bound to soil particles and by the mineralization of organic phosphorus (Figure 1.10). Phosphorus can be added to soil as an inorganic fertilizer or by organic material such as livestock manure. Although phosphorus is relatively immobile in soil because it is bound to clay particles and other minerals, it can accumulate within the top 15 cm of the soil. On the soil surface, phosphorus can be transported by erosion and runoff events to surface water. Phosphorus is also a macronutrient in water and promotes the growth of aquatic plants and algae.

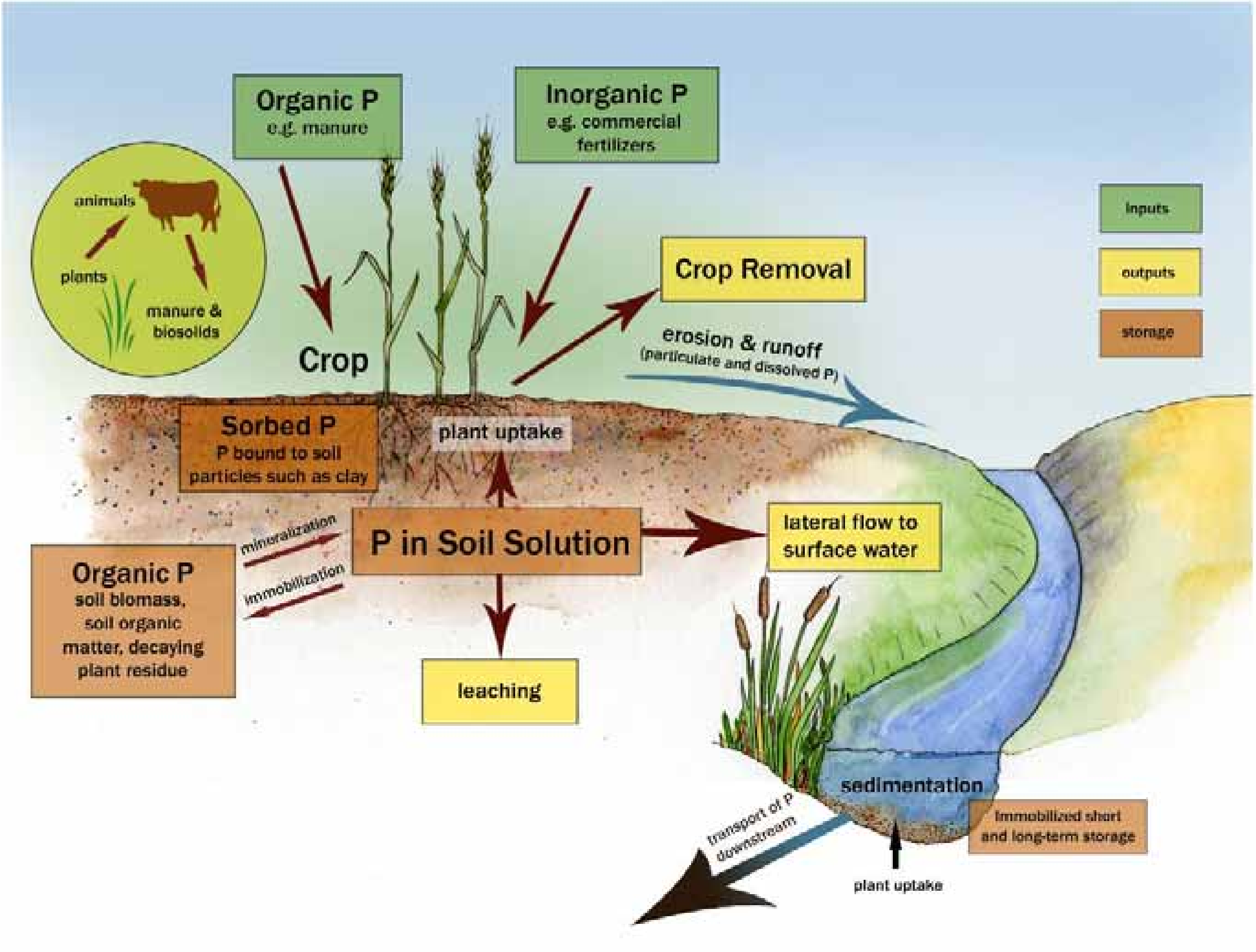


Figure 1.10. The soil phosphorus cycle (modified from Paterson et al. 2006).

Even small amounts of phosphorus can cause increased aquatic plant and algae growth. Blue-green algae blooms may produce toxins that can cause death in wildlife and livestock. A decrease in dissolved oxygen concentration in surface water, due to the death and subsequent decomposition of these additional algae and aquatic weeds, can cause fish kills, as dissolved oxygen is essential for the survival of aquatic organisms. Many surface water bodies in Alberta are naturally eutrophic or nutrient rich, and further additions of phosphorus can accelerate the process of nutrient enrichment and be detrimental to aquatic life. Eutrophication can also affect recreation and tourism industries and have significant economic and environmental implications on public and animal health (Howard et al. 2006).

Phosphorus losses from the soil are normally minimal until a critical threshold concentration is exceeded. These threshold values are much higher than what is required for optimal growth of crops. When the adsorption (holding) capacity for phosphorus in the soils is exceeded, it has a greater potential to be transported to surface waters.

The majority of phosphorus movement into surface waters occurs during spring snowmelt, when more than 80% of the total runoff occurs (Nicholaichuk 1967). Frozen soils lead to decreased infiltration rates, and dissolved and particulate phosphorus that may be on the soil surface from manures, inorganic fertilizers or decomposed litter materials can be transported by runoff into surface waters (Granger et al. 1984; Ryden et al. 1973; Timmons et al. 1977).

Phosphorus loss also occurs throughout the year, during and after a precipitation event, as particulate phosphorus within sediments is transported with runoff and erosion. Quantifying the amount of phosphorus transported by runoff and soil erosion is complex and is influenced by geography and climate (Howard et al. 2006).

Most agricultural soils in Alberta can hold a large amount of phosphorus, as they are generally deficient in plant available phosphorus. However, if phosphorus is applied as a soil amendment, it can build up and become surplus (Soil Phosphorus Committee and LandWise 2006). Soils that are fine to medium textured, such as those that are generally found in the agricultural areas of Alberta (Figure 1.5), can, through adsorption and deposition, hold large surpluses of phosphorus. As phosphorus increases in the soil and is adsorbed onto soil particles or reacts with elements such as calcium and iron, more phosphorus accumulates in the soil solution (Havlin et al. 2005). This increased phosphorus in solution can potentially cause even more phosphorus to be transported by runoff from soil to surface water.

Nitrogen

The soil organic nitrogen pool, which contains 95 - 99% of the nitrogen in the soil, receives nitrogen by decomposition of plant and animal residues, dry and wet deposition (e.g., dust and precipitation), and fertilizer applications (organic and inorganic nitrogen) (Figure 1.11). Agricultural sources of nitrogen include manure, inorganic fertilizers and legumes. Nitrogen mineralization is the only soil-based microbiological means of converting nitrogen from organic nitrogen into ammonium (NH_4^+) and nitrate (NO_3^-), the nitrogen forms usable by plants (Abril et al. 2001) (Figure 1.11). Nitrate is the preferred form of nitrogen plants can take up, though plants can take up ammonium as well.

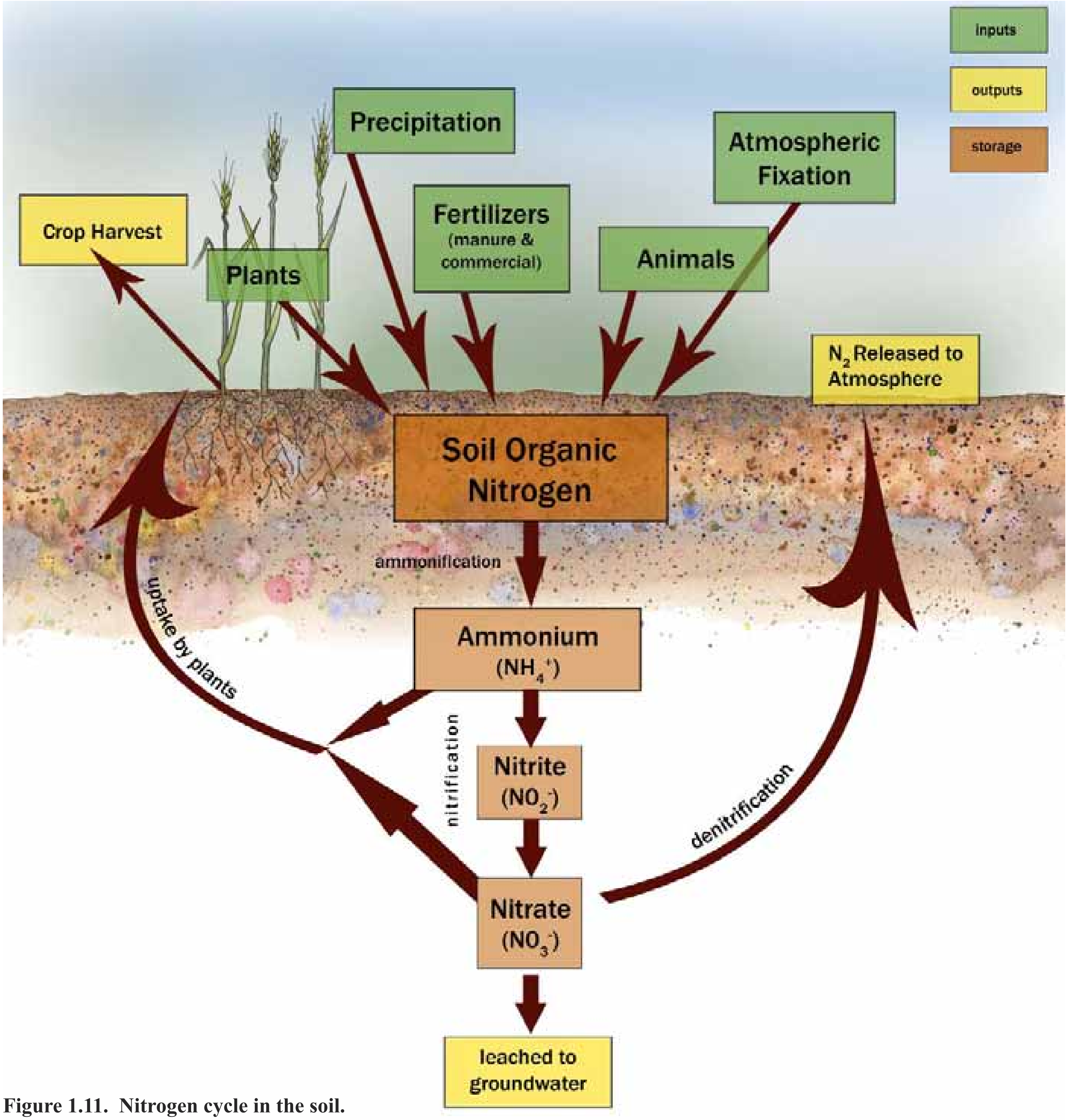


Figure 1.11. Nitrogen cycle in the soil.

Nitrate can be transformed in different ways:

- Immobilized as soil organic nitrogen;
- Taken up by plants;
- Returned to the atmosphere as N_xO or N_2 through denitrification; and
- Leached into groundwater and subsequently transported to surface waters because it is highly mobile and very soluble in water.

Leaching of NO_3^- from the soil profile is a real concern because it may cause loss of plant productivity and serious environmental problems. Leaching occurs as a function of climate (especially precipitation), the amount of surplus nitrate, and soil properties (Janzen et al. 2003). Timing of fertilizer nitrogen application is very important, not only in terms of when the plant will use it, but also to prevent nitrate leaching.

As with phosphorus, excessive nitrogen application on crops can leave a pool of residual nitrogen in the soil at the end of each growing season. This surplus has the potential to pollute surface and groundwater during spring snowmelt (Cross and Cooke 2002). When excess runoff occurs, nitrate can reach surface water by overland flow, or can percolate down the soil profile into the groundwater and discharge into surface water. High concentrations of nitrogen in surface and groundwater, in the form of nitrate, can cause methanoglobinemia (blue baby syndrome) in young infants. Nitrate can also contribute to weight loss and poor feed conversion in livestock.

Nitrogen can be removed from the soil by runoff when a relatively large concentration of organic nitrogen is adsorbed onto particulate matter. Transport of nitrogen in runoff from land-applied livestock manure is dependent on application rate, slope, climate, and soil type. The amount of nitrate in surface runoff is generally small, but other forms of nitrogen, such as dissolved organic nitrogen and particulate mineral or organic nitrogen, can go through the mineralization and nitrification process to form additional nitrate in runoff waters.

The majority of nitrogen that is leached out of the soil profile and into groundwater is in the form of nitrate. Nitrate is very soluble and mobile in water and is flushed downward through the soil by infiltration of rain or irrigation water. Nitrate leaching can occur in all types of soils, but excessive leaching happens more often on coarse (sandy) textured soils, because these soils cannot retain nutrients or water. An eight-year study near Lethbridge measured the effects of cattle manure on soil and groundwater quality (Olson et al. 2003). Results showed that nitrate-nitrogen from the manure moved down the soil profile more rapidly at coarse-textured sites, than at medium-textured sites. On medium textured soils, nitrate-nitrogen tended to accumulate in a bulge and then move slowly down the soil profile. These results were reflected in groundwater concentrations; nitrate-nitrogen from the medium-textured site had not reached the water table, while the coarse-textured site had higher groundwater nitrate-nitrogen concentrations.

Pesticides

Pesticides are any substance or mixture of substances that prevent, destroy, repel, or mitigate pests. Herbicides, insecticides, fungicides, and rodenticides are used in crop production to control weeds, insects, plant pathogens, and rodents. Agriculture now accounts for 70 to 80% of total pesticide use in the United States; 60% of that is herbicide use (US Geological Survey 1999). In Alberta, common active ingredients found in herbicides are 2,4-D, dicamba, MCPA and glyphosate.

Pesticides can negatively affect water quality and result in adverse effects in sensitive organisms, aquatic ecosystems and human health (Schulz 2004; Rice et al. 2007). Some herbicides and insecticides are found in runoff water and can persist in the environment longer than is required to kill target weeds and insects. Excess pesticide can be introduced into surface water by snowmelt and spring precipitation, either in dissolved form in runoff water or adsorbed onto eroded soil particles (Klöppel et al. 1997;

Carter 2000; Reichenberger et al. 2007). Once in the surface water, pesticides can accumulate in the food chain (e.g., in the fatty tissue of fish) and be consumed by predators in toxic dosages. Pesticides can also be found in point sources, due to runoff from hard surfaces such as farmyards and storage facilities, from filling and cleaning sprayers, from improper handling of excess tank mixes, and from leaking of faulty equipment (Carter 2000; Reichenberger et al. 2007).

Fecal Coliform Bacteria

Fecal coliform bacteria are found in the intestinal tract of mammals and are a common indicator of pollution. The presence of fecal coliforms in water implies the presence of microorganisms that are pathogenic to humans (Entry et al. 2000). Livestock such as beef cattle shed large amounts of bacteria in feces that can cause fecal pollution of water if transported to surface water via runoff. During precipitation events, improper storage and handling can cause manure to run off into surface waters, causing downstream health problems including respiratory, gastrointestinal, eye, ear, skin, and allergy illnesses. These may be fatal to pregnant women, the very young, the elderly, and people with immuno-compromised systems (Hooda et al. 2000; Burkholder et al. 2007).

Land Use and Management Influence Nutrient Losses

The potential for nutrient transport from agricultural land to surface water varies according to local site conditions (e.g., soil type and topography) and individual land management practices on the farm. Land management practices that influence risk of nutrient loss include:

- Application of inorganic (commercial) or organic (manure) fertilizer above agronomic thresholds,
- Method and timing of application,
- Tillage practices, and
- Crop or cover type.

Application of fertilizer. Application of fertilizer above agronomic thresholds can result in the transport of excess nutrients into surface water by rain or snowmelt. Inorganic or commercial fertilizer is easily mobilized and is in a form readily available for plant uptake either on the land or in the water. Nutrients found in organic fertilizers (manure) must first be broken down or mineralized before nutrients are available to plants. Manure application above crop requirements may result in the organic nutrients being slowly released and becoming available over a long period. The impacts of inorganic fertilizer may be immediate, whereas the impact from organic fertilizer may persist for years.

Method of application. The methods used to apply fertilizer influence the amount of nutrients that may be lost in runoff water and also whether the lost nutrients are in nutrients dissolved or particulate form. When inorganic fertilizers and manures are surface applied at rates above agronomic thresholds, phosphorus and nitrogen are more easily transported in dissolved forms. When amendments are incorporated into the soil, particulate forms of phosphorus and nitrogen are lost (Römkens et al. 1973; Ginting et al. 1998; Eghball and Gilley 1999; Zhao et al. 2001).

Tillage and cropping practices. Conventional tillage (e.g., moldboard plough) and conservation tillage (e.g., no-till) are two contrasting farming methods, each with variable impacts on nutrient loss from land to water. Conservation tillage generally reduces runoff volumes as well as particulate phosphorus and nitrogen losses, because the soil surface is not disturbed. Due to the increase in crop residue remaining on the soil surface, however, dissolved nitrogen and phosphorus can increase under conservation tillage, as the nutrients may leach from crop residues (Römkens et al. 1973; Angle et al. 1984; Gaynor and Findlay 1995; Eghball and Gilley 1999).

Johnes (1996) found that total phosphorus loss tends to be greater from crops with low surface residue cover such as row crops, while particulate phosphorus and nitrogen losses were found to be higher where there was the least crop cover (Burwell et al. 1975).

Generally, nutrient losses from native grassland (or pasture) are expected to be lower than losses from cultivated land; the majority of export occurs during spring snowmelt. Nutrients from grassland come from soil, living and dead plant material, animal wastes, and inorganic fertilizer. Export by surface runoff is most likely to come from overgrazed areas, where land is compacted and vegetation cover is sparse. Livestock wintering sites pose an additional risk of nutrient loss to surface water, because frozen compacted soil reduces infiltration (Granger et al. 1984). Generally, the amount of nutrient loss from grassland is dependent on the presence of livestock in a watershed, the proximity of the livestock to the watercourse and the presence of livestock during spring snowmelt and seasonal runoff events (Jawson et al. 1982; Mitchell and Hamilton 1982; Schepers et al. 1982; Gillingham and Thorrold 2000).

Phosphorus losses may be greater on irrigated lands, compared to dryland areas, because of increases in soil-water content, dissolved phosphorus and possibly, particulate phosphorus, depending on irrigation methods and crop management (Sharpley et al. 1999). In a study of an irrigation project in Alberta, dissolved phosphorus and nitrogen were higher in irrigation return flows compared to the supply water (Joseph and Ongley 1986). Newer irrigation systems that reduce runoff volumes, such as sprinkler irrigation, tended to reduce nitrogen losses, compared to furrow irrigation (Ebbert and Kim 1998).

Agricultural land use and management have a significant impact on water quality in Alberta's watersheds. The National Water-Quality Assessment Program (NAWQA) in the United States found that nitrogen and herbicides were more frequently detected and at higher concentrations in agricultural streams compared to urban streams (Hamilton et al. 2004). Seasonal trends in nutrient runoff concentrations into surface water were more apparent, especially after application of manure or fertilizers on the land. Steeply sloped lands, insufficient vegetation and compacted and clay textured soils underlain by poorly drained sediment or bedrock also contributed to higher concentrations of nutrients and pesticides in surface water (U.S. Geological Survey 1999; Migliaccio et al. 2007; Poor and McDonnell 2007). Assessing agricultural impacts in Alberta's agricultural landscapes is essential to achieving an environmentally sustainable industry.

2.0 AESA Soil Quality Monitoring Project[1]

2.1 Introduction

The soil resource is an essential component of agricultural production. Soil provides a medium for plant growth, regulates water supply, recycles wastes, provides habitat for organisms, and supports human infrastructure. Soil supports and sustains crop, range and woodland production and maintains water, air and wildlife habitat (Winder 2003). Soil quality has been defined as the capacity of the soil to function (Karlen et al. 2003), and measurement of soil properties can identify how well the soil is able to perform these functions (Winder 2003).

The Alberta Environmentally Sustainable Agriculture (AESA) Soil Quality Resource Monitoring Project was initiated in 1997 in response to increasing awareness of the impacts of human activity on the soil resource. The AESA monitoring project followed the 1994 to 1997 Canada-Alberta Environmentally Sustainable Agriculture (CAESA) Soil Quality Project that collected baseline data on wind and water erosion, soil salinity, organic matter content, and land use (Wang et al. 1994).

The establishment of benchmark sites throughout the agricultural areas of Alberta in 1997 and 1998 was a significant expansion of the soil monitoring program. The three main objectives of the program were to determine:

1. The state of soil quality across the province of Alberta,
2. The risk of change in soil quality with various management practices, and
3. How soil quality integrates into environmental sustainability.

Information from the benchmark sites was also used as a tool to increase awareness regarding environmental sustainability within Alberta's agricultural industry.

2.2 Methods

Soil Benchmark Site Selection and Characteristics

Soil benchmark sites were selected in 1998 and 1999 using the soil and landscape information for eco-districts provided in the *Agricultural Region of Alberta Soil Inventory Database* (AGRASID 3.0) (CAESA - Soil Inventory Project Working Group 1998) and in the *National Ecological Framework for Canada* (Ecological Stratification Working Group 1995). The benchmark sites were selected to:

- Provide baseline soil information,
- Evaluate landscape effects on soil quality,
- Provide a dataset to test and validate simulation models (i.e., crop growth),
- Monitor changes in soil quality with time on a field landscape basis, and
- Provide data on annual changes in soil fertility and landscape effects (upper, mid and lower slope positions) on soil properties (Cannon 2002).

Forty-two soil benchmark locations were selected within the Boreal Plains and Prairies ecozones, representing seven ecoregions (Figure 2.1). The ecoregions represent zones of similar abiotic/biotic environments, such as rainfall patterns and temperature regimes, soil types and natural vegetation (Ecological Stratification Working Group 1995). The benchmark sites were selected according to the following criteria:

- They represented one-third of the 100 ecodistricts in the agricultural area of Alberta,
- They were distributed geographically across the province,

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[1] *Cathcart et al. 2008a*

- They enabled comparisons by major land use and landscape patterns among other initiatives and databases, and
- They were available for long-term monitoring, with little disruption to farmers during the growing season.

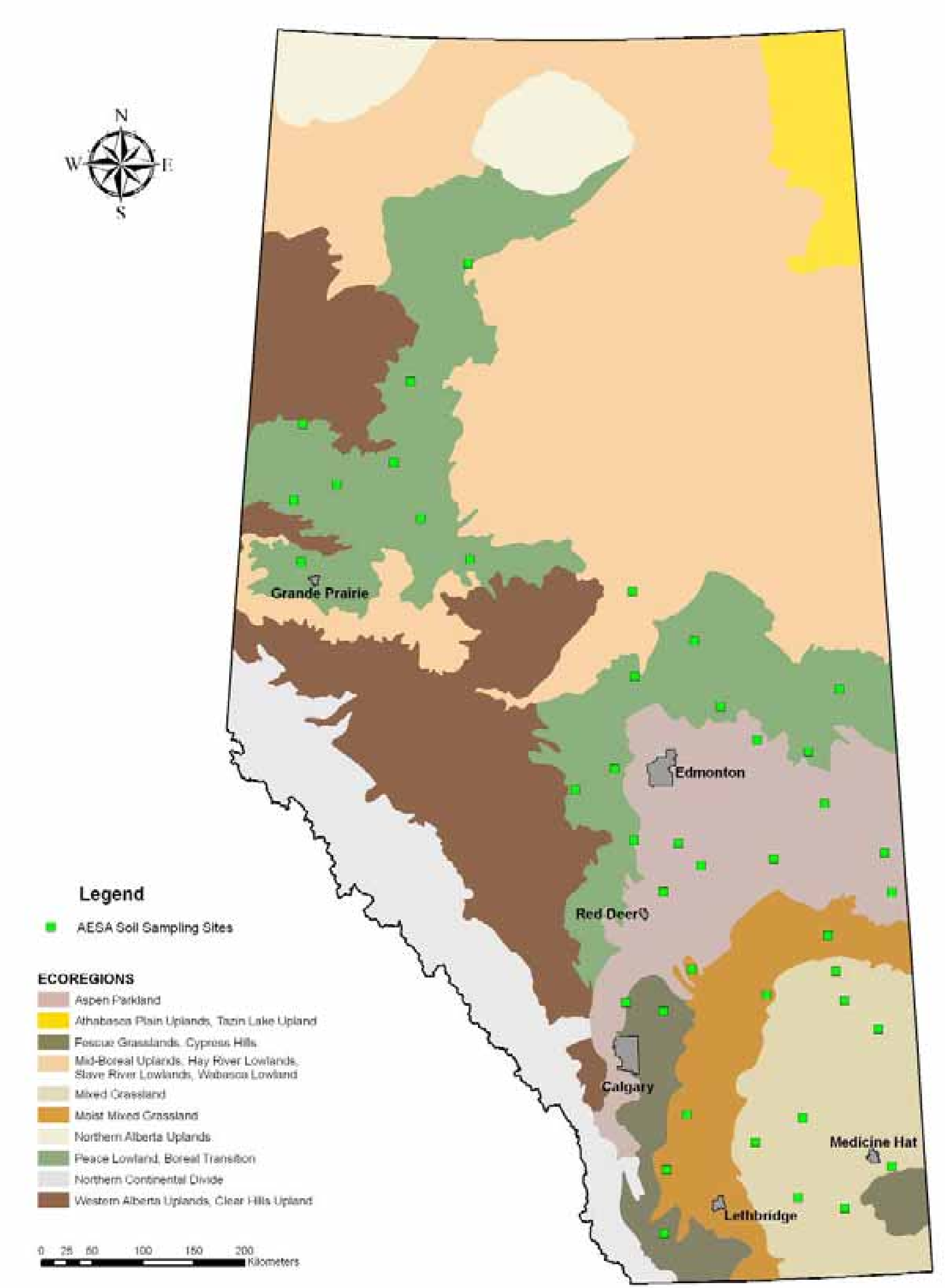

Figure 2.1. AESA Soil Quality Monitoring Program benchmark sites within ecoregions.

Generally, the benchmark sites represent a range of agricultural practices, including annual cultivation, pasture/grass, dryland, and irrigated sites (Table 2.1). The majority of the sites (65%) were developed on morainal parent material and the most common surface landform was undulating. Seventy percent of the benchmark sites had slopes ranging from 0 to 5% (level to very gentle slopes) and nearly all sites had a loamy surface soil texture.

Table 2.1. Prominent features of the 42 soil benchmark sites (adapted from Cannon 2002). The site numbers represent the ecodistricts as described by the Ecological Stratification Working Group (1995).

Ecodistrict Benchmark Site	Farm Area (ha)	Surface Form	Parent Material Texture	Soil Order and Great Group	Land Use
Peace Lowland Ecoregion					
586, 588, 590, 592, 593, 594, 595, 598, 599	2,392,427 (11.40%)[1]	level, nearly level, very gentle slope, gentle slope or moderate slope	clay, silty clay loam, loam, clay loam, loamy sand	Gray/Dark Gray Luvisol and Dark Gray Chernozem	cultivated
Mid Boreal Uplands Ecoregion					
615	215,223 (1.00%)	very gentle slope	clay loam	Gray Luvisol, Gleysol and Brunisol	cultivated
Boreal Transition Ecoregion					
678, 680, 681, 684, 687, 688, 692, 703	3,127,493 (14.80%)	level, nearly level, very gentle slope, gentle slope or undulating	clay, silt, clay loam, silty clay loam, sandy loam, sandy clay loam	Gray Luvisol and Dark Gray Chernozem	cultivated or pasture
Aspen Parkland Ecoregion					
727, 728, 730, 738, 739, 740, 743, 744, 746	5,457,399 (25.90%)	undulating, nearly level, very gentle slope, moderate slope, hummocky or very strong slope	clay loam, silty clay loam, loam or very fine sandy loam	Black Chernozem	cultivated or pasture
Moist Mixed Grassland Ecoregion					
769, 781, 786, 791, 793	2,871,283 (13.60%)	nearly level, very gentle slope, undulating or moderate slope	loam, clay, clay loam or loamy sand	Dark Brown Chernozem and Solonetzic	cultivated
Fescue Grassland Ecoregion					
798, 800	1,391,000 (6.60%)	very gentle slope or nearly level, undulating	loam or clay	Dark Brown Chernozem	cultivated
Mixed Grassland Ecoregion					
804, 806, 809, 812, 815, 823, 828A, 828B	4,012,162 (19.00%)	level, nearly level, very, gentle slope, gentle slope or strong slope	clay loam, sandy clay loam, sandy loam, silt clay loam, or loam	Brunisol, Brown Chernozem and Solonetzic	cultivated or cultivated (irrigated)

[1] Value in parentheses represents the percentage of total farm area of Alberta (i.e., % of 21,067,489 ha). Summing the percent farm area for each ecoregion will not add up to a 100%, as some ecoregions are not included as part of the AESA Soil Quality Monitoring Program (approximately 8% of total farm area).

The benchmark sites were considered representative of the dominant Chernozemic and Luvisolic soils found in the agricultural areas of Alberta (Cathcart et al. 2008b). Of the 42 selected benchmark sites, only two, (sites 586 and 592 in the Peace Lowlands as indicated on Figure 2.1), did not fully reflect their respective ecoregions. Each had a darker coloured A horizon, caused by higher organic matter, compared to the dominant soil. Ninety percent of the sites had a loamy surface texture (characteristic of central and southern Alberta) and the remaining 10% of surface soils were sandy textured. Higher clay contents occur primarily in northwestern Alberta as a result of tills derived from Cretaceous marine shale. Sandy tills occur throughout the area adjacent to the Precambrian shield in eastern Alberta (Pawluk and Bayrock 1969).

***Growing degree days (GDD)** is the annual sum of days where heat is available for plant growth during the growing season. This is used to estimate the growth and development of crops and is based on the assumption that plant growth will only occur if the air temperature exceeds a minimum base temperature (typically 5^0C for cereals) for a minimum number of days.*

Climate

Climate conditions, such as growing degree days (>5ºC), January and July mean daily temperatures and annual precipitation, were calculated for each of the ecoregions in which benchmark sites occurred, based on the 1961 to 1997 climate normals. Generally, the Mixed Grassland and Moist Mixed Grassland ecoregions had the highest July temperatures and greatest number of growing degree days (GDD), but also had the lowest annual precipitation (Table 2.2). In comparison, the Peace Lowland had the fewest GDD and coolest annual temperatures.

Table 2.2. Climate data for the ecoregions with AESA Soil Quality Benchmark Sites.

Ecoregion	Mean Elevation	Climatic Zone	Mean temperature		Mean precipitation	GDD
	(m, ASL)		Jan. (ºC)	July (ºC)	(mm)	(>5 ºC)
Peace Lowland (9 Sites)	536	Sub-humid Low Boreal	-17.2	13.3	435 - 517	1118 -1305
Mid-Boreal Upland (1 Site)	640	Sub-humid Mid-Boreal	-16.4	15.5	508	1225
Boreal Transition (8 Sites)	697	Sub-humid Low Boreal	-15.0	15.9	428 - 535	1287 - 1384
Aspen Parkland (9 Sites)	775	Transitional Grassland	-14.3	16.4	391 - 478	1280 - 1486
Moist Mixed Grassland (5 Sites)	880	Semiarid Grassland	-10.8	17.0	368 - 422	1482 - 1556
Fescue Grassland (2 Sites)	1100	Chinook Belt	-9.5	15.6	427 - 537	1290 - 1362
Mixed Grassland (8 Sites)	795	Semiarid Grassland	-12.8	17.9	314 - 363	1459 - 1774

Field Methods

Soil chemical and physical properties were analysed in the initial soils investigation in 1997, with annual soil fertility analyses conducted from 1998 to 2006. Annual soil sampling was conducted at the same time each year during the fall season, after harvest and prior to fertilization and fall freeze-up.

Soils were sampled at the three landscape positions for each benchmark site, representing upper, middle and lower slope positions. Five to ten soil cores were collected within a radius of 2 m from the central marker at each landscape position. Samples were taken at the 0 to 15 cm and 15 to 30 cm depths. Although several parameters were monitored, only soil cation exchange capacity (CEC), soil bulk density, soil organic carbon, and nitrogen and phosphorus as indicators of soil fertility are highlighted here. For the complete report, refer to Cathcart et al. (2008a).

Weather data were collected from the weather stations most appropriate for each benchmark site. Rain gauges were also provided to landowners, to voluntarily obtain more accurate data on precipitation during the growing season (i.e., April to the end of September). Landowners were asked to make note of events such as frost or hail, and were asked to provide information about past and current cropping histories and agronomic practices, including crop rotations and crop cultivars, fertilizer applications, tillage systems, herbicide applications, harvest methods, crop yields, and dates of field operations. Statistics were used to compare soil quality properties among ecoregions, years, soil depths, landscape positions, sampling sites and crop type.

2.3 Results

Soil Quality

Results from the initial investigation of the 42 soil benchmark sites showed great variability among the sites. Observed differences occurred mainly in the A horizon and were the result of farm management practices. Sand and clay contents differed across the province in the A and B horizons, with sand higher in the south and central regions of Alberta and clay higher in the Peace Lowland region. Differences associated with landscape were essentially confined to the A horizon, which is highly influenced by soil erosion caused by wind and water. Generally, upper landscape positions were characterized by coarser soil textures (i.e., sand) and lower landscape positions by finer textures (i.e., silts and clay).

Cation exchange capacity (CEC) followed a pattern similar to soil texture, with higher values observed in areas having high clay contents. The CEC did not vary in response to landscape position.

***Cation Exchange Capacity** is the capacity of a soil to exchange positively charged ions (cations) between the soil and soil solution. It is used as a measure of fertility, nutrient retention capacity, and the capacity to protect surface and groundwater from contamination. The CEC is determined by the amount of clay and/or humus that is present, as these properties improve the nutrient and water holding capacity of the soil. Sandy soils with very little organic matter have a low CEC, but heavy clay soils with high concentrations of organic matter have a much greater capacity to hold cations. A high CEC is advantageous as the soil can bind cations (such as nutrients) and immobilize them before they reach surface or groundwater.*

Differences in electrical conductivity (EC) varied throughout the province, from 0.34 to 0.68 deciSiemens per metre (dS/m), particularly in areas with high salinity and/or Solonetzic soils. However, all EC measurements were within acceptable concentrations for crop production.

Similar to EC, pH values (the measure of the acidity or alkalinity of a solution or the concentration of hydrogen ions) were found within the acceptable range for crop production in Alberta (ranging from 6.2 to 7.2). The pH measured in soils in the Mixed Grassland was higher compared to other ecoregions. This was attributed to low annual precipitation, which reduces leaching potential of carbonates from the surface soil layer. The Mixed Grassland also has a shallower soil profile and is thus closer to calcareous bedrock materials.

Bulk density ranged from 1.18 to 1.36 g/cm^3 during the study period (1998 to 2006). Generally, bulk density was greatest during years of low precipitation (1999 through 2002), and lowest in wetter years (from 2003 through 2006). High bulk density levels in 2002 reflected that year's province-wide drought, which limited root growth and crop productivity. The 2003 growing season was unusually long, resulting from above normal temperatures and precipitation in the late summer/early fall (Figure 2.2).

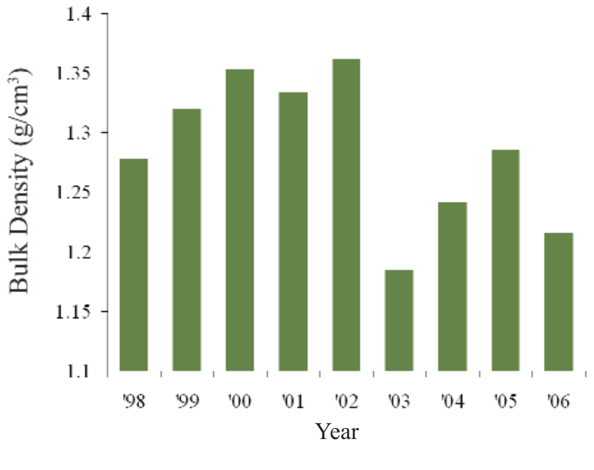

Figure 2.2. Variation in bulk density by year, 1998 to 2006 (provincial averages).

Soil Bulk Density *is defined as the weight of soil particles divided by the volume they occupy, measured as grams per cubic centimetre. The volume includes the space between particles and the space inside the pores of individual particles. Bulk density is important in calculating soil moisture movement within a soil profile. High soil bulk densities suggest the soils are compacted, which results in reduced water infiltration and increased runoff volumes.*

Soil bulk densities also varied among landscape slope positions (i.e., lower, middle and upper). Generally, soil bulk densities were lower at the lowest slope position, in the 0 to 15 cm horizon, compared to the mid or upper slope positions, corresponding to higher soil organic carbon concentrations (Figure 2.3).

Differences in bulk density among landscape position likely resulted from the differences in soil texture (and crop productivity). Soil texture often varies across slopes as the process of wind and water erosion moves topsoil from upper slope positions to the lower slope position, exposing more compact subsoil layers in the upper position. This expected pattern (i.e., higher bulk density in the upper landscape position) was observed in the Aspen Parkland, Boreal Transition and Mixed Grassland ecoregions, but was not observed in the Fescue Grassland, Mixed Moist Grassland or Peace Lowland ecoregions (Figure 2.3). The variation in the two study sites in the Fescue Grassland and the gentle slope of the Peace Lowland likely reduced the effect of landscape position on soil bulk density in these ecoregions.

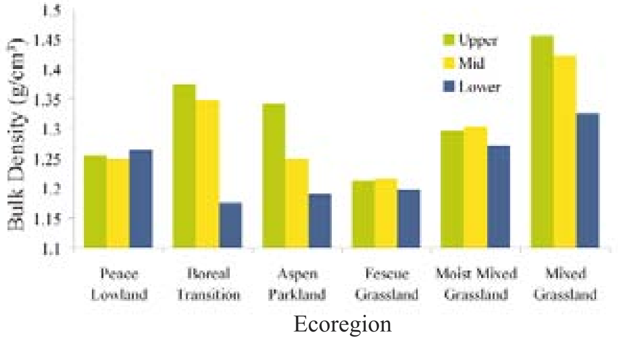

Figure 2.3. Soil bulk density at three landscape positions in each ecoregion.

Soil organic carbon, derived from decaying plant material, was significantly greater in northern Alberta compared to the south. A comparison among the ecoregions showed soil organic carbon was generally similar, although somewhat lower, in the dry Mixed Grassland (Figure 2.4). Organic carbon concentrations were lower in the upper and mid slope positions of the 0 to 15 cm horizon (24 and 26 g/kg, respectively). This is likely a result of erosion, drier soil conditions and poorer crop growth that results in a reduction of organic residues.

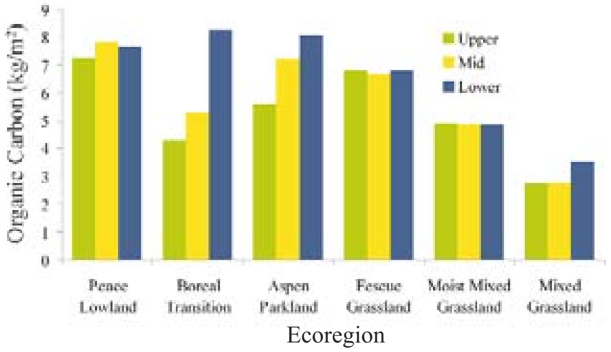

Figure 2.4. Soil organic carbon concentrations at three landscape positions in each ecoregion.

Mean soil organic carbon measurements at the benchmark sites were similar to organic carbon in native soils for each respective ecoregion, with the exception of the Aspen Parkland and Fescue Grassland, where organic carbon was lower (Table 2.3). These differences may be due, in part, to the difference in the number of sites sampled in each program (e.g., nine sites were sampled from native soils and 210 sites were sampled at benchmark locations in the Aspen Parkland to derive mean soil organic carbon).

Table 2.3. Comparison of organic carbon content of native soils and benchmark site soils in six ecoregions across Alberta.

Ecoregion	Soil profile	Sampling depth (cm)	Mean soil organic carbon (kg/m²)	Minimum soil organic carbon (kg/m²)	Maximum soil organic carbon (kg/m²)
Aspen Parkland	Native (n=9)[1]	18	10.1	8.4	12.0
	Benchmark sites (n=210)	15	6.8	1.8	13.2
Boreal Transition	Native (n=8)	16	5.9	1.0	9.9
	Benchmark sites (n=193)	15	6.0	1.4	18.1
Fescue Grassland	Native (n=2)	17	11.6	8.6	14.6
	Benchmark sites (n=54)	15	6.7	2.7	9.0
Mixed Grassland	Native (n=8)	13	2.5	1.2	3.4
	Benchmark sites (n=184)	15	3.0	1.5	5.6
Moist Mixed Grassland	Native (n=5)	14	4.6	2.8	6.7
	Benchmark sites (n=126)	15	4.9	2.2	8.1
Peace Lowland	Native (n=8)	14	6.3	3.4	11.0
	Benchmark sites (n=211)	15	7.5	3.1	14.2

[1] n=number of sites from where soils were sampled

Soil test phosphorus (STP) concentrations across the province ranged from 16.7 to 25.8 mg/kg in the 0 to 15 cm depth, and were half that concentration (8.6 to 13.0 mg/kg) in the 15 to 30 cm depth, indicating STP buildup in the surface soils. Most fields were managed using reduced tillage practices; therefore, STP tended to remain in the upper soil layer due to low water solubility, low mobility and continued fertilizer application. The range of STP values observed at the 0 to 15 cm layer was similar to the 12 to 24 mg/kg range reported by Kryzanowski (1993) for 48 stubble fields in Alberta. The findings of the current study and that of Kryzanowski (1993) also supported the conclusion of Manunta et al. (2000) that most soils in Alberta are deficient (<7.5 to 12.5 mg/kg) or marginal (12.5 to 25 mg/kg) in STP.

Fertility *refers to the nutrients in the soil that support plant life. Fertile soil has sufficient nutrients for basic plant nutrition. In this study, soil fertility, as indicated by soil test phosphorus (STP) and soil nitrogen (NO_3-N), were compared among ecoregions and among years.*

Phosphorus Availability

The availability of soil test phosphorus (STP) is influenced by soil pH, with STP becoming less available to plants at extremes of the pH scale. Since pH ranged from 6 to 7 in the current study, we can assume that STP availability was not limited.

STP concentrations observed in this study were approximately half of the recommended agronomic limit of 60 mg/kg necessary to achieve optimum yields of wheat, barley, canola and peas (Howard 2006). Initially, benchmark sites were selected to avoid manured fields, although a few landowners reported the occasional application of manure during the course of the study (Cathcart et al. 2008b). Thus, the reported STP concentrations at the benchmark sites were much lower in comparison to fields that have a history of heavy manure application. Hao et al. (2008) reported STP concentrations of 877 mg/kg in their study of long-term cattle manure applications in southern Alberta. The authors concluded that repeated application of manure in excess of crop needs leads to a large accumulation of STP in the soil, which threatens surface and groundwater quality.

Soil test phosphorus tended to increase during the nine-year study (Figure 2.5), which may indicate increased fertilizer use consistent with the observed increase in provincial fertilizer sales (Alberta Agriculture and Food 2006). Soil test phosphorus concentrations were highest in 2002 and 2004, which were both comparatively dry years.

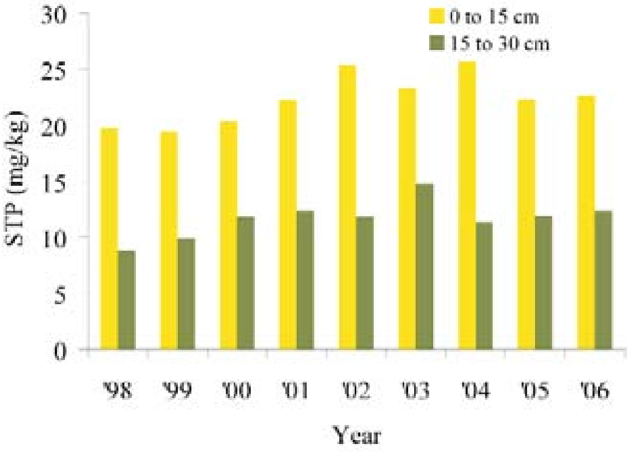

Figure 2.5. STP in the 0 to 15 cm and 15 to 30 cm sampling depths from 1998 to 2006 (provincial averages).

Soil test phosphorus also tended to accumulate in the lower landscape position within all ecoregions except the Moist Mixed Grassland (Figure 2.6). Soil erosion was likely the main transport mechanism that carried soil-bound phosphorus from the upper slope position down slope. The accumulation of phosphorus at the bottom of the slope was most pronounced in the Aspen Parkland, Boreal Transition and Mixed Grassland ecoregions, all of which contained the steepest slopes.

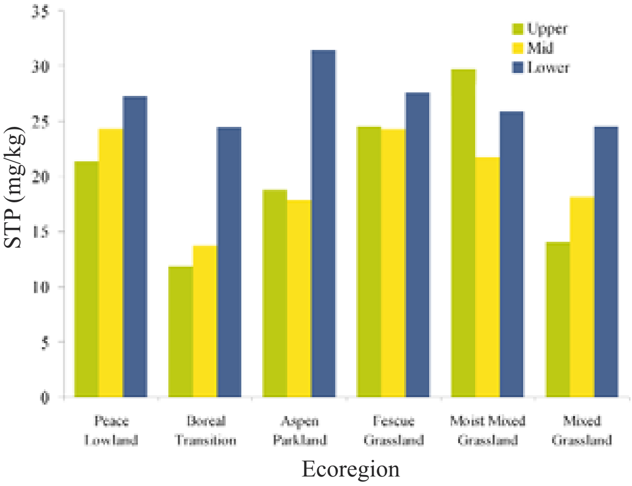

Figure 2.6. STP at three landscape positions in each ecoregion.

Overall, soil nitrate-nitrogen (NO_3-N) concentrations following crop harvest were influenced by sample depth, ecoregion and landscape position in the fall. As expected, NO_3-N concentrations across ecoregions tended to be higher at the 0 to 15 cm sampling depth (6.6 to 13.3 mg/kg) (Figure 2.7) than at the 15 to 30 cm depth (4.4 to 9.0 mg/kg). Higher NO_3-N concentrations at the 0 to 15 cm sampling depth are typical of increased mineralization, common to upper soil horizons. Upper horizons may be warmer, better aerated and have higher levels of biological activity relative to lower soil horizons.

Residual NO_3-N concentrations were generally similar across different years; however NO_3-N concentrations were significantly lower in 2005 compared to 2002 and 2003 (Figure 2.7). Higher NO_3-N soil concentrations in 2002 may have been due to reduced crop uptake under the drought conditions experienced that year, while higher concentrations in 2003 could have been due to increased crop productivity in terms of crop residue production and increased mineralization due to the long, warm fall season experienced in 2003. Lower concentrations in 2005 may have been caused by the wetter growing season that increased leaching of NO_3-N from the soil. Analysis revealed no significant change in soil NO_3-N concentration at the provincial level during the nine-year study.

Nitrogen

Nitrogen is essential for plant growth and is available to plants in the form of nitrate (NO_3-N) and ammonium (NH_4-N). Nitrate is most at risk of loss from the system, due to its high mobility, particularly in water (Brady 1990). Nitrogen availability is also highly dependent on biotic factors/biological systems. Optimum conditions under which biota operate are highly linked to other soil parameters, such as soil pH, moisture, temperature and soil aeration. Extremes in any of these factors lead to decreased availability of nitrogen resulting in reduced crop growth and productivity (Brady 1990; Marschner 1995; Potash and Phosphate Institute (PPI) 2003).

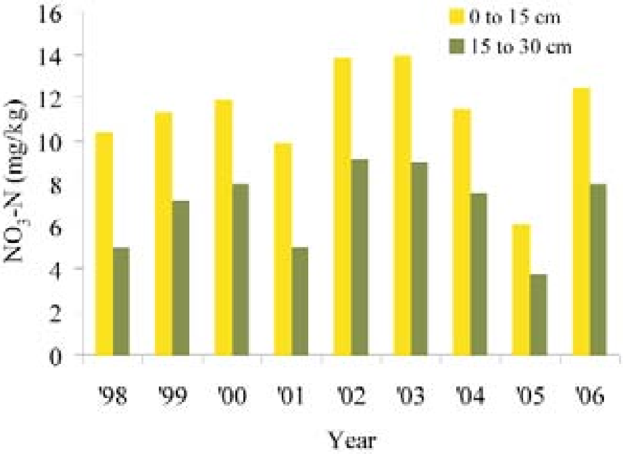

Figure 2.7. Nitrate-nitrogen in the 0 to 15 cm and 15 to 30 cm sampling depths from 1998 to 2006 (provincial averages).

Overall, the lower landscape positions tended to be higher in NO_3-N (12.5 mg/kg at 0 to 15 cm, 7.8 mg/kg at 15 to 30 cm) than the upper position (9.6 mg/kg at 0 to 15 cm, 6.0 mg/kg at 15 to 30 cm) (Figure 2.8). This is similar to what was observed by Penney (2004). Exceptions were seen in the Aspen Parkland and Mixed Grassland at the 0 to 15 cm depth and in the Aspen Parkland in the 15 to 30 cm depth (data not shown). Though not significantly different from other ecoregions, it is interesting to note that NO_3-N concentrations were generally lower in the Boreal Transition (Figure 2.8), which may be due to a higher concentration of forage crops and, depending on species, less fertilizer application since these crops are often capable of fixing their own atmospheric nitrogen (i.e, alfalfa forages). In fields seeded to annual cereal and oilseed crops, nitrogen may undergo mineralization after the crop is harvested, leading to higher NO_3-N levels at the time of sampling in the fall.

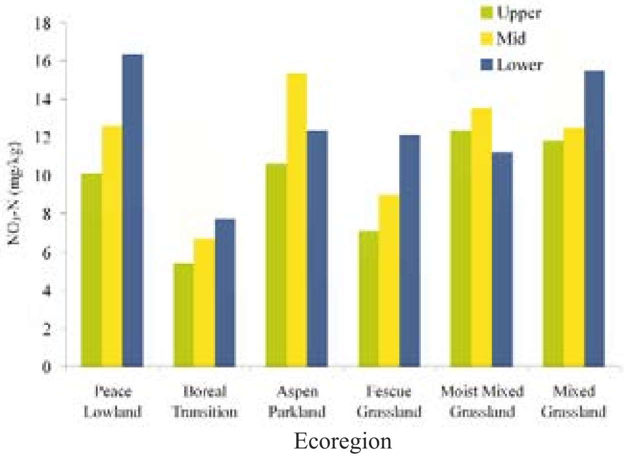

Figure 2.8. Nitrate-nitrogen at three landscape positions in each ecoregion.

2.4 The Role of Field Management on Soil Quality Parameters

Although field management practices were not analysed as part of this report, research has been conducted that may explain some of the observed relationships. Analyses performed on the 1998 to 2005 agronomic data revealed that management practices on participating farms tended to be driven by soil characteristics, highlighting the importance of the soil resource in annual production systems in Alberta (Watson et al. 2007).

Analysis indicated that production practices differed among ecoregions, but were often related to soil characteristics (e.g., fertility level). More fertilizer is applied on farms in the Aspen Parkland and Peace Lowland, as the soils in these ecoregions tended to have high fertility requirements. In the Peace Lowland, there was also a tendency for late spring fertilizer application dates, likely due to the relatively cool, wet climate in the Peace Region of Alberta. In the Boreal Transition, farms tended to have greater application rates of sulphate (SO_4-S) and potassium (K), and greater overall fall fertilizer applications. Deeper seeding depths, an increased use of specialty crops (e.g., sugar beets and corn) and the use of wheat-fallow rotation sequences were all characteristics of the drier Mixed Grassland ecoregion. Although limited in the number of observations, the Foothills Grassland tended toward farms that required and received an increased application rate of phosphorus, and generally later fall fertilizer applications. Interestingly, the Moist Mixed Grassland was not distinguished by any agronomic practices relative to the other ecoregions in the study (Watson et al. 2007).

Watson et al. (2007) identified yearly differences in farm production practices, specifically between 1998, 2000, 2002, 2003, and 2004, with 2002 being markedly different from all other years in the study. This supports the previous discussions on the importance of climatic variability and its affect on soil parameters, as 2002 was the driest year of the study period (1998 to 2005).

Production practices, such as seeding date and total fertilizer applied to the fields were associated with the year 2002, indicating that producer behaviour changed in response to drought conditions. Other associations were made between year and farming practices, including differences in the timing of tillage operations (i.e., spring or fall) in 1998 and 2001, and late fall crop harvests in 2003 and 2004, supporting the long wet fall observed in 2003.

2.5 Key Findings

Research on the AESA Soil Quality Benchmark Sites assembled an extensive database which includes soils data from three landscape positions within the main agricultural ecoregions of Alberta (42 sites). This information establishes a baseline that characterizes the current state of soil quality throughout Alberta's agricultural landscape and makes it possible to document future changes from that state.

Soil quality in Alberta remained relatively constant under production practices during the 9-year study. Provincially, only soil bulk density and STP concentration showed significant trends with time. Bulk density appears to have decreased with time, reflecting reduced tillage and the increased use of forages in rotation. Although soil test phosphorus appears to have increased during the study period, it remained well below the agronomic threshold of 60 mg/kg (120 kg/ha) at the non-manured benchmark locations.

3.0 AESA Surface Water Quality Monitoring Project[2]

3.1 Introduction

A safe supply of good quality water for all Albertans is essential. For Alberta's agricultural producers, clean water helps produce food and other products efficiently, maintains the industry's reputation in the marketplace for producing safe, high quality food in a clean environment and contributes to a healthy environment for farm families, communities and wildlife (Alberta Agriculture and Food 2006).

The first comprehensive study documenting water quality in Alberta's agricultural areas was conducted under the Canada-Alberta Environmentally Sustainable Agriculture (CAESA) Agreement in 1995. This study compared the water quality of streams in agricultural watersheds having low, moderate and high agricultural intensity (Anderson et al. 1998a). The general conclusion was that higher nutrient levels and more frequent pesticide detections were found in streams that drained higher agricultural intensity watersheds (Anderson et al. 1998a, b). Water quality concerns in Alberta's agricultural areas have continued to grow following the initial study. Under the 1997 Alberta Environmentally Sustainable Agreement (AESA), a strong commitment was made to continue to monitor water quality in small agricultural watersheds. The goals of the AESA Water Quality Monitoring Program were:

- To learn more about how stream water quality is impacted by low, moderate and high intensity agriculture in Alberta;
- To track changes in water quality as the industry grows and agricultural management practices change; and
- To identify water quality trends in watersheds of various agricultural intensities and how they are influenced by the rate of movement of nutrients and other chemicals from land to water.

3.2 Methods

Watershed Selection

From 1999 through 2006, the AESA Water Quality Monitoring Project monitored water quality in 23 small watersheds across Alberta, including a subset of 15 streams that were sampled under the previous CAESA Agreement (Depoe 2006). The watersheds were selected to meet the following four criteria:

1. A minimum drainage area of 50 km^2, a maximum drainage area of 1500 km^2 and the presence of a streamflow gauging station.
2. No major urban or industrial developments within the watershed boundary.
3. The watersheds covered the typical range of agricultural intensity for the province as a whole and for individual ecoregions.
4. The streams had well developed natural drainage (Type I landscapes) and a high runoff potential. Dryland and irrigation watersheds were selected to reflect natural and agricultural characteristics within Alberta. Irrigation watersheds were differentiated from dryland watersheds due to their unique basin characteristics.

Regional climate was also considered in the site selection process (Anderson et al. 1999).

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[2] *Lorenz et al. 2008*

Defining Agricultural Intensity and Runoff Potential

The identification of agricultural intensity on a provincial scale was conducted to provide an estimate of the degree to which agriculture may affect nutrient levels in surface and groundwater.

The Agricultural Intensity Index was used to define the 23 AESA watersheds as low, moderate or high intensity agricultural areas (Figure 3.1). This Index combined fertilizer and chemical expenses and manure production information to determine ratings since these parameters are linked to the presence of agricultural contaminants in surface water (Anderson et al. 1998 a, b; Johnson and Kirtz 1998; Anderson et al. 1999; Statistics Canada 1996) (Table 3.1). Livestock production is an important factor in the index as it may contribute to nutrient loading, pathogens and odour (Alberta Agriculture, Food and Rural Development 2005).

In addition to the provincial Agricultural Intensity Index, the potential for runoff based on landform and soil characteristics was used to identify further risk to surface water by overland runoff. Potential for surface runoff based on landform characteristics were classified using the following criteria:

- Landforms with well-developed natural drainage, having a high potential to deliver runoff to streams (Type I).
- Landforms with closed, poorly developed natural drainage (knob and kettle, potholes) that can trap runoff and have a low potential to deliver runoff (Type II).
- Landforms that are flat to low undulating, with poorly drained landscape, but fine-textured soils. Likely to be artificially drained (e.g., tile drained) (Type III).
- Watersheds that have more than one of the above characteristics were considered mixed.

Potential for surface runoff based on soil characteristics were divided into three types:

- **High potential for runoff** - soils with restrictive layers and soils with shallow Ah or Ap horizons and fine soil textures such as silt or clay loam. Ah defines a surface soil horizon that originates from enrichment by organic matter; Ap defines a surface horizon where organic matter has accumulated and then been disturbed by clearing and cultivation.
- **Moderate potential for runoff** - soils with a moderately deep Ah or Ap horizon and a moderately fine soil texture (loam, silt loam, fine sandy loam).
- **Low potential for runoff** - soils with a deep Ah or Ap horizon and moderate to coarse soil texture (loam, silt loams and sands).

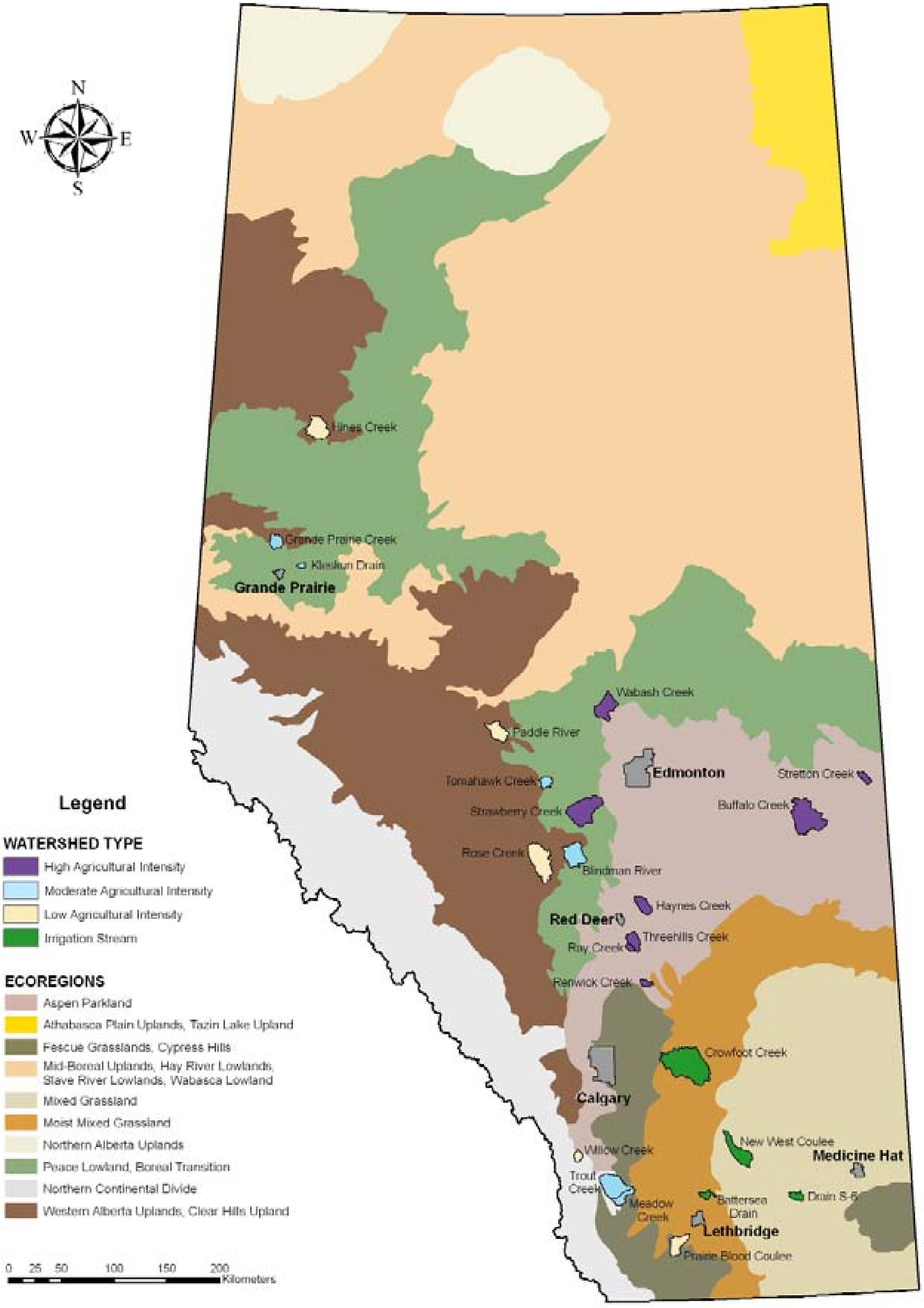


Figure 3.1. Map of 23 AESA watersheds selected on the basis of ecoregion and agricultural intensity.

Table 3.1. Summary of characteristics for the 23 AESA watersheds selected for the water quality monitoring project.

Stream Name	Ecoregion	Agricultural Inputs			Runoff Potential		Agricultural Intensity Rating
		Total Manure Production (tonnes/hectare)[1]	Total Fertilizer Expense ($/hectare)[1]	Total Chemical Expense ($/hectare)[1]	Landform	Soil	
Hines Creek (HIN)	Clear Hills Upland	0.10	$47.77	$23.48	Type I	mixed	low
Paddle River (PAD)	Western Alberta Upland	1.42	$3.46	$0.91	Type I	high	low
Rose Creek (ROS)	Western Alberta Upland	1.73	$3.06	$0.62	Mixed	mixed	low
Grande Prairie Creek (GRA)	Peace Lowland	0.84	$17.35	$8.38	Type I	high	moderate
Kleskun Drain (KLE)	Peace Lowland	1.69	$32.05	$16.01	Type I	high	moderate
Blindman River (BLI)	Boreal Transition	4.16	$9.04	$2.22	Mixed	high	moderate
Tomahawk Creek (TOM)	Boreal Transition	3.01	$7.46	$1.85	Type II	high	moderate
Strawberry Creek (STW)	Boreal Transition	3.05	$19.45	$7.56	Type I	high	high
Wabash Creek (WAB)	Boreal Transition	4.21	$37.21	$19.18	Type I	mixed	high
Stretton Creek (STT)	Aspen Parkland	2.86	$31.95	$18.58	Type I	low	high
Buffalo Creek (BUF)	Aspen Parkland	1.90	$31.88	$16.31	Type II	low	high
Haynes Creek (HM6)	Aspen Parkland	4.24	$44.38	$20.06	Mixed	moderate	high
Ray Creek (RAY)	Aspen Parkland	4.82	$47.77	$23.48	Type I	moderate	high
Threehills Creek (THR)	Aspen Parkland	3.63	$47.62	$22.56	Type II	moderate	high
Renwick Creek (REN)	Aspen Parkland	2.76	$61.33	$28.17	Type I	mixed	high
Prairie Blood Coulee (PRA)	Fescue Grassland	0.51	$9.44	$2.08	Type I	high	low
Trout Creek (TRO)	Fescue Grassland	2.88	$4.10	$0.89	Type I	high	moderate
Meadow Creek (MEA)	Fescue Grassland	3.18	$7.98	$2.03	Type I	high	moderate
Battersea Drain (BAT)	Moist Mixed Grassland	10.75	$37.51	$16.33	Type I	moderate	high (irrigation)
Crowfoot Creek (CRO)	Moist Mixed Grassland	1.49	$28.91	$17.96	Type I	high	high (irrigation)
Drain S-6 (DS6)	Mixed Grassland	2.99	$59.23	$33.48	Type I	high	high (irrigation)
New West Coulee (NEW)	Mixed Grassland	2.07	$26.39	$14.33	Type I	high	high (irrigation)
Willow Creek (WIL)	Northern Continental Divide	0.25	$0.37	$0.10	Mixed	moderate	low

[1] Based on 1996 Census Data, Statistics Canada 1996

Field Methods

Water sampling was based on the standard AESA Stream Survey sampling protocol (Depoe and Fountain 2003). Water samples were collected near the middle of the stream, upstream of any local disturbances and near a stream gauging station which was used to determine the discharge (water volume) at the time of sampling. Nutrient and bacteria samples were collected twice each week during runoff periods, once each week as runoff subsided, then biweekly and monthly as stream flow returned to baseflow conditions. Pesticide samples were collected once each week during peak runoff, then once biweekly to once monthly, as stream flow decreased. In all 23 watersheds, stream water quality was tested for nutrients, bacteria, other measurements related to inorganic chemistry, and pesticides (Table 3.2) (Depoe 2006).

Table 3.2. Water quality parameters measured in the 23 selected streams from 1999 to 2006[1].

Parameter	Description
Nutrients	Phosphorus: Total Phosphorus (TP), Total Dissolved Phosphorus (TDP), Total Particulate Phosphorus (TPP) (calculated) Nitrogen: Total Kjeldähl Nitrogen (TKN), Nitrite plus Nitrate Nitrogen ($NO_2 + NO_3$-N), Nitrite (NO_2-N), Ammonia Nitrogen (NH_3-N) (detects both NH_4^+ and NH_3 forms of N), Total Nitrogen (TN) (calculated), organic nitrogen (Org N) (calculated)
Bacteria	*Escherichia coli*, Fecal Coliforms
Other	Suspended Solids (Non-filterable residue), Total Dissolved Solids, pH, Temperature, Conductivity
Herbicides	2,4-D, 2,4-DB, Atrazine, Bentazon, Bromacil, Bromoxynil, Clodinafop-Propargyl, Clopyralid, Cyanazine, Dicamba, Dichlorprop, Diclofop-Methyl, Diuron, Ethalfluralin, Ethofumesate, Fenoxaprop-P-Ethyl, Fluazifop, Fluroxypyr, Imazamethabenz-Methyl, Imazamox, Imazethapyr, Linuron, MCPA, MCPB, MCPP, Metolachlor, Metribuzin, Picloram, Quinclorac, Quizlofop, Simazine, Triallate, Triclopyr, Trifluralin, Napropamide **Degradation By-products**: 2,4-Dichlorophenol, 4-Chlor-2-Methylphenol, Clodinafop-Acid Metabolite, Desethylatrazine, Desisopropylatrazine
Insecticides	Aldrin, Chlorpyrifos-ethyl, Diazinon, Dieldrin, Dimethoate (Cygon), Disulfoton (Di-syston), Ethion, Gamma-Benzenehexachloride, Guthion, Malathion, Methoxychlor, Parathion, Phorate, Pyridaben, Terbufos, Aldicarb, Methomyl, Thiamethoxam **Degradation By-products:** Alpha-Benzenhexachloride, Alpha-endosulfan
Fungicides	Carbathiin (Carboxin), Chlorothalonil, Iprodione, Metalxyl-M, Propiconazole, Hexaconazole, Oxycarboxin, Vinclozolin

[1] Not all pesticide active ingredients were measured annually. More parameters were added as the project proceeded.

3.3 Results and Discussion

Phosphorus

Median annual total phosphorus (TP) flow-weighted mean concentrations ranged from 0.04 to 0.88 mg/L in the AESA watersheds during the eight- year study. Generally, phosphorus concentrations increased as the agricultural intensity in the dryland watersheds increased from low to high (Figure 3.2).

Streams draining high agricultural intensity areas tended to have a higher proportion of phosphorus in the dissolved form (Figure 3.2). Dissolved forms of phosphorus are free ions that are readily available for use by algae, aquatic plants and micro-organisms. Nuisance algal growth can cause taste and odour problems in drinking water, reduce recreation enjoyment, and impact aquatic life.

Streams in irrigated watersheds contained similar concentrations of phosphorus compared to the low agricultural intensity watersheds. However, the proportion of dissolved phosphorus was greater in the irrigation streams, similar to proportions measured in higher intensity agricultural watersheds (Figure 3.2).

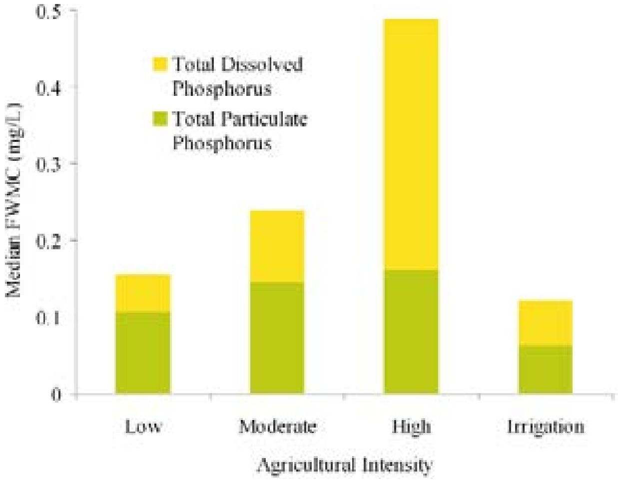


Figure 3.2. Median total phosphorus (TP) concentrations for all streams from 1999 to 2006 by agricultural intensity.

Flow-Weighted Mean Concentrations
Results of the water quality monitoring study are reported in terms of flow-weighted mean concentrations (FWMC) for nutrients (phosphorus and nitrogen).

FWMCs are calculated by dividing the total mass or load of a measured parameter by the total flow for a given time period (e.g., a year). This standardized measure allows for comparisons among different sized streams with varying flow regimes.

Forms of Phosphorus
Phosphorus in the environment is found in particulate and dissolved forms. Particulate forms are generally attached to soil particles, minerals or organic matter such as plant or animal materials. Dissolved forms are free ions that are readily available for use by algae, aquatic plants and micro-organisms. The total amount of phosphorus (TP) is considered the sum of both forms.

Total phosphorus instream concentrations were compared to Alberta's Surface Water Quality Guidelines (ASWQG) to determine the number of samples that met the guideline for the protection of aquatic life (less than 0.05 mg/L TP; AENV 1999).

From 1999 through 2006, the average concentration of total phosphorus in streams sampled in all agricultural intensity and irrigation watersheds met water quality guidelines less than 60% of the time (Figure 3.3). Total phosphorus concentrations in streams located in the high agricultural intensity watersheds almost always exceeded the guideline, with percent compliance only ranging from 1 to 11%. As a comparison, streams in low agricultural intensity watersheds were compliant 41 to 58% of the time. The irrigation streams had the largest range of sample compliance, ranging from 18 to 60%.

These findings suggest that as agricultural intensity increases, phosphorus concentrations tend to increase above acceptable guidelines. This may be due to greater manure production in higher intensity watersheds compared to lower intensity watersheds as shown in Table 3.0. On the other hand, watersheds described as irrigated tended to have a high compliance rate, similar to low intensity agricultural watersheds in dry years and similar to moderate intensity watersheds in wet years (Figure 3.3). Irrigated watersheds are all located in southern Alberta, where precipitation tends to be lower. Also, source water for irrigation is generally of good quality and may contribute to a dilution effect.

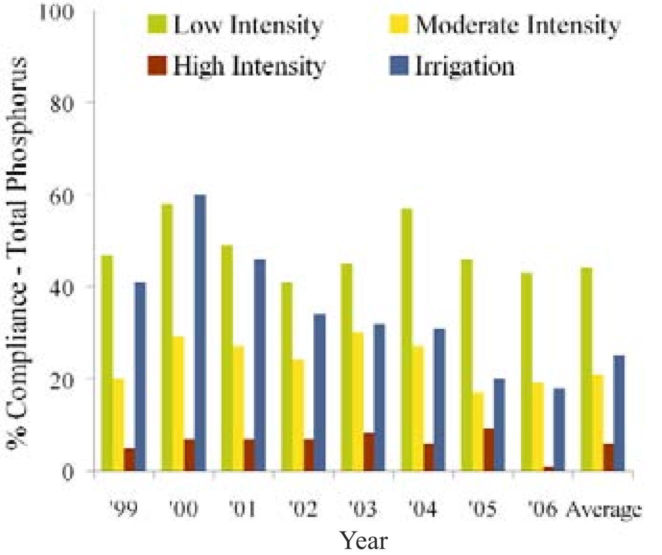


Figure 3.3. Percent sample compliance by year based on the ASWQG for the Protection of Aquatic Life (0.05 mg/L) for total phosphorus from 1999 to 2006.

Phosphorus concentrations in streams tended to vary according to season and precipitation events. Generally, water quality was poor in the springtime as snowmelt runoff carried excess nutrients to streams. Similarly, rainfall events throughout the growing season can mobilize dissolved and particulate forms of phosphorus, depending on the severity of the event. This trend can be seen in Figure 3.3, where sample compliance was greatest in the drier years (2000 to 2004) compared to years of higher precipitation (2005 to 2006). This trend is more apparent in low and moderate agricultural intensity watersheds and irrigated watersheds, compared to high agricultural intensity watersheds. The latter consistently exceeded water quality guidelines for the protection of aquatic life.

Nitrogen

During the eight-year study, median annual total nitrogen (TN) flow-weighted mean concentrations ranged from 0.28 to 5.07 mg/L in the 23 AESA watersheds. Similar to phosphorus, higher concentrations of nitrogen were observed in streams draining higher intensity agricultural watersheds (Figure 3.4).

Most of the nitrogen measured in the 23 streams was in the particulate, organic form, rather than in the dissolved form (Figure 3.4). In low intensity agricultural watersheds, 20 times higher particulate organic nitrogen was observed compared to dissolved inorganic nitrogen (NO_2+NO_3-N+NH_3-N). As agricultural intensity increased, higher concentrations of dissolved inorganic nitrogen were observed. Irrigated watersheds experienced the highest concentrations of dissolved inorganic nitrogen compared to particulate organic nitrogen. Studies have shown that dissolved forms of nitrogen tend to leach more through glacial till on irrigated land compared to non-irrigated land (Rodvang et al. 2004), reaching surface water through groundwater. This was observed in early spring, when nitrogen concentrations in irrigation streams tend to be high prior to irrigation, reflecting high baseflow concentrations contributed by groundwater.

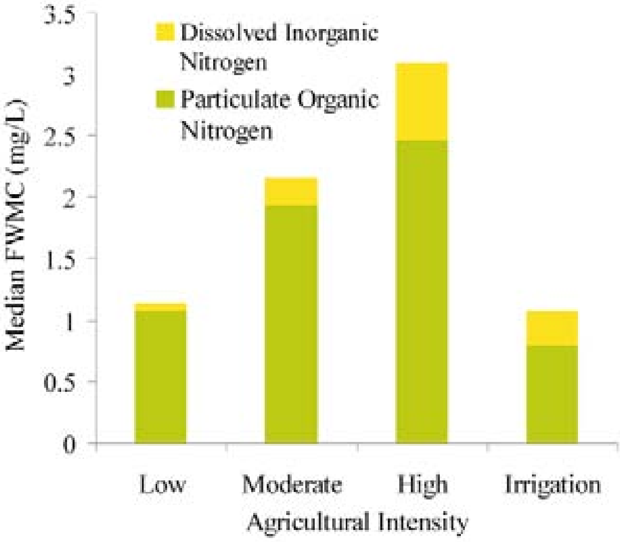
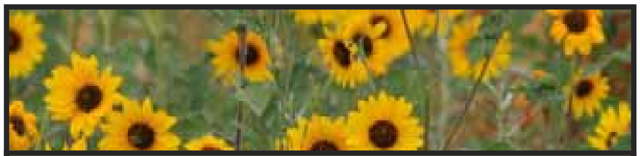


Figure 3.4. Median organic nitrogen and dissolved inorganic nitrogen (NO_2-N + NO_3-N+NH_3-N) concentrations for all streams from 1999 to 2006 by agricultural intensity.



Forms of Nitrogen

The main source of nitrogen in soils is from organic matter developed from plant and animal residues. Organic forms of nitrogen are not readily available to plants. Bacteria found in soils convert organic forms of nitrogen into dissolved inorganic forms such as nitrite-nitrogen, nitrate-nitrogen and ammonia-nitrogen (NH_3*-N) that plants can use. Organic nitrogen plus inorganic nitrogen equals total nitrogen (TN).*

Total nitrogen instream concentrations were also compared to the ASWQG to determine the number of samples that met the guideline for the protection of aquatic life (1.0 mg/L TN; AENV 1999).

From 1999 through 2006, streams located in high agricultural intensity watersheds were least likely to meet the total nitrogen water quality guideline, meeting the

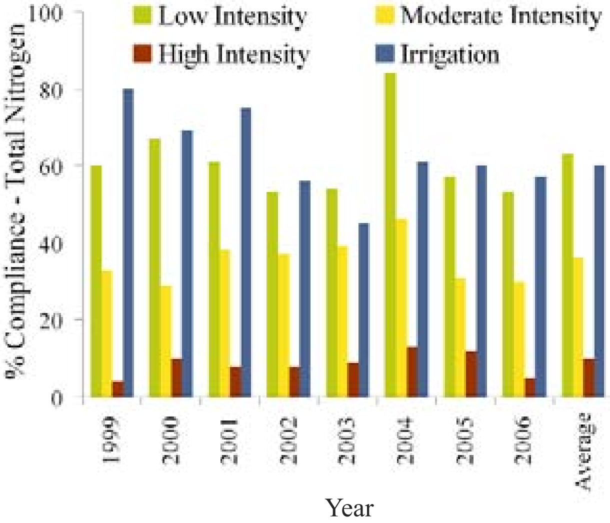


Figure 3.5. Average percent compliance by year for total nitrogen (1.0 mg/L), based on the ASWQG for the Protection of Aquatic Life.

guideline in only 4 to 15% of samples (Figure 3.5). Total nitrogen in streams located in the low agricultural intensity watersheds and irrigated watersheds tended to meet water quality guidelines most often, ranging from 53 to 84% and from 45 to 80%, respectively.

Nitrite (NO_2-N), a dissolved form of nitrogen, was also compared to the ASWQG for the protection of aquatic life (0.06 mg/L NO_2-N). Generally, nitrite concentrations met the guideline more than 98% of the time within all low and moderate intensity agricultural watersheds and met the guideline 78 to 97% of the time within high intensity and irrigated watersheds.

Pesticides

From 1999 through 2006, 37 of the 68 pesticides analysed in the water quality monitoring program were detected at least once. Herbicides were the most common type of pesticide detected in all streams, particularly 2,4-D and MCPA (Figure 3.6).

As with nutrients, pesticide detections were associated with agricultural intensity. Low intensity agricultural watersheds generally had fewer pesticide detections compared to moderate and high intensity agricultural watersheds (Figure 3.6).

The frequency of pesticide detections in streams generally reflected the chemical sales and runoff potentials summarized in Table 3.1 for those watersheds. For example, the frequency of all detections was highest in Wabash Creek, Haynes Creek, Crowfoot Creek, and Kleskun Drain (Figure 3.6). These four watersheds were characterized by above average chemical sales and high runoff potential (Table 3.1).

A number of pesticides were unique to either irrigation streams or to dryland streams (Table 3.3). Simazine and ethofumesate, for example, were two herbicides only found in irrigation streams having average detection frequencies of 18% and 24%, respectively. Simazine is generally applied to alfalfa, field corn and sweet corn crops, while Ethofumesate is generally applied to sugar beet crops (AAFRD 2007).

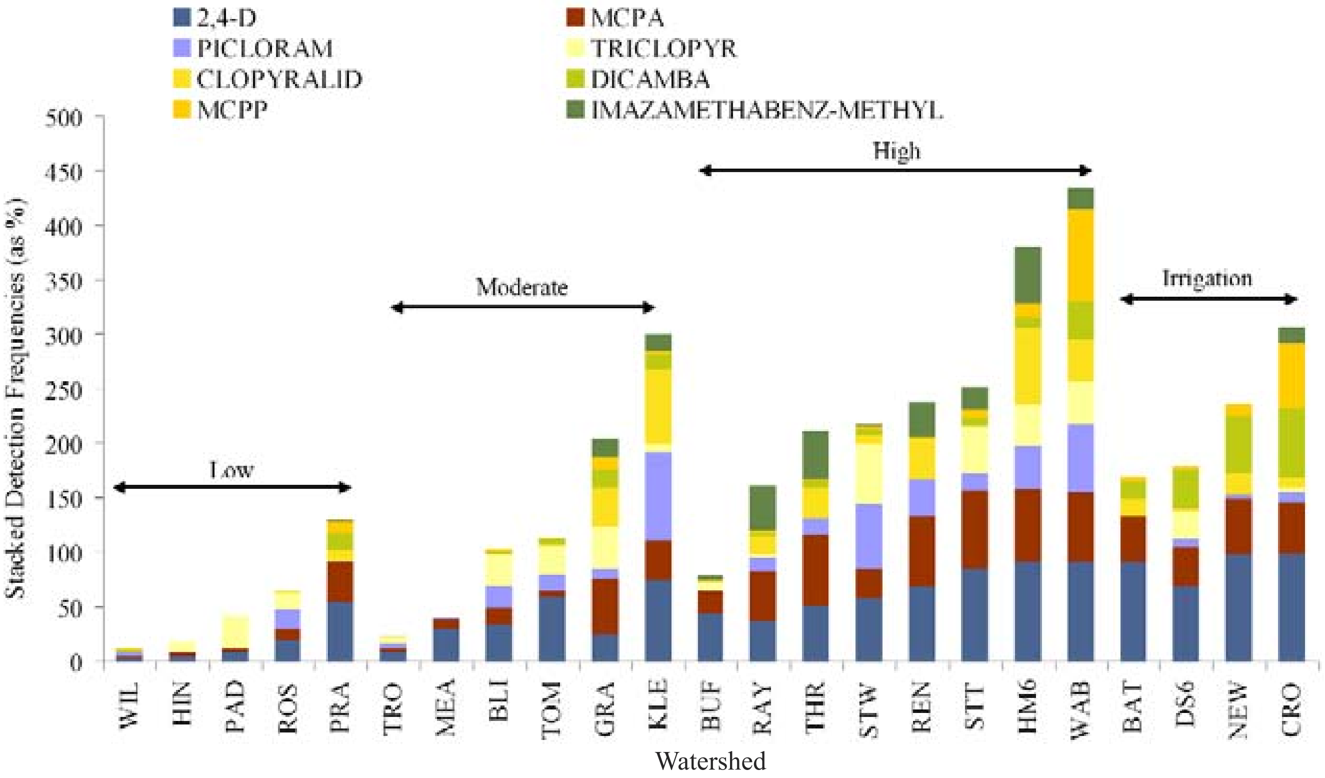


Figure 3.6. Summary of pesticide detections in the 23 AESA watersheds by agricultural intensity.

Table 3.3. Summary of pesticide detections by stream type (irrigation vs. non-irrigation).

Pesticide Types	Irrigation Streams	Non-Irrigation Streams
Herbicide	Simazine Ethofumesate Ethafluralin Metribuzin 4-Chloro-2-Methylphenol (degradation product) Desipropylatrazine (degradation product)	Bromacil* Clodinafop acid metabolite* (degradation product) Diuron Quinclorac* Trifluralin
Insecticide	Chlorpyrifos-ethyl	Alpha-benzenehexachloride (degradation product) Gamma-benzenehexachloride
Fungicide	Metalaxyl-M	Iprodione Oxycarboxin*

*Compounds only detected in High Intensity watersheds.

Pesticide concentrations were compared to the ASWQG (AENV 1999) for irrigation and for the protection of aquatic life. Irrigation guidelines indicate the potential for damage to sensitive plant species if stream water is used for irrigation purposes. Only 30 of the 68 pesticides monitored in this program have associated water quality guidelines; therefore, some of the impacts related to these compounds are unknown.

Approximately 11% of all samples that contained MCPA and dicamba exceeded the ASWQGs for irrigation. These two compounds also exceeded the guidelines by the greatest amount. Seven other compounds exceeded water quality guidelines, either for irrigation or for the protection of aquatic life, but these exceedences occurred in less than 1% of the samples collected.

Of the 22 compounds detected that are without guidelines, four were detected in greater than 10% of the samples collected (i.e., imazamethabenz-methyl, MCPP, clopyralid and triclopyr). These more frequently detected compounds should be flagged as important substances for guideline development, in order to assess the risks for aquatic life, irrigation, livestock watering and human consumption.

Bacteria

Median *Escherichia coli (E. coli)* counts ranged from 59 colonies per 100 mL in the low agricultural intensity watersheds to 358 colonies in the moderate intensity watersheds (Figure 3.7). Similarly, median fecal coliform counts were 63 and 441 colonies per 100 mL in the low and moderate agricultural intensity watersheds, respectively. Unlike nutrient concentrations, bacteria counts did not increase with increasing agricultural intensity.

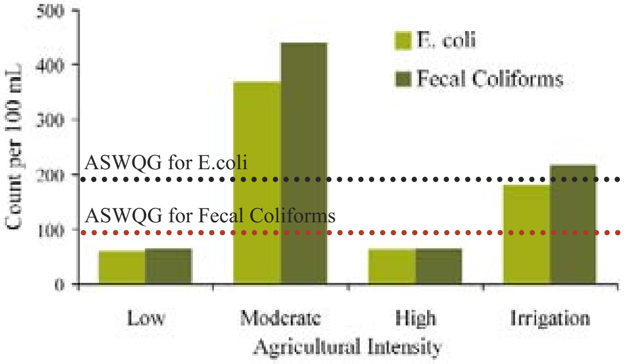


Figure 3.7 Median counts of *E. coli* and fecal coliforms in the AESA watersheds.

Higher bacteria counts were observed in the moderate agricultural intensity watersheds located in the Grassland and Boreal Ecoregions. The two grassland streams, Trout Creek and Meadow Creek, consistently contained higher bacteria counts likely due to cattle grazing on the high percentage of pasture land in these watersheds. Similarly, the Boreal watersheds have a higher proportion of shrub and forest cover also used for livestock grazing and by wildlife. Bacteria counts in Boreal streams coincided with peaks in discharge and suspended sediment, and this suggests that bacteria are following similar pathways as particulate phosphorus and organic nitrogen in storm event runoff entering the streams.

Water Quality Guidelines for Bacteria

Alberta's surface water quality guideline (ASWQG) for E.coli is 200 colonies per 100 mL for the protection of recreational activities. The ASWQG for fecal coliforms is 100 colonies per 100 mL of sample for the protection of irrigation water (AENV 1999).

In contrast, all of the high intensity watersheds, with the exception of Strawberry Creek, are located in the Aspen Parkland Ecoregion where cropland is the dominant land cover. In these watersheds, *E. coli* and fecal coliform counts tended to be lower.

Although median bacteria counts were generally low, most of the watersheds did experience the occasional spike in *E. coli* and fecal coliform bacteria numbers. Generally, peaks in bacteria concentrations coincided with peaks in stream flow, and this suggests that runoff from rain events transported bacteria to streams. Bacteria counts tend to be consistently high throughout the irrigation season (May to October) in streams receiving irrigation return flows. Potential sources of bacterial contaminants include surface runoff from pasture or cropland to which manure has been applied, drainage from livestock feedlots, direct release of waste matter from livestock and wildlife.

Average compliance with water quality guidelines for the protection of recreation waters for *E. coli* during the eight-year study was approximately 90% for low and high agricultural intensity, 65% for moderate agricultural intensity watersheds and about 80% for irrigation watersheds (Figure 3.8). Fecal coliforms met water quality guidelines for the protection of irrigation waters 80% of the time in low and high agricultural intensity watersheds, just 46% of the time in moderate agricultural intensity watersheds and about 60% of the time in irrigation watersheds.

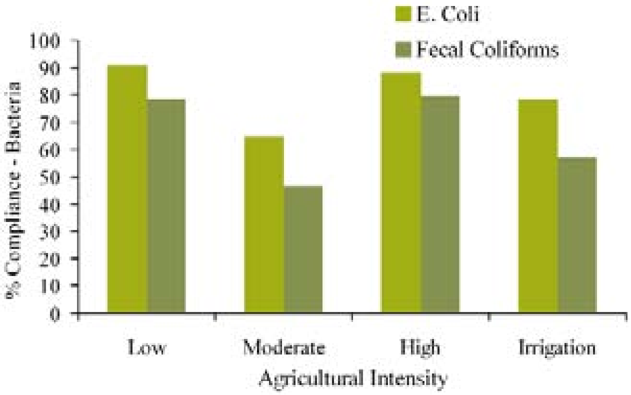


Figure 3.8 Average percent compliance for *E. coli* (200 colonies per 100 mL) and for fecal coliforms (100 colonies per 100 mL) from 1999 to 2006, based on the ASWQG for the Protection of Irrigation Water.

Nutrient Export from Watersheds

Nutrient exports reflect the mass of nitrogen and phosphorus transported by a stream system within a given drainage area during a particular time period. Quantification of these exports is important because they can impact other downstream water users. While nutrient concentrations, described earlier, are influenced to a large extent by agricultural intensity, nutrient exports are driven largely by climate-related factors within the ecoregions.

Total phosphorus exported from the 23 AESA watersheds during the study period ranged from 0.017 kg/ha/yr in the Grassland ecoregion to 0.214 kg/ha/yr in the Boreal ecoregion. Watersheds located in the Boreal ecoregion had the highest phosphorus exports (Figure 3.9) and nitrogen exports (Figure 3.10). In the Parkland and Continental Divide ecoregions, nutrient exports were intermediate. Streams monitored in watersheds located in the Grassland region had the lowest nutrient export coefficients.

Export Coefficients

Export coefficients measure the annual load of nutrients that are transported from a watershed by the receiving stream. Export coefficients are calculated by dividing the amount of nutrient in the stream (kg) by the watershed area (ha). Export coefficients standardize data, so watersheds of different sizes can be compared to each other.

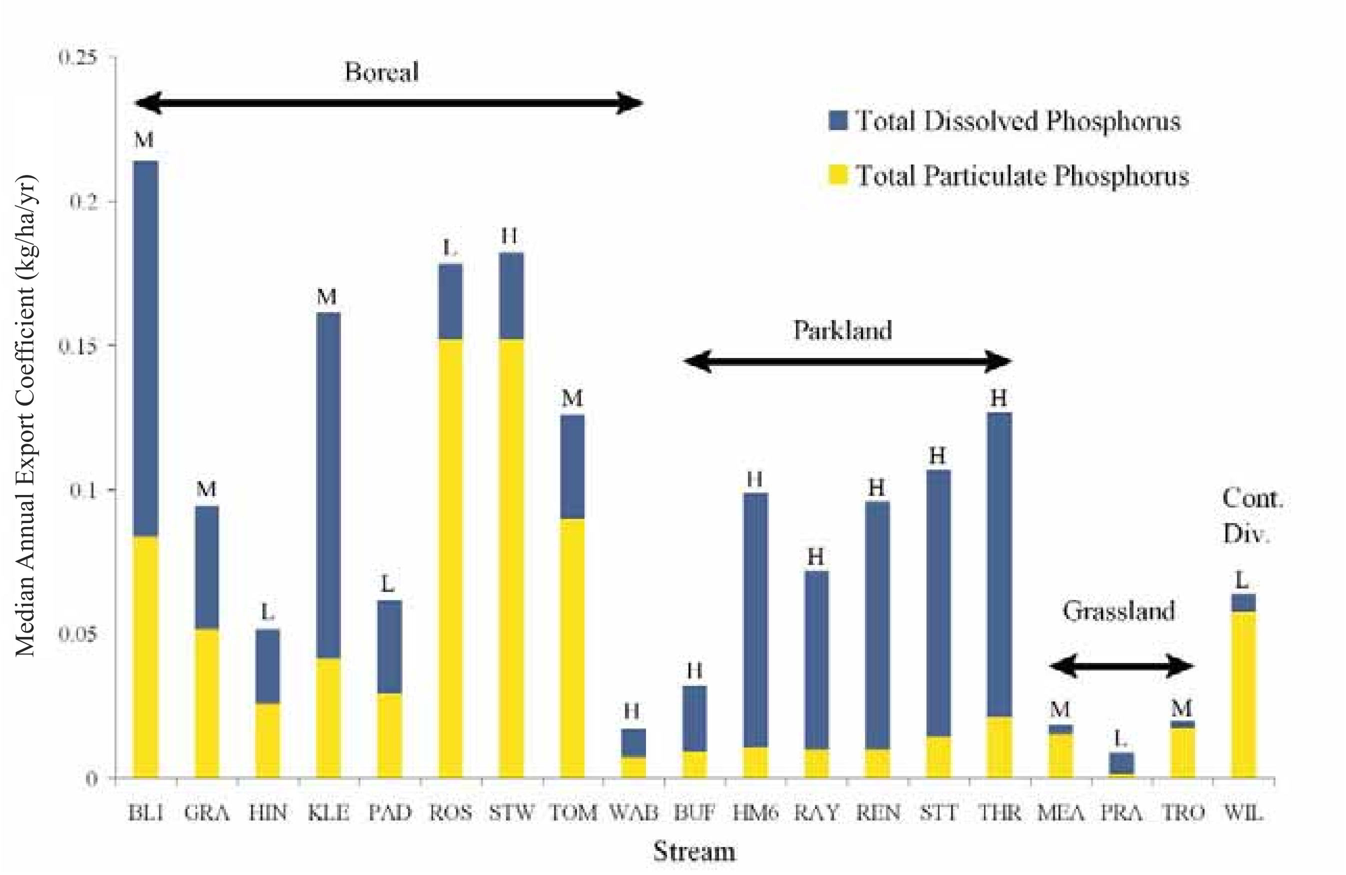


Figure 3.9. Median total phosphorus annual export coefficients from 1999 to 2006. Letters represent the agricultural intensity of the watershed (H - high, M - moderate, L - low).

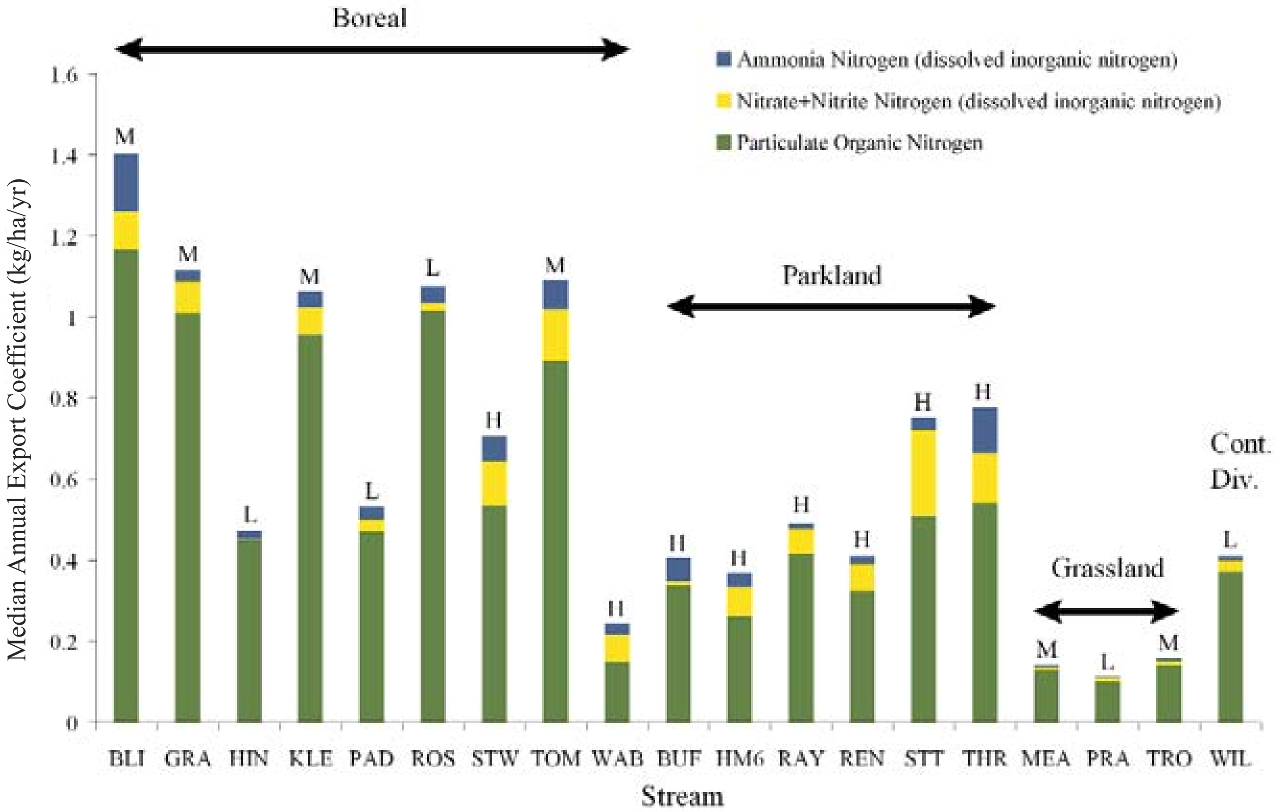


Figure 3.10. Median total nitrogen annual export coefficients from 1999 to 2006. Letters represent the agricultural intensity of the watershed (H - high, M - moderate, L - low).

Although streams in higher agricultural intensity watersheds generally contained higher nutrient concentrations, Figure 3.9 and Figure 3.10 illustrate that ecoregion characteristics have a great influence on nutrient export from watersheds. For example, nutrient exports from low intensity agricultural watersheds in the Boreal ecoregion were generally greater than those from high intensity agricultural watersheds in the Parkland ecoregion.

The potential for runoff and the subsequent transport of nutrients from the land to surface water increases with increasing precipitation. Generally, the Boreal ecoregion receives a greater amount of precipitation each year compared to the more southern ecoregions (Table 3.4). It is likely that climate contributed to the larger nutrient exports from low and moderate intensity agricultural watersheds in the Boreal ecoregion compared to the high intensity agricultural watersheds in the Parkland ecoregion. The impact of climate is also reflected in the Grassland ecoregion where drier conditions reduce runoff potential and lower nutrient exports (Figures 3.9 and 3.10). In addition to climate, factors such as seasonality, land cover and instream processes contribute to nutrient exports.

Table 3.4. Precipitation summary for the ecoregions represented in the AESA water quality monitoring program. **(Ecological Stratification Working Group 1996).**

Ecoregion	Precipitation (mm)
Boreal Plains	
Clear Hills Upland	400 - 600
Peace Lowland	350 - 600
W. Alberta Upland	450 - 600
Boreal Transition	450 (West) - 550 (East)
Parkland	
Aspen Parkland	400 - 500
Prairies	
Fescue Grassland	400 - 450
Moist Mixed Grassland	350 - 400
Mixed Grassland	250 - 350
Montane Cordillera	
N. Continental Divide	600 - 700

Figure 3.11 shows the phosphorus and nitrogen export distribution by season for the four ecoregions. The Boreal and the Parkland ecoregions show the greatest export in early spring (March and April), which corresponds to spring snowmelt in central and northern Alberta (Figure 3.11 a and 3.11 b). There is a delayed response in the seasonal export of nutrients from the Continental Divide and the Grassland ecoregions. This results from the slower snowmelt and the higher June precipitation in the southern watersheds. These findings are consistent with studies that reported greater than 80% of runoff water in the prairie provinces occurs from snowmelt (Nicholaichuk 1967).

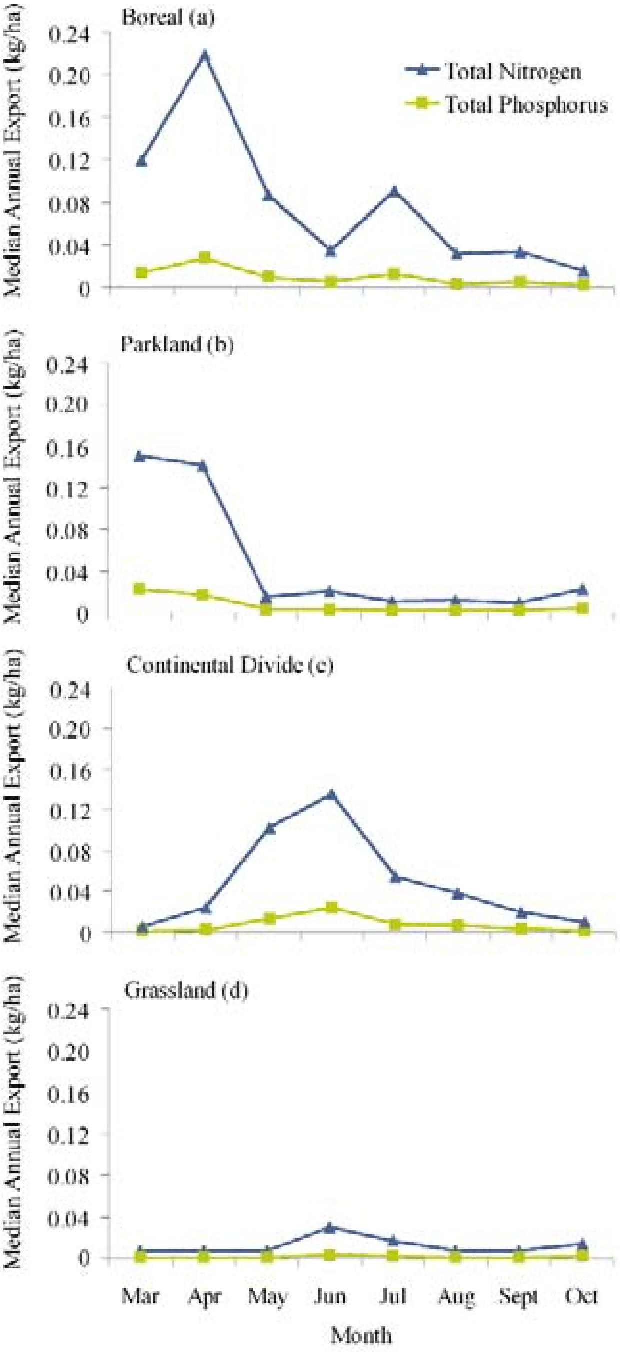


Figure 3.11. Seasonal trend in median annual export coefficients of total phosphorus and nitrogen for Boreal (a), Parkland (b), Continental Divide (c) and Grassland (d) ecoregions.

Three streams representing low, moderate and high agricultural intensity watersheds demonstrate the range in watershed characteristics and water chemistry observed in this study: Paddle River (low), Tomahawk Creek (moderate) and Threehills Creek (high) (Figure 3.12).

The Paddle River, in the Boreal ecoregion, is a low agricultural intensity watershed. Land cover within the Paddle River watershed includes cropland (6%), forage (3%) and grassland/shrubs/trees (90%) (Figure 3.12a). Median total phosphorus concentrations exceeded water quality guidelines by a factor of four; however, the export coefficients were quite low, 0.067 kg/ha/yr TP and 0.558 kg/ha/yr TN compared to watersheds of higher intensity (Table 3.5).

Tomahawk Creek, also in the Boreal ecoregion, is a moderate intensity agricultural watershed. Land cover includes cropland (11%), forage (24%) and grassland/shrubs/trees (65%) (Figure 3.12b). Similar to the Paddle River, median nutrient concentrations in the creek were high; median total phosphorus concentration was seven times greater than water quality guidelines, and total nitrogen concentration was three times greater. Export coefficients were approximately twice that of the low intensity Paddle River watershed.

Threehills Creek is a high intensity agricultural watershed in the Parkland ecoregion. Land cover includes cropland (52%), forage (8%) and grassland/shrubs/trees (39%) (Figure 3.12c). In comparison to the other two watersheds, Threehills Creek exceeded the water quality guidelines by the greatest magnitude, 11 times for total phosphorus and 3.5 times for total nitrogen.

Total phosphorus export from the high intensity agricultural watershed was greater than the low and moderate intensity agricultural watersheds. However, total nitrogen exports from Threehills Creek (high intensity)

a) **Low Agriculture Intensity (Boreal)**
Paddle River

Mean Elevation: 853 m asl
Mean Slope: 3%
Effective Drainage Area: 25,300 ha

Land Use (1990)
6% Cropland
3% Forage
23% Grassland
67% Trees and Shrubs

Total Manure Production (1996)
1.42 tonnes/hectare

Fertilizer & Chemical Expense (1996)
$4.36/hectare

FWMC
(Median)
TP: 0.20 mg/L
TN: 1.35 mg/L

Nutrient Export Coefficient
(Median)
TP: 0.067 kg/ha/yr
TN:0.558 kg/ha/yr

b) **Moderate Agriculture Intensity (Boreal)**
Tomahawk Creek

Mean Elevation: 790 m asl
Mean Slope: 1.5%
Effective Drainage Area: 9,500 ha

Land Use (1990)
11% Cropland
24% Forage
34% Grassland
31% Trees and Shrubs

Total Manure Production (1996)
3.01 tonnes/hectare

Fertilizer & Chemical Expense (1996)
$9.31/hectare

FWMC
(Median 1999-2006)
TP: 0.36 mg/L
TN: 2.92 mg/L

Nutrient Export Coefficient
(Median 1999-2006)
TP: 0.125 kg/ha/yr
TN: 1.123 kg/ha/yr

c) **High Agricultural Intensity (Parkland)**
Threehills Creek

Mean Elevation: 956 m asl
Mean Slope: 2%
Effective Drainage Area: 13,800 ha

Land Use (1990)
52% Cropland
8% Forage
32% Grassland
7% Trees and Shrubs

Total Manure Production (1996)
3.63 tonnes/hectare

Fertilizer & Chemical Expense (1996)
$70.18/hectare

FWMC
(Median 1999-2006)
TP: 0.55 mg/L
TN: 3.57 mg/L

Nutrient Export Coefficient
(Median 1999-2006)
TP: 0.139 kg/ha/yr
TN: 0.777 kg/ha/yr

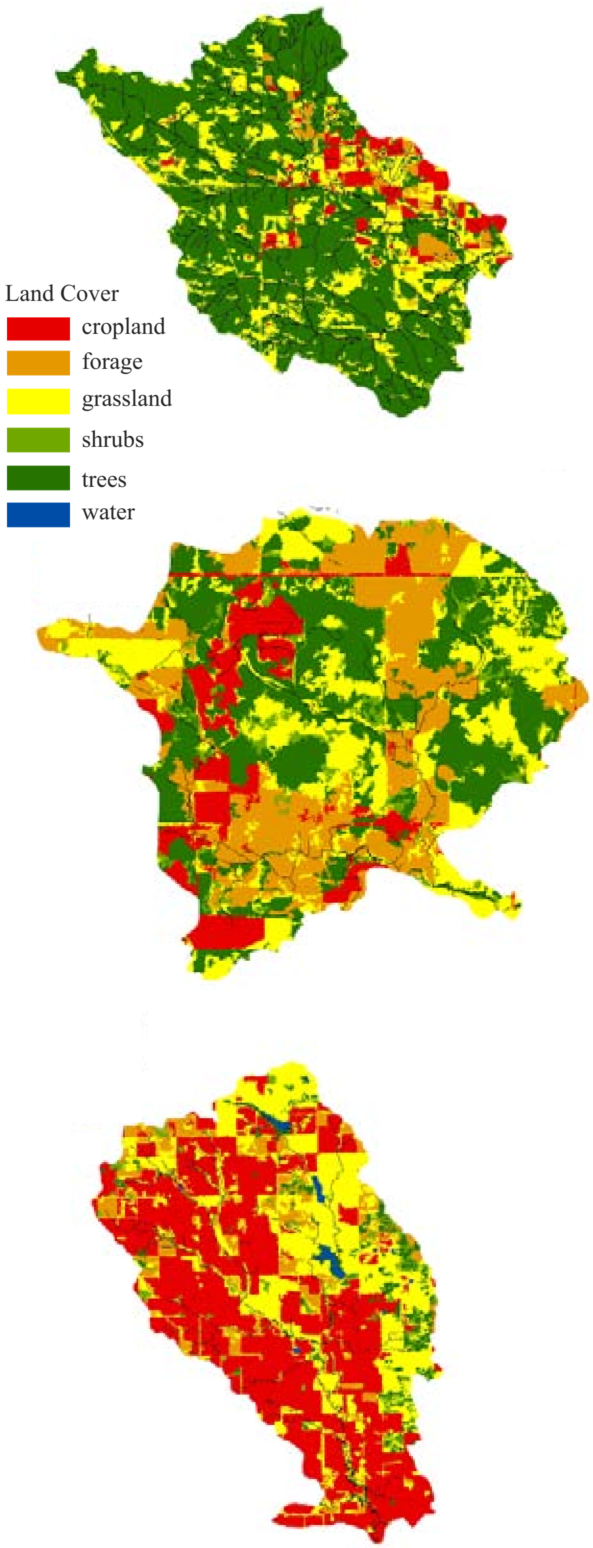


Figure 3.12. Three typical AESA watersheds showing (a) low intensity, (b) moderate intensity and (c) high intensity agriculture. Total manure production and fertilizer and chemical expenses were based on 1996 census data.

were less than the moderate intensity Tomahawk Creek. This suggests that other factors in addition to agricultural intensity, are influencing nitrogen export from the watershed.

In addition to agricultural intensity and runoff potential previously discussed, other factors such as land cover and instream processes likely contributed to the range observed in total phosphorus and total nitrogen exports from the watersheds. This is apparent in some of the watersheds where agricultural intensity did not explain the value of the export coefficients. Wabash Creek and Buffalo Creek watersheds, for example, had lower than expected phosphorus export coefficients, considering the high agricultural intensity surrounding these streams.

Instream nutrient cycles are complex and influenced by a variety of factors, including biological activity and the physical and chemical properties of water, such as temperature and pH. The biological activity of plants and organisms help to retain nutrients during phases of growth and reproduction and release nutrients during phases of death and decomposition. Wetland and riparian vegetation in a watershed can be a source of nutrients and a sink for nutrients (i.e., storage area), influencing the overall export of nutrients from the system (refer to Figure 1.10).

The export coefficients that were measured in the 23 AESA watersheds (Table 3.5) were consistent with or lower than those reported for other agricultural watersheds (Table 3.6). A literature review prepared by Riemersma et al. (2006) reported export coefficients ranging from 0.0 to 38.0 kg/ha/yr total phosphorus and 0.085 to 54.000 kg/ha/yr total nitrogen in agricultural watersheds. In addition to agricultural sources, atmospheric deposition, groundwater, urban stormwater and forested land may contribute to overall nutrient export coefficients. These other sources may contribute up to 1.487 kg/ha/yr total phosphorus and 136.000 kg/ha/yr total nitrogen (Table 3.6) (Riemersma et al. 2006).

Table 3.5. Range of total phosphorus and total nitrogen export coefficients in the AESA watersheds.

Ecoregion	Agricultural Intensity	Sample Size	TP Export (kg/hectare/yr)	TN Export (kg/hectare/yr)
Parkland	High	6	0.035-0.139	0.423-0.777
Boreal	High	2	0.022-0.169	0.256-0.686
Boreal	Moderate	4	0.099-0.214	1.110-1.412
Boreal	Low	3	0.057-0.197	0.474-1.069
Grassland	Moderate	2	0.017-0.020	0.142-0.158
Grassland	Low	1	0.012	0.155
Continental Divide	Low	1	0.064	0.411

Table 3.6. Summary of literature values of phosphorus and nitrogen export coefficients from various watershed sources (Riemersma et al. 2006).

Source	Total Phosphorus kg/ha/yr	Total Nitrogen Export kg/ha/yr
Agricultural		
Cultivated Land	0.000-38.000	0.085-54.000
Grassland	0.020-9.400	0.057-5.676
Irrigated Land	0.002-11.150	1.000-10.600
Other		
Atmospheric Deposition	0.021-1.487	0.332-4.459
Groundwater	0.010-0.390	0.304-136.000
Urban Stormwater	0.156-0.201	1.000-9.000
Forested Land	0.046-0.350	0.040-3.160

3.4 Key Findings

The results of the AESA Water Quality Monitoring Project support previous studies that concluded as agricultural intensity increased, water quality deteriorated. Surface water quality guidelines for the protection of aquatic life were exceeded nearly 90% of the time for total phosphorus and 85% of the time for total nitrogen in Alberta's high intensity agricultural watersheds. Pesticide detections and concentrations also increased with agricultural intensity. Many of the pesticides detected were active ingredients in the most commonly used herbicides (e.g., 2,4-D, MCPA and dicamba). Only four of the eight most frequently detected herbicides have water quality guidelines specified. Unlike nutrients and pesticides, the presence of fecal coliform bacteria was more closely related to ecoregion characteristics, which reflect differences in livestock management and wildlife communities.

Although streams located in high agricultural intensity watersheds had higher nutrient concentrations, the same streams tended to be located in low to moderate runoff watersheds which reduced overall nutrient exports. The variability in water quality observed among the watersheds can largely be attributed to agricultural intensity. However, climate and other factors unaccounted for (e.g., land cover and instream processes) also influenced runoff volumes and overall nutrient export from watersheds.

4.0 Phosphorus Limits Study

4.1 Introduction

Phosphorus is an important nutrient for plant production and growth. When organic and inorganic fertilizers build up on the soil surface, however, there is a risk of phosphorus transport from land to surface water. Lakes and streams in Alberta are naturally highly productive in terms of plant growth (eutrophic), but surface waters in the province can experience more prolific algae and weed growth with phosphorus enrichment (Howard et al. 2006).

Water quality studies in Alberta showed that with increased agricultural intensity in watersheds, there was increased phosphorus in streams (CAESA 1998 - Water Quality Committee). The *Agricultural Operation Practices Act* (AOPA) came into effect on January 1, 2002 to regulate the processes for confined feeding operation expansion, address dust and odor issues and indirectly address soil and water quality issues through manure management.

The manure application limits outlined in the AOPA were based on nitrogen concentrations in soil rather than on phosphorus concentrations, though the latter pose an even greater risk to surface water. With increasing concerns about phosphorus in Alberta surface waters, the Alberta Soil Phosphorus Limits Project was established in 1999 to:

1. Develop recommendations for phosphorus limits for agricultural land in Alberta,

2. Determine implications of soil phosphorus limits to the agricultural industry,

3. Identify management options for soil phosphorus limit implementation, and

4. Develop recommendations for an action plan and a timeline for implementation of limits (Paterson et al. 2006).

The Alberta Soil Phosphorus Limits Project was implemented in two phases:

Phase 1 (1999 to 2002) included a collection and review of background material related to agricultural phosphorus issues, a laboratory-scale simulated rainfall study, and field studies in central Alberta. These studies helped define the scope and direction for the project.

Phase 2 (2002 to 2006) was comprised of hydrology and computer modeling studies designed to:

- Collect and assess soil quality and water quality data under Alberta field conditions to better understand the relationship between soil phosphorus and phosphorus in runoff from agricultural land;
- Define relative risk of runoff for Alberta's agricultural areas to calculate site-specific soil phosphorus limits; and
- Determine soil test phosphorus limits (STP) needed to maintain phosphorus concentrations in runoff water below set limits.

A series of research studies were completed as part of the Soil Phosphorus Limits Project and are briefly described in the following sub-sections. Although part of the larger study, research conducted on soil sampling for phosphorus and the economic assessment of soil phosphorus limits is not presented here. For the complete reports, please refer to the individual research reports.

4.2 Agronomic Thresholds for Soil Phosphorus in Alberta

Introduction

Agronomic thresholds were identified to support the development of soil phosphorus limits for agricultural land in Alberta (Howard 2006). An agronomic threshold is defined as the soil phosphorus level beyond which there is no practical economic yield increase or crop yield response from the addition of phosphorus. The concentration of phosphorus is determined by STP analysis. This study reviewed the agronomic thresholds for phosphorus that apply to different crops and soil types in Alberta and also the implications for the application of non-commercial nutrient sources.

Methods

A comprehensive literature review was conducted that identified agronomic thresholds for phosphorus that applied to different crops and soil types in Alberta. The review identified work by McKenzie et al. (1995) and McKenzie et al. (2001). In this work, agronomic thresholds were determined by creating yield response curves developed from a range of STP values taken from the top 15 cm of various soils growing wheat, barley, canola (McKenzie et al. 1995) and peas (McKenzie et al. 2001) (Figure 4.1).

Results

Crop response to phosphorus occurred mainly in the range of 20 to 60 mg/kg STP (Figure 4.1). The results showed no yield response or increase in crop production from the addition of phosphorus at STP concentrations greater than 60 mg/kg. At this concentration, relative yields (RY) for wheat, barley and canola were 100%. Based on the Alberta data, there was no evidence that indicated a practical yield advantage from the addition of STP concentrations greater than 60 mg/kg (approximately 120 kg/ha STP).

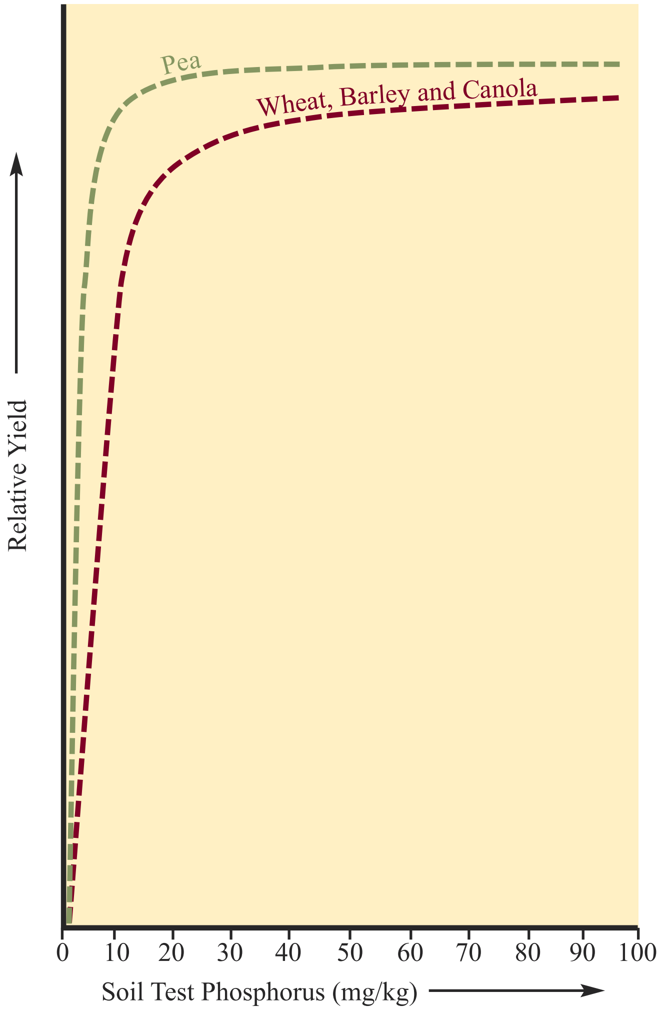
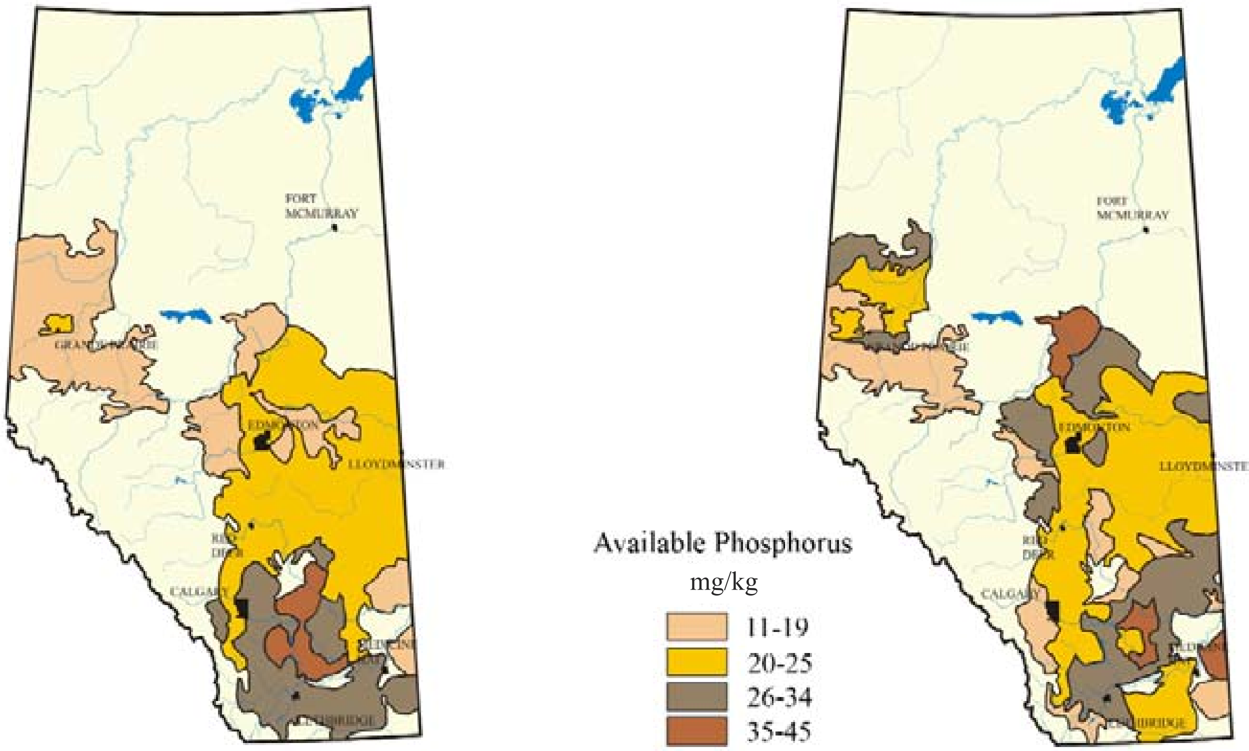


Figure 4.1. Correlation of relative yield of wheat, barley, canola and pea with soil test phosphorus for all soil zones in Alberta (modified from McKenzie et al. 1995).

To understand current STP concentrations within Alberta soils, a province-wide study examined more than 56,000 soil analysis records from 1993 to 1997. The authors found that the majority of Alberta soils had a mean STP value ranging from 25 to 30 mg/kg (Manunta et al. 2000) (Figure 4.2a). These values were significantly below the agronomic threshold of 60 mg/kg identified for optimum crop production. The relatively low provincial STP concentrations suggest producers can apply more phosphorus to the soil to obtain optimal yields, although caution should be used when applying phosphorus in critical zones, such as riparian areas, where phosphorus can move into surface waters. Soil test phosphorus concentrations observed in the 1990s were also compared with those recorded for the period 1963 to 1967. The results showed STP concentrations were virtually unchanged between these two periods for most agricultural areas in Alberta (Manunta et al. 2000) (Figure 4.2).


a) 1993 to 1997

b) 1963 to 1967

Figure 4.2. Soil test phosphorus for dryland annual crops in (a) 1993 to 1997 and (b) 1963 to 1967.

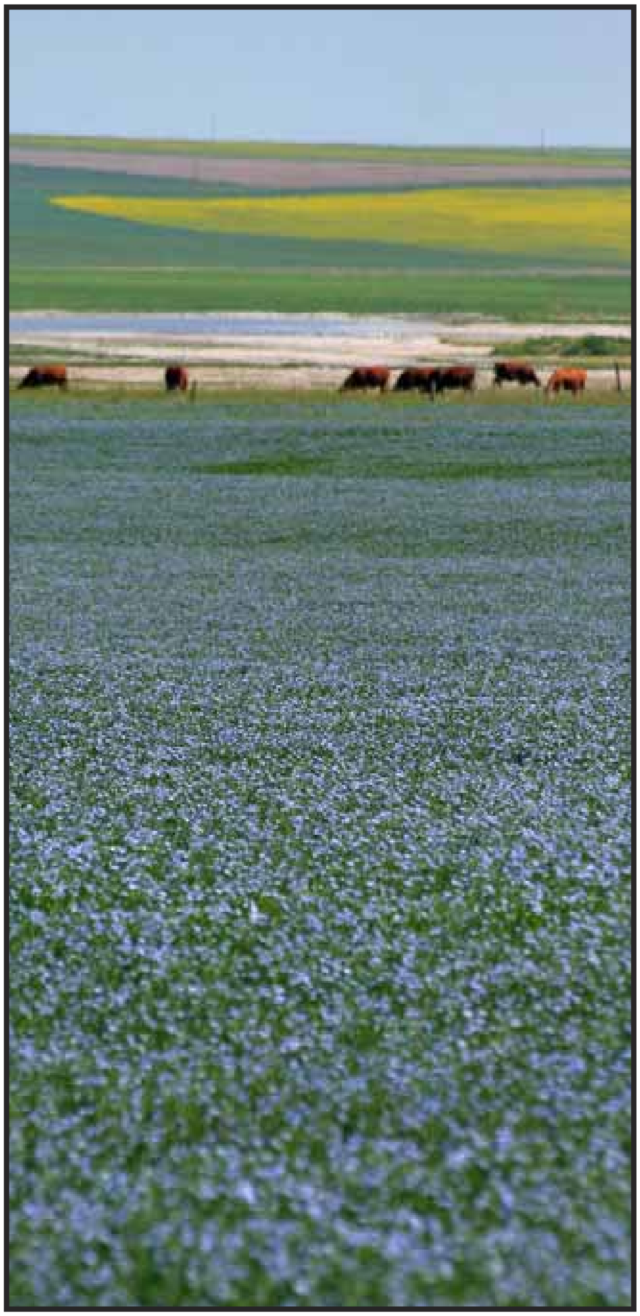
Implications for Manure Application and STP Availability

Although STP concentrations are low in the majority of agricultural soils in Alberta, phosphorus transport is a significant contributor to surface water quality degradation. Livestock production, including cow-calf operations and confined feeding operations, is considered a primary source of phosphorus in the environment. Manure spread on fields, when improperly managed, may be a source of excess phosphorus in surface water. The review found that the risk of phosphorus on manured land to water quality is likely lower in the early years of manure application, as soluble forms of phosphorus are fixed (i.e., immobilized) in the soil by clays and minerals. However, the long-term, repeated applications of manure and commercial fertilizers can cause a build up in the soil, as more phosphorus is applied than is immediately taken up by crops.

Phosphorus availability. *Phosphorus in manure is not immediately available to plants, compared to commercial fertilizers. Manure acts as a slow-release fertilizer source, because phosphorus is in an organic form and has to be transformed into a plant available form. Manure is also variable in nutrient content. In contrast, commercial fertilizers have known amounts of phosphorus and are designed for nutrients to be immediately available. Thus, both forms of nutrients increase the risk of phosphorus transport to surface waters, particularly when applied in excess of crop requirements.*

Conclusion

Soil test phosphorus concentrations greater than the agronomic threshold of 60 mg/kg in the top 15 cm of the soil profile will not result in an increase in crop yield for most agricultural crops in Alberta. Further understanding of the application of non-commercial phosphorus sources will aid in the research of agricultural phosphorus issues, especially the role of phosphorus and its impact on water quality.



4.3 Relationships between Soil Phosphorus and Nitrate-Nitrogen Concentrations in Runoff from Eight Microwatersheds

Introduction

A study was undertaken to determine the relationship between nutrient concentrations found in soils and nutrient concentrations found in surface runoff flowing from these soils following rainfall or snowmelt events. The studies were conducted on field-size watersheds (microwatersheds) in Alberta (Little et al. 2006; Casson et al. 2008).

***Runoff potential** is a calculation to determine how much water could potentially run off a particular landscape. It is based on topography, slope, vegetative cover and other factors.*

Methods

Although this study originally focused on phosphorus, nitrogen data was also collected and analysed in 2008 (Casson et al. 2008). Eight microwatersheds were selected from across the province, ranging from 2 to 248 ha (Figure 4.3). These microwatersheds extended across agricultural land that represented a range of precipitation and runoff potential (Table 4.1).

Figure 4.3. Location of selected microwatershed sites.

Table 4.1. Names of the eight microwatersheds and associated land use.

Name of site	Land use
Stavely (STV)	Ungrazed grassland
Crowfoot Creek (CFT)	Cultivated, non-manured
Grande Prairie Creek (GPC)	Cultivated, non-manured
Threehills Creek (THC)	Cultivated, non-manured
Wabash Creek (WAB)	Cultivated, non-manured
Renwick Creek (REN)	Cultivated, non-manured
Ponoka (PON)	Cultivated, heavy applications of cattle manure
Lower Little Bow River (LLB)	Cultivated, moderate applications of cattle manure

Results

Phosphorus

STP values ranged from 3 to 512 mg/kg in the top 15 cm of soil among the eight microwatersheds (Table 4.2) (Little et al. 2006). The ungrazed grassland site (STV) contained the lowest STP concentrations, ranging from 3 to 5 mg/kg. Manure was not applied to the grassland site and this is reflected in the low STP concentrations. On the five non-manured cultivated sites, fertilizer was banded with the seed. These sites contained STP concentrations ranging from 20 to 39 mg/kg. The two manured crop sites (LLB and PON) contained the highest concentrations of STP, ranging from 236 to 512 mg/kg.

Table 4.2. Mean STP values at the 0 to 15 cm soil depth on 3 sampling dates.

	Fall 2002	Fall 2003	Fall 2004
Site		mg/kg	
		Ungrazed grassland site	
STV	3	5	5
		Non-manured sites	
CFT	34	39	35
GPC	33	35	27
REN	20	24	21
THC	26	27	23
WAB	35	32	25
		Manured sites	
LLB	269	236	242
PON	512	446	366

Approximately 90% of the total annual runoff volume at the microwatershed sites occurred during spring snowmelt. Seasonal total phosphorus (TP) concentrations at the eight sites ranged from from 0.1 to 8.0 mg/L. Most of the phosphorus observed in the runoff water was in the dissolved form as dissolved reactive phosphorus (DRP). Concentrations ranged from 0.01 to 7.4 mg/L.

The phosphorus concentrations in runoff at the non-manured sites ranged from 0.01 to 1.04 mg/L DRP and 0.30 to 1.57 mg/L TP. The lower values at some sites may be a reflection of clays and minerals in the soil that are able to hold more phosphorus, or may simply be a result of low runoff volume, where decreased contact with phosphorus sources such as soil and decaying vegetation resulted in less phosphorus being transported to surface waters. The ungrazed grassland site (STV) received no fertilizer applications and, similar to the low STP concentrations observed at this site, contained the lowest phosphorus concentrations in runoff (0.06 to 0.18 mg/L DRP and 0.10 to 0.52 mg/L TP).

At the heavily manured site (PON), there were very high phosphorus concentrations in runoff; DRP was 16.5 mg/L and TP was 24.0 mg/L during the spring 2003 sampling. Manure was applied in fall 2002 and it was poorly incorporated and visible on the surface at the time of soil sampling. In addition, the PON site showed a high degree of dissolved phosphorus saturation (DPS), suggesting the soil had little capacity left to bind phosphorus and was more likely to release the nutrient to runoff water.

Using an average of all soil sampling points, STP in the top 15 cm of the soil was found to be a good predictor of total phosphorus concentrations in runoff. As STP concentrations increased, the amount of total phosphorus in runoff also increased (Figure 4.4). When manure applications ceased, a decrease in STP concentrations in the soil and a decrease in phosphorus concentrations found in runoff also occurred.

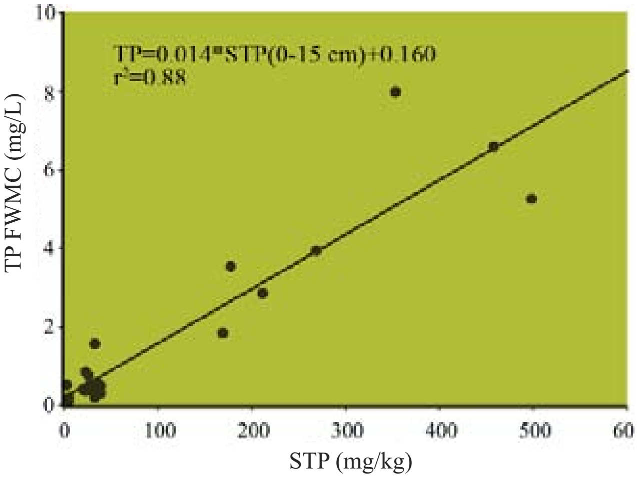


Figure 4.4. Relationship between soil test phosphorus (STP) in the 0 to 15 cm soil layer and total phosphorus (TP) flow-weighted mean concentration (FWMC) in runoff water.

Nitrogen

In addition to phosphorus, nitrogen data were collected at the eight microwatershed sites (Casson et al. 2008). Generally, moderate to high fertilizer application rates caused higher NO_3-N levels in the soil. In the 0 to 15 cm layer, the mean NO_3-N concentrations ranged from 1.6 to 163 mg/kg (Table 4.3). The lowest NO_3-N concentrations (1.6 to 5.5 mg/kg) were measured at the ungrazed grassland site (STV); soils at the manured site (PON) had the highest NO_3-N concentration (58 to 163 mg/kg). The five non-manured, cropped sites had soil NO_3-N concentrations that ranged from 4.8 to 51 mg/kg. Higher soil NO_3-N concentrations were observed in the non-manured, crop sites in the spring, compared to the previous fall (Table 4.3).

Table 4.3. Mean extractable nitrate nitrogen values in the 0 to 15 cm soil layer at each microwatershed site.

	Sampling Date					
Site	**Fall 2002**	**Spring 2003**	**Fall 2003**	**Spring 2004**	**Fall 2004**	**Spring 2005**
			mg/kg			
			Ungrazed grassland site			
STV	2.4	ns[z]	1.6	ns	5.5	ns
			Non-manured sites			
CFT	12	41	12	42	17	51
GPC	19	30	21	17	6.5	33
REN	11	13	4.8	34	12	29
THC	5.5	12	7.5	28	32	15
WAB	14	40	9.4	40	11	49
			Manured sites			
LLB	34	27	35	74	31	56
PON	163	59	144	58	67	134

[z] not sampled

Seasonal NO_3-N concentrations in runoff ranged from below detection limits to 43.4 mg/L; the total nitrogen (TN) concentrations in runoff ranged from 0.43 to 1.06 mg/L. The lowest NO_3-N concentrations were observed at the ungrazed site (STV), where levels ranged from below detection limits to 0.04 mg/L and TN ranged from 0.43 to 2.39 mg/L. Nitrate N at the non-manured sites ranged from 0.04 to 10.6 mg/L and TN ranged from 2.32 to 13.4 mg/L. Similar to phosphorus concentrations, the greatest concentrations of NO_3-N and TN concentrations in runoff were observed at the manured sites, where concentrations ranged from 0.41 to 43.4 mg/L NO_3-N and 3.80 to 105.9 mg/L TN. As observed with DRP and TP, NO_3-N and TN in runoff were greatest at the heavily manured site (PON) during spring 2003 sampling, which followed the fall 2002 manure application at the site.

Results from the nitrogen data showed a similar trend to phosphorus; when NO_3-N in soil increased, both TN and NO_3-N in runoff also increased. However, further analysis showed this relationship was driven by a single source from the manured PON site in spring 2003. When this point source was removed from the analysis, soil NO_3-N was found to be a weak predictor of NO_3-N or TN in edge-of-field runoff water.

Conclusion

Moderate to high application rates of manure resulted in higher nutrient concentrations in the soil. Soil test phosphorus was found to be a good predictor of phosphorus concentrations in most runoff events, given that the vast majority of runoff in Alberta occurs in the spring. Soil extractable NO_3-N was found to be a weak predictor of NO_3-N or TN in field runoff water.

Figure 4.5. Rainfall simulator, runoff frame and collection tray used at the three field sites.

4.4 Phosphorus Losses in Simulated Rainfall Runoff from Manured Lands

Introduction

This study was undertaken to determine the effects of manure application rates and incorporation methods on phosphorus concentrations in runoff from cropped agricultural land (Ontkean et al. 2006). Phosphorus concentrations were measured immediately after manure application and one year later, at three plot sites in Alberta. Four manure application rates and two types of incorporation method (incorporated and unincorporated) were applied to each plot (Table 4.4). A rainfall simulator was used to generate precipitation events and a collection tray was used to capture runoff water (Figure 4.5).

Table 4.4. Site description, soil properties, slope, and manure application rates.

Site Name	Soil Type	Texture	Slope	Manure Application Rates
Wilson	Orthic Dark Brown Chernozem	Clay loam - clay	6%	0, 100, 200 and 400 kg/ha TP
Lacombe	Orthic Black Chernozem	Sandy clay loam	10%	0, 50, 100 and 200 kg/ha TP
Beaverlodge	Dark Gray Luvisol	Clay loam	5%	0, 25, 50 and 100 kg/ha TP

Results

Generally, runoff volumes and phosphorus concentrations did not change significantly with one-pass manure incorporation. This method of application also had no significant effect on phosphorus transport at any of the sites one year later. After each simulated rainfall event, only small concentrations of manure-applied phosphorus were transported by runoff, indicating that a large amount of phosphorus remained in the soil for future transport during runoff events. Less than 3% of manure-applied phosphorus was removed by runoff from freshly manured soils and less than 1% was removed by runoff one year after application.

Total phosphorus (TP), soil test phosphorus (STP) and dissolved reactive phosphorus (DRP) concentrations measured in applied manure generally had strong relationships with TP concentrations in runoff. As phosphorus in the upper soil profile increased, phosphorus concentrations in runoff increased in the non-manured and manured soils. The relationship between STP and TP concentrations in runoff from the Lacombe and Wilson sites was similar to that observed in the eight microwatersheds study (Figure 4.6) (Little et al. 2006).

Generally, after 6 to 12 months, when the manure had equilibrated or come into balance in the soil, STP and phosphorus concentrations in runoff decreased at all sites (Figure 4.6).

Conclusion

When studying phosphorus losses in simulated rainfall from cropped manured lands, Ontkean et al. (2006) found that as STP concentrations increased, phosphorus concentrations in runoff water from agricultural soils also increased. These findings agree with other field-scale monitoring studies. Maintaining STP concentrations below agronomic thresholds of 60 mg/kg will decrease the risk of phosphorus being transported into surface waters. In this way, the agronomic threshold of 60 mg/kg may also be considered an environmental threshold.

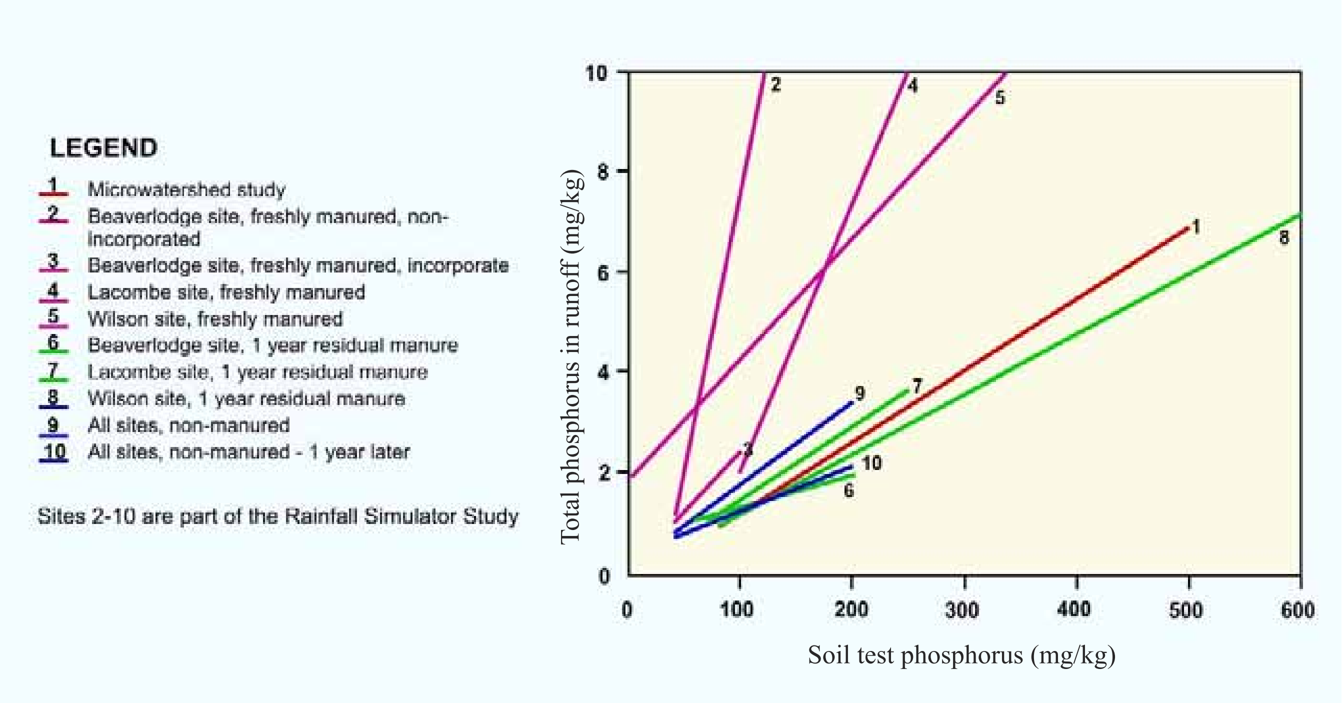


Figure 4.6. Relationships between soil test phosphorus concentration and total phosphorus concentration in runoff water.

4.5 Phosphorus Sorption and Saturation Thresholds in Soil

Introduction

Phosphorus is immobilized in the soil by binding to soil particles. As more phosphorus binds to the soil particles, the number of available binding sites for phosphorus decreases. The degree of soil phosphorus saturation (DPS) is a measure of the available binding sites for phosphorus. The DPS is considered high when there are very few sites in the soil for phosphorus to bind. Fewer binding sites in the soil increases the risk of phosphorus loss to surface water. Thus, DPS is identified as a potential phosphorus transport risk indicator because it has a strong relationship with runoff phosphorus concentrations (Little et al. 2006).

This study investigated the risk of phosphorus transport from agricultural land to surface and groundwater by measuring the DPS in 13 Alberta soils (Casson et al. 2006), using archived soil samples from three field studies that had examined manure rates, tillage, rainfall simulations, soil test phosphorus (STP), and phosphorus in runoff (Olson et al. 2003; Ontkean et al. 2006; Little et al. 2006).

Results

For all 13 soils, the average critical DPS threshold corresponded to STP concentrations close to the agronomic thresholds of 60 mg/kg in the top 15 cm for crops grown in Alberta (Table 4.5). The study showed 35% or 54% of phosphorus in the soil (based on the method used to calculate the desorption rates) could be transported before it exceeds the threshold of 1 mg/L of phosphorus concentration in runoff.

Table 4.5. Degree of phosphorus saturation (DPS) critical thresholds, water-extractable phosphorus (WEP) plateau and soil test phosphorus (STP) values for soils from the three studies.

Experiment	Soil Texture (Site)	DPS Critical Threshold (%)	WEP plateau* (mg/L)	STP (mg/kg)
8-yr manure site	Coarse	44	1.37	57
	Medium	3	0.43	44
Manure rate and tillage	Medium - Fine (Beaverlodge)	n/a	n/a	n/a
	Coarse - Medium (Lacombe)	44	2.52	96
	Medium (Wilson)	40	1.57	68
Microwatersheds	Medium (8 sites)	47	1.02	56
All (13 soils)		35	1.03	52

Experiment	Soil Texture (Site)	DPS Critical Threshold (%)	$CaCl_2$-P plateau* (mg/L)	STP (mg/kg)
8-yr manure site	Coarse	48	0.83	46
	Medium	11	0.28	61
Manure rate and tillage	Medium - Fine (Beaverlodge)	n/a	n/a	n/a
	Coarse - Medium (Lacombe)	49	1.74	103
	Medium (Wilson)	51	0.68	57
Microwatersheds	Medium (8 sites)	59	0.47	64
All (13 soils)		54	0.61	65

*WEP and $CaCl_2$ are estimates of phosphorus that could be transported by runoff. Please see Casson et al. (2006) for more detail.

Conclusion

Soils with STP concentrations greater than the agronomic threshold of 60 mg/kg in the top 15 cm are generally more susceptible to phosphorus transport in runoff water than soils with lower STP concentrations. Therefore, to minimize phosphorus transport from agricultural land, maintaining STP concentrations at or below the agronomic threshold is recommended.

4.6 Development of Soil Phosphorus Limits

Introduction

The Alberta Soil Phosphorus Limits Project was initiated in 1999 to develop agricultural soil phosphorus limits for the protection of surface water quality. The objective was to develop a method for the calculation of soil phosphorus limits for agricultural land using field-scale relationships and information obtained from various studies carried out within the project (Jedrych et al. 2006). The proposed method was applied to six watersheds and seven microwatersheds in Alberta. Information from four landscape scales (i.e., watershed, soil polygon, microwatershed, and hillslope) was used to calculate soil phosphorus limits. The method calculates total phosphorus (TP) export coefficients based on hypothetical TP runoff water quality limits of 0.5 to 1.0 mg/L, for calculated runoff flow volumes at the watershed scale.

Results

A hypothetical TP runoff water quality limit of 0.5 mg/L showed STP limits of 60 mg/kg or less were identified in the top 15 cm of soil for most land within the selected watersheds (Figure 4.7a). With a hypothetical TP runoff water quality limit of 1.0 mg/L, the majority of the selected watershed areas had STP limits from 30 to 120 mg/kg.

When applied at the provincial scale, the hypothetical TP runoff water quality limit of 0.5 mg/L showed STP limits were less than 60 mg/kg for 84% of the agricultural land base, 60 to 180 mg/kg for 14% of the land base, and greater than 180 mg/kg for 2% of the land base. Using the hypothetical TP runoff water quality limit of 1.0 mg/L, STP limits were less than 60 mg/kg for 43% of the agricultural land base, from 60 mg/kg to 180 mg/kg for 48% of the land base and greater than 180 mg/kg for 9% of the land base.

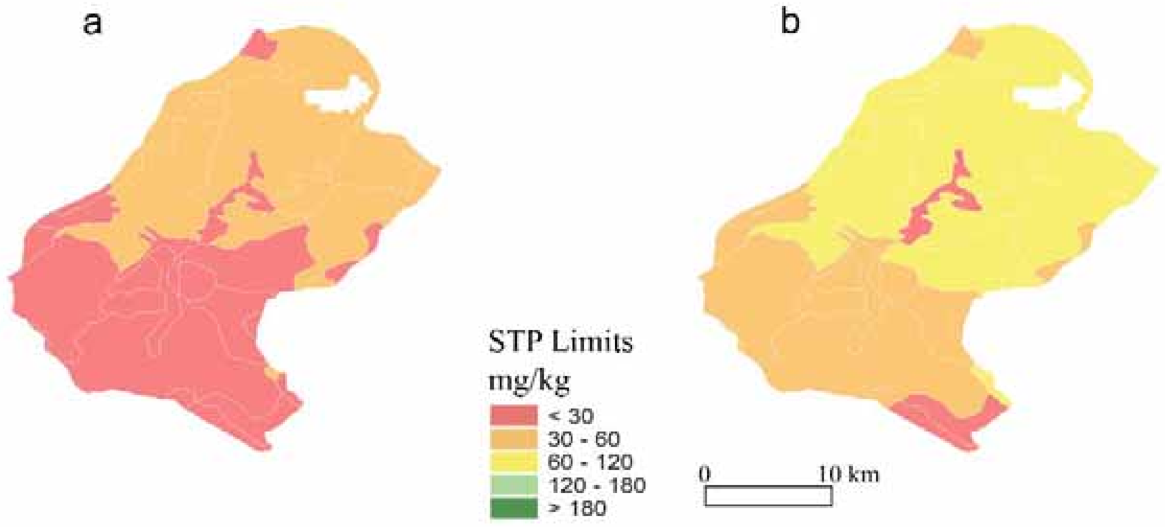


Figure 4.7. Examples of calculated soil test phosphorus (STP) limits for total phosphorus runoff water quality limits of (a) 0.5 mg/L and (b) 1.0 mg/L in the Wabash watershed.

Conclusion

Soil test phosphorus limits were determined for all agricultural land in Alberta using: soil test phosphorus and runoff phosphorus relationships, long-term climatic and hydrometric data, provincial soil and landform information, and hydrological modeling. Based on the agronomic threshold of 60 mg/kg STP and using a hypothetical TP runoff water quality limit of 1.0 mg/L, about 1.9 million ha of agricultural land would need to maintain STP levels below 30 mg/kg, or half of the agronomic threshold of 60 mg/kg. Producers on 8.9 million ha would need to maintain STP levels between 30 mg/kg and 60 mg/kg.

5.0 Predicting Phosphorus Losses from Agricultural Areas[3]

5.1 Introduction

Alberta soil-runoff phosphorus (P) relationships aim to quantify the relationship between phosphorus levels in soil (as soil test phosphorus (STP)) and phosphorus concentrations in runoff from cultivated land (as Total Phosphorus (TP)). Soil-runoff relationships were developed on a site-specific basis in Alberta, as described in Chapter 4, Section 4.3 of this report (Little et al. 2006; Casson et al. 2008). The study concluded that as STP in soil increased, TP and total dissolved phosphorus (TDP) flow-weighted mean concentration (FWMC) in runoff increased in a predictable fashion. The soil-runoff relationships were developed using field scale data and it was anticipated these equations would show a similar relationship at the watershed scale. At a watershed scale, the relationships could help to predict instream concentrations and export coefficients for TP and TDP in agricultural watersheds. To evaluate the watershed scale application of these relationships, two assessments were made, one on Haynes Creek M1 watershed (2,600 ha) and another on selected *AESA Stream Survey* watersheds (3,200 to 70,350 ha).

The objectives of this project were to analyse existing Alberta soil and runoff P data to:

1. Evaluate the performance of previously derived Alberta soil-runoff P relationships at small (Haynes Creek M1) and moderate (AESA) watershed scales,

2. Apply soil-runoff relationships to calculate P export coefficients at small and moderate watershed scales, and

3. Identify critical source areas in terms of the contribution of P loads at a small watershed scale and develop P Export Risk Categories for both small and moderate sized watersheds.

5.2 Assessment 1: Haynes Creek M1 Watershed

The Haynes Creek M1 (HM1) watershed (2,600 ha) is located near Red Deer, Alberta (Figure 5.1). Soil texture ranges from medium to moderately fine, although there are significant coarse-textured soils along streams and in bedrock outcrops. In 2000, there were 1,500 hogs in the watershed and approximately 125 cow-calf pairs during the summer grazing periods (Svederus et al. 2006). Cow-calf pairs increased to 900 animals during the winter. Manure from wintering sites and hog operations was spread on several cultivated fields.

Figure 5.1. Location of the Haynes Creek M1 watershed.

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[3] *Jedrych 2008*

Methods

Soil-Runoff P Relationships:

For the assessment of the soil-runoff relationships, two data sets are required: 1) soil (STP) data for input into the equation, and 2) water quality data (as FWMC) to verify whether the predicted values are accurate.

The two soil-runoff relationships derived to predict phosphorus losses from agricultural fields (Little et al. 2006; Casson et al. 2008) are:

1. TP FWMC = 0.014 * $STP_{(0\text{-}15\ cm)}$ + 0.16
2. DRP FWMC = 0.014 * $STP_{(0\text{-}15\ cm)}$ - 0.175

Where:
STP is the soil-test phosphorus at the 0 -15 cm level
FWMC is the flow-weighted mean concentrations (water quality data)
TP is Total Phosphorus
DRP is Dissolved Reactive Phosphorus*
* note: DRP is equivalent to Total Dissolved Phosphorus (TDP)

Soil-test phosphorus data. Composite soil samples from 351 sites and from two depths (0 to 5 cm and 0 to 15 cm) within the HM1 watershed were obtained for use in the soil-runoff relationships (Svederus et al. 2006). These soil samples ranged from 13.9 to 90.6 mg/kg and only two sub-watersheds had higher STP values than 60 mg/kg. The STP variability among sampling locations (0 to 5 cm and 0 to 15 cm depths) was very high. The majority (89%) of the 0 to 15 cm depth soil samples contained STP concentrations at or below the agronomic threshold of 60 mg/kg (Howard 2006).

Water quality data. This assessment used annual nutrient chemistry and stream flow data collected from the mouth of Haynes M1 Creek watershed during the *AESA Stream Survey* program to verify the output from the soil-runoff relationship. Annual flow volumes and TP and TDP FWMCs were measured from 1995 to 2006 (Lorenz et al. 2008). The TP FWMC ranged from 0.695 to 0.768 mg/L and TDP ranged from 0.541 to 0.599 mg/L during the 2000 and 2001 period.

SWAT Model Predictions of runoff potential. The HM1 watershed was divided in 35 sub-watershed units, ranging from 6 to 228 ha in size (Figure 5.2) and the SWAT model (Arnold et al. 1998) was used to estimate the distribution of runoff potential within the watershed. To undertake this task, the model required the input of four data sets: soil, topography, climate, and land use conditions. Soil input data was derived from the Agricultural Regions of Alberta Soil Database (AGRASID) (MacMillan and Pettapiece 2000). Topographic characteristics (i.e. sub-watershed areas, slope steepness and length) were derived from 25 m x 25 m Digital Elevation Model (Figure 5.2). Thirty-four years (1970 to 2003) of climate data were used in the model, including daily precipitation, temperature, solar radiation, wind speed, and relative humidity values (Shen et al. 2000). Finally, land use data was extracted from satellite images taken between 1993 and 1995. Haynes Creek M1 land use included 57% annual crops, 27% hay fields, 10% pastures, 6% forests, and 0.2% wetlands.

Runoff simulations were conducted for all 34 years with climate data (1970 to 2003), although only the last nine years of simulations were used to assess the SWAT runoff predictions.

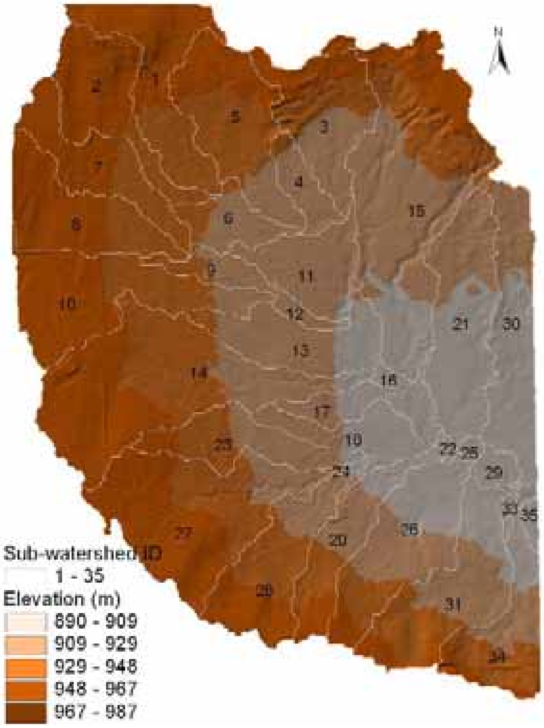

Figure 5.2. Distribution of 35 sub-watersheds and elevation ranges within HM1 watershed.

Critical source areas and Export Coefficients. The STP data collected at the 351 sites within HM1 were used to calculate an average STP value for each of the 35 sub-watersheds as described above. Critical source areas and export coefficients were calculated using average sub-watershed STP, SWAT-calculated runoff potential, and sub-watershed area.

Results and Discussion

Assessment of soil-runoff phosphorus relationships. Assessment of the Alberta-derived soil-runoff phosphorus equations in the HM1 watershed compared instream measured TP and TDP FWMC with TP and TDP FWMCs estimated from the soil-runoff relationships. Results suggested that over 90 and 82% of TP and 49 and 54% of TDP measured in 2000 and 2001, respectively, can be directly related to measured STP concentrations in the top 15-cm soil depth (Table 5.1). The data also showed that only 10 and 18% of TP and 51 and 46% of TDP instream can be attributed to other sources in the HM1 watershed, such as confined cattle wintering sites or other point sources. The results are encouraging for the prediction of instream TP FWMCs provided there is adequate STP data available. On the other hand, the estimated TDP concentrations are less reliable and suggest that STP concentration is not a good predictor of TDP FWMC when applying the equation at a small watershed scale. This finding is supported by Elrashidi et al. (2005) who suggested that edge-of-field measurements may not relate with instream values as phosphorus concentrations could be reduced by 17% after flowing from the edge-of-field due to factors such as change in water chemistry and removal of the nutrient from the system by aquatic plants.

Table 5.1. Comparison between measured and estimated TP and DRP FWMC in Haynes Creek M1 watershed.

Year	Estimated Mean STP (mg/kg)	Stream observed FWMC (mg/L)		Estimated FWMC (mg/L)	
		TDP	TP	TDP	TP
2000	33.6	0.599	0.695	0.295	0.630
2001		0.541	0.768		

Assessment of SWAT predictions. The application of the SWAT model in the HM1 watershed showed high variability in runoff potential within sub-watersheds, ranging from 0.3 mm to 34.8 mm. The majority of the runoff occurred during snowmelts events (~ 62%); the annual runoff depth was related more to spring weather conditions than to annual total precipitation. The predicted runoff depths were also related to land use, as perennial crop fields had lower values than annual crop fields.

Defining Critical Source Areas and Calculating Export Risk. An estimate of sub-watershed vulnerability to TP export was made by combining SWAT calculated runoff potential and subwatershed STP data. Calculated export coefficients were placed into P Export Risk categories based on previous targets as defined by Anderson (2006). Exports larger than 0.069 hg/ha/yr were classified as high while exports between 0.035 and 0.069 kg/ha/yr were classified as moderate and finally, those exports below 0.035 kg/ha/yr were classified as low. It was interesting to note that the sub-watersheds having higher STP concentrations did not always export the highest amount of TP and TDP, and that other watersheds having lower STP concentrations did not export the lowest amount of TP and TDP. The highest amount of TP and TDP was consistently exported from those areas where high runoff potential coincided with elevated STP (Table 5.2).

Critical source area analyses showed high-risk areas accounted for 45% of the watershed and contributed 64% of TP to the stream (Figure 5.3). The data also showed that there would be very little change at the mouth of the watershed (0.3%) in TP load to the stream if STP levels were maintained below the agronomic threshold of 60 mg/kg in the HM1 watershed. If the runoff volume was reduced (i.e. through run-on diversion) by 10% in the "High" risk area, it was predicted that there would be a much higher reduction (6.4%) in the TP export.

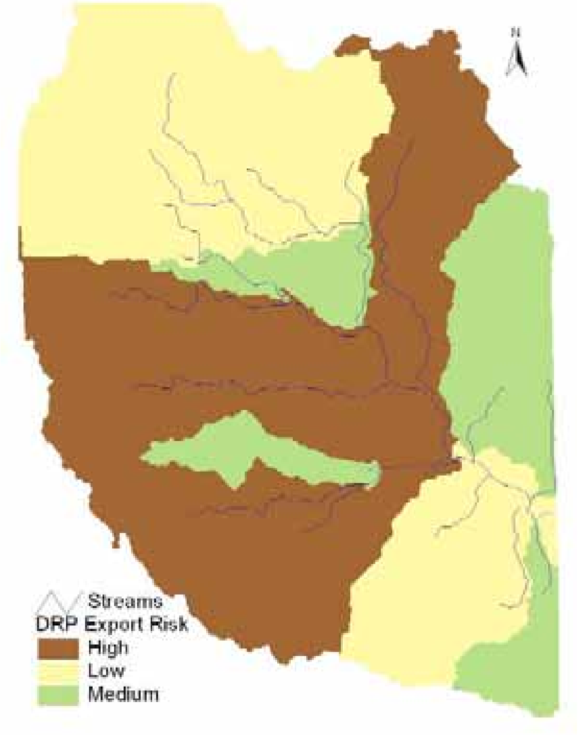

Figure 5.3 P Export Risk areas within HM1 watershed.

Table 5.2. Estimated average TP and TDP export coefficients and P Export Risks for selected HM1 sub-watersheds.

Selected Sub-watershed ID#	Area (ha)	Runoff depth (mm)	STP (mg/kg)	Estimated Average		
				TP export coefficient (kg/ha/yr)	TDP export coefficient (kg/ha/yr)	P Export Risk
6	41	34.2	16.1	0.132	0.017	Low
3	97	2.0	76.5	0.025	0.018	Low
9	27	34.0	24.5	0.171	0.057	Medium
34	82	19.9	36.2	0.133	0.066	Medium
17	44	34.1	48.5	0.286	0.172	High
16	6	20.4	90.6	0.291	0.223	High

5.3 Assessment 2: Evaluating Soil-Runoff Relationships in Selected AESA Watersheds

The *AESA Stream Survey* program examined water quality in 23 small agricultural watersheds across Alberta. The watersheds represented different levels of agricultural intensity (low, moderate, high) and types (dry-land versus irrigation) across a range of runoff, soil, and climate conditions (Anderson et al. 1999). The selected 15 watersheds used in this section ranged in size from 3,220 ha (Kleskun Drain) to 70,350 ha (Buffalo Creek). Land cover was also variable with up to 81% cropland in intensively cultivated watersheds like Renwick Creek in the Aspen Parkland ecoregion, as compared to only 4% cropland in Blindman River watershed in the Boreal ecoregion.

Methods

Soil-runoff phosphorus relationships. Similar to HM1, the two relationships derived in the Phosphorus Limits study were used to calculate TP and TDP FWMC using STP data.

STP data. Unlike HM1, a comprehensive STP database was not available for the AESA watersheds. Two existing provincial scale soil datasets (1993 to 1997 (Manunta et al. 2000), and 2000 to 2005 (unpublished)) were selected to match the 1995 to 2006 water quality dataset. In total, only 15 of the 23 AESA watersheds had soil data available for the period. Generally, the number of samples per watershed ranged from 3 to 336, which was a great deal lower than the density used for HM1. Soil-test phosphorus means ranged from 6 to 54 mg/kg in the selected watersheds. These low STP values indicate that the sampling was biased towards fields that had low nutrient concentrations and may not represent the spatial variability of the actual soil nutrient levels within each watershed.

Water quality data. Total P and TDP FWMC were incorporated from *AESA Stream Survey* for the 15 watersheds (Lorenz et al. 2008). Water sampling frequency varied in each watershed from 3 to 35 samples per year per watershed. The observed annual average TP and TDP FWMC ranged from 0.184 to 0.717 mg/L and from 0.011 to 0.619 mg/L during the 1995 to 2006 period, respectively.

Results and Discussion

Assessment of soil-runoff phosphorus relationships. The comparison of observed STP values in 15 AESA watersheds and their respective instream TP and TDP FWMCs did not show any correlation. This was not surprising since the mean STP concentrations were in a narrow range (6 to 54 mg/kg) relative to the wider STP range (3 to 512 mg/kg) used to develop the Alberta-derived soil-runoff phosphorus relationships. In addition, there was limited spatial STP variability within each watershed. Due to these limitations, the AESA STP data was considered unsuitable for evaluation of the soil-runoff phosphorus relationships, identification of critical source areas, and estimation of P export coefficients in these watersheds. As such, P export coefficients and P Export Risk Categories for the AESA watersheds must rely on estimated soil (STP) data.

5.4 Assessment 3: Estimated P Export Risk Categories in Selected AESA Watersheds

Methods

Two hypothetical STP scenarios were assumed to define critical source areas and to calculate expected TP and TDP FWMCs in runoff in the AESA watersheds lacking sufficient STP data. Scenario 1 considered STP concentrations associated with high agricultural intensity watersheds (STP = 30 mg/kg), similar to the HM1 watershed. Scenario 2 considered STP concentrations similar to the agronomic threshold (STP = 60 mg/kg).

Due to some uncertainty associated with delineation of effective drainage area and calculations of runoff potential, only 15 of 23 AESA watersheds could be used for runoff depth and critical source area analyses (Table 5.3). Jedrych et al. (2006) previously estimated the runoff distribution polygons within these watersheds using the Water Erosion Prediction Model (WEPP) (Flanagan and Livingston 1995) and these values were adopted in the study. It is important to note that WEPP simulations were conducted at the AGRASID defined soil polygon scale and two major assumptions were made:

1. Land cover is 100% cropland with continuous barley production, and
2. Landscape conditions are uniform.

Though the assumptions generalize land cover and landscape conditions, they emphasize relative difference in runoff potential among polygons.

Results and Discussion

Watershed scale analysis. Results of TP and TDP export coefficient calculations are shown in Table 5.3. The calculated values varied proportionally to the change in STP concentrations and to runoff depth (i.e., volume). Total P and TDP export coefficients increased by approximately 70% and 170%, respectively, when STP increased from 30 to 60 mg/kg. In addition, as runoff depth increased, TP and TDP export also increased by a similar proportion. The median measured *AESA Stream Survey* export coefficients, from 1999 to 2006, are also included in Table 5.3. Although the estimated export coefficient did not necessarily correspond with the actual measured export coefficient, both were generally in the same order of magnitude (i.e. same number of decimal points). The inconsistency between measured and estimated export coefficients can be attributed to the limitation of available STP and runoff data.

Table 5.3. Summary of calculated runoff depths, estimated TDP and TP export coefficients, and measured export coefficients for 15 AESA watersheds.

Ecological Regions	Watershed Name	2001 Ag-Intensity Ranking	Observed Runoff Depth (mm)	Estimated Export Coefficient (kg/ha/yr) for:				Median Measured Export Coefficient (kg/ha/yr) for:	
				STP = 30 mg/kg		STP = 60 mg/kg		1999 to 2006	
				TDP	TP	TDP	TP	TDP	TP
Parkland	Haynes Creek (M6)	High	11.1	0.027	0.064	0.074	0.111	0.088	0.1
Parkland	Stretton Creek	High	14.1	0.035	0.082	0.094	0.141	0.093	0.104
Parkland	Renwick Creek	High	15.4	0.038	0.089	0.102	0.154	0.086	0.103
Parkland	Threehills Creek	High	24.9	0.061	0.144	0.166	0.249	0.106	0.139
Parkland	Ray Creek	High	29.6	0.073	0.172	0.197	0.296	0.062	0.072
Parkland	Buffalo Creek	Medium	29.9	0.073	0.174	0.199	0.3	0.023	0.035
Boreal Forest	Wabash Creek	Medium	7.7	0.019	0.045	0.052	0.078	0.02	0.022
Boreal Forest	Strawberry Creek	Medium	38.5	0.097	0.229	0.262	0.394	0.03	0.169
Boreal Forest	Tomahawk Creek	Low	53.8	0.153	0.361	0.414	0.623	0.036	0.125
Boreal Forest	Blindman River	Low	90.3	0.23	0.544	0.623	0.937	0.13	0.214
Grassland	Prairie Blood Coulee	Medium	15.4	0.038	0.089	0.102	0.154	0.007	0.012
Grassland	Meadow Creek	High	40.7	0.1	0.236	0.271	0.407	0.003	0.017
Grassland	Trout Creek	Low	60.5	0.148	0.351	0.402	0.605	0.002	0.02
Peace Lowland	Kleskun Drain	Low	40.9	0.1	0.237	0.272	0.409	0.12	0.161
Western Upland	Paddle River	Low	69.2	0.174	0.412	0.472	0.71	0.032	0.067

AGRASID scale analysis. In this assessment, critical source areas were identified by sorting calculated TP and TDP export coefficients in ascending order and grouping them into five arbitrarily defined P Export Risk categories (negligible, low, medium, high and extreme) (Table 5.4). Total P export coefficients ranged from 0.037 to 1.544 kg/ha/yr, while TDP export coefficients ranged from 0.087 to 2.332 kg/ha/yr when both 30 and 60 mg/kg STP scenarios were used (Table 5.4). Reckhow et al. (1980) reported a similar range of TP export coefficients (0.08 to 3.25 kg/ha/yr) in their review of available literature on mixed agricultural watersheds in Canada and the United States.

Additional calculations were conducted at the AGRASID scale for Scenario 1 (30 mg/kg STP) to evaluate the effects of the proposed P Export Risk categories on the overall calculated TP export in the selected AESA watersheds. Scenario 1 was selected because it represents more realistic STP concentrations in Alberta soils. The results showed that when combined Negligible and Low P Export Risk categories accounted for 41.8% of the total AGRASID defined sub-watershed areas and 13.3% of the total amount of TP export (Table 5.5). However, the combination of High and Extreme Export Risk categories represented 40.7% of the defined polygon area, but accounted for a much larger amount of TP exported (i.e., 71.1% of the total).

Table 5.4. Summary of Phosphorus Export Risk categories, associated runoff depths and TP and TDP maximum export coefficients based on runoff depths.

P Export Risk	Annual runoff depth (mm)	Estimated maximum export coefficient (kg/ha/yr) for:			
		STP = 30 mg/kg		STP = 60 mg/kg	
		TP	DRP	TP	DRP
Negligible	<15	0.037	0.087	0.1	0.15
Low	15-23	0.057	0.136	0.155	0.234
Medium	23-39	0.094	0.223	0.256	0.385
High	39-58	0.143	0.338	0.388	0.583
Extreme	>58	0.569	1.347	1.544	2.322

Table 5.5. Distribution of the estimated area and estimated TP load among the P Export Risk categories based on available data for the 15 selected AESA watersheds.

P Export Risk categories	Number of selected AGRASID polygons	Polygon area		TP load (assumed STP = 30 mg kg^{-1})	
		Ha	% of total	kg $year^{-1}$	% of total
Negligible	140	75693.3	21.2	596541.7	5.1
Low	131	67264.5	18.8	950514.7	8.2
Medium	150	68802.5	19.2	1797642.3	15.5
High	131	58354.6	16.3	2135826.6	18.4
Extreme	140	87352.1	24.4	6112710.6	52.7
Total	**692**	**357467**	**100**	**11593236**	**100**

Since the proposed P Export Risk categories are directly related to runoff potential, low runoff watersheds have the lowest risk of P export. Haynes Creek and Wabash Creek had the largest areas in the Negligible and Low categories (Figure 5.4). The Buffalo Creek, Ray Creek, and Threehills Creek watersheds are examples of watersheds with large proportions of the area in the Medium P Export Risk category while the Blindman River, Paddle River and Trout Creek watersheds had the largest estimated proportion of area in the High and Extreme category.

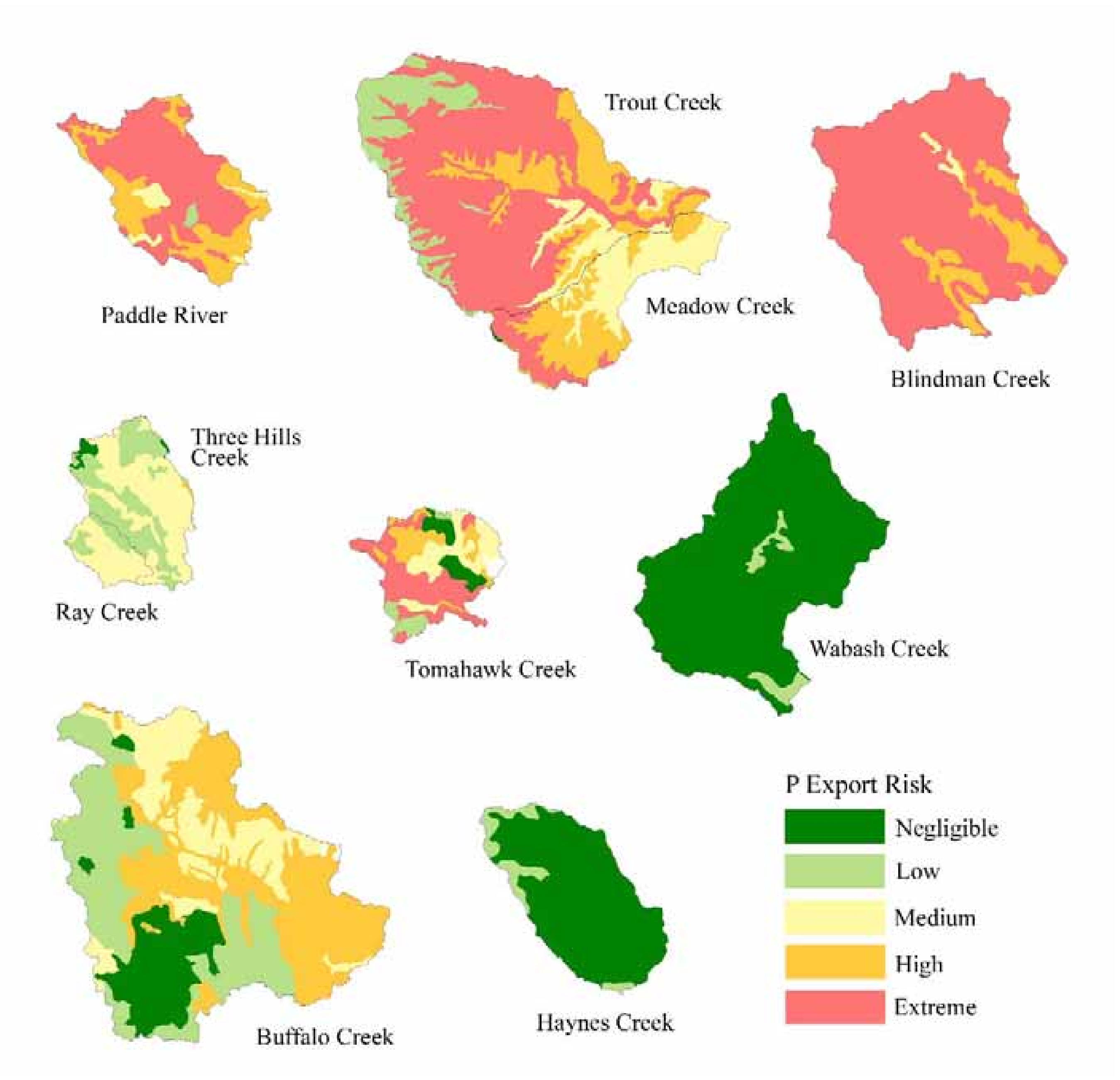

Figure 5.4. Distribution of P Export Risk categories within selected AESA watersheds.

5.5 Key Findings

The application of the soil-runoff relationship in the HM1 watershed could predict 82 to 90% of TP and 49 to 54% of TDP concentrations instream. The TP results are encouraging and suggesting that the equation is a potential tool that can predict TP loading from small watersheds (2,600 ha), provided there is adequate STP data available.

The comparison of observed STP values in 15 AESA watersheds and their respective TP and TDP FWMCs data did not show any correlation. The lack of correlation was attributed to a narrow range of AESA STP as well as poor representation of the actual spatial STP variability within each watershed. Due to these limitations, the AESA STP data was not considered suitable for evaluation of the Alberta derived soil-runoff phosphorus relationships or for identifying critical source areas and estimating export coefficients in these watersheds.

Critical source areas, areas where high runoff potential coincides with elevated STP, are likely responsible for the majority of nutrient losses from agricultural land. Phosphorus export coefficients were directly related to site-specific runoff potential and average STP concentrations. A reduction in STP concentrations and control of runoff from high-risk areas (i.e., run-on and run-off management practices) would be the most effective way to reduce TP loading into surface waters. Identification of critical source areas will help to direct land management practices to areas that will experience the greatest environmental benefit.

Limited field measurements of STP and runoff values in AESA watersheds and other issues caused by data extrapolation from a field to a watershed scale resulted in estimated P export coefficients for the 15 selected AESA watersheds that were unrelated to actual P export coefficients. However, the analysis illustrates the process of defining critical source areas, identifies gaps in the availability of the existing data, and provides a starting point for the ground-truthing of critical source areas (i.e., collection of additional STP data and detailed runoff potential information).

6.0 Conclusions

1. **A comprehensive soil and surface water quality database is now available for Alberta's agricultural areas.**

   - Data were collected through the Alberta Environmentally Sustainable Agriculture (AESA) soil (1998 to 2006) and water quality (1997 to 2006) projects for representative agricultural regions of Alberta.
   - Soil quality data from 42 sites were representative of cropland managed under progressive practices in Alberta.
     - The benchmark sites represented non-manured agricultural soils in Alberta.
     - The data set includes soil quality parameters (nutrients, bulk density, and soil organic carbon) for different landscape positions (lower and upper slope positions) and ecoregions across Alberta's agricultural zone.
   - Water quality data from 23 small watersheds represented the varying degrees of agricultural intensity (low, moderate, and high) and agricultural management (dryland and irrigated).
     - The data set includes nutrient, bacteria, and pesticide data for individual watersheds, agricultural intensity classifications, and ecoregions across Alberta's agricultural zone.

2. **Provincial-scale soil and surface water quality have remained relatively constant during the last decade.**

   - Most key measures of soil quality were unchanged during the monitoring period, with the exception of agronomic soil test phosphorus (STP) levels and bulk density.
     - Soil test phosphorus increased during the nine-year study in the 0 to15 cm layer, which may indicate increased fertilizer use consistent with the observed increase in provincial fertilizer sales. However, STP levels remained below the agronomic threshold of 120 kilograms/hectare at the benchmark sites.
     - Soil bulk density tended to decrease with time as practices improved to include more reduced tillage and use of forages in rotation. Soil bulk density ranged from 1.18 to 1.36 g/cm^3 and was highest during years of low precipitation and lowest at the lower slope position in the upper soil layer, which corresponds to higher soil organic carbon concentrations.
   - Overall, nitrogen and phosphorus concentrations in surface water did not change in agricultural watersheds during the monitoring period.
     - Patterns in nutrient loads through time were related to discharge, climate, and precipitation.
     - Nutrient flow-weighted mean concentrations (FWMCs) were influenced to a large extent by agricultural intensity, while exports were driven largely by ecoregional characteristics (i.e., climate and landscape features).

3. **A field-scale relationship exists between phosphorus concentrations in the soil and surface water runoff; however, a relationship between nitrogen in the soil and surface water was not apparent.**

   - Non-manured benchmark AESA soils averaged less than 70 kilograms/hectare of STP; however, soils with long histories of heavy manure application could have higher STP values.
     - Other studies have reported STP values in excess of 1,000 kilograms/hectare and greater for soils receiving long-term cattle manure applications in southern Alberta. The continuous application of manure in excess of crop needs leads to a large accumulation of STP in soil, which can impact surface and groundwater quality.
   - The Alberta-derived relationship between phosphorus in soil and surface runoff found that the risk of phosphorus loss to runoff water increased with increasing STP concentrations.
     - Soils that were amended with manure and had STP concentrations above the agronomic threshold lost more phosphorus to surface waters.

4. **Surface water quality guidelines for nutrients were generally exceeded in Alberta's agricultural watersheds.**

   - Water quality guidelines were exceeded more frequently as agricultural intensity increased.
     - In the high agricultural intensity watersheds, water quality guidelines for total phosphorus (TP) and total nitrogen (TN) were most often exceeded. On average, total phosphorus met the protection of aquatic life guideline <12% of the time, and TN met the guideline <16%.
     - Low agricultural intensity watersheds met TP and TN guidelines for the protection of aquatic life on average <59 and <85% of the time, respectively.
   - Phosphorus and nitrogen concentrations in streams were generally highest in spring as a result of snowmelt runoff carrying excess nutrients to streams and rainfall events that mobilize dissolved and particulate phosphorus and nitrogen.

5. Surface water quality will deteriorate if agricultural intensity increases using current management practices.

- The AESA data support previous studies that show as agricultural intensity increases, water quality decreases.
- Nutrient and pesticide concentrations and detection frequencies increased with agricultural intensity.
- Bacteria data did not follow the same trend with increasing agricultural intensity.
  - The presence of fecal bacteria in agricultural streams appeared to be more closely related to ecoregion characteristics which reflect differences in livestock management and wildlife communities.
  - Median bacteria counts were generally low with occasional spikes in *E. coli* and/or fecal bacteria numbers. In the Boreal ecoregion, these spikes usually coincided with peaks in stream flow and suspended sediment levels, suggesting runoff produced by storm events transported bacteria to streams and/or resuspended bacteria from the bottom of the streams.
  - Bacteria counts tended to be consistently high throughout the irrigation season (May to October) in streams receiving irrigation return flows.

6. Low level concentrations of a variety of pesticides were commonly found in agricultural watersheds.

- Thirty-seven of 68 pesticides analysed in the water quality monitoring program were detected at least once from 1999 through 2006.
- Most of the pesticides detected were herbicides. The eight most common herbicides detected were 2,4-D, MCPA, dicamba, clopyralid, triclopyr, MCPP, picloram, and imazamethabenz-methyl.
- The types of herbicides detected in each watershed tended to be associated with increased agricultural intensity and management.
  - Low intensity agricultural watersheds generally had fewer pesticide detections compared to moderate and high intensity agricultural watersheds.
  - The frequency of pesticides detected in streams generally reflected the chemical sales and runoff potentials for those watersheds.

7. **There are concerns about possible cumulative impacts of the various herbicides found in the water.**

- Only 30 of the 68 pesticides that were analysed have water quality guidelines.
    - Of the 8 most commonly detected herbicides, only 4 have water quality guidelines. The 4 that do not have guidelines are clopyralid, triclopyr, MCPP, and imazamethabenz-methyl.
    - Approximately 11% of all samples that contained MCPA and dicamba exceeded the Alberta Surface Water Quality Guidelines for irrigation. These two compounds also exceeded the guidelines by the greatest amount. Seven other compounds exceeded water quality guidelines, either for irrigation or for the protection of aquatic life, but these exceedences occurred in less than 1% of the samples collected.
- Current guidelines do not account for possible synergistic effects of herbicides with the same mode of action or possible chemical interactions.
    - Multiple pesticides were detected simultaneously in many of the agricultural watersheds.

8. **The Alberta derived soil-runoff phosphorus relationships were able to predict TP and TDP concentrations at a sub-watershed scale.**

- The Haynes Creek M1 watershed soil-runoff relationship suggested that about 80% of TP and 50% of TDP measured in the stream could be directly related to STP values from the top 15 cm soil depth.
    - Approximately 20% of TP in the HM1 watershed was attributed to point sources.
- Detailed data sets including STP and area specific runoff values are required to assess the relationships for larger watersheds.
    - Although the soil-runoff phosphorus relationship was able to predict phosphorus concentrations at a sub-watershed scale, the relationship was not as strong at the larger watershed scale using STP and area specific runoff data currently available.

9. **Critical source areas, or areas with high nutrient levels and risk of runoff, are likely responsible for the majority of phosphorus losses from agricultural land.**

- A modeling study in the HM1 watershed showed that while the critical source areas with high STP levels represented approximately 45% of the watershed, these areas accounted for 64% of the TP export.
- Other areas within the watershed will also contribute over time and with multiple runoff events.

7.0 Recommendations

1. **Alberta's agriculture industry must focus efforts on reducing nutrient loads from agricultural lands into watersheds through improved on-farm and critical source area management**.

   - Continue to develop science-based, practical, and economical mitigation solutions (Beneficial Management Practices) that producers can implement to reduce nutrient loading to surface waters.
   - Implement appropriate on-farm and critical source area management practices in Alberta's watersheds through producer-led watershed stewardship groups.

2. **Develop surface water quality targets for nutrients in agricultural watersheds that are achievable, protective, and allow for sustainability in the long term given best agri-environmental management practices.**

   - Current water quality guidelines may restrict agricultural production, particularly livestock development, even with current technology and best management practices.
   - Establish nitrogen and phosphorus water quality targets for agricultural streams based on
     - ambient nutrient concentrations in watersheds with minimal human disturbance;
     - protection of water quality for aquatic ecosystem health, and;
     - livestock development with the best environmentally sustainable management practices.

3. **Assess the impacts of low levels of multiple pesticide residues in surface waters on aquatic ecosystem health.**

   - Low levels of pesticides commonly co-occur in Alberta's surface waters.
   - There are increasing concerns about the cumulative impact of pesticides on the health of aquatic ecosystems.
   - Without water quality guidelines, it is difficult to determine whether pesticides pose a threat to aquatic ecosystems, human drinking water, irrigated crops, or agricultural livestock.
     - support the development of surface water quality guidelines by the Canadian Council of Ministers of the Environment (CCME) for the four most frequently detected pesticides in Alberta surface waters (imazamethabenz-methyl, MCPP, clopyralid, and triclopyr).
   - Support implementation and further development of Alberta Environment's Pesticide Risk Assessment tool to evaluate the potential impacts of multiple pesticides on aquatic ecosystem health.

8.0 Glossary

Agricultural inputs. Fertilizers, pesticides, seed, fuel, feeds and other supplies purchased to operate a farm. Inputs are an important measure of agricultural intensity.

Baseflow. Stream discharge or flow composed of groundwater drainage and delayed surface drainage. Baseflow is typically characterized as that portion of stream flow not related to precipitation-induced runoff.

Beneficial management practice. Management practices that have been determined to be the most effective and practical in terms of production efficiency, environmental protection and social acceptance.

Buffer strips. Identified as one beneficial management practice (BMP) that can help protect surface water quality. It is an overland flow treatment system that can retain contaminants from runoff water by slowing the velocity of runoff water to facilitate settling out of suspended solids, infiltration of runoff and soluble pollutants, uptake of soluble nutrients by plants, and adsorption of contaminants to soil and plant surfaces.

Bulk density. The weight of soil particles (organic and inorganic) divided by the volume that they occupy. Most mineral soils that are composed of less than 20 to 35% organic matter, have bulk densities between 1.0 and 2.0 g/cm^3. Bulk densities are important in calculating soil moisture movement within a soil profile.

Cation exchange capacity. The capacity of a soil to exchange positively charged ions (cations) between the soil and soil solution. It is used as a measure of fertility, nutrient retention capacity, and the capacity to protect surface and groundwater from contamination.

Chernozemic soils. These surface soils are high in organic matter (ranging from 3 to 10%), well to imperfectly drained and are associated with grassland vegetation. The soils groups within this order are divided up by the colour of the surface soil: Brown, Dark Brown, Black, and Dark Gray which reflects the soil organic matter content of the soil. The darker surface colour of the soils reflects the greater organic matter content.

Conservation tillage. Crops are grown with minimal cultivation of the soil. Stubble or plant residues are not completely incorporated and most or all remain on top of the soil rather than being plowed or disked into the soil. The new crop is planted into this stubble or small strips of tilled soil. Weeds are controlled with cover crops or herbicides rather than by cultivation. Fertilizer and lime are either incorporated earlier in the production cycle or placed on top of the soil at planting.

Denitrification. The reduction of nitrate into nitrogen gases when oxygen is depleted.

Dissolved phosphorus. Often referred to as total dissolved phosphorus (TDP). After infiltration through a 0.45 µm (micrometres) filter, the total phosphorus in the filtrate is measured, usually first by digesting a sample of the filtrate. This includes dissolved inorganic and organic phosphorus. The phosphorus fractions that pass through the filter are assumed to be dissolved and the fractions that do not pass through are in particulate form.

Dissolved reactive phosphorus. The fraction of phosphorus that reacts with molybdenum-blue colorimetric reaction after a water sample has been past through a 0.45 µm filter.

Ecoregion. Distinctive regional similarities in plant and animal species, climate, soils, and the general topography of the landscape.

Eluviation. The movement of humus, chemical substances and mineral particles from the upper layers of a soil to the lower layers by the downward movement of water through the soil profile.

Eutrophication. Is the process whereby water bodies receive excess nutrients that stimulate excessive plant growth. This enhanced plant growth, often called algal bloom, reduces dissolved oxygen in the water when dead plant material decomposes and can cause other organisms to die.

Fecal Coliform bacteria. Coliforms are a large group of naturally occurring bacteria, commonly found in topsoil, bodies of water and animal wastes. Fecal coliforms, a particular group of coliform bacteria, which live in the digestive systems of warm and cold-blooded animals, help the body process food. *Escherichia coli (E. coli)* bacteria are the most common type of fecal coliform. In water analyses, fecal coliforms are used as an indicator of the presence of animal wastes.

Flow-weighted mean concentration. Flow-weighted mean concentration (FWMC) is calculated by dividing the total mass or load of a pollutant by the total flow for a given time period. The FWMC is mass normalized for flow.

Furrow irrigation. Method of surface irrigation in which feeding narrow furrows very close to one another are used to guide water across the field

Grassed waterway. Broad, shallow, saucer-shaped channels designed to move surface water across farmland without causing soil erosion. The vegetative cover in the waterway slows the water flow and protects the channel surface from erosion and are often constructed in natural depressions where the water collects and flows to an outlet.

Groundwater. Water in porous rock strata or soils. Groundwater may come to the surface naturally in seeps, springs or other water bodies. Wells are used to tap groundwater sources for human use. Groundwater is the highest greatest source of freshwater on the planet.

Immobilization. Immobilization is the opposite of mineralization and is the process whereby plant accessible nutrients are absorbed by microorganisms and are no longer accessible to plants.

Load. Is the total amount or mass of a water quality variable passing through a stream during a given time period, often seasonally or annually. A load reflects the combined contributions of surface runoff and groundwater discharge from a specific watershed, as measured at a monitoring station.

Luvisolic soils. These soils are associated with mixed forest vegetation, have a sandy loam to clay texture and are well to imperfectly drained. Under native conditions, the surface layer of Luvisolic soils are overlain with a layer of decomposing litter. The Luvisolic soils generally are light-coloured, eluvial surface horizons and a subsurface horizon where clay has accumulated.

Mineralization. Mineralization is a process whereby nutrients, such as nitrogen and phosphorus in organic matter, decompose into plant accessible forms.

Nitrification. Biological oxidation of ammonia with oxygen to form nitrite followed by the oxidation of nitrite into nitrate. It is part of the mineralization process.

Non-point source pollution. Applied to pollutants entering a water body in a diffuse pattern rather than from a specific, single location (e.g., land runoff).

Nutrients. Essentially nitrogen, phosphorus and potassium, which form the basic components of plant nourishment. In surface water, excess nitrogen and phosphorus promote excessive growth of aquatic plants.

Organic carbon. The amount of elemental carbon bound in an organic compound which can be used as a non-specific indicator of water quality. It is material derived from decaying vegetation, animals, bacterial growth, and metabolic activities of living organisms or chemicals.

Organic matter. Matter that came from a recently living organism, is capable of decay, or the product of decay; or is decomposed of organic compounds. In the soil, organic matter improves soil structure, maintains tilth and minimizes erosion and stores and releases nutrients through decomposition.

Parent material. Material from which soils are formed. An example of parent material is morainal till deposited during glaciation (the ice age).

Pedogenic. The process of soil evolution (formation). The process by which soil is created and is affected by factors such as climate, organisms and parent material (rock from which soil is formed).

Pesticides. Any substance or mixture of substances that prevent, destroy, repel or mitigate any pest. Herbicides, fungicides and insecticides are types of pesticides.

Point source pollution. Applied to pollutants entering a water body from a single, well-defined source such as a pipe or ditch.

Runoff. Precipitation that flows overland before entering a defined stream channel.

Soil A horizon. The mineral horizon that forms at or near the surface. It is the zone where leaching or eluviation of materials occurs or where most of the in situ soil organic matter will accumulate.

Soil B horizon. The subsurface mineral horizon that is characterized by an enrichment of organic matter or clay; or by the development of soil structure; or by a color change that indicates reduction or oxidation of minerals such as iron.

Soil C horizon. The subsurface soil horizon that is not as affected by pedogenic processes than A or B. Exceptions are gleying, accumulation of calcium and magnesium carbonates and soluble salts.

Sorption. The removal of an ion or molecule from solution by adsorption or absorption onto or into particulate material. It is often used when the exact nature of the mechanism of removal is not known.

Soil test phosphorus. The portion of soil phosphorus that is readily available for plant uptake. It is determined by extracting a soil sample with an aqueous extraction solution at room temperature. Also referred to as plant available or mineral phosphorus.

Summerfallow. Cropland left idle during the growing season.

Total suspended solids. Water quality measurement that describes particulate weight obtained by separating particles from a water sample using a filter.

Watershed. The total land area drained by a stream or river system.

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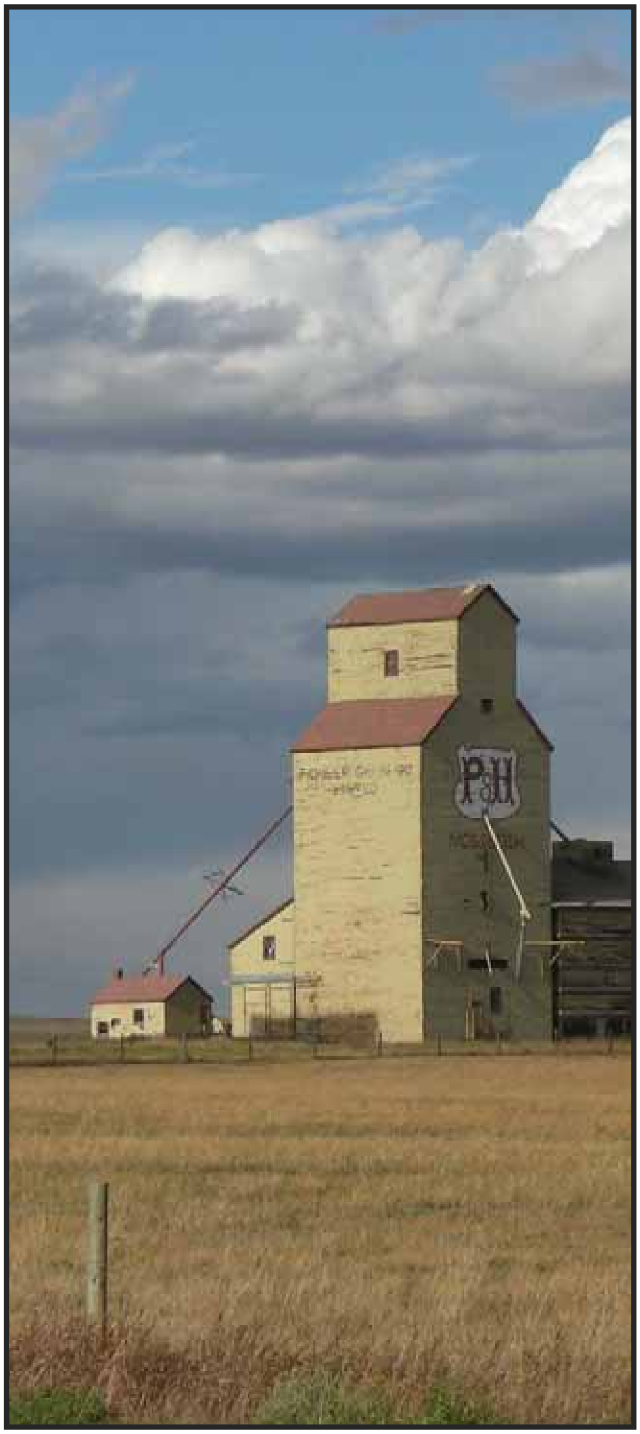

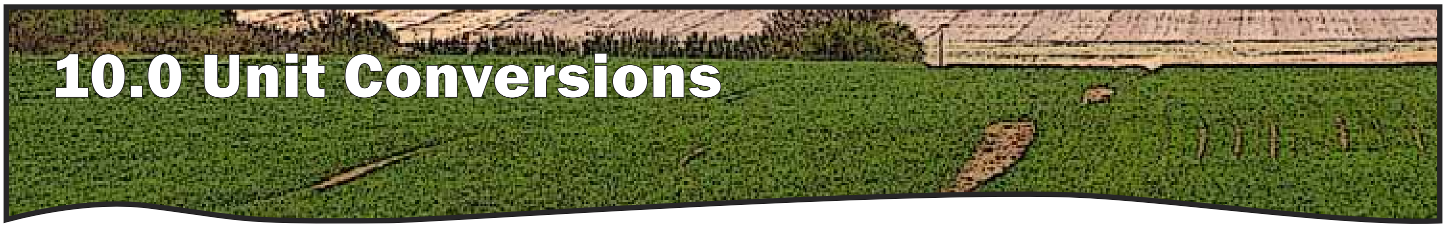

10.0 Unit Conversions

Metric to Imperial

Area:		
1 hectare (ha)	=	2.471 acres (ac)
1 square kilometre (km^2)	=	0.3861 square miles (mi^2)
Length:		
1 kilometre (km)	=	0.6214 miles (mi)
1 metre (m)	=	1.094 yards (yd)
1 metre (m)	=	3.281 feet (ft)
1 millimetre (mm)	=	0.0394 inches (in)
Volume:		
1 litre (L)	=	0.220 imperial gallons (gal)
1 cubic metre (m^3)	=	2.308 cubic yards (yd^3)
Weight:		
1 kilogram (kg)	=	2.2046 pounds (lb)
1 megagram (Mg)	=	1.1023 tons (tn)
Rate or yield:		
1 kilogram per hectare (kg/ha)	=	0.8922 pounds per acre (lb/ac)
1 megagram per hectare (Mg/ha)	=	0.4461 tons per acre (tn/ac)

Metric to Metric

1 hectare (ha)	=	10 000 square metres (m^2)
1 kilometre (km)	=	1 000 metres (m)
1 metre (m)	=	100 centimetres (cm)
1 metre (m)	=	1 000 millimetres (mm)
1 litre (L)	=	1 000 millilitres (mL)
1 megagram (Mg)	=	1 tonne (t)
1 megagram (Mg)	=	1 000 kilograms (kg)
1 kilogram (kg)	=	1 000 grams (g)
1 gram (g)	=	1 000 milligrams (mg)
Concentration		
milligrams per kilogram (mg/kg)	=	parts per million (ppm)
milligrams per litre (mg/L)	=	parts per million (ppm)

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