Phosphorus Standards in Alberta: Potential Impacts on the Agricultural Industry

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2006

Alberta Soil Phosphorus Limits Project

Citation
Soil Phosphorus Limits Committee and LandWise Inc. 2006. Phosphorus standards in Alberta: Potential impacts on the agricultural industry. 57 pp. ***In*** Alberta Soil Phosphorus Limits Project. Volume 5: Background information and reviews. Alberta Agriculture, Food and Rural Development, Lethbridge, Alberta, Canada.

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

Printed in Canada

Copies of this report are available from
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Alberta Agriculture, Food and Rural Development
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GLOSSARY AND ABBREVIATIONS

A number of references were used to compile the following definitions including USDA-NRCS (1999a), Hesketh and Brookes (2000), Call et al. (1987), Brodison et al. (1989), Brintrup et al. (1993), Van der Peet-Schwering (1997), Erickson et al. (1999), and Valk and Sebek (1999).

AFO: Animal feeding operation.

Algae-available phosphorus: Phosphorus that is in a soluble and available form, for uptake by algae and other micro-organisms in the water column.

AU: The number of animals of a particular category of animal that will excrete a standard amount of nutrients in a 12-mo period.

Available soil phosphorus: A chemically extracted amount of phosphorus from the soil that represents the portion of phosphorus that is available to a growing plant. This extracted amount of phosphorus is correlated to a field test, measuring yield for the crop.

Bioavailable phosphorus: The form of phosphorus that is absorbed by biological organisms, such as plants and animals. Mostly orthophosphates, but can be some forms of organic phosphorus.

BMP: Beneficial or best management practice. A structural or management technique recognized as an effective and practical means of achieving sustainable agriculture in terms of the environment, economics, and social acceptance.

Bray P: One of several extraction methods used for extracting phosphorus from the soil.

Buffer strip: A strip of vegetation, usually grass and/or trees, between a farm field and surface water, designed to increase the distance, and to retain and/or remove nutrients from runoff water before it enters surface water.

CAFO: Concentrated animal feeding operation.

Catchment area: The land (and including the streams, rivers, wetlands, and lakes) from which water runs off to supply a particular location in a freshwater system. The term watershed is generally used in North America, but in the United Kingdom watershed means the line separating two adjacent catchments.

Catch basin (settling basin): An excavated, diked or walled catchment used to collect and hold runoff from animal feeding sites including feedlots, pens and from manure piles. It is used to prevent possible point source pollution by diverting, and then holding, runoff waters.

CNMP: Comprehensive nutrient management plan.

Cyanobacteria: Also called blue-green algae; the most diverse and widely distributed group of photosynthetic bacteria responsible for the surface scum associated with algal blooms.

Dissolved phosphorus: Phosphorus, either in organic or inorganic form, in solution with water. Determined after passing through a 0.45 micron filter.

EAA: Everglades Agricultural Area.

EPA: Environmental Protection Agency.

Eutrophication: Aging of a lake or river. It is associated with a high concentration of plant nutrients entering a body of water, particularly phosphorus. This process may be accelerated by human activity.

Extractable soil phosphorus levels: Phosphorus that is extractable from a soil or sediment sample using various dilute solutions, as opposed to phosphorus that is not available until the sample is totally digested with strong acid.

Fixed phosphorus (non-labile): Adsorbed phosphorus bonded to mineral material in the soil (including iron, aluminum, and calcium) so tightly that the phosphorus is unavailable to plants and animals. This is the least soluble component and provides very little plant nutrients in the first year of manure application but serves as a long-term storehouse.

GAAMP: Generally accepted agricultural management practices.

ILO: Intensive livestock operation.

Infiltration: The downward entry of water into the soil. This is distinctive from percolation, which is movement of water through soil layers or material.

Inorganic phosphorus: Mineral or orthophosphate form of phosphorus.

Labile phosphorus (active phosphorus): Phosphorus that is weakly adsorbed or bound in the soil to minerals and organic material and can easily be extracted by some chemical or plant root and released into soil solution for plant uptake. The labile phosphorus, (active phosphorus) will supply phosphorus over the growing season.

Leachate: Liquids that have percolated through a soil that carry substances in solution or suspension.

LU: Livestock units.

Mineralization: The conversion of an element by soil organisms from an organic form to an inorganic form.

Modified Kelowna: One of several extraction methods used for analyzing plant available phosphorus in the soil.

Nutrient balance: Ratio of nutrient concentrations necessary for optimum growth and yield. An imbalance results when one or more nutrients are present either in deficit or in excess.

Nonpoint source pollution: Pollution arising from an ill-defined and diffuse source, such as runoff from cultivated fields (which have had fertilizer, manure or chemical application), grazing lands, or urban areas.

NPDES: National Pollutant Discharge Elimination System.

NRC: National Research Council.

NRCS: Natural Resources Conservation Service of the United States Department of Agriculture.

Olsen P: One of several extraction methods used for extracting phosphorus from the soil.

Organic Phosphorus: Phosphorus that is bound with organic carbon and forms organic molecules.

Orthophosphate: The inorganic form of phosphorus that is plant available. Two species are $H_2PO_4^-$ and $H_2PO_4^{-2}$.

Particulate Phosphorus: Phosphorus that is attached to mineral or organic material on the soil surface and carried as sediment by erosion.

Phosphate: In fertilizer terminology, phosphate is the sum of water-soluble and citrate-soluble phosphoric acid (P_2O_5), also referred to as available phosphoric acid.

Phosphorus: Essential nutrient both for plants and animals. Makes up cell walls, DNA, and energy transfer molecules. Phosphorus is often the limiting nutrient for the growth of aquatic plants and algae.

Phosphorus Index: An assessment tool that indicates the relative vulnerability of a location to off-site movement of phosphorus. The phosphorus index must be customized to fit the predominant soils, landforms, hydrology, and climate of the area in which it will be used. The phosphorus index is generally based on factors that affect phosphorus transport (including soil, topography, and distance to water) and source management characteristics (including phosphorus application rates and methods).

P_2O_5: Phosphorus pentoxide designation on the fertilizer label that denotes the percentage of available phosphorus.

PPM: Parts per million. A means of expressing concentration, generally by weight. Equivalent expression include milligrams per liter (mg L^{-1}) and milligrams per kilogram (mg kg^{-1}).

Phosphorus threshold: Critical soil-test phosphorus levels, established by soil series, above which phosphorus application is restricted.

Point source pollution: Pollution arising from a well-defined origin, such as a discharge from an industrial plant, sewage effluent, or manure storage facilities.

Soil test: A chemical, physical, or biological procedure that estimates the plant availability of nutrients to support plant growth.

Soil-test phosphorus: The plant-available phosphorus, as determined by the soil extraction method typically used in a jurisdiction.

Soluble phosphorus: Phosphorus that mixes and is transported as a solution by water. The phosphorus can be in the organic or inorganic form.

Superphosphate, concentrated: Also called triple or treble superphosphate, made by reaction of phosphate rock with sulfuric acid, usually containing 19 to 21% phosphorus (44 to 48% P_2O_5).

Superphosphate, normal: Also called ordinary or single superphosphate, made by reaction of phosphate rock with sulfuric acid, usually containing 7 to 10% phosphorus (16 to 22% P_2O_5).

Suspended solids: Particles of sediment and solid in water.

Surface water: Means any body of flowing or standing water, whether naturally or artificially created, including but not limited to a lake, river, creek, spring, swamp, wetland, and marsh, including ice on any of them.

Total phosphorus: The sum of all the phosphorus forms contained in the material including organic, particulate, and soluble forms.

TMDL: Total maximum daily load.

TNRCC: Texas Natural Resource Conservation Commission.

USDA: United States Department of Agriculture.

Vegetated filter strips (VFS): Are intended to remove sediment or other contaminants in runoff from cropland or livestock sites before they reach surface or groundwater. VFS reduces contamination by promoting infiltration of water and water soluble constituents, increasing adsorption of contaminants into the vegetation and upper soil horizons and increasing the absorption of nutrients into plants.

Watershed: The surrounding area that drains into a lake, river, or river system.

INTRODUCTION

Alberta has a wealth of high-quality streams, rivers, and lakes that are used for drinking, irrigation, fishing, recreation, and aesthetic enjoyment. In today's society, it is important to find a balance between sustaining the environment and the well-being of all those who enjoy the benefits that water provides.

A recent Alberta water quality assessment revealed that nitrogen and phosphorus concentrations often exceeded water quality guidelines for the protection of aquatic life. This was apparent, particularly in regions of intensive agricultural production (CAESA 1998). Figure 1 identifies the agricultural areas of greatest concern in the province. Degradation of water as a natural resource, because of nutrient enrichment, is an important issue for all involved in the agriculture industry.

Phosphorus Sources

Sources of phosphorus are defined as either point or non-point. Point sources include municipal and industrial wastewater effluent, overflows from sewer or manure handling systems, and waste disposal sites. Point sources are relatively simple to identify and monitor, and are often controlled by treatment at the source. Most of the progress in reducing phosphorus contamination has been through control of point sources.

Non-point sources of phosphorus usually include extensive areas of land. Factors such as time and space impact these sources, and phosphorus may be transported overland, underground, or through the atmosphere to receiving waters (Carpenter et al. 1998). Non-point sources are therefore very difficult and costly to identify, monitor, or control.

Phosphorus from agricultural sources can be in organic and inorganic forms. Non-point field sources include applied manure and inorganic fertilizer. Intensive livestock operations, cow-calf wintering sites, and animal watering locations are more likely to be considered as point sources of phosphorus. When phosphorus is applied at rates greater than the crop can use, it builds up in the soil. Phosphorus accumulation is defined as a surplus situation, while a deficit situation results in phosphorus depletion.

Soils can hold phosphorus, but only to specific limits based on the soil organic matter content, texture, clay content, topography, and landscape factors. While most soils in Alberta have a considerable capacity to hold phosphorus, no soil has an infinite capacity for adsorption of phosphorus (Gilliam 1995). Phosphorus losses are generally small until a critical threshold concentration is exceeded. These threshold values are significantly greater than required for optimal crop growth in most soils. For example, concentrations of phosphorus in drainage water from two Rothamsted soils in the United Kingdom increased rapidly only when the phosphorus concentration in the soil exceeded 60 mg kg^{-1}. For these same soils, optimum crop yields were obtained when the soil phosphorus concentrations exceeded 25 mg kg^{-1} (Higgs et al. 2000).

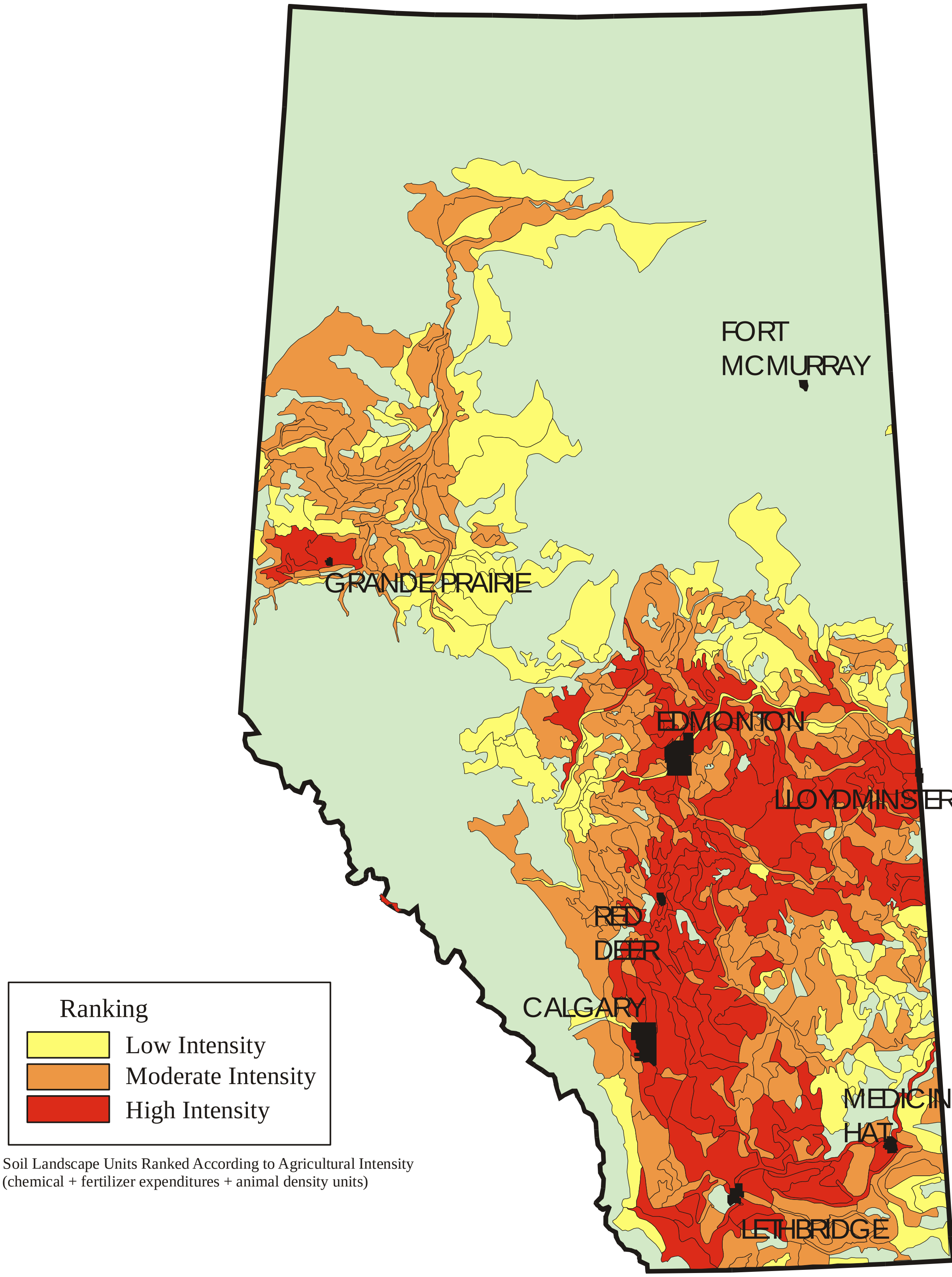

Fig. 1. Agriculture intensity in Alberta (CAESA 1998)**.**

When the adsorption capacity of soils is exceeded, phosphorus has great potential to move into surface waters. However, the relationship between soil-test phosphorus concentration and phosphorus movement to receiving water bodies varies with site-specific soil and landscape conditions, and background phosphorus levels in the receiving water.

Runoff and soil erosion are the two most common processes that transport phosphorus to surface water (Fig. 2). Surface runoff occurs mainly during spring snowmelt and following periods of rainfall that are intensive enough to exceed soil infiltration and storage. Phosphorus enriched material can also be transported from livestock wintering sites and from recently manured fields, and fields that have received phosphorus applications in considerable excess of crop requirements for a sustained period. Degraded riparian areas, which are often rich in phosphorus, may also contribute phosphorus to surface waters.

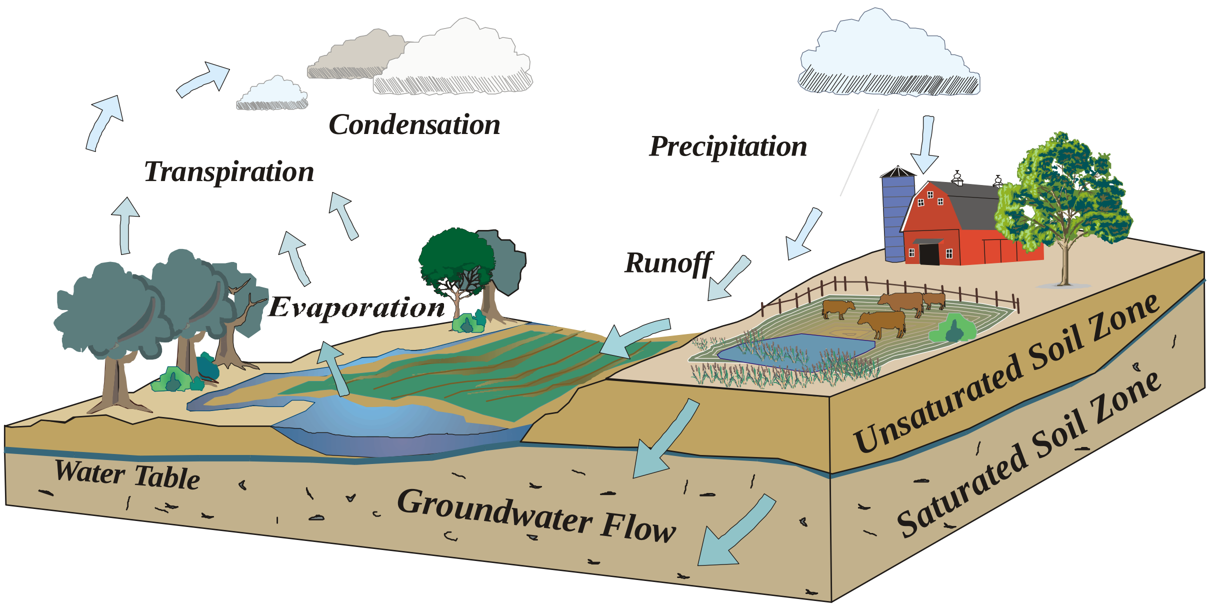

Fig. 2. Runoff from agricultural areas.

Impact of Phosphorus on Surface Water

High concentrations of nutrients, including nitrogen and phosphorus, promote aquatic weed and algal growth in water sources. Eutrophication is a process where nutrient enrichment accelerates the natural aging of lakes and streams. Eutrophication can have many adverse effects on water systems (Moss 1996; Carpenter et al. 1998), including the following.

- Blooms of cyanobacteria contribute to summer fish kills, foul odours, unpalatability of drinking water, water treatment problems, and possible harmful effects on livestock (Fig. 3).
- Increased incidence of fish kills, loss of desirable fish species, and reductions in harvestable biomass.
- Enhanced growth of plants that impair recreational uses and impair aesthetic value.
- Reduced diversity of plant and animal species.

Fig. 3. Algal bloom.

Study Approach

To control or reverse eutrophication, phosphorus sources must be identified and inputs reduced. While agriculture is recognized as a contributor, other sectors can potentially contribute to phosphorus loading. These include the food processing and manufacturing industries; urban centers, including wastewater and municipal sewage; cottage and country residential sewage; bio-solid waste application sites; forestry; energy; mining; construction; and natural sources such as precipitation and wildlife. The extent to which each sector contributes to the overall loading problem is known in some watersheds in Alberta. However, identifying specific contributions is difficult, and extrapolation of the results to most basins is complicated by regional and site-specific factors.

To help address these concerns, Alberta Agriculture, Food and Rural Development established the Alberta Livestock Regulatory Stakeholder Advisory Group. This group, in addition to developing regulations related to Alberta's intensive livestock industry, requested that soil phosphorus standards be developed by 2001. As a result, the Soil Phosphorus Steering Committee was formed in 1999.

In addition to developing soil phosphorus limits, the Steering Committee recognized the importance of assessing the implications on the agriculture industry in Alberta of setting and implementing phosphorus standards. As a result, a study was carried out, with the following action steps.

- Step 1. Review of actions by countries around the world that may have relevance to Alberta conditions.
- Step 2. Select four jurisdictions that are particularly relevant to Alberta for more detailed study.
- Step 3. Evaluate the Alberta situation relative to phosphorus issues.
- Step 4. Based on steps 1 to 3, assess implications of setting phosphorus standards for Alberta and recommend specific actions.
- Step 5. Develop phosphorus management guidelines for Alberta producers.

This report reviews the actions other countries have implemented regarding phosphorus limits. The development, implementation, and success of guidelines/regulations from other jurisdictions will be assessed

- to evaluate the economic and environmental implications of implementing phosphorus standards in Alberta,
- to evaluate mechanisms and time-frames for implementing phosphorus standards in Alberta,
- to identify management options to assist producers to meet phosphorus standards.

From this information, a number of practical methods are presented that will assist Alberta producers implement and achieve selected management options that are feasible for their farming conditions.

ASSESSMENT OF WORLD ACTIONS

Countries with mandates to reduce or control agricultural losses of phosphorus were identified and reviewed. To accomplish this task, keyword searches using several Internet (i.e., InfoSeek) search engines were carried out. In addition, agricultural agency (i.e., Agricola) search engines were reviewed and recent agricultural publications were studied. A total of 16 jurisdictions were selected and further assessed as a result of this search.

The template shown in Table 1 was developed to evaluate all jurisdictions that had a significant history of efforts to control agricultural phosphorus losses.

Table 1. Template to assess jurisdictions with efforts to control agricultural phosphorus losses.

1. **Jurisdiction**	8. **Description of regulations**
2. **Start years**	8.1. Who is responsible for meeting requirements?
2.1. Legislation	8.2. Requirements
2.2. Program	8.3. Who is responsible for ensuring compliance?
2.3. Efforts	8.4. Rewards/penalties
3. **Driving Forces (e.g., water quality problems)**	8.5. Who pays?
4. **Climate and physiography**	8.6. % Compliance
5. **Profile of livestock industry**	9. **Description of strategies/programs**
5.1. Beef	9.1. Target participants
5.2. Dairy	9.2. Description
5.3. Swine	9.3. Who developed?
5.4. Poultry	9.4. Who delivers?
6. **Cropping systems**	9.5. Who Pays?
6.1. Cultivated hectares	9.6. % Participation
6.2. Dominant cropping systems	10. **Impact on environmental P levels**
7. **Fertilizer inputs**	10.1. How monitored?
7.1. Mg or kg of P	10.2. Achievements
7.2. kg P per ha	11. **Impact on management practices**
	12. **Impact on industry structure**
	13. **Planned or suggested changes or improvements**

The assessment of the 16 countries identified six specific factors that related to the phosphorus issue and the potential applicability to Alberta conditions. These are listed as follows.

- environmental pressures
- approaches to phosphorus limits
- economic impact
- societal impact
- regulation and enforcement
- mitigation actions

Environmental Pressures

Those jurisdictions that had an appreciable degradation of valuable water resources, a sustained high level of excessive phosphorus inputs and were at high risk of soil phosphorus loss, all had a history of trying to control agricultural losses of phosphorus.

Table 2 provides an overview of environmental pressures within the 16 jurisdictions studied. For example, the Everglades and Lake Okeechobee are highly valued water bodies in Florida that have experienced appreciable degradation from eutrophication. As a result, farming in Florida is now highly regulated in an attempt to reduce the loss of phosphorus from intensive agricultural operations on soils that have a limited capacity to hold phosphorus. In the Netherlands and Maryland (United States of America), livestock concentrations are very high, and both areas have experienced significant eutrophication problems.

Table 2. Environmental issues for phosphorus.

Jurisdiction	Environmental pressures	Phosphorus surplus (kg ha^{-1} yr^{-1})	Au[z] (x 10^6)	Au[z] per ha	Major livestock
Australia	1000 km toxic algal bloom, '91		44.9	0.9	Cattle Sheep
Denmark	Groundwater pollution, loss of 'natural' areas		4.4	1.9	Swine
Germany	River and lake eutrophication, esp. in NE	25[y]	21.5	1.8	Swine Cattle Chickens
Netherlands	Severe lake, groundwater and canal pollution	60	10.9	11.7	Swine Chickens Dairy
New Zealand	Eutrophication in agric. Regions		15.9	4.8	Sheep Dairy
United Kingdom	Toxic algal blooms (1988)	9[y]	20.1	3.1	All
United States		26[y]	122.6	0.7	All
Florida	Everglades protection	Manure > crop removal in 8 counties[x]	5.2	1.2	Beef Broilers
Idaho	Sport fishing concerns	Manure > crop removal in 3 counties[x]	2.1	0.4	Beef
Kansas	Primarily groundwater (nitrates)	Manure > crop removal in 13 counties[x]	8.0	0.4	Beef Swine
Maryland	Chesapeake Bay; toxic algal bloom in 1997	Manure > crop removal in 3 counties[x]	7.1	8.1	Broilers
Michigan	Great Lakes protection	Manure > crop removal in 3 counties[x]	2.0	0.5	Swine Beef
Nebraska	Primarily groundwater (nitrates)	Manure > crop removal in 5 counties[x]	8.9	0.5	Beef Swine
Oklahoma	Primarily groundwater (nitrates)	Manure > crop removal, 13 counties[x]	11.4	0.8	Beef Swine
Texas	Eutrophication concerns in surface waters	Manure > crop removal, 32 counties[x]	25.3	0.2	Beef Dairy
Wisconsin	Lake and river degradation	Manure > crop removal in 8 counties[x]	6.3	1.0	Dairy Beef

[z]Animal units, data from FAO 2000; [y] Carpenter et al. (1998); [x] Lander et al. (1998).

While other jurisdictions have less severe environmental problems, there are often localized areas of excess soil phosphorus.

Managing Phosphorus

The jurisdictions evaluated used a variety of approaches to manage phosphorus applications to land in an environmentally safe manner.

Water monitoring. Limit phosphorus application rates to maintain the phosphorus load or concentration below a critical level in water being discharged from a property. This is the best method for minimizing phosphorus losses from any system. However, it is very difficult and expensive to monitor due to the point and non-point nature of phosphorus losses from the land. This parameter was used for farms in Okeechobee Lake Basin, Florida (Goldstein and Ritter 1993), but is more often used to document performance on a watershed basis.

Phosphorus balance. Phosphorus application rates are limited to levels that meet crop requirements plus an allowable surplus. The Netherlands and Denmark use this approach to ensure that phosphorus does not build up in the soil. Many of the soils in these jurisdictions already have high levels of phosphorus. The application of phosphorus in excess of crop requirements contributes directly to phosphorus losses, particularly for sandy soils. For a system being proposed in the United States, soils with high phosphorus concentrations can only receive application rates based on crop requirements (National Conservation Research Board 1999b).

Soil monitoring. Phosphorus application rates are limited when soil phosphorus levels exceed a critical level. Extractable soil phosphorus levels have long been used to predict how a crop responds to added phosphorus. Environmental losses are likely to be minimal in all but the most sensitive soils if applications are limited to levels that provide just enough phosphorus for optimal crop growth (Higgs et al. 2000). However, extracting soil phosphorus to estimate the upper limit for safe application is complicated because the actual loss of phosphorus from a specific soil will vary with soil characteristics and landscape position (Sharpley et al. 1996; Sims et al. 2000). Several approaches have been utilized.

Single limit approach **-** Rates of phosphorus application are reduced or eliminated when soils exceed a single critical value of extractable soil phosphorus. This approach is used in a number of jurisdictions, but is not considered to have a strong scientific basis because of the importance of soil characteristics and landscape position on phosphorus losses (Sharpley et al. 1996). However, in regions with relatively uniform soils, this approach could provide a simple mechanism to ensure safe phosphorus levels in the soil profile.

Percent saturation or threshold approach **-** The potential for phosphorus to stay in and be leached from most soils increases rapidly after a soil capacity of 25% has been exceeded (Schoumans and Groenendijk 2000). This threshold level is relatively consistent for any given soil, and may be related to more readily available soil-test values (Schoumans and Groenendijk 2000). Hesketh and Brookes (2000) suggest a simple method of determining the critical value of soil-test phosphorus based on the relationship between 0.01 M $CaCl_2$ extractable phosphorus and soil-test phosphorus. This approach is most appropriate for phosphorus losses through drainage. It may also be useful for regions with high levels of soluble phosphorus loss in runoff.

Soil index approach **-** This approach integrates the risk of phosphorus transport with soil phosphorus test information to determine the appropriate areas and application rates (Lemunyon and Gilbert 1993). Factors that are included in the most recent version of the index include soil erosion, runoff class, return period, distance from water, and method of phosphorus application (Gburek et al. 2000). The index approach provides the most flexibility to assess and manage phosphorus losses through surface runoff.

Economic Impact

Major costs associated with excessive phosphorus loading in the case studies include

- impaired fisheries,
- reduced recreational use of lakes and streams,
- increased treatment requirements for drinking water,
- possible additional health costs associated with ingestion of algal toxins.

Environmental problems have caused considerable economic impacts on the livestock industry in many parts of the world. The Natuur En Milieu Environment Group estimates that the total costs of eutrophication and acidification resulting from agriculture in the Netherlands is $450 to $600 million Dutch guilders (DLG) per year (10 DLG = $6 CDN, Sept. 2000). If eutrophication and acidification are not arrested, the group estimates the costs will rise to $1 billion DLG.

In jurisdictions impacted by agriculture, livestock numbers have typically stabilized or decreased in the affected jurisdictions. The cost of entering or remaining in the industry has increased, thus making it more difficult for small operations to remain viable or for new operations to become established. Relocation costs are severe for producers and the public purse. It is recognized that careful planning is essential to avoid the necessity of closing or relocating industries.

There are also costs associated with voluntary and regulatory programs for nutrient management, including administration, staff training and hiring, monitoring and enforcement, education and awareness; research, nutrient management planning, technical assistance, and implementation of beneficial management practices.

Applying manure at agronomic rates based on phosphorus uptake generally requires four to six times more land than is needed for nitrogen application. Livestock operators will be required to work out spreading agreements with neighbors or find additional land, which will entail additional transportation costs for manure. It is estimated that nutrient management planning costs farmers approximately $7.40 to $37 per hectare, of which soil sampling and record keeping are the main expenses.

If regulations are not implemented soon enough to prevent a crisis situation, costs associated with remediation, closure and/or relocation of farms can be significant. For example, the closing of 18 dairies in the Lake Okeechobee Basin of Florida in the mid-1990s cost nearly $600,000 U.S. per dairy, with the public funding more than 60% of that cost.

Regulations that arise out of conflict situations can have major negative impacts on producers. These impacts may include costly control measures, fines, decreased land values, and the possibility that some producers will have to either relocate or exit the region and/or the business.

Societal Impact

There has been negative public support for agriculture in many of the identified jurisdictions where eutrophication has been a problem. This is particularly the case where little to no action has been taken, or when action was not taken at an early enough date. Forced relocations or closures of livestock industries, such as those that occurred in the Lake Okeechobee Basin in Florida, have caused massive disruption in rural communities.

In several jurisdictions studied, the agricultural community feels it has been unfairly targeted. For example, farmers in the Chesapeake Bay area of Maryland feel they have been unfairly singled out, since there is no clear evidence that the outbreak of ***Pfiesteria sp.*** in Chesapeake Bay was related to phosphorus.

The consequences of “non action” in relation to control of agricultural phosphorus loading can be severe. Failing to implement preventative measures, and be seen by the public as implementing those measures, has resulted in major conflicts between public interest groups and farm producer interests. This is a conflict that farmers cannot win over the long term, and is very divisive and costly. This is evident in the Netherlands as well as several states in the United States, notably Maryland, Florida, and the dairy region of central Texas. Experience from the Netherlands illustrates that the attitude of most citizens is now decidedly anti-agriculture, due to public concerns regarding over-production; environment, including pollution and odour; and competition for land by agriculture, development, recreation, or natural areas. Today, Dutch farmers are viewed by many as polluters, and are identified as a social problem. The future outlook for farmers continues to be negative, and young people are less attracted to the industry.

Regulation and Enforcement

In the United States, some regulations and resources have been targeted at operations that exceed a certain size, based on sensitive or non-sensitive lands (USEPA 1999a). Arguments have been made that smaller operations and activities, other than livestock production, are also contributing to water quality problems. European jurisdictions have focused on the intensity of livestock production or nutrient use rather than focusing just on size of operation.

Another targeting method is based on the identification and prioritization of degraded or sensitive watersheds (Parry 1998). Sensitive watersheds that have been targeted include Florida’s Lake Okeechobee Basin and the Delmarva Peninsula adjacent to Chesapeake Bay along the eastern seaboard of the United States.

A controversial issue in many jurisdictions is the question of who should develop and implement controls on agricultural activities. Controls may exist at the national, state/provincial, or municipal, regional, industry, or individual level. Control at the local level increases the likelihood that local concerns will be addressed. However, industry groups often favour a higher level of control to avoid potential confusion that might result from a patchwork of local controls (Copeland and Zinn 1998). When controls are limited to the local level, industry will often locate where the rules and regulations are most relaxed.

In order for controls at the local level to work, boundaries must be aligned with watersheds, and expertise and resources must be sufficient (Dummermuth 1997). The following provides a range of options, based on the experiences of other areas.

- **New Zealand:** Regional councils have the principal responsibility for water, soil, pollution, and coastal management. There are about 90 councils in the country, and were realigned on a watershed catchment basis in 1989.

- **Wisconsin, Minnesota, and South Dakota:** Counties have the primary responsibility to develop and implement land and water resource management plans, including regulatory measures. Similarly, counties in Minnesota and South Dakota have responsibility for zoning, environmental rules, fees, setbacks, and enforcement (Dummermuth 1997).

- **Nebraska and Idaho:** Advisory groups, based on drainage basins, are responsible to monitor water quality and develop and implement water quality plans. These advisory groups advise state authorities on problems, but are not responsible for enforcement.

- **Oklahoma, Maryland, and many other states:** State agriculture or environment departments have the authority to regulate agricultural practices. There is a wide variation in the level of stakeholder input and degree of cooperation among the government departments.

Implementation

Many of the jurisdictions evaluated used a combination of regulation, incentives, education, and extension for implementing phosphorus standards. Choosing an appropriate implementation strategy is often dependent on available resources and the urgency of the phosphorus problem. Generally, agricultural producer actions are related to the promise of potential benefits (economic return, timeliness, ease of use, familiarity, etc.), reduced risk of negative consequences, social acceptability, and environmental safety. How they are motivated is likely to vary widely, and must be taken into account for any plan where relatively few actions can have a disproportionate impact (Shepard 1999; Withers et al. 2000). Cash payments, cost-sharing and/or value gained through initiatives can be utilized to influence producers' attitudes and ultimately their management practices. Table 3 shows those practices used to reduce the over-application of phosphorus on agricultural land throughout the world.

Table 3. Practices used to reduce phosphorus loading problems.

Practice	Literature review findings
	Incentives
• Fertilizer savings or increased crop yields	• Component of all educational efforts • Minimal benefit for farms with a nutrient surplus and high fertility status (Beegle et al. 2000) • Norway imposed additional taxes on fertilizer to increase incentive to save on fertilizer costs (van Zeijts 1999; Vedeld and Krogh 2000)
• Alternative markets for manure	• Numerous farms throughout the world sell manure or compost but many have discontinued this due to economic losses (Messenger and Kelley 1999) • Maryland provides up to $22 per tonne to offset poultry litter testing, loading and transportation costs
• Grants, cost-share or low interest loans for capital projects	• Widely used, e.g., Environmental Quality Incentives Program (USDA-NRCS 1999b) with maximum at 70% but 80% if "economic hardship" is confirmed
• Free or subsidized technical assistance, including nutrient management planning	• A number of jurisdictions provide free or subsidized nutrient planning, soil testing and other types of technical assistance.
• Requirements for receiving subsidies	• Being discussed in the United States and Europe, but not imposed except in some cost support programs
• Exit package for producers	• Lake Okeechobee Basin in Florida: funds were provided for closure or relocation of intensive livestock operations
• Tax reductions	• In some regions of Florida, farmers receive a tax reduction credit for implementing nutrient control BMPs • Denmark provides tax reductions for reduced fertilizer use (Schou 2000)
	Education and awareness
• Familiarity and expertise increased through training, education (e.g., BMP publication), and local demonstrations	• Widely used throughout the world. • Requires availability of beneficial and practical methods (Shepard 1999)
	Regulations
• Levies on nutrient imbalance	• Netherlands: Levies imposed on phosphorus surplus
• Fines on violations found during regular inspections or in response to complaints	• Most jurisdictions with mandatory regulations use fines
• Operating requirements	• Operations must meet regulatory requirements
• Expansion requirements	• Operations that would like to expand require a sound development plan that addresses all potential environmental concerns
• Liability from neighbours or environmental authority	• Nuisance suits (e.g., see Michigan case study).
	Social pressure
• Participation in local environmental planning groups	• Landcare groups in Australia and United Kingdom • Watershed Advisory Groups, Idaho (Idaho Soil Conservation Commission 1999b)
• Comparison with industry standard	• Numerous industries including food processors have developed voluntary standards
• Regular inspections	• Often tied to permitting requirements, and effective as an educational tool
• Neighbors	• Working together for local and societal goals (e.g., water quality)
• Environmental commitment	• All farmers desire to protect their environment, but may not be convinced that their actions are contributing to an environmental problem or may not be able to afford the implementation of a plan to protect the environment

DETAILED CASE STUDIES

An analytical framework to record and document information from 16 jurisdictions around the world was developed. The jurisdictions were investigated for their experiences in implementing nutrient standards, specifically for phosphorus. Substantial information was collected through a review and assessment of the available literature and other resources. The information from each of the reviewed jurisdictions helped to select the most appropriate jurisdictions that were most relevant to Alberta conditions.

The main criteria used to identify the jurisdictions to investigate further included the presence of a significant eutrophication problem and if the jurisdictions attempted to control phosphorus inputs to aquatic systems.

Each case study was assessed using following criteria.

- **Climate:** Maritime versus continental, temperate versus subtropical, etc.
- **Urban and rural mix:** Whether the populations are predominantly rural, urban, or an equal mix; whether there is significant urban pressure on rural land and agricultural production. Jurisdictions with 70 to 80% urban population compare well with Alberta.
- **Water systems and surface geography:** Type and proportion of water systems, whether predominantly streams, lakes or estuaries. Physiography (relief and land "shape") of the major agricultural areas. Glaciated and undulating, hummocky and inclined landscapes are most applicable for Alberta.
- **Livestock systems:** Animal populations, with an approximation of density. Predominantly beef production with secondary populations of other livestock types are the most applicable for Alberta.
- **Cropping systems:** Major crop area and estimate of phosphorus fertilizer use. Annual cereals with oilseeds and forages are the most applicable for Alberta.
- **Agricultural processing:** Qualitative estimate of size of food processing industry.
- **Problems with eutrophication:** Qualitative assessment of severity, and whether major impacts were to streams, lakes, or estuaries. Lakes and streams are of more importance to Alberta.
- **Monitoring approach:** The approach used to monitor the effectiveness of farm management practices on phosphorus losses were assessed. Approaches based on monitoring of farm nutrient balances were deemed to be the most applicable for Alberta.
- **Program history:** Length of time programs aimed at mitigating nutrient contamination have been in place, plus the availability of information on implementation, adoption, and success. Programs with a longer history are most valuable to Alberta.
- **Regulatory versus voluntary programs:** Whether programs aimed at mitigating nutrient contamination are predominantly voluntary or regulatory.
- **Cost and effectiveness:** Qualitative estimate of the cost of a system and its implementation, and of the overall effectiveness to achieve desired goals.

Based on the above criteria, 4 of the 16 jurisdictions were selected as detailed case studies for this assessment. These include The Netherlands, and the states of Michigan, Texas, and Wisconsin in the United States. A project team member and an industry or government representative traveled to each of these four jurisdictions to gain firsthand knowledge. Table 4 provides the main factors for choosing the detailed case study areas of Michigan, The Netherlands, Texas, and Wisconsin.

Table 4. Detailed case study areas.

Michigan	The Netherlands
• Temperate continental climate (some influence of Great Lakes), glaciated landscape. • Extensive stakeholder involvement. • Proactive design and promotion of a nutrient management strategy. • Recent strategies, programs and regulations tied to 1981 Right to Farm Act. • Nutrient management emphasis.	• A worst-case scenario with much to learn for Alberta. • Program in place since the 1980s. • Strong science, a “nutrient laboratory”. • Staged regulations. • Highly intensive agriculture. • Polarized urban versus rural populations
Texas	**Wisconsin**
• Arid to humid climates, with semi-arid areas, similar to southern Alberta. • Dryland and irrigated croplands. • Beef feedlots on the High Plains. • Calcareous prairie soils. • Recent regulations, including voluntary compliance. • Detailed water quality studies carried out. • Nutrient management and indexing. • Strong impetus to maintain landowner integrity.	• Temperate continental climate (some influence of Great Lakes), glaciated landscape. • Number one dairy state, but also has moderate beef density. • Reports of poor adoption of recommended BMPs under voluntary programs. • Forage and corn each 41% of cropped area. • Includes nutrient management, landscape indexing and water monitoring. • Significant history of point and non-point pollution control efforts.

The Netherlands

The Netherlands is one of the world's most densely populated countries, and has one of the most intensive livestock and crop production sectors. The country is a major exporter of food products, and is well known around the world as a leader in agricultural production, processing and related sciences and technical innovation.

This unique combination of dense human and livestock populations on a small land base, makes the Netherlands a 'living laboratory.' In effect, the Dutch experience provides a wealth of real life experience and instruction to other jurisdictions that may be facing similar situations.

The Netherlands case provides a socio-economic backdrop including the causes, responses and effects of its phosphorus problem.

The following provides an overview of the Netherlands salient features.

- The Netherlands has a human population of 16 million people. Its record for economic growth is one of the best in the European Union.
- The country has only two major cities: Amsterdam and Rotterdam. Population in both cities is approximately one million. The remaining human population is distributed across a large number of smaller centres located predominately in the western and southern regions of the country.
- The entire country is approximately four million hectares in size, with about half of that devoted to agricultural production. The balance of the area is comprised of water, roads, urban areas, and nature areas.
- The country is predominately flat, with about 40% of the landmass below sea level. The eastern part of the country is comprised of sandy soils. Historically, the eastern region was less developed economically and did not become a productive agriculture region until after World War II.
- The livestock density in the Netherlands is 3.7 animal units per hectare compared to the European average of 0.9 animal units per hectare. The livestock industry includes
  - An annual output of 20 million hogs, located mainly in the southern and eastern regions of the country. This region is approximately 600,000 hectares in size.
  - 1.5 million dairy cows located in the central and northern regions.
  - A poultry industry consisting of 40 million layers, 44.6 million broilers.
  - A sheep population in excess of 1.5 million.

This intensive nature of Dutch agriculture led to a major imbalance between mineral inputs from fertilizer and manure that are much higher than outputs contained in milk, meat, and crops. The net phosphorus surplus in the late 1980s and early 1990s was 40 kg ha^{-1}, which was higher than any other country in the world (Carpenter et al. 1998). By 1997, the phosphorus surplus is estimated to average 60 kg ha^{-1}. The agriculture industry in the Netherlands occurs mainly on sandy soils, often over shallow aquifers that are highly vulnerable to contamination. As a result, groundwater has become contaminated, which is particularly serious as groundwater is a major source of drinking water in the Netherlands.

Despite Dutch successes in agriculture, the political climate within the country has gradually changed from being supportive of the agriculture industry to being critical. This situation has developed because of livestock over-production, competition between agricultural and recreational land use, and negative environmental impacts from intensive livestock operations.

Phosphate, nitrogen, and ammonia contamination has contributed to water pollution. The country has many shallow lakes, canals, and ditches where eutrophication is a major problem (Van der Molen et al. 1998). The eutrophication problem is compounded because intensive poultry and swine operations are often located on sandy soils with low phosphorus adsorption capacity. According to the Dutch Ministry of Agriculture, livestock manure accounts for 38% of total phosphate pollution and 64% of total nitrogen pollution to the environment.

Degraded air quality due to manure emissions is also a concern. It is estimated that nitrogen losses through precipitation and emissions from manure spreading, housing, and storage are 320 kg ha^{-1} yr^{-1} compared to the European average of 75 kg ha^{-1} yr^{-1}.

The growing livestock populations and manure loads during the 1970s caused public concern about the intensive nature of agriculture in the Netherlands that culminated in a movement to control manure, and consequently, livestock production. Voluntary measures to control the distribution of manure started in 1980. A milk quota was instituted in 1984, with the objective to reduce livestock waste. This resulted in a decrease in milk production to 15% of previous levels. In 1986, the Dutch government enacted policy to stop the growth in swine and poultry numbers.

Clearly, the Netherlands finds itself in a high-pressure situation with respect to the nature and the intensity of its nutrient imbalance. Strict and far-reaching measures will be required to realign environmental conditions within acceptable levels. Due to the high intensity of farming, the economic consequences are expected to be very significant.

Management options. The Dutch government has implemented a number of programs to mitigate the impacts of agriculture's impacts on water quality. The following provide a summary of the various programs being enacted.

Managing nutrients - Controls were initially based on manure production rights associated with livestock numbers. The use of average values resulted in significant margins of error in the amounts of nutrient produced, including the phosphorus excreted by each animal and the actual manure production by each animal type. It was recognized that simply managing excess manure was not sufficient and that a complete nutrient management system was required.

The Dutch government now has a clear focus on managing nutrients, particularly phosphorus and nitrogen. This program took approximately 15 yr to move from a manure management system to the present-day mineral management system. The nutrient management plans are based on the goal of equilibrium fertilization, defined as the fertilization rate required for crop uptake with acceptable losses to the environment. The goal of the Dutch mineral accounting program is to reduce phosphorus levels to <0.15 mg L^{-1} in surface water and groundwater, as well as to reduce nitrate levels.

Dutch regulations - Dutch law makes it mandatory for all farms with livestock to manage their phosphorus and nitrogen inputs and can levy fines for overproduction of nutrients.
Each farm requires a plan that prescribes the maximum allowable loss of phosphorus and nitrogen. The plan can either accurately measure the quantities of phosphorus and nitrogen entering and leaving the farm; or estimate the nutrient inputs and outputs using official, fixed values. While the latter options is simpler and less costly than the former, it is also less accurate. The official Dutch values are deliberately set higher than the average real-life values to encourage farmers to choose in favor of specific accounting.

Through this regulation, the allowable surplus of phosphorus for each hectare of arable land and grassland will gradually decrease from 40 kg P_2O_5 per hectare in 1998 to 20 kg P_2O_5 per hectare by 2008-2010. Levies of US $2.50 per kg for the first 10 kg P_2O_5 surplus per hectare and US $10 for each successive kg are prescribed.

Presently a Total Minerals Management program (MINAS) measures all inputs and outputs on a total-farm basis. Farms regulated by the mineral accounting system includes the following.

- As of 1998, all intensive livestock producers with livestock densities in excess of 2.5 livestock units per hectare. A livestock unit is one dairy cow or two farrowing sows.
- As of 2000, all livestock producers with more than 0.5 livestock units per hectare.
- As of 2001, all crop producing (arable) farmers.

Levies were also established on nitrate and phosphate surpluses in 1998. The allowable surplus is being reduced approximately every 2 yr. For example, in 2002 the allowable surplus is 20 kg ha^{-1} phosphate.

In 2000, water companies in the Netherlands are estimated to spend $30 million DLG on water purification due to nutrient losses from agriculture. This corresponds to $1.875 DLG per Dutch citizen per year. (10 DLG = $6 CDN, Sept. 2000). Farmers in the Netherlands estimate that between 3 and 15% of their annual income is used for record keeping required for the mineral accounting system (MINAS). The public cost of the 400-person institution required to administrate the MINAS program is $54 million DLG. Currently the farmer levies collected based on nutrients exceeding guidelines is $43 million DLG.

These regulations have not been without problems. Two or three large expensive central manure processing plants were constructed in the southern part of the Netherlands in an attempt to coordinate the management of excess manure. However, manure reprocessing turned out to be far more expensive than was initially thought, on account of high costs for the development of new technology, expensive treatment processes, and the difficulty of finding outlets for the reprocessed products. In addition, it was too costly for farmers who had to pay for transportation of the manure to the facility, plus the manure processing. It was less costly for them to transport manure greater distances for spreading, and avoid the processing costs. In addition, the market for processed manure products was not yet developed.

In spite of the challenges, the Netherlands has demonstrated that a clearly focused program can show demonstrable results. From 1987 to 1996, the Netherlands reduced total phosphate losses to land by 25%. It did this by instituting a dairy quota reduction of 15% and forcing a decline in the number of milk cows, focusing on nutrition and digestibility of nutrients, and reducing the use of inorganic fertilizers by 30%.

Features for consideration in Alberta. The experience gained from the assessment of the Netherlands' programs provide a number considerations that are relevant to Alberta.

- Link animal production with land - either owned land or land on contract in close proximity to receive manure. Don't get into a situation where livestock densities exceed land capacities for manure handling!

- Introduce a mineral (or nutrient management) bookkeeping system as an extension tool. Farmers are generally willing to adopt a management system that is beneficial to the environment and have positive economic results.
- Ensure the objectives of a nutrient management program are clear and those results can be measured. Justify regulation with accurate monitoring.
- Include all farmers in the programs. This will provide more options for satisfactory ways to utilize manure on croplands.

Texas

Texas has the second largest population in the United States, and is the second largest beef producer. Most of the Texas population occurs in the eastern sub-humid and humid areas, whereas most of the high-value agriculture occurs in the northern areas bordering Oklahoma and New Mexico. Surface water and groundwater sources in central and western Texas are scarce, and surface-water collection reservoirs are the main source of drinking water. Several drinking-water reservoirs are highly eutrophic, and water treatment costs have escalated. The focus in the 1980s in Texas was for control on point source contamination. Water quality continued to deteriorate throughout the 1980s, and programs began to focus on non-point sources in the 1990s. Mechanisms that target impaired watersheds have attained some positive results in the Bosque River watershed of central Texas.

Fed beef production in Texas occurs mainly in the High Plains, which ranges in elevation from 1,200 to 1,300 m. Many of the animal feeding areas are located near rivers to take advantage of the water source. Intensive beef production on the High Plains is combined with dryland and irrigated cropping. However, a large volume of feed is transported from other regions in the United States, resulting in a growing phosphorus surplus in the region. The main dairy-producing areas in Texas radiate about 160 km from the city of Dallas. One major dairy-producing county, Erath County, has serious water quality problems related to excess phosphorus. Gonzales County in south central Texas is the main poultry-producing area.

Regulations. The Texas Natural Resources Conservation Commission administers legislation related to phosphorus. At present, Nutrient Utilization Plans (NUPs) must be submitted annually to the Commission by the following agricultural operations.

- Operations with more than 1,000 animal units (700 dairy cattle or 1,000 feeder cattle) are defined as concentrated animal feeding operations. The Commission also requires that these intensive operations must have the capability to store enough water from a 1-in-25-yr, 24-h storm event.
- All concentrated animal feeding operations with soil-test phosphorus exceeding 200 mg kg^{-1}. Producers must apply phosphorus at rates recommended by the nutrient utilization plan until soil testing indicates that extractable phosphorus levels are reduced to below 200 mg kg^{-1} in the top 15 cm of the soil profile.
- All operations that have more than 200 dairy cattle or 300 feeder cattle, and do not have the capability to contain a 1-in-25-yr, 24-h storm event (TNRCC 1999a).
- All operations located in nutrient-impaired watersheds on the Commission’s Impaired Waters List. For example, the Dairy Outreach Program Area of Texas covers the majority

of the Bosque River watershed in central Texas. Segments of the Bosque River watershed have been included on the impaired waters list since 1992 (McFarland and Hauck 1999). The Bosque River drains to Lake Waco, which is the drinking-water source for the Waco area (population 140,000) (McFarland and Hauck 1999).

The plans must be certified by qualified persons, filed with the executive director of the Commission, and inspected annually (TNRCC/TSSWCB 1999). These plans must include a description of waste handling procedures, the assumptions and calculations used for determining land application rates for manure, and any nutrient analysis data.

If soil phosphorus levels in the top 15 cm exceed 200 mg kg^{-1}, the Nutrient Utilization Plan require that producers apply phosphorus at recommended rates until a soil analysis indicates that phosphorus levels in the soil have been reduced to below 200 mg kg^{-1}. Producers within the Dairy Outreach Program Area must apply manure and wastewater according to the following guidelines (Table 5). It is expected that Nutrient Utilization Plans will be required for all agricultural producers in Texas in the future.

Table 5. Manure and wastewater application guidelines in Texas.

Soil-test phosphorus level in 0- to 15-cm layer	Manure management requirement
0 – 62 mg kg^{-1}	Apply manure at two times the phosphorus utilization rate for the planned crop
63 – 120 mg kg^{-1}	Apply manure to meet 1.5 times the phosphorus utilization rate for the planned crop
120 – 200 mg kg^{-1}	Apply manure to meet the phosphorus utilization rate for the planned crop
> 200 mg kg^{-1}	No manure application allowed

Producers subject to Nutrient Utilization Plans that wish to apply manure or wastewater to fields must obtain an annual soil analysis for extractable phosphorus. Producers must also obtain an annual analysis of the manure and/or irrigation wastewater. The analysis must include the total nitrogen, phosphorus, and potassium. The results of the soil, manure, and wastewater analyses must be maintained by the producer.

For producers not subject to the Nutrient Utilization Plans, land application rates for manure and wastewater are generally based on available nitrogen content in the soil profile. Operators are expected to control runoff from the sites where manure and wastewater are applied. Manure cannot be stored or applied in the 1 in 100 yr floodplain or near water courses unless protected by adequate berms or other structures. Manure cannot be stored or applied in groundwater recharge zones. Where land application sites are isolated from surface water and groundwater, and no potential exists for runoff to reach any waters, manure and wastewater application rates may exceed crop nutrient uptake only upon written approval of the Executive Director of the Texas Natural Resources Conservation Commission. Inspections by the Texas Natural Resources Conservation Commission are conducted only in response to complaints.

Management. The Texas case study highlights two key components that are essential for efficient and effective control of non-point source pollution, and promoting environmental and economic sustainability.

Planning **-** Early and ongoing planning is essential. Numerous problems occur when agricultural growth is allowed to increase without sufficient planning. Ongoing assessments and sampling must take place to ensure that the phosphorus carrying capacity of the soil is not exceeded. The lack of planning ultimately leads to entrenched problems that are much more difficult and expensive to resolve. Careful planning saves money for operators and government, since control programs are generally much less expensive and less intrusive if they are implemented early.

Control of non-point source pollution **-** An effective Texas strategy for controlling non-point source pollution is the Planned Intervention Micro-watershed Approach (PIMA). This program relies on a strong voluntary promotion of pollution control on a small watershed basis, firmly backed by regulations for operators that do not comply.

The PIMA program offers several advantages.

- It avoids the prohibitive expense, large fines, and selective enforcement of regulation.
- The voluntary approach focuses on pollution prevention rather than punitive measures.
- The PIMA program promotes direct stakeholder involvement in comfortable working forums. Policies that support proactive approaches using local solutions have been shown to offer the best response (Pratt et al. 1997).
- The PIMA program allows for site-specific solutions.

The PIMA program also has a couple of weaknesses.

- Funding: A major obstacle to the development and implementation of non-point source management programs is the lack of funding, which impacts basic soil and water conservation programs (TNRCC/TSSWCB 1999). While state and federal cost-share programs exist to help intensive livestock operators with implementation of beneficial management practices for nutrient management, funds have only met a relatively small percentage of the overall applications. For example, in 1997 and 1998, EQIP funds respectively met 55 and 29% of the requests for assistance (Featherston 1999).
- Planning: It is recognized that many of the environmental problems being experienced in Texas could have been resolved through proper planning. The Texas dairy industry experienced rapid, unchecked growth between 1980 and 1990. Properly managed, water quality problems associated with the dairy industry could have been prevented.

Attention is now focused on mitigation in hot spots determined through a survey identifying impaired surface waters. The Upper North Bosque River was identified in 1989 by the Texas

State Soil and Water Conservation Board. A 17-yr mitigation plan was established in 1998, confirming that effective nutrient reduction may require significant time. Other impaired watersheds in Texas are also being identified, and further water management plans are being established. Relying on fines for compliance has decreased by allowing a more significant grace period for voluntary compliance.

Features for consideration in Alberta. Based on the assessment of the issues and programs in Texas, the following considerations are worthwhile to note for Alberta.

- Early planning to resolve environmental issues will always pay dividends. Continue planning throughout the design and implementation of the programs.
- Wherever possible, promote voluntary compliance with best management practices. This should also be backed with firm, practical regulations.
- All sufficient time for education and awareness programs to become effective.
- Provide limited funds to those watersheds where significant issues exist.
- Provide clear and scientifically supported rules. However, promote the development and implementation of regional solutions that are flexible.
- Build on major points of consensus among agencies and producers.

Michigan

Michigan has a land area of about 147,630 square kilometres and a population of almost 10 million people. Approximately 46,000 farms are located on almost 4 million ha of agriculture land. Michigan is the leading state in the United States for crops such as beans, blueberries, cherries, cucumbers grapes, and bedding plants (flowers). It has a relatively small livestock industry, with about 1 million cattle (1.1% production in the United States) and a similar number of hogs (1.8% production in the United States). Dairy is the main livestock industry, with about 4,000 operations having almost 300,000 milk cows. In 1999, approximately 200,000 cattle were on feed for slaughter. Many natural streams, lakes, and wetlands in agriculturally intensive areas of Michigan are eutrophic. Human population and land use competition continue to exert pressure on the quality of water resources in the state.

Environmental planning. In early 1998, Michigan unveiled a new initiative to address environmental pollution on the farm. The Pollution Prevention Strategy for Michigan Agriculture (Michigan Department of Agriculture 1997b) balances producers' right-to-farm with the need to protect the state's environment.

An implementation plan was also developed in response to the prevention strategy. It emphasizes preventing pollution at all stages of agricultural production, with the dual goal of preserving the quality of the environment and the financial soundness of farms. The new initiative is voluntary but can be enforced by "last resort" legislation.

Michigan is currently in the process of launching the Michigan Agricultural Environment Assurance Program (MAEAP). The purpose of this program is to help farmers better understand nutrient management, using a "whole farm planning" concept. The cost of this program, to the

State and United States governments, will be about $42 million, or $15,000 per farm. The major costs include farm environmental assessments, auditing and certification.

Right to farm act. The strategy used existing successful programs like the Right to Farm Act and was developed with input from many stakeholders. The resulting strategy outlines the responsibilities and obligations of stakeholders.

- **Zero discharge:** The United States Federal Clean Water Act and the Michigan Natural Resources and Environmental Protection Act empowers the Michigan Department of Environmental Quality to act against those who cause or allow pollution. Initial compliance is voluntary, using recommended pollution prevention practices. Enforcement occurs only as a "last resort".
- **Right to farm act:** This act ensures that farmers can perform the activities necessary for farming as long as these activities fall within accepted agricultural guidelines.
- **Generally accepted agricultural and management practices:** These agricultural guidelines are documented by the Michigan Agriculture Commission and were developed by all stakeholders, relying on research from Michigan State University.
- **Michigan agricultural environmental assurance program:** This is a new quality auditing process that supports the "whole farm planning" concept. Farmers can sign up to be assessed, audited, and certified. The intent of the program is prevent pollution.
- **Memorandum of understanding:** This agreement, between the Michigan Department of Agriculture and the Department of Environmental Quality, clarifies responsibilities and ensures cases are dealt with expediently and consistently.
- **Coordinated research and extension network:** This network supports the programs with sound research, technical expertise, and extension activities. This network also directs research and publicizes new findings.

The Right to Farm Act embraces generally accepted management practices, one of which focuses on how to manage manure odour and nutrients. It is designed to promote the efficient use of manure nutrients for crop production, while addressing potential contamination of surface waters and groundwater.

Nutrient loading guidelines. Manure nutrient loading guidelines for phosphorus for the state are summarized as follows.

- If the soil test phosphorus levels are greater than 188 kg ha^{-1}, manure may be applied at rates that will meet the agronomic nitrogen needs of the crop, based on Michigan State University recommendations.
- If the soil test phosphorus levels are between 188 and 336 kg ha^{-1}, manure may be applied at rates such that phosphorus levels in the manure does not exceed what the harvested crop removes.
- If the soil test phosphorus levels are greater than 336 kg ha^{-1}, manure applications should be discontinued until the crops reduce phosphorus soil-test levels to below 336 kg ha^{-1}.

These guidelines were based on research conducted by Michigan State University since the mid 1970s. Leaching of phosphorus was detected in sandy soils when soil test phosphorus levels reached 224 kg ha^{-1}. This prompted the state to adopt the 188 kg ha^{-1}guideline. A separate study found that soil-test phosphorus levels of about 336 kg ha^{-1}resulted in soluble phosphorus in runoff from fine-textured soils. Thus, the 336 kg ha^{-1} guideline above was adopted.

The process of dealing with a pollution complaint is carried out using the following process.

- The department of agriculture inspects the farm within 7 d of receiving a complaint and assesses if the farm operation is being managed using generally accepted practices.
- If the practices used are acceptable, the complainant, city, and county are notified.
- If the practices are not considered acceptable, the producer is advised that changes are required. If changes cannot be implemented within 30 d, an implementation plan must be submitted to the Department of Agriculture, and include a schedule to complete the necessary changes.
- A follow-up visit is scheduled and the city and county are notified of the inspection results.
- If the preceding measures are unable to bring the operation into compliance, the operation is referred to the Department of Environmental Quality.
- The Michigan Department of Environmental Quality can enforce the Natural Resources and Environmental Protection Act and other appropriate environmental statutes and rules to bring the operation into compliance.

The advantages of this program are as follows.

- The voluntary structure of this program makes it desirable to agricultural producers. A key incentive for participating is protection from nuisance suits under the Right to Farm Act, as long as environmental responsibility is demonstrated.
- The program is balanced, promoting viable agricultural production while protecting the environment.
- The Environmental Assurance Program will help farmers formulate a whole-farm plan to help prevent degradation of surface water and groundwater resources.
- The State can spend its limited environmental budget on the areas where the need is greatest.

The disadvantages of this program are as follows.

- Environmentalists consider the voluntary nature of the program to be a weakness.
- Bad actors can still find a way to avoid following generally accepted management practices.
- There is some question as to whether current research is sufficient to accurately recommend phosphorus standards.
- Ongoing measurement of water quality is lacking. As a result, there is concern regarding the impact of the program on improvement of water quality.

Features for consideration in Alberta. The experience gained from the assessment of Michigan’s programs provide a number considerations that are relevant to Alberta.

- Michigan’s environmental programs were developed with input from all significant stakeholders.
- The overall aim of the system being implemented in Michigan is to protect the environment while maintaining agricultural profitability.
- The proposed Environmental Assurance Program helps farmers to plan for prevention rather than remediation. Farmers who adopt “whole-farm planning” can be assessed, audited, and certified.
- Legislation and programs, such as the Right to Farm Act, are useful and friendly to farmers, thus providing them with important incentives to comply. This legislation gives legitimate agricultural operators an avenue for protection from nuisance suits and harassment complaints.
- Limited resources are being targeted at the most environmentally threatened areas in Michigan.
- Critical components such as extension programs, nutrient management certification, legislation and accepted management practices should be developed prior to launching the program.

Wisconsin

Wisconsin is located between Lake Superior, Lake Michigan, and the Mississippi River in the United States midwest. It has an area of about 145,040 square kilometres and a population of about 5.3 million people. The state has a cultivated agricultural land base of almost 3.5 million ha. Major crops include hay, corn, and soybean. Dairying is the most dominant business in Wisconsin, with about 1.4 million milk cows. Dairy products account for almost 70% of the total value of livestock, poultry, and their products sold in 1997. Other livestock include 3.6 million head of beef, 1.6 million hogs, and 33 million broiler chickens.

Water quality degradation impacts about 40% of the streams, 90% of the inland lakes, plus substantial areas of groundwater and wetlands throughout Wisconsin. In addition, many harbours and coastal waters of the Great Lakes are also impacted. Urban and rural non-point sources are considered Wisconsin's greatest cause of water quality problems. The competition for land and the human population growth continue to exert pressure on the quality of water resources. Significant contributors of phosphorus, in addition to agriculture, include cottage residential, manufacturing, and urban areas. Transitional lands (lands left bare during development) are a major contributor to phosphorus loading.

The effects of polluted runoff include destroying fish habitat, killing fish, reducing drinking water quality, silting of harbours and streams, and a decline in recreational use of lakes.

Water quality management. Wisconsin began implementing programs to address water quality problems in the late 1970s. Voluntary programs were introduced in 1978 to promote best management practices and support priority watershed and lake restoration and protection projects. While there were some local successes, adoption of voluntary programs for the agriculture industry has not been widespread (Wolf 1995; Shepard 1999).

Wisconsin's Department of Natural Resources has regulated point sources of pollution under the Wisconsin Pollutant Discharge Elimination System (WPDES) since 1984. It sets effluent limits for total phosphorus in wastewater discharged to surface water throughout the State. The effluent limit applies to any public or private operation that discharges wastewater to surface water, including runoff from animal feeding operations having more than 1000 animal units. Smaller operations may require permits if there have been complaints registered against them.

Legislation. While the state has had a long-term pollution plan, renewed political interest has resulted in recent legislative action. Sweeping changes have been proposed - directed mainly toward non-point source pollution control measures administered by the Department of Natural Resources and the Department of Agriculture, Trade and Consumer Protection.

New and amended rules are currently in the review process and include the following.

- Statewide performance standards and prohibitions will apply to livestock operations of all sizes, and most farming operations.
- Animal-feeding operations with WPDES permits will require a Nutrient Management Plan to dispose of manure.
- Enhanced regulatory authority and enforcement control will be introduced to support nitrogen, phosphorus, and sulphur (NPS) pollution abatement programs, including a new emphasis on phosphorus, and nitrogen-based rules.
- Farmers in high-priority watersheds must have an annual nutrient management plan by December 31 2006. All other farmers will need to develop these plans by December 31, 2010.
- New and revised conservation practices will include managing soil erosion and riparian areas, storage and application of manure, annual nutrient management plans, and certification of nutrient management planners.

While the proposed legislation is sweeping, the state is providing technical and financial assistance to help farmers meet these new regulations. These include the following.

- Cost sharing of up to 70% for farmers to implement recommended conservation practices.
- State financial support, through the departments of Natural Resources and Agriculture, Trade and Consumer Protection, to assist counties operate environmental protection programs at the local level.
- Policies and programs, developed at the federal and state levels, and delivered at the local or county level. At present, 65 of 72 counties in Wisconsin have Land Conservation departments and a Quality Assurance team oversees the development of regional and local nutrient management plans.
- Implementation of the proposed programs will be staged as follows.
    - High-priority watersheds by December 31, 2006, and non-priority areas by December 31, 2010.
    - Standard practices for managing nutrients will begin with basic protection, with added protection later to minimize the entry of nutrients to groundwater and surface water.

The projected cost for all of the programs related to agricultural pollution prevention in Wisconsin are about $1.2 billion over the next 10 yr (D. Jelinski, personal communication, 2000).

The advantages of the Wisconsin programs, existing and proposed, include the following.

- The application of phosphorus from fertilizer and manure sources has been substantially reduced from the 1970s to the 1990s. Phosphorus removed by crops was estimated to have increased over the same period. As a result, storage of excess phosphorus in the soil has been substantially reduced. This has been achieved while still increasing dairy production and crop yields.
- The programs have resulted in improved farmer awareness and attitude, improved communication among stakeholders, and additional research on nutrient reduction.
- Farmer-friendly extension programs, projects, and publications
- The expanding use of conservation tillage over the last decade has helped to reduce erosion and runoff volume as well as phosphorus loading (if the phosphorus is not stratified at the soil surface).

Concerns with the programs include the following.

- There was a lack of producer and commodity group involvement during the early development of pollution abatement programs.
- There appears to be a lack of coordination between existing programs.
- The complexity of the pollution control system has received an unfavourable public perception and requires significant technical expertise to guide producers through the processes.
- Lack of consistent nutrient standards over time has also hurt public perception, including the proposed change toward the use of phosphorus-based standards.
- Beneficial management practices designed to improve water quality on mixed farms by managing crop nutrients have not been extensively adopted (Shepard 1999). In 1998, 1,928 mixed farms were surveyed to determine nutrient application rates. Results indicated two of three farmers applied excess nitrogen, while four of five applied excess phosphorus for corn production.
- There is insufficient baseline data to monitor the impact of the programs for the protection or recovery of lakes and streams.
- Identifying all potential phosphorus pollution sources is questionable due to lack of accurate scientific data.

Features for consideration in Alberta.

- Rules are needed for vulnerable “transitional” land (areas under construction and development) where very high runoff per-hectare can happen without controls.
- Record keeping is vital in nutrient management planning.
- Voluntary programs with the “threat” of regulation seem to be the most effective.
- Infrastructure for delivery and technical assistance must be adequate.

- New non-point source standards must be aimed at rural, urban, and transitional lands.
- Quality Assurance Teams are very beneficial for overseeing regional and local nutrient management plans.

CASE STUDY CONCLUSIONS RELEVANT TO ALBERTA

Significant findings from the detailed case studies are discussed in this section, particularly the environmental, societal, and economic impacts of phosphorus standards, mechanisms, and timelines. They are summarized based on their applicability to Alberta and their importance to implementing phosphorus standards.

Environmental Impacts

The majority of soils in the Netherlands are saturated with phosphorus, while in Texas, Michigan, and Wisconsin, soils in the high-intensity agricultural areas are saturated or becoming saturated with phosphorus. Saturated soils serve as a long-term source of phosphorus, with the potential to continually impair surface water in the watersheds.

Experience from the case studies shows that agriculture is a major contributor of nutrients causing water quality degradation. Point source discharge was the focus of phosphorus control by several of the jurisdictions in the early years. Only later was attention diverted to non-point sources. The experiences from these jurisdictions indicate that it is difficult to clearly characterize non-point source phosphorus contributions from the various sources. It is also difficult to extrapolate the data from one basin to others because of regional and site-specific factors.

Regulations for non-point source nutrient loading in the four case study areas were implemented between the late 1980s and late 1990s. There has been insufficient time to observe the effectiveness of these programs in decreasing phosphorus levels in the water or soil. The case studies showed that implementing nutrient standards is the beginning of a long-term process to reduce nutrients in water bodies. Many years are required to bring about changes in farming practices, and many more years after that are required to observe the impacts.

Implementation of Programs

Key, relevant mechanisms for the management of phosphorus are discussed below.

- **Successful implementation mechanisms include voluntary programs with enforcement as a last resort to achieve compliance.** Voluntary programs combine education, awareness, extension, demonstration, and communication. All case studies have shown that when voluntary adoption of beneficial management practices is promoted, regulatory backup is rarely necessary.

  The Michigan and Texas experiences illustrate that it is possible to develop a program that is voluntary for producers, yet provides avenues for enforcement. Such a program protects farmers whose management practices follow predetermined guidelines, while providing a mechanism for effectively dealing with farmers that refuse to comply. It is recognized that a challenge exists to determine what the guidelines should be, and to develop a framework that allows government and industry to work together in educating and motivating producers. Michigan focused on bringing all stakeholders to the table, with the idea that people will support what they help create. The Planned Intervention Micro-watershed Approach (PIMA) in Texas provides a grace period to implement suitable site-specific management practices.

- **If sufficient numbers of producers within a watershed adopt point and non-point-source beneficial management practices, regulatory backup may rarely be necessary:** This experience was identified by a number of the case study jurisdictions. It was recognized that the initial focus should be to identify the issues and set watershed goals. Appropriate remedial measures can then be implemented through education, extension, demonstration and communication. Watersheds with identified water quality problems have been selected for initial action by most of the United States case studies evaluated.
- **The single phosphorus limit approach is unrealistic and impractical:** The impact of soil phosphorus loading on water quality varies significantly as a result of soil, climate, physiography and farming systems. The case studies confirmed that setting a single soil phosphorus limit for a state, province, or country was not scientifically sound.
- **Nutrient management is the recommended procedure for water quality management:** Nutrient management planning enables state, provincial, or federal goals and strategies to be established, and translate into specific practices at the farm level. In the Netherlands, a national policy on mineral management was formulated based on maximum phosphorus application rates for three crop types: grass, corn, and other arable crops (cereals, flax, oilseeds and others). Specific allowable losses of phosphate were legislated in 1998, and will be further reduced in 2003. Levies are assigned on losses that exceed particular levels. Michigan, Texas, and Wisconsin are now actively promoting and implementing nutrient management planning as a tool to better manage phosphorus and mitigate water quality concerns.
- **Developing standards for phosphorus and other nutrients is a process that will evolve as scientific knowledge and experience grows. Standards should be developed carefully, supported by monitoring that measures progress against clear objectives:** Wisconsin implemented general nutrient standards in the 1980s, but its focus changed appreciably in 1998 when phosphorus was highlighted. Farmers were concerned at the change, and the credibility of agencies and the current regulatory program suffered.

Table 6 summarizes mechanisms used to control phosphorus and relevant findings from the four case studies.

Table 6. Case study mechanisms used to manage phosphorus.

Mechanisms	Detailed case study findings
	Incentives
• Fertilizer savings or increased crop yields	• Important to target all agricultural landowners for nutrient management planning. The benefits are promoted by plan participants. Wisconsin is targeting all farms with >$1000 in annual receipts, which will included about 78,000 farms. • Michigan has a GAAMP category dealing with chemical fertilizers.
• Alternative markets for manure	• Texas is supporting a grading criteria for manure quality • Netherlands subsidizes manure redistribution • Michigan has implemented an Internet manure-brokering program.
• Grants, cost-share or low interest loans for capital projects	• The Environmental Quality Incentives Program provides cost-share funds limit is $50,000., with a yearly limit of $10,000, and a maximum 75% cost share.
• Requirements for receiving subsidies	• In all case study areas, there was a general trend of tying environmental and conservation compliance to participation in government-led agricultural support programs.
• Exit package for producers	• Netherlands: In 1997 the government announced a policy to reduce hog numbers by 20% using various incentives including a financial package for those who closed down operations. This policy was contested in court by farmers, and hog numbers currently are very similar to numbers in 1997.
• Free or subsidized technical assistance including nutrient management planning	• Wisconsin provided 100-million US$ per year on implementing BMP's (Jelinski 2000, Pers. Comm.)
• Premium on food products	• The United States is investigating a per litre premium on milk to help dairy producers implement BMPs. A $0.004 per litre premium could generate $2 billion (US) over 7 yr.
• Tax reductions	• Tax rebates recently available in Michigan for recognized environmental compliance.
	Regulations
• Levies on nutrient imbalance	• Netherlands: For phosphate surpluses above 40 kg ha^{-1}, a levy of 2.50 DLG ($1.50) kg ha^{-1} is imposed. For surplus above 50 kg ha^{-1}, a 10 DLG ($6.00) kg ha^{-1} levy is imposed.
• Fines on violations found during regular inspections or in response to complaints	• After repeated warnings, the TNRCC imposed hefty fines against Texas dairy operators who had inappropriate runoff catchment designs. ($490,000 against nine dairies in 1989, Frarey and Jones 1994)
• Operating requirements	• A Texas feedlot operator indicated that the strict environmental regulations of TNRCC resulted in increased efficiency for runoff control and manure handling at his site. The operator had full return on his investment, which was required by regulation, within 5 yr.
• Expansion requirements	• In several counties in Michigan, urbanization has increased over 10% in 15 yr, entirely at the expense of agricultural land. This has direct and severe implications for present or expanding livestock operations needing additional land for phosphorus-based application of manure.
• Liability from neighbours or environmental authority	• Michigan Right to Farm" Act (1981) was strengthened in 1989 by tying it to current GAAMPs, and by improving the compliant investigation process. There was further improvement in 2000 with the "Agriculture Environment Assurance Program"(MAEAP).
• Regular inspections	• From all case studies, it was evident that regular inspections are extremely costly and invasive. A strong recommendation is to rely on flexible voluntary programs backed by firm regulation, with random investigations.
	Education and awareness
• Familiarity and expertise increased through training, education (e.g., BMP publication), and local demonstrations	• The "De Marke" demonstration farm in the Netherlands is illustrative of the success that can be achieved using BMPs. • Texas Institute for Applied Environmental Research initiated three on-farm demonstration projects to provide both large and small dairy farmers with guidelines and recommendations to implement waste-management plans.

Table 6. Case study mechanisms used to manage phosphorus. (continued)

Mechanisms	Detailed case study findings
	Social pressures
• Participation in local environmental planning groups	• Planned Intervention Micro-watershed Approach (PIMA), Goose Branch, near Stephenville Texas. Group of approximately 12 to 15 land owners within areas of 1214 to 2024 ha are assisted by local and state officials in improving local water quality.
• Comparison with industry standard	• Throughout the United States, the National Pork Producer's Council (NPPC) programs provide producer education, assessment of farm operations, and certification where appropriate. They are funded by the mandatory checkoff of 0.45% of the value of each hog sold.
• Neighbours	• Importance of working together for local and societal goals (e.g., community involvement is evident in the Lake Mendota watershed in Wisconsin).
• Environmental commitment	• Michigan Pork Producers are readily adopting proactive conservation practices to improve or maintain environmental quality, and to protect themselves from nuisance suits. • The Netherlands programs have presented a clear message to farmers that environmental management is absolutely paramount. Farmers who fail to achieve the established standards will be severely penalized.

Case Study Timelines

Key findings regarding timelines and targeting used in the case studies are provided in the following discussion.

- **Non-action or delay in establishing regulations will lead to conflict situations:** The case studies showed the importance of establishing a realistic timeline for implementation of environmental programs. Even if timeline goals are modest, they indicate to society that environmental goals are being seriously pursued by the agricultural community. In the Netherlands, some scientists were advising of a nutrient problem in the 1970s, but no action was initiated until 1984. This delay increased the nutrient loading problem, and costs to society and producers rose significantly. In the dairy region of Texas, regulations were implemented, but were not initially taken seriously. This delay ultimately led to conflicts and serious financial impacts on producers.
- **There is a need to focus on priority issues in agricultural regions where phosphorus is a known and/or potential problem:** Clear rules should be established at the outset of any program, and attention focused on problem areas through awareness, education, technical assistance, and development of beneficial management practices. Education and awareness should be a constant for all programs.

A change in farming systems with respect to nutrient management is a long-term process, and will take time to address and implement. Case studies from the United States indicated at least 7 to 10 yr are required to cause significant practice change.

BENEFICIAL MANAGEMENT PRACTICES TO MANAGE PHOSPHORUS

An extensive literature and Internet review was conducted to identify and document appropriate beneficial management practices to reduce phosphorus loading. Findings from other jurisdictions indicate that technology and extensive knowledge exists to reduce and improve phosphorus problems. The practices also help minimize the potential for regulatory action against agricultural producers.

These management practices have also proven to be cost-effective in reducing phosphorus loading. For example, for a continuously cropped corn system in the eastern United States, it was estimated that phosphorus savings from \$0.80 to \$4.70 per kg ha^{-1} yr^{-1} occurred (Sharpley and Rekolainen 1997).

The following is an overview of general beneficial management practices that are used throughout many jurisdictions to reduce soil phosphorus loading. Each general practice is described, and its applicability and effectiveness to Alberta is discussed.

Farm Planning

Thorough planning for new and expanding operations is highly effective to avoid phosphorus problems in the future. Existing operations can also assess their environmental status through a comprehensive evaluation of facilities and management operations. The following provide some specific recommendations to help assess the environmental sustainability of an agricultural operation.

- **Site selection:** Livestock facilities should be designed and located to avoid any runoff of animal wastes or wastewater, and to avoid recharge to shallow aquifers (Section 2.2, AAFRD 1999). Ensure that sensitive environmental locations, or locations that are highly susceptible to phosphorus losses, are well managed so they do not become contributing areas to water pollution (pp. 36-41, LandWise Inc. 1999a; AAFRD 1995; LandWise Inc. 1999b).
- **Land base:** Avoid excessive accumulation of phosphorus, nutrients, trace elements, or salts by planning ahead. Take into account factors such as livestock population, feed rations, manure handling and storage, and crop uptake (AAFRD 1995).

Crop Management

Sound crop management practices can maximize the efficiency of phosphorus use from inorganic or organic amendments, allowing maximum crop production with modest concentrations of available soil phosphorus and reduced risk of phosphorus losses. Kimmell et al. *(*1999) found that subsurface banding of phosphorus fertilizer on no-till or ridge-till generally resulted in lower concentrations of soluble and bio-available phosphorus in runoff compared with broadcasting. Subsurface placement of phosphorus generally increased uptake and grain yield of corn and sorghum (Schwa et al.1999).

If critical environmental levels of soil phosphorus are reached, it takes much more time for phosphorus to decline to acceptable levels than to build up. There are two reasons for the delay: crop phosphorus uptake in soils with high phosphorus status is moderate, and most soils buffer (fix) available soil phosphorus so that it is not readily available to plants.

The following are specific recommendations that can improve overall phosphorus crop uptake efficiency.

- **Soil test:** A soil test determines required phosphorus additions for crop growth (pp. 54-55, LandWise Inc. 1999a).
- **Band phosphorus amendments:** Banding gives maximum phosphorus availability to crops, and this results in a reduced phosphorus application rate when compared with broadcasting. If phosphorus amendments must be broadcast, apply when antecedent soil moisture is low (AAFRD 1997b). Vary application rates to match expected crop response (pp. 59-60, LandWise Inc. 1999a).
- **Use crops with high phosphorus requirements in rotation:** If soils are high in available phosphorus, consider using crops with the highest phosphorus requirement. Western Canadian crops that use the greatest amount of phosphorus include corn, potatoes, peas, fababeans, sugar beets, and legume forages (Canadian Fertilizer Institute 1998). Unfortunately, most of these crops are generally grown under irrigation in Alberta, and therefore may have limited applicability.

Soil Conservation

While many studies indicate that a significant amount of phosphorus losses are adsorbed to soil particles, Anderson et al. (1998) found that most phosphorus loss in runoff from the Haynes Creek watershed in central Alberta occurred in the dissolved form. Regardless, it is generally agreed that any practice that reduces soil erosion also reduces phosphorus losses.

Soil erosion can be decreased by any practice that reduces the amount of runoff, the velocity of water flowing over the land, or the ease with which soil particles are detached (Sturgul et al. 2000). For example, establishing perennial crops on erodible land can be a highly effective method to reduce soil and phosphorus losses. In Manitoba, phosphorus losses were very low for alfalfa, somewhat higher for wheat, and were highest for a corn/fallow rotation (Hargrave and Shaykewich 1997).

When tillage can be conducted without an increase in soil erosion, it can reduce phosphorus loss in runoff by redistributing phosphorus from the surface layer to deeper layers. Zero-till can reduce soil erosion and increase water infiltration (Coutts and Smith 1991).

While reduced tillage reduces the loss of particulate phosphorus in surface runoff, it does increase the loss of soluble phosphorus to groundwater (Logan 1999). For example, a southern Ontario corn study conducted on a poorly drained soil with subsurface drains found that average losses of soluble phosphorus were 1.7 to 2.7 times higher from conservation tillage plots than from conventionally tilled plots. Losses were also highest on the zero-till plots (Gaynor and Findlay 1995). A Kansas study found that loss of particulate phosphorus was higher under ridge till and conventional (chisel+disc) till, but that loss of soluble phosphorus was higher under zero till (Janssen et al. 1999).

Studies conducted primarily in the southern United States found that grassed buffer strips can also reduce phosphorus losses by 21 to 90% (Chaubey et al. 1995; Srivastava et al. 1996; Barfield et al. 1998; Lim et al. 1998; Younos et al. 1998). In Idaho, filter strips composed of hybrid poplar removed two to three times as many nutrients from dairy waste runoff as grass filter strips (Haag 2000). Vegetated filter strips can be very effective in removing solids from runoff, but only moderately effective in removing nutrients or very fine suspended sediments (Brach 1991; Landry and Thurow 1997). A study found that filter strips were effective at trapping nearly 70% of the sediment from a demonstration field in Montana (Fasching and Bauder 1999).

Filter strips are not effective under snow-covered or frozen conditions, or if the area becomes clogged with sediments (Brach 1991; Landry and Thurow 1997).

The following provide more specific recommendations to help promote soil conservation practices, and thereby reduce phosphorus losses from the land and reduce phosphorus inputs to surface water.

- **Crop residues:** Keep adequate crop residues on the soil surface to prevent erosion, reduce runoff and improve water infiltration. Practices including reduce tillage, crop rotations, and returning sufficient residue to the land surface after harvesting provide good erosion protection (LandWise Inc. 1999a).
- **Vegetated areas:** Establish and maintain perennial vegetation on portions of the landscape that are susceptible to erosion (LandWise Inc. 1999a, pp. 10-12).
- **Vegetated filter strips:** Establish and maintain vegetated filter strips to remove sediment or other contaminants in runoff from cropland or livestock sites before they reach surface water or groundwater (LandWise Inc. 1999a). Filter strips require dense, vigorous, matted vegetation, such as the crown of grasses or other close-growing vegetation, to slow water and trap sediment deposited from the runoff. The trapped water and nutrients can then be used by the vegetation.
- **Riparian buffer strips and grassed waterways:** Riparian buffer strips are strips of vegetation, usually grass and/or trees, located between a farm field and the surface water. They are designed to retain and/or remove nutrients from runoff water before they enter the surface water (LandWise Inc. 1999a). Grassed waterways are natural or constructed channels with permanent vegetation, usually broad and shallow, which control sediment losses (LandWise Inc. 1999a).
- **Strip farming and contour farming:** These are effective practices used to reduce erosion from sloping land (Hickman et al. 1994).
- **Soil amendments:** Soil amendments such as wheat straw can reduce phosphorus losses, and may be economic for limited areas with high erosion potential (Marsh and Groenevelt 1992; Shock et al. 1997; Lentz et al. 1998).

Manure Management

Proper handling and storage of livestock wastes is essential to prevent surface water pollution. Waste management systems that fail are fortunately rare, but when they do occur, they often have a significant impact (Ackerman and Taylor 1985). Manure storage structures are required to prevent manure application on frozen, saturated, or snow-covered soils. For example, design and construction of manure storage structures in Vermont allowed manure application to occur only at appropriate times. This single action reduced phosphorus loading to Lake Memphremagog by about 10% (Stanley et al. 1999).

Incorporation of manure without delay is recommended to reduce the loss of soluble and particulate phosphorus in surface runoff, and to reduce odour problems (Gupta et al. 1997; Eghball and Gilley 1999). For example, applying manure and immediately discing the field reduced the dissolved phosphorus concentration in surface runoff from greater than 1 mg L^{-1} to less than 1 mg L^{-1} (Eghball and Gilley 1999). This method is less effective at reducing phosphorus losses when subsurface flow is important (Gangbazo et al. 1997). Manure should never be applied to frozen, snow-covered, or saturated fields.

The timing of application with respect to a rain event may also affect surface runoff losses. In a study conducted in Oklahoma, dissolved phosphorus losses in runoff decreased by almost half when manure was applied and incorporated 35 d before rain, compared to when rain occurred immediately after application (Sharpley 1997). Therefore, do not apply manure if significant rain is forecast before manure can be incorporated.

Preferential application of manure to fields or segments of fields that have a low risk of phosphorus transport can be an effective means of reducing phosphorus losses (Gburek and Sharpley 1998). Application depends on the knowledge of phosphorus transport and the availability of land with a low risk of phosphorus loss.

Adding aluminum, iron, and calcium to bind phosphorus in poultry litter reduced phosphorus concentrations in runoff water by 87%. Soluble phosphorus concentrations in leachate were also lower (Shreve et al. 1995). Adding calcium is unlikely to be effective or economically feasible for most soils in southern and eastern Alberta because they are already calcareous. Additions of alum to poultry litter reduced phosphorus concentrations in runoff by 70 to 86% compared to un-amended poultry litter (Isensee and Codling 1999).

If land for safe application of manure is not available in the vicinity of a livestock operation, improvements in the transport and value of manure are essential. Systems to separate liquid and solids are being used and tested for swine, pork, and dairy operations. However, these are only in occasional use at present.

Composting and other value added processing is being effectively used by some producers (Messenger 1999). Nagy et al. (1999), at Burr, Saskatchewan, determined that the economic hauling distance for manure was up to13.6 km. The economic hauling distance for composted feedlot manure in Texas is about 40 to 60 km (Warlick, personal communication[1]). Numerous intensive livestock operations in Alberta are now composting.

The following provide more specific manure management recommendations for producers.

- **Storage:** Store manure in an approved storage structure. The most recent Alberta Code of Practice (2000) outlines the steps required.
- **Nutrient management planning:** The ten critical steps to building a nutrient management plan (Ontario Ministry of Agriculture and Food and Rural Development 1996) are summarized below (McNeil et al. *20*00).
  - Test the manure.
  - Test the soil.
  - Account for residual nutrients.
  - Select how and when to apply manure and the time before incorporation. Inject or incorporate applied manure immediately after application. On sloping land, incorporation should follow the contour (LandWise Inc. 1999a, pp. 36-41). Do not apply manure on sloping land any time a runoff event is likely, or on frozen, snow-covered, or saturated soils. Preferably apply manure so that nutrients are released close to the time of active crop uptake (AAFRD 1995).
  - Select fields and determine application rates.
  - Choose your supplemental fertilizer.
  - Calibrate the fertilizer spreader.
  - Be aware of sensitive areas and follow accepted beneficial management practices. Avoid or reduce fertilizer application to those portions of the landscape that contribute most to runoff (Gburek and Sharpley 1998). If manure is applied on flood plains or close to surface waters, it is essential that incorporation take place immediately, and manure should not be applied at rates that exceed potential crop uptake. On fine-textured soils that are subject to shrink-swell and are tile-drained, land should be cultivated before manure application so that manure will be less likely to reach subsurface drains directly (Hilborn 1992).
  - Inventory and document the available nutrient sources.
  - Conduct a yearly evaluation of the plan and carry out an extensive review approximately every 5 yr.
- **Manure amendments:** Phosphorus can be immobilized by the addition of aluminum, iron, or calcium to manure and/or soil (Shreve et al.1995). Iron sulphate or fly-ash may lower the solubility of phosphorus in manure, and also effectively reduce phosphorus loss to water (Moore and Miller 1994).
- **Value-added products:** Composting manure increases the value of manure to off-farm customers by improving ease of transport, nutrient value, and consistency (Chaw and Abiola 1999). Weed seed viability in the manure also decreases, making it a more desirable product.

Michigan has developed a manure brokering system that is internet-based. The Netherlands promotes the transport of manure to regions that do not have a nutrient

[1] Scott Warlick, president of North Plains Compost Inc., Texas.

excess. Texas has developed a composting network that the Department of Highways uses to reclaim ditches and right-of-ways.

Livestock Diet

Beef. If grains contain relatively high concentrations of phosphorus, feedlot animals require little supplementation of phosphorus in the diet. Even in the early part of the feeding period for young calves, the concentration of phosphorus required in the diet will normally be less than 0.35%. Since average Alberta barley contains 0.35 to 0.37% phosphorus (Suleiman 1995), there is little need for supplementation except with young calves. Testing all feed supplies is an important requirement to ensure sufficient phosphorus is present.

Dairy. The dairy sector in the Netherlands reduced phosphorus losses in excretion by 30% between 1984 and 1996. This was possible through in-depth interdisciplinary research programs (van Bruchem et al. 1999).

The current National Research Council (NRC 1989) recommends that 0.28 to 0.48% phosphorus be present in the diet, assuming that 50% of the phosphorus is absorbed by dairy cattle. In comparison, the National Research Council (1996) assumes an absorption value for beef of 68%. It is suggested that this value may be applicable to diary and beef, which means that the phosphorus requirements for lactating dairy cattle are too high. Even the 68% figure may be too conservative. In a recent study, the true digestibility of corn silage in non-lactating cows was between 80 and 94% (Martz et al. 1999). These values were similar to the 84% measured previously in lactating cows (Martz et al. 1990).

Valk and Šebek (1999) concluded that diets containing 0.28% phosphorus were adequate for cows producing 9,000 kg milk per lactation but that 0.24% phosphorus was not adequate. Experiments of Call et al. (1987), Brodison et al. (1989), and Brintrup et al. (1993) all confirm that 0.33% or lower dietary phosphorus is adequate for dairy cows producing between 5,000 and 7,500 kg milk per lactation.

Pigs and poultry. Feed additives and feed strategies can reduce excreted phosphorus in monogastric livestock. The use of phytase in poultry feed will be required as of December 31, 2000 in Maryland. The Dutch government is also endorsing the use of phytase, although the recommendation is not currently backed by legislation.

Several practices are summarized in Table 7 (adapted from Schwarz 1998; Viaene and Verbeke 1998; Baidoo 1999).

The following outlines some specific recommendations that producers can apply.

- **Manage diets:** Farm livestock diets are generally formulated to achieve maximum animal performance, with less regard to the amount of phosphorus excreted. It is common practice to add “safety margins” that are greater than the animals estimated requirements. These margins are justified by the variation in the phosphorus content of feeds, variation in performance among animals, errors in feed analysis and feed mixing, lack of knowledge as to the actual phosphorus requirements of animals, and a misguided belief that excess phosphorus improves animal performance or skeletal integrity (Kornegay and Harper 1997). It is recommended that diets be formulated without these excessive safety margins. This will not only save money, but will reduce phosphorus losses in the excretions.

Table 7. Effectiveness of additives and feeding strategies to reduce phosphorus excretion from monogastric livestock.

Factor	Estimated achievable reduction in phosphorus excretion (%)
Feed additives	
Phytase	25-30
Growth promoting substances	5
Feeding strategies	
Formulation closer to requirements	10-15
Phase feeding	10-22
Use of highly digestible feed ingredients	5

- **Formulate rations based on animal type and size:** As animals and birds gain weight, the requirements for nutrients expressed as a percentage of the total diet decreases. Frequent changes in diet formulation, called phase feeding, are a more precise way to meet the nutrient needs of growing livestock.

  Phosphorus excretion in slaughter pigs can be reduced by 12 to 22% (Baidoo 1999; Beers et al. 1991) through phase feeding. Daily requirement for minerals can also be formulated for different groups of livestock. For example, the mineral requirement of pregnant sows is much lower than for lactating sows. Van der Peet-Schwering (1997) estimated that phosphorus output from sows could be reduced by 20% per year by using separate diets for each stage of production. Feed conversion efficiency of pigs can be also improved by split-sex or separate-sex feeding (Cromwell et al. 1993; Kornegay and Harper 1997).

  Phosphorus output from dairy cows can be reduced if multiple rations are fed over the lactation cycle. For example, a diet containing 0.45% phosphorus meets the requirements for a cow milking 45 to 55 kg but provides about 140% of the daily requirements for a cow producing 18 to 23 kg d^{-1} (Grant 1998).

- **Correct other nutrient deficiencies:** If other nutrients are limited in the diet, animals will not respond to supplemental nutrients. Where a phosphorus deficiency exists, there are other deficiencies as well. A well planned nutrient management plan is invaluable.

- **Analyze feeds for phosphorus:** The phosphorus content in feeds can be quite variable. To correctly formulate diets, the phosphorus content of feed must be tested, and the bioavailability of phosphorus within the feed determined.

- **Diet amendments:** Phytate phosphorus accounts for 46 to 80% of the total phosphorus in cereal seeds (Baidoo 1999). While Phytate phosphorus is readily available to ruminants, only about 30% of it is available to monogastric animals. Inorganic sources of phosphorus must therefore be added to meet monogastric animal dietary needs. Many studies demonstrate that phosphorus digestibility, and the efficiency with which phosphorus is retained in monogastrics, is significantly improved when the phytase enzyme is added to the diet. (Kornegay and Harper 1997; Kornegay 1998; Michal and Froseth 1999). The cost of adding phytase to rations is offset by the reduced need for inorganic phosphorus supplementation. Use phytase to increase phosphorus digestion by non-ruminants.

- **Feed crop varieties with low phytate phosphorus:** New hybrids of corn with low phytate phosphorus have been developed, and one variety of barley is currently being tested. Feed options are expected to improve in the future.

- **Feed supplements with high phosphorus availability:** Phosphorus supplements should be highly bioavailable to reduce the amount of supplement excreted. For example, monocalcium is a more bioavailable supplement than dicalcium phosphorus.

- **Maximize animal productivity while optimizing profitability:** Livestock require phosphorus for maintenance. If levels of production are increased, the amount of phosphorus required to produce each kilogram of gain or milk is decreased because maintenance costs are spread out over more units of production. It should be noted, however, that improvements in phosphorus utilization efficiency decrease at higher levels of productivity.

  Areas where animal productivity and feed conversion efficiencies can be improved include animal genetics, disease levels, environmental conditions, feed processing (pelleting and grinding), feeder design to reduce feed wastage, and use of growth promoters.

- **Eliminate free-choice feeding wherever possible:** Livestock do not voluntarily consume the correct amount of phosphorus in their diet. Over- and under-consumption can occur.

Livestock Grazing and Over-Wintering

Discouraging the tendency of livestock to congregate near riparian areas reduces the potential for phosphorus inputs to surface water through manure. It also reduces erosion associated with overgrazing or trampling, thereby improving water quality. In addition, these practices may improve livestock performance, pasture utilization and longevity, of surface water sources.

In Montana, supplemental watering away from the riparian areas quickly resulted in improvements to the riparian zone of an important fishery stream (Flaherty and Johnson 1995). In Virginia, the amount of sediment in stream water was reduced by 89% when cattle had drinking troughs located away from the stream and riparian area (Sheffield et al. 1997).

Wintering areas are an important source of phosphorus to surface waters in Alberta (CAESA 1998), but low-cost changes in management can often minimize phosphorus inputs. Cattle should not be fed or bedded in stream channels. Fencing, rotational grazing, and timing of grazing in riparian areas can all be effective practices for reducing phosphorus input to surface water bodies.

The following recommendations provide specific management practices that producers can use to reduce phosphorus inputs to surface water.

- **Grazing management:** Provide water to grazing livestock through off-site watering systems. Minimize direct access to all surface water and riparian areas to reduce the risk of direct contamination of water. Minimize livestock activity in areas with a high risk of degradation (LandWise 1999b; Adams and Fitch 1998).
- **Wintering areas:** Locate wintering areas away from water sources to avoid risk of contamination of surface waters through contaminated runoff. Avoid overcrowding of wintering areas, as this will increases manure build-up in the concentrated areas. Minimize manure accumulation by providing alternative water sources, and by distributing shelter, feed, and bedding areas. Provide a vegetated buffer strip between the site and surface water bodies.

Water Management

The use of settling basins and vegetated filter strips to treat runoff water from intensive livestock facilities reduced total phosphorus in two watersheds by 85 and 87% in Wisconsin (Stuntebeck and Bannerman 1995). Settling ponds are most effective at reducing phosphorus associated with soil particles and less effective at reducing soluble phosphorus concentrations (Logan 1993).

Constructed wetlands are being explored as a means to remove contaminants from agricultural runoff in Alberta. Climatic conditions and costs may limit the applicability and effectiveness of this practice in Alberta. The Prairie Farm Rehabilitation Administration has a constructed wetland demonstration site east of Edmonton that shows the environmental value in relation to the cost of development.
The following are specific management practices that producers can use to reduce phosphorus loading in surface water.

- **Runoff control:** Ditches or berms can be used to direct runoff water away from surface water or to prevent runoff water from flowing through manure storage areas or feedlot pens. Proper design of intensive livestock operations and wintering sites will incorporate numerous methods for runoff control. As well, manure storage facilities, silage facilities, and feeding areas should implement runoff control to prevent contamination of surface water.

- **Construct catch or settling basins:** These facilities help store runoff and allows phosphorus to settle out (LandWise 1999a). The water and associated soluble phosphorus can be reapplied to cropland by irrigation. Sediments enriched with phosphorus can be applied to the land when the catch basin is dry. Water in these basins can also be amended with chemicals such as ferric aluminum sulphate to increase settling rates (Dils and Heathwaite 1999). It is important to ensure that catch or settling basins are not located near waterways.
- **Construct wetlands:** Wetlands can store runoff water and allow phosphorus to settle out. Nutrients in the runoff can be utilized by wetland vegetation, which can later be harvested and removed (LandWise 1999a). Wetland sites should have impervious soils and negligible recharge. Some type of liner may be required if soils are too permeable.
- **Water-table management:** Open-ditches, subsurface tiles or conduits in conjunction with control structures help to control the depth of the water table and drain excess water from fields. Most agricultural regions of Alberta do not have tile drainage, and this option is not generally cost-effective for Alberta.

Examples of management practices applicable to phosphorus that were promoted and used in Texas, Michigan, Wisconsin, and The Netherlands are summarized below.

Nutrient Management Planning

Case studies have shown nutrient management planning to be one of the most successful practices for managing soil phosphorus loading and reducing phosphorus impacts on water resources. Farmers who use nutrient management planning frequently note the economic and environmental benefits of soil sampling, which allow the operators to determine agronomic nutrient application rates. This not only optimizes crop quality and yield, it also reduces waste and input cost.

In Wisconsin, nutrient management is being promoted for all farms with gross receipts greater than $1,000. This effort has been initiated in the year 2000 with extensive “train-the-trainer” sessions, and could ultimately deliver plans for up to 78,000 farms.

The De Marke demonstration farm in the Netherlands is being used to demonstrate sustainable management of phosphorus to farmers and the agricultural community. The demonstration farm is located on coarse-textured (sandy) soils, and shows that average-intensity dairy farms can effectively manage nutrients for crop production and attain water quality targets. Nutrient levels are closely monitored on the De Marke farm to determine rates and timing for nutrient application. Nutrients are applied several times during the growing season, based on crop needs. Frequent applications at low rates also significantly reduce nutrient leaching.

Another Dutch program established nutrient management monitoring on 240 farms throughout the Netherlands. By 1998, 25% of the farms involved in this project were achieving environmental standards that were required by the year 2008.

IMPLEMENTATION OF PHOSPHORUS STANDARDS IN ALBERTA

Conclusions

The case studies and related research conducted for this project provide the following conclusions regarding the implementation of phosphorus standards for Alberta.

- Implementation of phosphorus standards in those watersheds where phosphorus levels in the soil are generally low will not have a significant, immediate economic impact on producers. However, in those watersheds where soil phosphorus levels are currently high, producers will incur additional costs to acquire land and transport manure for spreading. All producers wishing to develop or expand intensive livestock operations will require an estimated 4 to 6 times the land base for manure spreading using phosphorus limts, compared with current land requirements using nitrogen as the limiting nutrient. The implementation of phosphorus standards will require all producers to regularly test soil and keep records.
- The consequences of “non action” related to phosphorus and overall nutrient management can be significant. Failure to take preventative measures, and to be seen by the public as taking preventative measures, will ultimately result in major conflicts between public interest groups and farm producer interests. This is a battle that farmers will not win over the long term and will prove divisive and costly. This is evident in the Netherlands as well as several states in the United States, notably Maryland, Florida, and the dairy region of central Texas.
- Regulations that arise out of conflict situations can have major negative impacts on producers. These impacts may include costly control measures, additional transportation and hauling costs, and the possibility that some producers will have to either relocate or exit the region and/or the business. There is clear experience with this in the Netherlands and Texas.
- A “one rule meets all” approach for soil phosphorus standards is unrealistic and impractical. There is significant variation in the capacity for soil phosphorus loading depending on soils, climate, physiography, and farming systems.
- The most realistic approach to managing soil phosphorus levels is through nutrient management planning, within the context of a clear provincial objective. Nutrient management planning enables the establishment of provincial goals and strategies, while meeting regional and municipal requirements. Implementation of these strategies can adopted into specific practices at the farm level.
- The adoption of beneficial management practices (BMPs) and nutrient management plans (NMPs) can make a significant contribution to managing and reducing phosphorus losses. These plans and practices need to be understood and communicated to all cropping and livestock producers.
- About 70 to 80% of Alberta soils are deficient in phosphorus for agronomic production. Strategic beneficial management practices (BMPs) will ensure that excess phosphorus loading does not become a problem.
- The development of standards for phosphorus and other nutrients is a process that will evolve as the science and experience improves. Standards should be developed carefully, supported by monitoring that measures progress against clear objectives. The timeframe

for the implementation of a phosphorus strategy is dependent on factors that include communication, infrastructure development, research needs, political will and policy, funding, and the degree of the problem.

- Change in farming practices with respect to nutrient management is a long-term process that will take time to address and implement. Implementation of a nutrient management program should be staged, and begin by focusing on priority issues and agricultural regions where phosphorus is a known and/or potential problem.
- If sufficient numbers of farms within a region or watershed adopt Beneficial Management Practices, regulatory action may rarely be required. Education, extension, demonstration, and communication should be priority programs to promote positive management changes at the farm level.
- The Michigan and Texas experiences illustrate that it is possible to develop programs that are voluntary for producers, yet provides avenues for enforcement. These programs protect farmers whose management practices fall within predetermined guidelines, while providing a mechanism for effectively dealing with producers who refuse to follow reasonable management practices.
- All of the case studies clearly demonstrate the need for early planning with respect to nutrient and phosphorus management. The earlier phosphorus management strategies are established, the less likely that phosphorus loading will become an issue.

Recommendations

Based on the results of the case studies, the following recommendations are provided.

- **Implementing soil phosphorus regulations should include a voluntary education program within a regulatory framework:** The case studies show that voluntary compliance through adoption of nutrient management plans was most successful in meeting environmental objectives. However, there must be a regulatory backup to achieve nutrient management objectives and to discourage violations. The case studies also show that reliance on regulation alone is cost prohibitive, intrusive, and ineffective. Efforts should be devoted to encourage producers to achieve compliance through the use of beneficial management practices and nutrient management planning.

- **Phosphorus regulations should be variable, depending on soil, climate, and landscape conditions:** Phosphorus limits should be regionally varied and take into consideration differences in soil characteristics, climate, topography, etc. The case studies show that setting one soil phosphorus limit across a political jurisdiction is not practical or credible. Careful investigation must take place to develop appropriate phosphorus limits for various soil landscape units within each region of the province.

- **Implementation of phosphorus standards should be staged:** For areas where soil phosphorus is in a deficit or balanced state, phosphorus limits should be implemented immediately. This would likely represent between 80 to 85% of the agriculture lands in Alberta. In areas of soil phosphorus surplus, phosphorus limits should be phased to allow producers the time to comply with the standards.

- **Monitoring should be required to ensure phosphorus standards are met:** Producers will be required to carry out a regular soil monitoring program and keep records to prove that soil phosphorus limits are not exceeded. In addition, the Alberta Government will be required to continue with long-term monitoring of representative watersheds to determine if environmental objectives are being met.

- **Implementation of soil phosphorus standards should be combined with a coordinated nutrient management strategy:** A provincial nutrient management strategy is required to provide producers and the agriculture industry with the necessary information and tools to manage soil phosphorus. This will require the selection and testing of beneficial management practices that are effective at the regional, local, and watershed levels throughout the province. Education, awareness, and demonstration of effective technologies need to be coordinated and implemented. Where effective technologies do not exist, applied research programs will be required.

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