ALBERTA SOIL PHOSPHORUS LIMITS PROJECT

Volume 1
Summary and Recommendations

Alberta Soil Phosphorus Limits Project
Index to Volumes

Alberta Soil Phosphorus Limits Project

Volume 1:

Summary and Recommendations

Brent A. Paterson, Barry M. Olson, and D. Rodney Bennett

Irrigation Branch, Alberta Agriculture, Food and Rural Development
Lethbridge, Alberta, Canada

2006

Alberta Soil Phosphorus Limits Project

Alberta Agriculture, Food
and Rural Development

Citation
Paterson, B.A., Olson, B.M., and Bennett, D.R. 2006. Alberta soil phosphorus limits project. Volume 1: Summary and recommendations. Alberta Agriculture, Food and Rural Development, Lethbridge, Alberta, Canada. 82 pp.

Published by
Irrigation Branch
Alberta Agriculture, Food and Rural Development
Lethbridge, Alberta, Canada

Printed in Canada

Copies of this report are available from
Irrigation Branch
Alberta Agriculture, Food and rural Development
Agriculture Centre
100, 5401-1 Ave. South
Lethbridge, Alberta
Canada T1J 4V6
Phone (403) 381-5140

ACKNOWLEDGMENTS

The project team expresses its appreciation for the significant amount of funding that was provided by: the Agricultural Funding Consortium, with contributions from the Alberta Livestock Industry Development Fund, the Alberta Crop Industry Development Fund, and the Alberta Agricultural Research Institute (project number 2003C0057R); the Canada Adaptation and Rural Development (CARD) Fund; and the Alberta Environmentally Sustainable Agriculture (AESA) Council.

Funding and resources were also provided by Alberta Agriculture, Food and Rural Development (Resource Management and Irrigation Division, Technical Services Division, Animal Industry Division, and Plant Industry Division).

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.

The authors are very grateful to Janna Casson, Frank Hecker, Andy Jedrych, Andrea Kalischuk, Joanne Little, Sheilah Nolan, Gerald Ontkean, and Barb Shackel-Hardman for reviewing earlier drafts of the Summary and Recommendations Report and for providing many valuable suggestions.

The Authors are particularly grateful to Bonnie Hofer of the Irrigation Branch, Alberta Agriculture, Food and Rural Development, for designing and coordinating the covers for the five volumes and the layout of Volume 1.

Contributions to the project were provided by the following staff from Alberta Agriculture, Food and Rural Development, Agriculture and Agri-Food Canada, Alberta Environment, and the University of Alberta.

Mohamed Amrani[1,2]
Anne-Marie Anderson[2,3]
Rod Bennett[1]
Janna Casson[1,5]
David Chanasyk[4,5]
Sandra Cooke[1,2]
Tom Goddard[1,2]
Dan Heaney[1,2]
Frank Hecker[1,5]
Kim Hodge[2,6]
Allan Howard[1,2]
Andy Jedrych[1]
Andrea Kalischuk[1,5]
Larry Kwasny[1,2]
Joanne Little[1,5]
Paolo Mantuna[1,2]
Tim Martin[1,2]
Dennis Mikalson[1,5]
Sheilah Nolan[1,5]
Barry Olson[1]
Gerald Ontkean[1,5]
Brent Paterson[1,7]
Murray Peters[1,5]
Sandi Riemersma[1,2]
Lawrence Schinkel[1,5]
Annette Svederus[1,2]
Douwe Vanderwel[1,2]
Callie Volf [4,5]
Ralph Wright[1,2]
Jamie Wuite[1,2]

[1]Alberta Agriculture, Food and Rural Development; [2]Phase 1 only (1999 - 2002); [3]Alberta Environment; [4]University of Alberta; [5]Phase 2 only (2002 - 2006); [6]Agriculture and Agri-Food Canada; [7]Project chair.

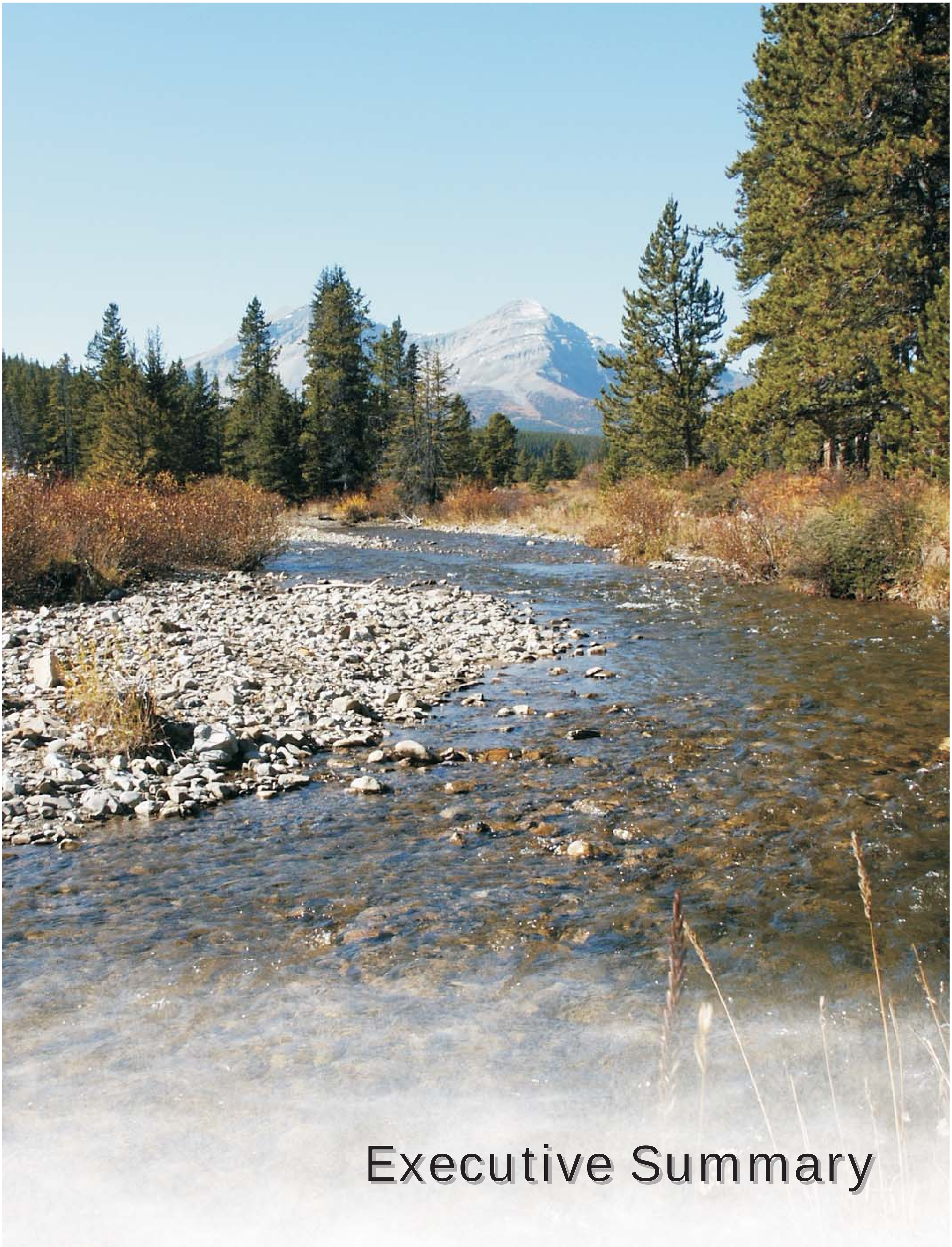
Two Steering Committees were established during the course of the project. The Steering Committee members provided valuable advice and direction to the Technical Working Group. The support from the livestock and crop industry members is greatly appreciated.

Steering Committee (1999 to 2001)

Doug Hall	Alberta Environmental Sustainable Agriculture Council
Dan Heaney	Alberta Agriculture, Food and Rural Development
Bill Mackay	W.C. Mackay and Associates
Barry Olson	Alberta Agriculture, Food and Rural Development
Brent Paterson (Chair)	Alberta Agriculture, Food and Rural Development
Barb Shackel-Hardman	Alberta Agriculture, Food and Rural Development
Gary Telford	Agriculture and Agri-Food Canada
Dave Trew	Alberta Environment
Joyce Van Donkersgoed	Intensive Livestock Working Group

Steering Committee (2004 to 2006)

David Chanasyk	University of Alberta
Ray Grimson	Lakeside Farm Industries Ltd.
Mike Hart	Alberta Egg Producers
Adrian Johnston	Phosphorus and Potash Institute
Bruce Konynenbelt	Alberta Pork
Erasmus Okine	University of Alberta
Rients Palsma	Alberta Milk
Brent Paterson (Chair)	Alberta Agriculture, Food and Rural Development
Barb Shackel-Hardman	Alberta Agriculture, Food and Rural Development
Stuart Thiessen	Alberta Beef Producers



Executive Summary

Introduction

The application of soil amendments, such as inorganic fertilizers, manure, biosolids, and wastewater, can improve soil fertility. However, many of these amendments, particularly organic materials such as animal manure, are often applied in excess of crop nutrient requirements. A build-up of nutrients in soil can be a significant risk to surface and ground water quality.

Phosphorus is an important nutrient for optimum crop production, but the movement of phosphorus from agricultural land to surface water can cause water quality degradation through accelerated eutrophication. Livestock production has been identified as a primary source of agricultural phosphorus in surface waters. Water quality studies in Alberta showed that as agriculture intensity increased in watersheds, the amount of phosphorus increased in streams.

The Agricultural Operation Practices Act was revised to protect soil and water quality through regulation of Alberta's confined feeding operations. The regulations under this Act include manure application limits based on nitrogen, but do not include soil phosphorus limits. It is well known that manure applied based on nitrogen will result in the accumulation of phosphorus in soil, which poses a risk to surface water quality. These concerns about phosphorus led to the establishment of the Alberta Soil Phosphorus Limits Project in 1999. The objectives of the project were:

1) To develop recommendations for phosphorus limits for agricultural land in Alberta;
2) To determine implications of soil phosphorus limits to the agricultural industry;
3) To identify management options for soil phosphorus limit implementation; and
4) To develop recommendations for an action plan and a time line for implementation of limits.

The Soil Phosphorus Limits Project was implemented in two phases. Phase 1 of the project (1999 to 2002) included the collection and review of background material related to agricultural phosphorus issues, a simulated rainfall study in the laboratory, and field studies in central Alberta. The following Phase 1 studies helped define the direction of the Soil Phosphorus Limits Project.

- Phosphorus loading effects on water quality in Alberta.
- Assessment of how other jurisdictions in North America and Europe have approached agricultural phosphorus issues.
- Assessment of agronomic phosphorus thresholds for Alberta crops.
- Assessment of phosphorus water quality limits in streams.
- Phosphorus sources and sinks in watersheds.
- Laboratory study to assess the relationship between soil-test phosphorus levels and phosphorus in runoff from representative Alberta soils.
- Assessment of soil-test phosphorus levels relative to phosphorus levels in the stream for an agricultural watershed.

Phase 2 (2002 to 2006) involved a series of research studies, hydrology studies, and computer modelling studies designed to:

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

The Phase 2 studies included the following actions.

- Assess the relationship between soil and runoff phosphorus in eight representative microwatersheds in Alberta's agricultural area.
- Assess the relationship between soil and runoff phosphorus in simulated rainfall runoff from manured land for representative Alberta soils.
- Relate phosphorus sorption to phosphorus runoff characteristics, and determine saturation thresholds for Alberta soils.

- Compare different core sampling techniques to a frame-excavation method to determine soil-test phosphorus concentrations for Alberta soils.
- Assess the economic impacts of legislated soil-test phosphorus limits on confined feeding operations in Alberta.
- Determine potential runoff volumes from Alberta landscapes using provincial soil and landform information, long-term climatic and hydrometric data, and hydrological modelling.
- Determine soil-test phosphorus limits for all agricultural land in Alberta.

Conclusions

The following general conclusions were developed from the background information and research findings generated through the Alberta Soil Phosphorus Limits Project.

Phosphorus as a nutrient

1. Phosphorus is an essential nutrient in agricultural systems and is important in nutrient management to achieve optimum crop production. Soil-test phosphorus (i.e., plant-available phosphorus) levels do not need to exceed 60 ppm (about 120 kg/ha) in the top 15 cm of soil to achieve optimum growth for most crops grown in Alberta. Crops grown on soils with phosphorus levels in excess of 60 ppm generally do not respond to phosphorus additions.

2. Most soils in Alberta are deficient in soil-test phosphorus. Analysis of soil test records from the agricultural areas has shown that most soils have soil-test phosphorus levels that are significantly below 60 ppm, which is considered the agronomic threshold level for most crops. Crops grown on these soils will benefit from addition of phosphorus. In general, soil phosphorus levels in the 1990s were similar to phosphorus levels in the 1960s for most agricultural areas in Alberta.

3. Even though soil-test phosphorus levels are generally low, phosphorus losses from agricultural land are recognized as a significant contributor to surface water quality degradation. Livestock production systems, including cow-calf operations and confined feeding operations, are considered the primary source of agricultural phosphorus losses. For cow-calf operations, over-wintering of cattle near surface water bodies can be a significant source of agricultural nutrient loss. Manure spreading related to confined feeding operations is also a significant source of excess phosphorus in surface water.

Phosphorus in runoff

4. Excess phosphorus in agricultural runoff appears to mainly affect water quality in streams and tributaries, and has little impact on the major river systems, such as the Bow and Oldman rivers. However, if agricultural impacts are not controlled, impacts on these major rivers could become significant in the future.

5. Surface water in Alberta tends to have naturally high nutrient concentrations, with many streams exceeding phosphorus water quality guidelines under natural conditions. Most streams are therefore sensitive to relatively small phosphorus additions. While the amount of phosphorus lost from land is usually very small compared to phosphorus additions and the concentration in soil, these amounts can have an adverse impact on phosphorus concentrations in surface water.

6. A large majority of surface runoff in Alberta's agricultural area occurs during the spring snowmelt. Even though runoff at the beginning of the snowmelt period occurs on fully or partially frozen ground, significant amounts of phosphorus are found in runoff water. Relatively few summer precipitation events result in significant runoff from fields, particularly those fields where forages are grown, or where annual crops have emerged.

7. There is a direct, linear relationship between soil-test phosphorus levels and the phosphorus concentration in runoff water in

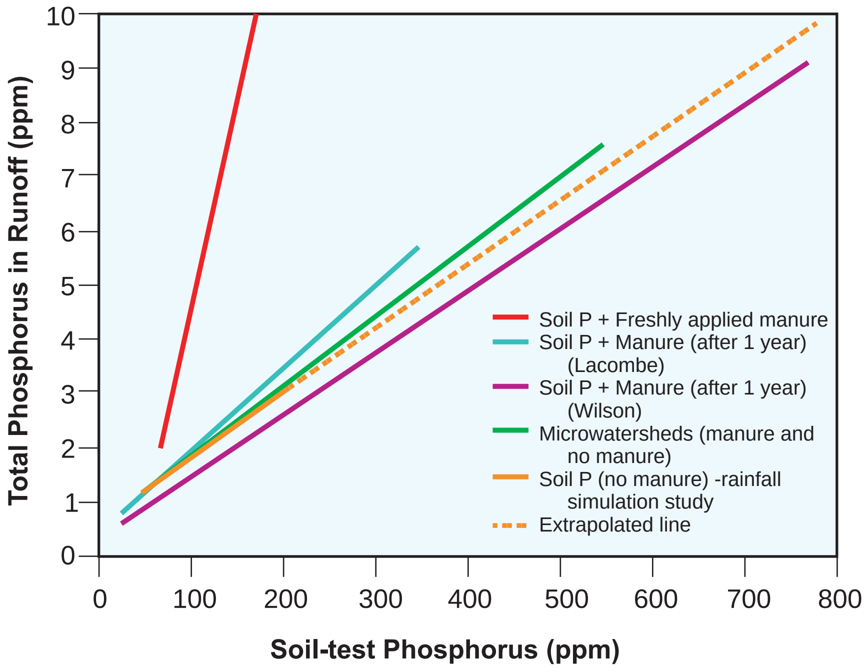


Figure ES-1. Relationships between soil-test phosphorus and total phosphorus in runoff water.

the agricultural areas of Alberta (Figure ES-1). As the amount of phosphorus in the upper soil profile increases, so does the concentration of phosphorus in runoff water. This relationship holds true regardless of whether the soil phosphorus is from non-manured or manured soil.

The standard composite core soil sampling depth of 0 to 15 cm which is currently recommended for producers to determine crop fertilizer requirements, is acceptable to compare actual soil-test phosphorus levels with the soil-test phosphorus limits.

8. A direct relationship was found between soil-test phosphorus levels and the phosphorus in simulated rainfall runoff from freshly applied manure and 1 year after manure application, although values of both variables were less with time. The relationship between soil-test phosphorus levels and phosphorus in simulated rainfall runoff from soils 1 year after manure application was similar to the relationship determined in other field-scale monitoring studies.

9. Runoff volumes and concentrations of phosphorus in runoff water decreased with manure incorporation for the freshly-manured soils near Beaverlodge. However, manure incorporation did not have a significant effect on runoff volumes and phosphorus concentrations in runoff water at the two rainfall simulation sites near Lacombe and Wilson. A relatively small portion (less than 3%) of the phosphorus applied with manure was actually removed by runoff from the freshly-manured soils and even less was removed 1 year after manure application.

Soil-test phosphorus limits

10. Soil-test phosphorus limits were determined for all agricultural land in Alberta (Figure ES-2). Using a hypothetical total phosphorus runoff water quality limit of 1.0 ppm resulted in soil-test phosphorus limits in the 0 to 15 cm layer that were:
    a. Less than 60 ppm for about 43% of the agricultural land base;
    b. 60 to 180 ppm for about 48% of the land base; and
    c. Greater than 180 ppm for about 9% of the land base.

The results of this research present a number of challenges for producers, researchers, and policy makers in Alberta. If the calculated soil-test phosphorus limits (based on a total phosphorus runoff water quality limit of 1.0 ppm) were adopted as part of Alberta's Agricultural Operation Practices Act, producers on 1.9 Million ha of agricultural land would be required to maintain soil-test phosphorus levels that are below 30 ppm, which is half of the agronomic threshold of 60 ppm. Producers on 8.9 Million ha would be required to

ppm – parts per million

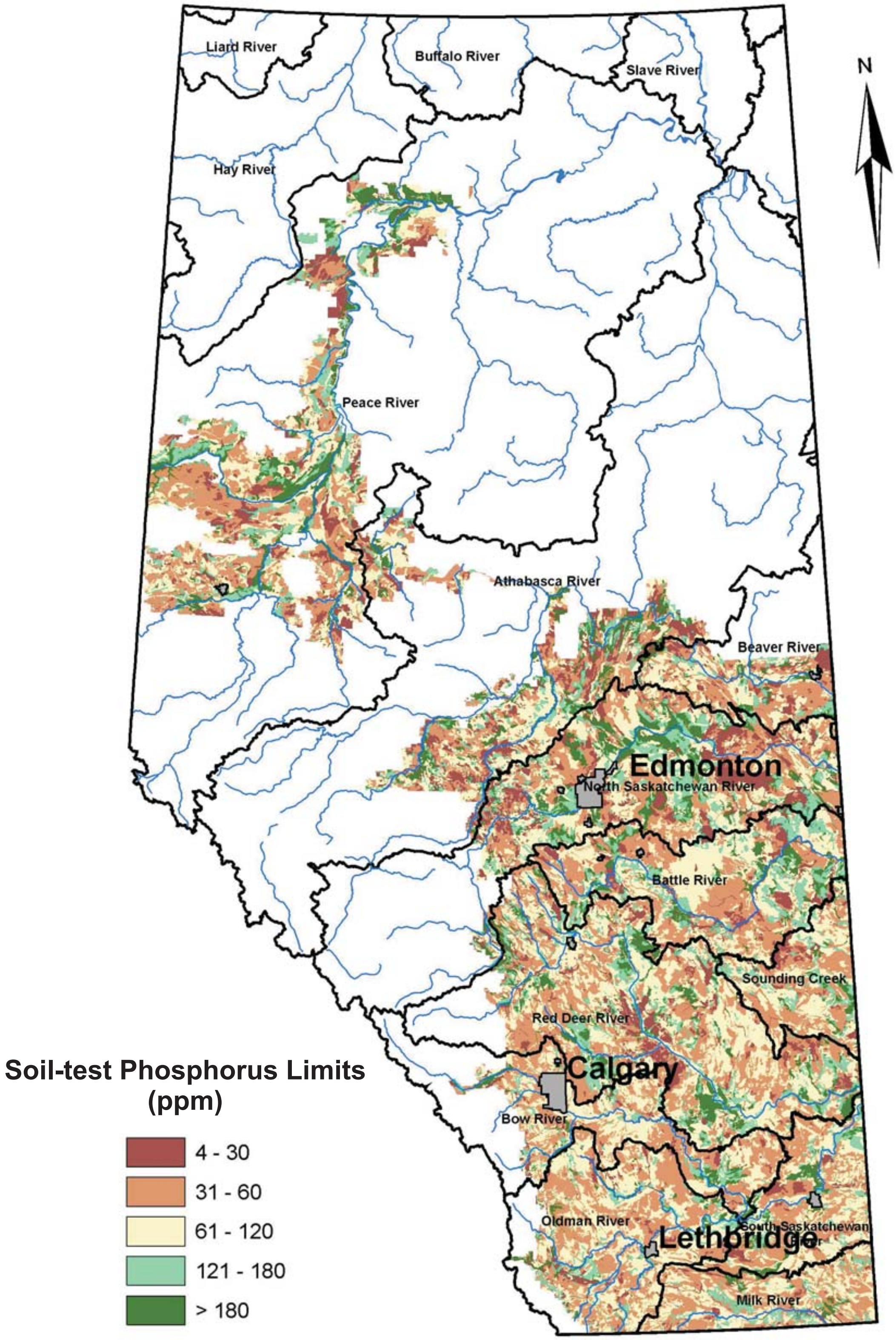


Figure ES-2. Calculated soil-test phosphorus limits for Alberta's agricultural land based on a runoff water quality limit of 1.0 ppm total phosphorus.

maintain soil-test phosphorus levels between 30 ppm and 60 ppm. Even crop producers who only apply commercial fertilizer at annual crop uptake rates would find it difficult, if not impossible, to operate under these soil-test phosphorus limits. It would prove even more difficult for Alberta's confined feeding operators.

11. From a policy perspective, it is not reasonable to require that agricultural producers maintain soil-test phosphorus levels below 60 ppm, except in specific areas, such as flood plains and riparian zones, where the risk of runoff and nutrient movement to surface water is high.

    If 60 ppm were to become the minimum soil-test phosphorus limit (except for very high risk areas), what potential impact could this have on surface water quality? The answer is dependent on the overall development expectations for each watershed. With the exception of a few regions, most agricultural watersheds in Alberta are predominantly occupied by crop producers, who generally apply phosphorus in the form of commercial fertilizers, and only at annual crop requirements. At present, only about 5% of Alberta's agricultural land base receives manure on a regular basis, and confined feeding operations generally occupy a relatively small part of most watersheds. It is unlikely that any watershed will be developed to the extent where soil-test phosphorus levels in all Agricultural Region of Alberta Soil Inventory Database soil polygons reach the soil-test phosphorus limit. Most watersheds will have a mix; some areas where soil-test phosphorus levels exceed the soil phosphorus limit, and other areas where soil-test phosphorus levels are less than the soil-test phosphorus limit. As a result, the impact on surface water quality should therefore not be unduly compromised.

Phosphorus management

12. It is recognized that regardless of the soil-test phosphorus limit, whether it is 40 ppm or 200 ppm, the same soil management system will have to be applied at some point in time to ensure that the limit is not exceeded.

    Ultimately, all producers will have to develop a nutrient management plan that balances phosphorus inputs to the land with phosphorus crop uptake or loss.

Economic impacts

13. Beef confined feeding operations generate the highest concentrations of manure per hectare of associated land. This was followed by hog operations, with dairy operations having the lowest concentrations. The most significant cost associated with manure management in Alberta is related to transportation and spreading, and ranges from $1.45/tonne to $13.33/tonne.

14. If soil-test phosphorus limits are applied to confined feeding operations in Alberta, a substantial increase in the amount of land will be required for spreading manure. Transportation and spreading costs may increase by 24 to 128% depending on the average increase in distance that the manure needs to be hauled.

15. Sustainable manure management in Alberta is essentially a transportation issue. There is more than enough cultivated land available to agronomically handle all of the manure generated by the confined feeding industry. More importantly, these lands would benefit from the additional nutrients and organic matter contained in manure. However, there are often large distances between the receiving land and the confined feeding operations, which can pose a significant financial burden to livestock operators.

16. While soil-test phosphorus limits will increase manure handling costs for all confined feeding operations, the most significant concerns will occur in geographic areas of the province with large livestock concentrations. Much of the existing land base in these areas already has high soil phosphorus levels, and new un-manured land is not available within a reasonable distance. Long-distance manure transportation, or

development of alternative management (composting) or uses (bio-energy) will have to be considered.

Beneficial management practices

17. There is limited testing in Alberta to assess the economics, effectiveness, and practicality of proposed phosphorus management beneficial management practices. However, there are several beneficial management practices that producers can apply that will not only reduce the likelihood of phosphorus runoff losses, but will also improve the health of riparian areas and aquatic ecosystems.

Recommendations

1. ***Legislated soil-test phosphorus limits should not be implemented at this time.***

The adoption of soil-test phosphorus limits cannot be supported at this time, even though it is recognized that the agricultural industry will need to move towards a phosphorus strategy that balances soil phosphorus inputs with outputs. Adequate time should be provided for the agriculture industry and governments to work together to develop the technologies and follow-up programs and policies that will allow producers to effectively manage phosphorus in the long term.

In addition, further research is required to:

- Develop and test equipment and technologies that can economically apply manure at rates that meet annual crop phosphorus requirements and reduce loss of manure nutrients during application;
- Develop and assess environmentally effective beneficial management practices that producers can economically and practically implement; and
- Determine maximum phosphorus limits for runoff from agricultural land and receiving streams and rivers.

The implementation of soil-test phosphorus limits may result in significant financial hardship to Alberta's intensive livestock industry, particularly the beef feedlot industry. Additional research and policy analyses are needed to develop alternate methods of managing excess manure from existing operations.

2. ***Regulation of soil-test phosphorus limits should be reviewed in 5 to 7 years to assess legislation requirements.***

Many jurisdictions in Canada and the United States are moving towards more regulation of the agricultural industry to minimize phosphorus losses to surface water systems. Alberta will need to assess the progress of the agricultural industry in developing and implementing a more sustainable phosphorus management strategy. Progress towards development of a sustainable phosphorus management system should be reviewed in 5 to 7 years.

3. ***The maximum soil-test phosphorus limit for Alberta should not exceed 200 ppm.***

The soil-test phosphorus limits calculated in this study show that the soil-test phosphorus limits can theoretically be greater than 600 ppm for some very limited areas within watersheds. Values in this range are many times the agronomic threshold limits for crop production, and may pose significant environmental risks that are as yet unknown. A number of states in the United States including Arkansas, Delaware, Ohio, Oklahoma, Michigan, Texas and Wisconsin have identified maximum soil-test phosphorus levels of between 150 to 200 ppm. These states recognize that soil-test phosphorus levels in excess of 200 ppm have the potential for unacceptable phosphorus losses in runoff that exceed any reasonable crop requirement concerns.

A maximum allowable soil-test phosphorus level of 200 ppm (about 400 kg/ha) for Alberta will encourage more efficient use of nutrients, and will ensure that watersheds, or parts of watersheds, cannot be considered as “phosphorus disposal sites”. In addition, since manure contains many other substances in addition to phosphorus (e.g.

nitrogen, bacteria, and metals), there is concern that allowing very high concentrations of phosphorus to accumulate in the soil profile increases the risk of surface water and groundwater problems by the other substances.

4. ***Design and implement management systems for high risk and sensitive landscapes.***

While broad-based legislation should not be enacted at this time, special consideration should be given to high risk riparian and flood plain zones. These areas are considered to be critical phosphorus source areas and sensitive ecosystems within any watershed, and should be treated differently than other landscape zones. Higher loss rates of phosphorus applied to these landscape zones are expected, and given the close proximity to streams and rivers, a greater percentage will end up in surface water. Phosphorus should, therefore, only be applied at annual agronomic rates, which generally excludes any form of manure application. Any nutrients applied to these high risk landscape zones should be incorporated into the soil profile through banding, placement with the seed, injection, or tillage.

5. ***Develop, test, and demonstrate beneficial management practices that work in Alberta.***

Alberta's agricultural industry will need to shift towards a more sustainable management program that balances soil nutrient inputs with nutrient outputs in order to minimize agriculture's impact on surface water and groundwater quality. Alberta Agriculture, Food and Rural Development, in partnership with the agricultural industry, should accelerate the development and field testing of beneficial management practices that can be financially and practically implemented by producers, and that will be environmentally effective in reducing phosphorus losses to surface water.

6. ***Implement an education and awareness program for phosphorus management.***

Most Alberta producers are interested in applying beneficial management practices that will minimize agriculture's impact on the environment. Adoption of these practices is more likely to be accomplished if producers are informed of the issues and understand their options for improving management practices. Alberta Agriculture, Food and Rural Development, in partnership with the agricultural industry, should accelerate the development of education and awareness programs that will provide objective, science-based phosphorus management recommendations that producers can implement for their specific operations. The education and awareness program should also work with crop producers throughout Alberta to promote the significant advantages of using manure as a nutrient source.

7. ***Develop and implement a manure management incentive program for Alberta livestock producers.***

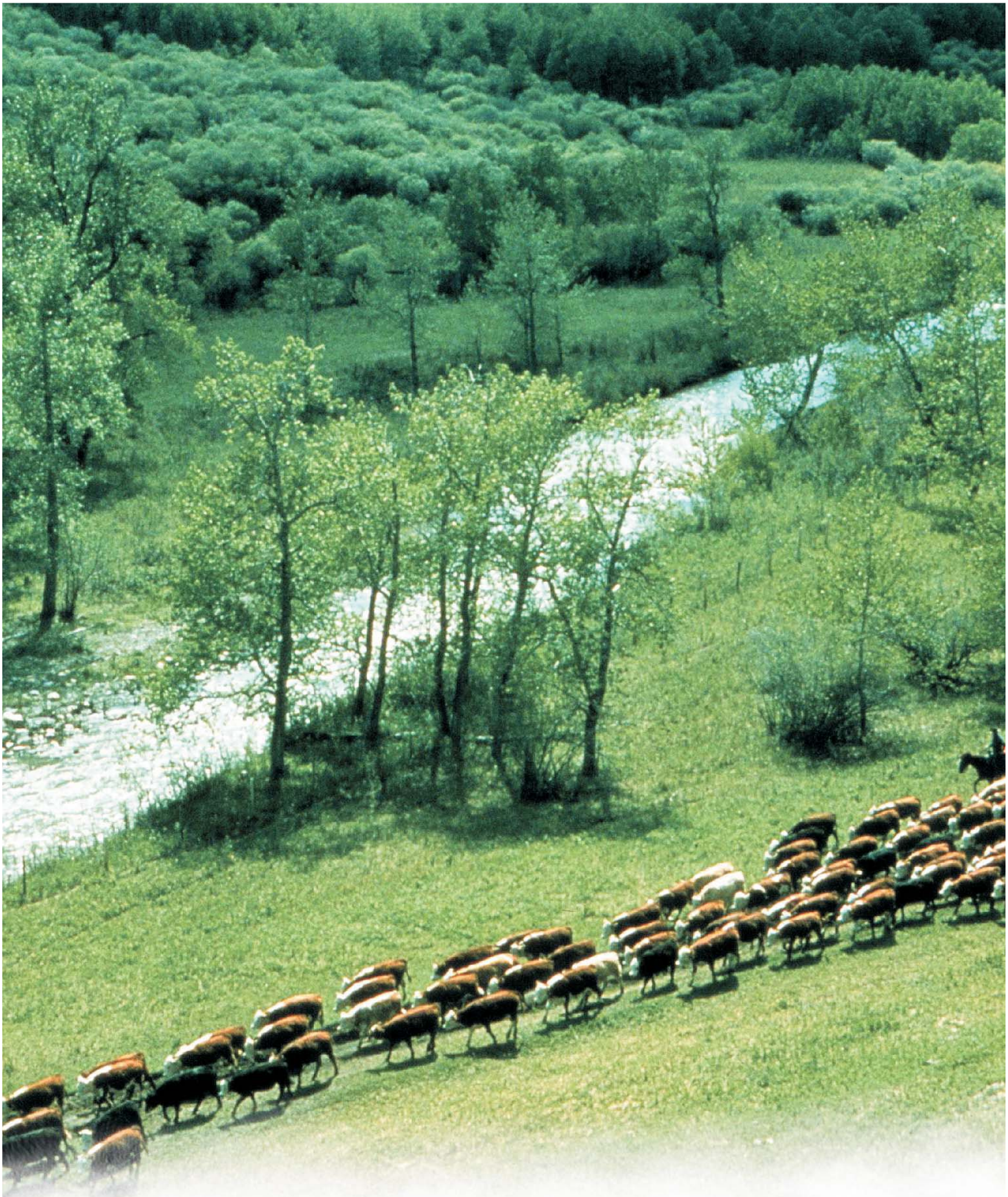
Implementation of soil-test phosphorus limit regulations could result in significant financial hardship to Alberta's intensive livestock industry, particularly the beef feedlot industry. Having an adequate land base to spread manure within a reasonable distance from the feeding operation is already a challenge for many confined feeding operations. If the industry is forced to move towards a phosphorus-based manure management program, even greater land base challenges will occur. These challenges will be greatest for those geographic regions where the historical development of confined feeding operations resulted in feeding operations being located relatively close to each other. Providing a transitional funding support program will reduce manure applications on existing land by promoting the transportation of excess manure greater distances. In addition, it will promote the significant benefits of manure to a greater area of cropland in the province, and reduce overall phosphorus losses to streams and rivers.

Table of Contents

List of Figures

List of Tables

List of Appendices



Introduction

Background

Phosphorus is present in organic and inorganic forms in the soil system. Total phosphorus (TP) in soils generally ranges from 100 to 3000 ppm, and typically about 30 to 65% is in organic form (Condron et al. 2005). The portion of TP in soil solution is usually less than 1% (less than 1 kg/ha) at any given time. Crops can take up 10 to 48 kg/ha phosphorus each year (Canadian Fertilizer Institute 2001). Therefore, phosphorus in soil solution has to be replaced several times during the growing season to meet crop phosphorus demand. This occurs by desorption and dissolution of inorganic phosphorus and by mineralization of organic phosphorus (Figure 1). The reverse processes (sorption, precipitation, immobilization) also occur and as a result soil-solution phosphorus is in equilibrium with solid-phase phosphorus. Phosphorus forms that readily enter soil solution are referred to as labile phosphorus, whereas those forms that slowly enter soil solution are referred to as non-labile or stable phosphorus.

For agricultural crops, phosphorus is important for seed formation, straw strength, root development, early maturity, and disease resistance.

Phosphorus is an essential element for life. Plants and microorganisms take up inorganic phosphorus (HPO_4^{-2}, $H_2PO_4^-$), which is incorporated into organic compounds. Phosphorus has many important functions in living organisms including energy storage and transfer, genetic material, and structural components. In particular, for agricultural crops, phosphorus is important for seed formation, straw strength, root development, early maturity, and disease resistance.

Phosphorus is often added to soil, either as inorganic commercial fertilizers or as organic materials such as livestock manure, municipal biosolids, or industrial by-products. The addition of phosphorus causes an immediate increase in phosphorus concentration in the soil solution. This phosphorus will undergo sorption, precipitation, and immobilization processes. Initial sorption processes are easily reversible and much of the added phosphorus is available for crop uptake or susceptible to losses in surface runoff (Pierzynski et al. 2005).

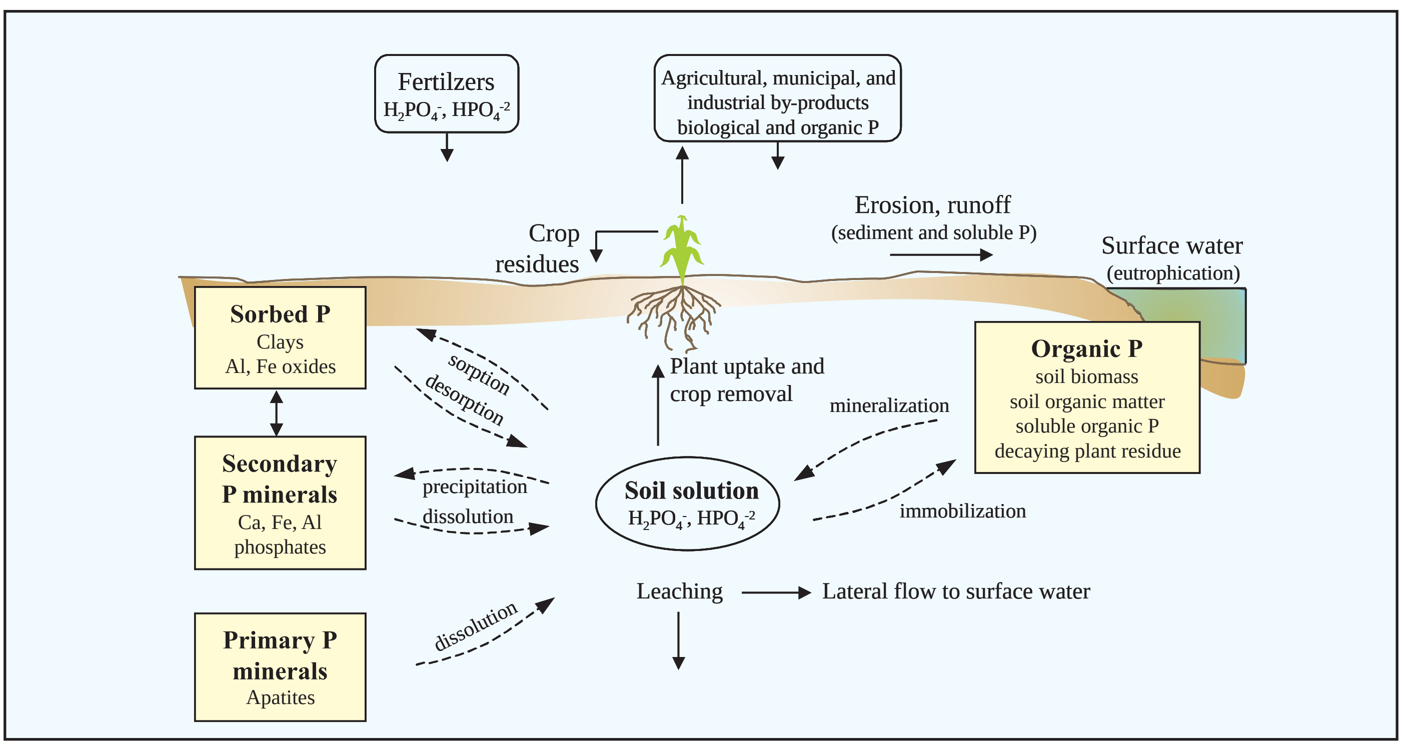


Figure 1. The soil phosphorus cycle (adapted from Pierzynski et al. 2005).

Phosphorus is relatively immobile in soil and when phosphorus is applied in excess of crop requirements it accumulates in the top 5 to 15 cm of soil. However, phosphorus can move downward in sandy soils with large amounts of added phosphorus, in highly organic soils, and in soils with cracks or extensive macropore development (Pierzynski et al. 2005). Because phosphorus accumulates near the soil surface, it is particularly prone to loss through erosion and runoff events. Phosphorus can be transported in runoff as dissolved phosphorus (DP) or associated with particulate inorganic and organic material referred to as particulate phosphorus (PP).

The portion of soil phosphorus analyzed for crop growth determination is referred to as soil-test phosphorus (STP), plant-available phosphorus, available phosphorus, or extractable phosphorus.

Soils are often sampled and analyzed for phosphorus content, usually to determine whether or not soil is deficient in phosphorus for crop growth. The portion of soil phosphorus analyzed for crop growth determination is referred to as soil-test phosphorus (STP), plant-available phosphorus, available phosphorus, or extractable phosphorus. Soil-test phosphorus (STP) is a small fraction of the total phosphorus in soil, and it is measured in the laboratory by extracting soil samples with an extraction solution. The results are used to make fertilizer recommendations or environmental assessments.

The movement of phosphorus from agricultural land to surface water can lead to accelerated eutrophication (Figure 2) (Correll 1998), which is ranked as the most widespread water quality impairment in the United States. Agriculture involving intensive livestock production has been identified as a primary source of phosphorus in surface waters in the United States (Sharpley et al. 2003). There is also clear evidence that phosphorus and nitrogen loading from human activity has contributed to eutrophication in Canada (Chambers et al. 2001).

Extractable phosphorus in Alberta soils is generally deficient or marginal for crop production. Manunta et al. (2000) reported that the majority of ecodistricts in Alberta had a mean extractable phosphorus value between 25 and 30 ppm in the top 15 cm of soil. Therefore, much of the agricultural land in Alberta can benefit from added phosphorus to obtain optimum crop yield.

Extractable phosphorus in Alberta soils is generally deficient or marginal for crop production.

[1]1 tonne (t) = 1000 kilograms (kg).

Figure 2. Eutrophication of water.

However, over-application of nutrients can greatly increase soil phosphorus levels. Olson et al. (2003) showed that after 8 years of annual application of a high manure rate (120 tonnes/ha wet cattle manure)[1] in southern Alberta, modified Kelowna extractable phosphorus in the top 15 cm ranged from 900 to 1150 kg/ha phosphorus (about 450 to 575 ppm), which is 10 or more times greater than what is required for crop growth. Whalen and Chang (2001) reported that after 16 years of annual beef manure application on continuous cropped land in southern Alberta, extractable Olsen phosphorus in the 0 to 15 cm soil layer ranged from 317 to 964 ppm, which varied with annual manure application rate (30 to 180 tonnes/ha wet cattle manure).

Water quality studies in Alberta show that agriculture is having a negative impact on water quality in streams and tributaries throughout the agricultural area. Monitoring the water quality of 23 streams in predominantly agricultural watersheds was carried out monthly throughout the summer period from 1999 to 2003 to assess water quality trends with time (Donoghue 2001; Carle 2002; Depoe and Westbrook 2003; Depoe 2004 and 2005). The watersheds were grouped into Low, Moderate and High intensity agriculture areas, based on the livestock density, and fertilizer and pesticide sales (CASEA 1998). High intensity agricultural watersheds included those in the top 25% of livestock numbers, and pesticide and fertilizer sales for the province. Moderate intensity agricultural watersheds include the middle 26% to 75% of chemical inputs and livestock numbers. Low intensity agricultural watersheds include the bottom 25%.

Total phosphorus concentrations in the streams varied considerably during the 6-year monitoring period as follows:

- Low intensity agricultural watersheds – TP ranged from 0.06 to 1.10 ppm with the average at 0.19 ppm;
- Moderate intensity agricultural watersheds – TP ranged from 0.02 to 0.41 ppm with the average at 0.21 ppm; and
- High intensity agricultural watersheds – TP ranged from 0.12 to 1.38 ppm, with the average at 0.53 ppm.

As crop livestock agriculture intensified in these watersheds, the amount of phosphorus in the water generally increased. These results are consistent with earlier monitoring work carried out in selected watersheds throughout Alberta (CAESA 1998). Other research has shown that as extractable phosphorus (bioavailable phosphorus) increased in soil, the concentration of phosphorus in runoff water also increased (Pote et al. 1996; Vadas et al. 2005).

While these water quality concentrations are considerably higher than Alberta's total phosphorus guideline for the protection of aquatic life, which is 0.05 ppm (AENV 1999), their impact on the water quality of the major river systems is not significant at this time. Synoptic water quality surveys carried out for the Oldman River in the summer of 1998 and 2000 showed that the total phosphorus concentration in the Oldman River did not exceed 0.05 ppm at any of the sampling sites along the length of the river during the sampling periods (Oldman River Basin Water Quality Initiative 2005), even though the total phosphorus concentrations in some tributary streams and surface drains exceeded these guidelines. Similar results were found for the Bow River, based on synoptic water quality surveys carried out in 1994 and 1995 (Sosiak 1996). This study concluded that the tributaries, individually, had relatively little influence on the total phosphorus concentration of the Bow River.

Phosphorus in runoff from agricultural land is not having a significant impact on water quality in the major river systems.

Several beneficial management practices have been suggested to control agricultural phosphorus losses from soil to water (Sharpley et al. 2000). In addition to beneficial management practices, soil phosphorus limits or phosphorus indices have been adopted in some jurisdictions.

Table 1. General interpretations and management guidance for the phosphorus index (adapted from Sharpley et al. 2003).

Phosphorus index value[z]	Rating	General interpretation	Management guidance
<60	Low	If current farming practices are maintained, there is low risk of adverse impacts on surface waters.	Fertilizer or manure application can be based on crop-nitrogen requirements.
60 to 79	Medium	Chance for adverse impacts on surface waters exists, and some remediation should be taken to minimize phosphorus loss.	Fertilizer or manure application can be based on crop-nitrogen requirements.
80 to 100	High	Adverse impact on surface waters. Conservation measures and phosphorus management plan are needed to minimize phosphorus loss.	Phosphorus application limited to crop removal of phosphorus.
>100	Very high	Adverse impact on surface waters. All necessary conservation measures and phosphorus management plans must be implemented to minimize phosphorus loss.	No phosphorus should be applied.

[z] Individual phosphorus indices may use different relative ranges of numerical values.

United States Approaches

The United States Department of Agriculture Natural Resources Conservation Service recently initiated national guidelines on nutrient management (Mallarino et al. 2002). The national guidelines suggested use of one of three phosphorus risk assessment tools: (1) agronomic soil-test phosphorus interpretation classes, (2) environmental soil phosphorus limits, or (3) phosphorus indices.

A phosphorus index approach is used in the majority of states in the United States to assess phosphorus source and transport factors and then generate an index value for the relative risk of phosphorus losses. Sharpley et al. (2003) reviewed several phosphorus indices used in the United States and provided a general interpretation of phosphorus index categories (Table 1). The smaller the index value, the lower the risk. Depending on the version of the phosphorus index, the index values are grouped into four to five categories, and each category triggers a certain management response.

The phosphorus indices are based on general assumptions and professional judgment. In most cases, no attempts have been made to relate phosphorus indices to actual phosphorus losses under local conditions. Phosphorus indices are not designed to quantify phosphorus losses (Sharpley et al. 2002).

> ***A number of U.S. states recognize that STP levels in excess of 200 ppm have the potential for unacceptable losses in runoff that exceed any crop requirement concerns.***

The single-point STP limits approach also varies in terms of numerical values and associated management responses (Sibbesen and Sharpley 1997). A number of states have identified

Table 2. A summary of the proposed soil-test phosphorus (STP) thresholds for regulating livestock manure application on cropland in Manitoba (Manitoba Phosphorus Expert Committee 2006).

STP threshold category[z] (ppm)	Intent of threshold category	Manure phosphorus application
<60	No restriction of phosphorus application.	Apply on the basis of crop nitrate nitrogen requirements.
60 to 119	Control soil phosphorus accumulation rate.	Apply phosphorus up to two times crop removal rate of phosphorus.
120 to 179	Prevent further increases in soil phosphorus concentrations.	Apply phosphorus up to one times crop removal rate of phosphorus.
>180	Depletion at a rate controlled by crop removal.	No manure application without written consent of the Director.

[z] **Olsen phosphorus extraction method or equivalent.**

maximum STP levels of 150 to 200 ppm. These states recognize that STP levels in excess of 200 ppm have the potential for unacceptable losses in runoff that exceed any crop requirement concerns. For example, Arkansas has a soil limit of 150 ppm, based on the Mehlich-3 soil phosphorus analysis. When STP is at or above this limit, no phosphorus can be applied from any source. The same condition is used in Delaware at a limit of 120 ppm, based on the Mehlich-1 soil phosphorus analysis. Michigan uses two soil limits: 75 and 150 ppm, based on the Bray-1 soil phosphorus analysis. When STP is between 75 to 150 ppm, the phosphorus application rate cannot exceed crop removal. When STP is greater than 150 ppm, no phosphorus can be applied from any source. In Texas, when STP is greater than 200 ppm, phosphorus can still be applied, but only at a rate that does not exceed crop removal (Sibbesen and Sharpley 1997).

Manitoba Approach

The STP limits approach, also referred to as thresholds, have recently been proposed for Manitoba (Manitoba Phosphorus Expert Committee 2006). The Manitoba proposal has four threshold categories (Table 2). The intent of the thresholds is to trigger appropriate management responses based on the level of risk. Development of the threshold categories was based on regulatory approaches used by other jurisdictions, such as Ontario and Minnesota, and with some consideration of phosphorus behaviour in Manitoba. However, it was acknowledged that the loss of phosphorus under Manitoba conditions was not well understood (Manitoba Phosphorus Expert Committee 2006). Ranges of STP threshold values were proposed because it was felt that a single STP value was too challenging to implement for regulatory purposes. The Manitoba Phosphorus Expert Committee (2006) suggested that long-term management of livestock manure application cannot exceed crop phosphorus requirements, but that some short-term STP accumulation would be acceptable. The committee proposed that multiyear rates of up to five times the annual crop phosphorus removal could be applied in a single year, followed by no manure application the following 4 years.

Alberta Approach

During 1998 and 1999, attempts were made in Alberta to develop regulations for confined feeding operations for livestock under the guidance of the Livestock Regulations Stakeholder Advisory Group (LRSAG). During this process, the Technical Expert Committee drafted the Standards Document, which was designed to support the regulations and replace the 1995 Code of Practice (Intensive Livestock Operations Committee 1995). Though phosphorus standards were not included in the draft guidelines, the LRSAG requested, upon advice from the Technical Expert Committee, that research be carried out to determine appropriate phosphorus guidelines in Alberta.

Regulations were adopted for confined feeding operations through amendments to the Agricultural Operation Practices Act (AOPA), which came into effect on January 1, 2002 (Province of Alberta 2001), and were revised in 2004 (Province of Alberta 2004)(Figure 3). In the regulations, manure applications are based on soil nitrate-nitrogen limits. Nitrogen-based application rates can result in the accumulation of phosphorus in soil. Excess phosphorus in agricultural land is a concern in Alberta, particularly for land that is sensitive to runoff.

Alberta Soil Phosphorus Limits Project

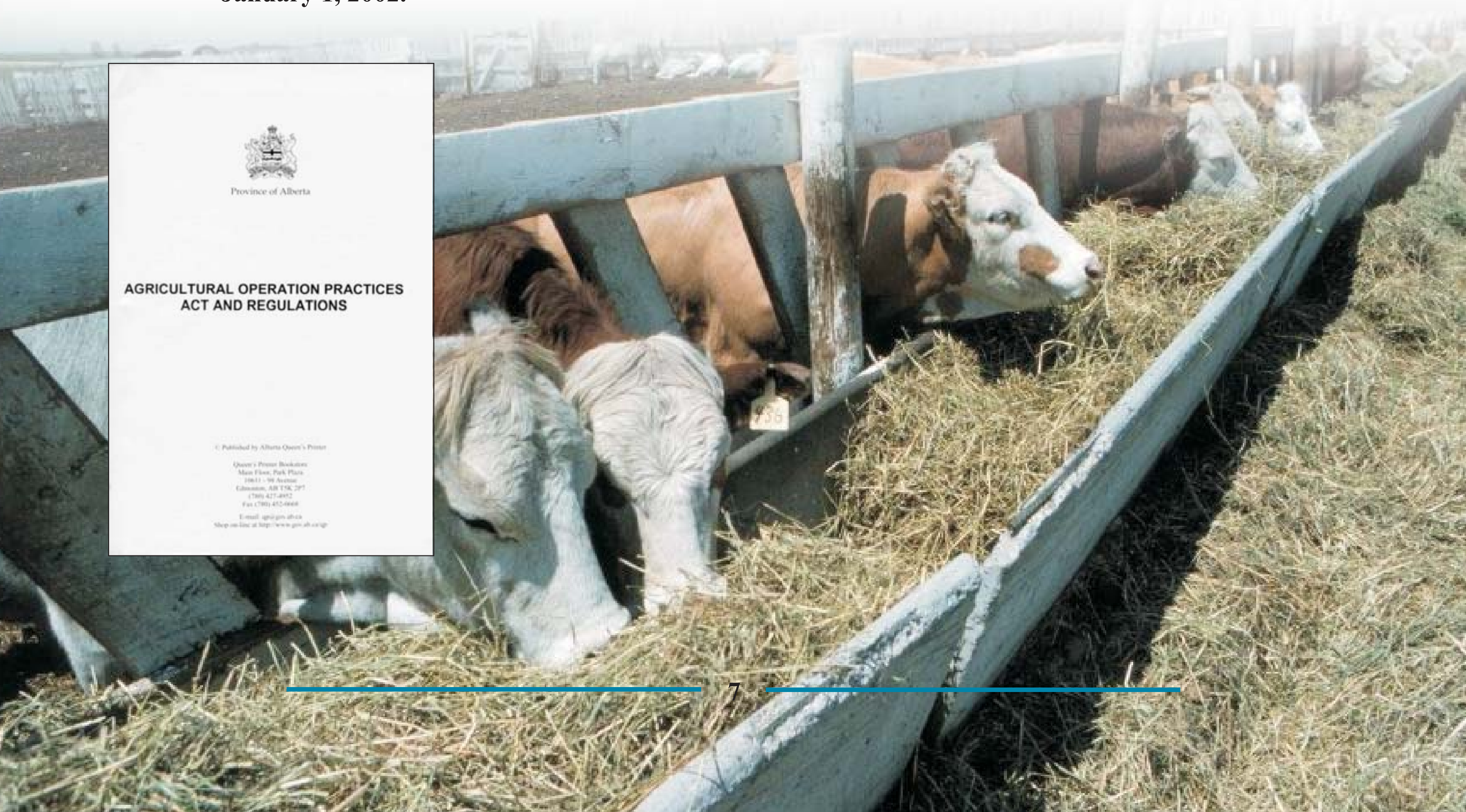
Alberta Agriculture, Food and Rural Development took the lead role and established the Alberta Soil Phosphorus Limits Project in 1999. Results from this project will provide a scientific basis for development of beneficial management practice recommendations, and for implementation of regulations for phosphorus-based manure application.

The Alberta Soil Phosphorus Limits Project had four objectives:

1. Develop recommendations for phosphorus limits for agricultural land in Alberta;
2. Determine implications of soil phosphorus limits on the agriculture sector;
3. Identify management options for soil phosphorus limit implementation; and
4. Develop recommendations for an action plan and a timeline for implementation of limits.

The Alberta Soil Phosphorus Limits Project was carried out in two phases from 1999 to 2006 (Figure 4). Phase 1 (1999 to 2002) included the collection and review of background material with a focus on agricultural phosphorus issues and the approaches taken by other jurisdictions in dealing with these issues. Consultation was also carried out with interested stakeholders. A separate research

Figure 3. Regulations for confined feeding operations came into effect on January 1, 2002.



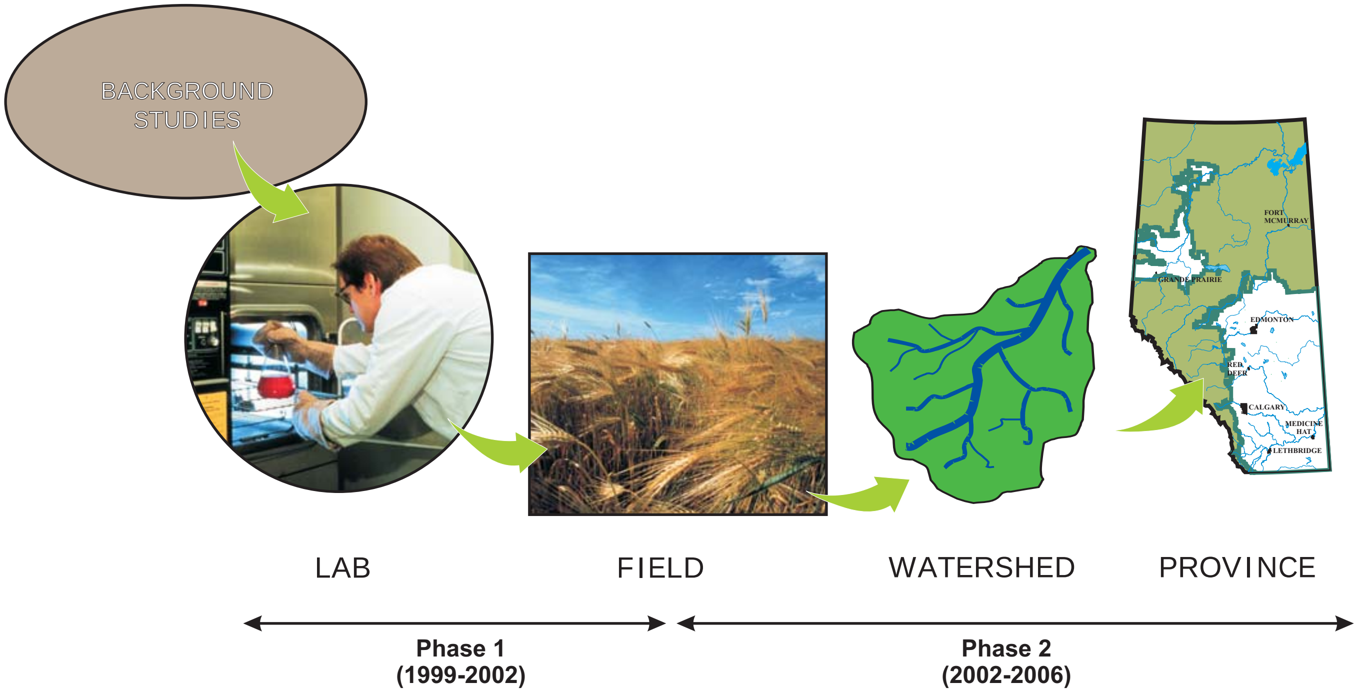


Figure 4. Alberta Soil Phosphorus Limits Project action plan.

study, led by Alberta Agriculture, Food and Rural Development, was started in 1998 to investigate phosphorus loading of soil and subsequent transport with runoff (Figure 5) (Wright et al. 2003; Wright et al. 2006). This study is referred to as the Phosphorus Mobility Study, and included laboratory and field studies. Based on the background information and the results from the Phosphorus Mobility Study, the Soil Phosphorus Limits Study team initiated the Phase 2 (2002 to 2006) research studies to assess the relationship between soil phosphorus and runoff phosphorus under Alberta field conditions.

Figure 5. Spring runoff at a central Alberta field site.

Review and Assessment Studies