Alberta Soil Phosphorus Limits Project

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INTRODUCTION

Agricultural systems often require added phosphorus to achieve optimum crop and livestock production. The application of soil amendments, such as inorganic fertilizers, manure, biosolids, and waste water, can improve soil fertility and help produce optimum crop yields. However, many of these amendments, particularly organic materials such as animal manure, are often applied in excess of crop nutrient requirements. A build up of nutrients in the soil can be a significant risk to surface and groundwater quality. The movement of phosphorus from agricultural land to surface water can lead to accelerated eutrophication, which is recognized as a significant water quality problem in the many parts of the world (Johnston et al. 1997; Correll 1998; Haygarth and Jarvis 1999; Haygarth et al. 2000; Sharpley et al. 2000; Campbell and Edwards 2001).

Generally, extractable phosphorus in Alberta soils are deficient or marginal for crop production. Manunta et al. (2000) reported that data from 1993 to 1997 showed that the majority of the ecodistricts in Alberta had a mean extractable phosphorus value between 25 and 30 mg kg⁻¹ in the top 0.15 m. Therefore, much of the agricultural land in Alberta can benefit from added phosphorus to obtain optimum crop yield. However, over application of nutrient sources can greatly increase soil phosphorus levels. Olson et al. (2001) showed that after seven years of annual application of a high manure rate (120 Mg ha⁻¹ wet beef manure) in southern Alberta, Modified-Kelowna extractable phosphorus in the top 0.15 m ranged from 900 to 1150 kg P ha⁻¹ (about 450 to 575 mg kg⁻¹), which is ten or more times greater than what is required for crop growth. Whalen and Chang (2001) reported that after 16 years of annual beef manure application on continuous cropped land in southern Alberta, extractable Olsen phosphorus in the 0 to 0.15-m soil layer ranged from 317 to 964 mg kg⁻¹, which varied with manure application rate (30 to 180 Mg ha⁻¹ yr⁻¹ wet-weight basis). A water quality study in Alberta showed that as agriculture intensified in watersheds, the amount of phosphorus increased in streams (CAESA 1998). Other research has shown that as extractable phosphorus (bioavailable phosphorus) increases in soil, the concentration of phosphorus in runoff water will also increase (Pote et al. 1996; Sims et al. 2000).

Several better management practices have been suggested to control agricultural phosphorus transfer from soil to water (Sharpley et al. 2000). In addition to better management practices, soil phosphorus limits or phosphorus indices have been adopted in some jurisdictions. The United States Department of Agriculture Natural Resources Conservation Services initiated national guidelines on nutrient management (Mallarino et al. 2002). The national guidelines suggested the use of one of three phosphorus-risk assessment tools: (1) agronomic soil test phosphorus interpretation classes, (2) environmental soil phosphorus limits, or (3) phosphorus index. Many states have adopted a version of the phosphorus index, which is a tool that is used to assess the relative risk of phosphorus loss from land to surface water (Lemunyon and Gilbert 1993; Gburek et al. 2000). The phosphorus indices are based on general assumptions and professional judgment. In most cases, no attempts have been made to relate phosphorus indices to actual phosphorus loss under local conditions. Phosphorus indices are not designed to quantify phosphorus loss (Sharpley et al. 2002). In Alberta, a project was initiated in 1999 to develop phosphorus limits for agricultural soils in the province. Rather than simply adopting a qualitative-based phosphorus index, it was decided to develop tools and relationships to determine site-specific soil-

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phosphorus limits that would meet identified phosphorus-export objectives to protect surface-water quality. The purpose of this paper is to present an overview of the Alberta Soil Phosphorus Limits Project.

PROJECT BACKGROUND AND OBJECTIVES

During 1998 and 1999, attempts were made to develop regulations for the confined feeding livestock industry under the guidance of the Intensive Livestock Stakeholder Advisory Committee (ILSAC). During this process the Technical Expert Committee drafted the Standards Document, which was designed to support the regulations and replace the 1995 Code of Practice (Intensive Livestock Operations Committee 1995). Though phosphorus limits were not included in the draft guidelines, the ILSAC requested, upon advice from the Technical Expert Committee, that phosphorus guidelines be developed, based on research in Alberta. In response to this, Alberta Agriculture, Food and Rural Development (AAFRD) established a multi-agency steering committee and a technical working group to address the request for developing soil phosphorus limits.

The Soil Phosphorus Limits Steering Committee was established in September, 1999, with the overall responsibility of managing the project. The nine-member committee included representatives from Alberta Agriculture, Food and Rural Development, Alberta Environment, Agriculture and Agri-Food Canada (Prairie Farm Rehabilitation Administration), Alberta Environmental Sustainable Agriculture (AESA) Council, Technical Expert Committee, and Intensive Livestock Working Group. The Steering Committee reported to Alberta Agriculture, Food and Rural Development’s Environmentally Sustainable Agriculture Committee (ESAC). The Steering Committee was disbanded after Phase 1 of the project and the project now reports to the Provincial Nutrient Management Strategy Committee.

The Soil Phosphorus Limits Technical Working Group was formed to carry out the required technical reviews, assessments, data collection, and data interpretation needed to develop science-based phosphorus limits. Membership of the Technical Working Group has varied over time depending on the Group’s activities.

The objectives of the Soil Phosphorus Limits Project are (Olson 2001):

1. Develop phosphorus limits for agricultural lands in Alberta.
2. Determine ramifications of implementing phosphorus limits.
3. Identify management options for implementing phosphorus limits.
4. Develop an action plan and time lines for implementation of limits.
5. Develop a process for future upgrading of the standards.
6. Develop a monitoring plan to determine the degree of compliance of the limits.

The initial attempt to adopt regulations for the confined feeding livestock industry was put on hold for a few years. In the interim, the 1995 Code of Practice (Intensive Livestock Operations Committee 1995) was replaced by the 2000 Code of Practice (AAFRD 2000). Eventually, regulations were adopted for confined feeding operations through amendments to the Agricultural Operational Practices Act, which came into affect on January 1, 2002 (Province of Alberta 2001). In the new regulations, manure applications are based on nitrogen, with no consideration for phosphorus at this time. Excess phosphorus in agricultural land is still a concern in Alberta, particularly land that is associated with confined feeding operations. This continued concern about phosphorus, along with the development of science-based information, may eventually lead to the incorporation of phosphorus-based management into the regulations.
PROJECT ACTIVITIES

A number of activities have occurred since the Soil Phosphorus Limits Project began, and some activities were already in progress and were incorporated into the project. Only a brief description can be presented here. The Soil Phosphorus Limits Project can be described in two phases. Phase 1 was carried out from 1999 to early 2002. Phase 2 began in 2002 and is currently in progress. To date, the Project has focused mainly on the first objective.

Project Activities - Phase 1

Literature review. A literature review was carried out with the following objectives: (1) to examine the science-based evidence for the relationship between soil phosphorus and water pollution risk, and (2) to present options for the development of a phosphorus management strategy in Alberta. The literature review presented four primary conclusions (Howard et al. 1999): (1) research has increasingly identified phosphorus pollution from municipal, industrial, and agricultural sources as a major threat to water quality; (2) pollution risk increases with higher levels of soil phosphorus; (3) surface waters in Alberta are extremely sensitive to further phosphorus enrichment; and (4) a desirable long-term goal for Alberta is a balanced nutrient management approach to land application of nutrient-bearing materials.

Assessment of implementing phosphorus standards. The Steering Committee recognized that other jurisdictions in North America and elsewhere in the world have either faced or are facing similar challenges of managing soil phosphorus in order to prevent or correct water contamination. The catalyst for action by other jurisdictions has often been related to the application of livestock manure. It was decided that a more detailed assessment of other jurisdictions would provide a learning opportunity for the project. A contract was awarded to LandWise Inc. and Toma & Bouma Management Consultants to carry out the assessment. An Internet and literature search of 16 jurisdictions throughout the world was carried out. Four case-study jurisdictions were then selected based on program history, applicability, and adaptation to Alberta conditions. The four case-study jurisdictions selected were Texas, Michigan, Wisconsin, and The Netherlands. A project team member and an industry or government representative traveled to each case-study jurisdiction and collected more detailed information. The teams collected information on environmental impacts, economic implications, and time frame for implementation. Based on the results of the case studies the following five recommendations were presented (Soil Phosphorus Limits Committee and LandWise Inc. 2001).

1. Implementing soil phosphorus limits should include a voluntary education program within a regulatory framework.
2. Phosphorus limits should be variable, depending on soil, climate, and topographic conditions.
3. Implementation of phosphorus limits should be staged.
4. Monitoring should be required to ensure phosphorus standards are met.
5. Implementation of soil phosphorus limits should be combined with a coordinated nutrient management strategy.

Phosphorus workshop. The Steering Committee recognized that ongoing communications with a variety of stakeholders is critical during the process of developing soil phosphorus limits for agricultural land. To assist with the Project’s communication strategies, a communications plan was developed by the Steering Committee. As part of the Project’s communication plan, a technical review workshop was held on April 10 and 11, 2000. The purpose of the workshop was to provide information on the phosphorus issue, to provide an update on the Soil Phosphorus Limits Project, and to give delegates the opportunity to provide constructive input into the overall approach to developing phosphorus limits and phosphorus management strategies in Alberta. About 70 people attended the workshop. A summary of the workshop proceedings was prepared by LandWise Inc. and AAFRD (2000).
**Phosphorus mobility study.** This project was initiated by AAFRD titled ‘Phosphorus Loading and Associated Mobility with Livestock Manure’, with external funding from the Canada-Alberta Hog Industry Development Fund (CAHIDF) and Canada-Alberta Beef Industry Development Fund (CABIDF) programs. The study, referred to as the Phosphorus Mobility Study, was started in the latter half of 1998.

The main objective of the study was to develop a methodology to assess the potential of phosphorus movement from the landscape on a site-specific basis (Wright et al. 2002). The Phosphorus Mobility Study was designed to assist in determining site specific phosphorus loss from agricultural soil within a watershed. The tools developed by this study can be used to calculate site-specific maximum soil phosphorus limits, once off-site phosphorus export limits have been determined by a secondary process. As a result, the Phosphorus Mobility Study became an integral part of the Soil Phosphorus Limits Project.

The Phosphorus Mobility Project consisted of six main parts.
1. Field catchment study: The measurement of natural surface runoff from three field-sized water catchments.
2. Field benchmark rainfall simulation study: The measurement of surface runoff from four benchmark field plots at different times of the year using a rainfall simulator.
3. Laboratory rainfall simulation study: The measurement of surface runoff from numerous soils in the laboratory using a rainfall simulator.
5. Enrichment of soil phosphorus in runoff sediment study: Determine the distribution of phosphorus in runoff sediment size fractions.
6. Manure/soil phosphorus prediction study: Develop the capabilities to predict the change in STP for a specific soil after receiving a specific amount of manure.

One of the main outcomes from the Phosphorus Mobility Study was the development of the Edge-of-Field Phosphorus Export Model (EFPEM), which was based on extensive laboratory rainfall simulations. A total of 66 soil-treatment combinations, representing 25 different soil types, were rained on in the laboratory. Modified-Kelowna phosphorus content in the soils ranged from 10 to 495 mg kg\(^{-1}\) (Wright et al. 2002). Soil samples were coarsely sieved and well mixed. Soils were placed into metal rain frames (0.5 m by 0.95 m) to a depth of 0.05 m and were subjected to simulated rainfall.

The rainfall simulation experiments showed a highly significant, linear correlation between dissolved inorganic phosphorus (DIP) flow-weighted mean concentration (FWMC) and soil test phosphorus (STP) (Figure 1). Wright et al. (2002) concluded that a single DIP versus STP relationship is applicable to a wide range of soils. The relationship is shown in the following equation.

\[
\text{DIP} = (0.0031 \times \text{STP}) - 0.0437
\]

Where:
- DIP = DIP FWMC in runoff at equilibrium flow (mg L\(^{-1}\))
- STP = Soil-test phosphorus as measured by the Modified-Kelowna method (mg kg\(^{-1}\))

In addition to the laboratory simulated rainfall experiments, a limited number of small field catchment studies were carried out. It was observed that DIP in runoff water from the catchment sites was an average of 5.9 times higher than observed in the laboratory. Even though this factor was based on very limited field data, it was used as a scaling factor to modify Equation 1. The right-hand side of Equation 1 was multiplied by 5.9 to give the following equation.
DIP = (0.0183 × STP) − 0.258

Wright et al. (2002) stressed that further work is needed to evaluate the scaling factor with more field data. The question is what factors contribute to the need for a scaling factor to adjust the laboratory-based relationship to fit field data. The experimental basis of Equation 2 and the actual STP stratification in the upper soil profile may have a role. Sharpley and Tunney (2000) summarized results from a field study, which was carried out to compare runoff from several 2-m$^2$ simulated rainfall plots within a 2-ha catchment to the runoff from the catchment as a whole. Dissolved phosphorus in runoff from the 2-m$^2$ plots ranged from 0.20 to 0.49 mg L$^{-1}$, whereas the runoff from the whole 2-ha catchment had a dissolved phosphorus concentration of 0.62 mg L$^{-1}$. The difference between plots and catchment was attributed to more soil phosphorus entrainment in the larger catchment and this resulted in more enrichment of dissolved phosphorus in runoff water.

Figure 1. Dissolved inorganic phosphorus (DIP) flow-weighted mean concentration (FWMC) in runoff water at runoff equilibrium as a function of Modified-Kelowna soil-test phosphorus (STP) under laboratory simulated rainfall conditions (Wright et al. 2002).

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The Phosphorus Mobility Study used the Water Erosion Prediction Project (WEPP) model with the phosphorus runoff relationship (Equation 2) to predict phosphorus loss from a specific site. The WEPP model is a process-based erosion model developed by the United States Department of Agriculture (Nearing et al. 1989). This model can predict the amount of runoff volume (Q) and sediment load loss. The amount of mass DIP lost in surface runoff can be calculated by multiplying the right-hand side of Equation 2 by the volume of runoff (Q), giving the following Edge-of-Field Phosphorus Export Model (EFPEM).

\[ \text{DIP}_{\text{exp}} = Q[(0.0183 \times \text{STP}) - 0.258] \]
Where:
- $DIP_{exp}$ = Mass of DIP exported in runoff (mg)
- $Q$ = Predicted runoff volume (L).
- STP = Soil-test phosphorus as measured by the Modified-Kelowna method (mg kg$^{-1}$)

The Soil Phosphorus Limits Project requires phosphorus loss predictions from larger landscapes, such as quarter sections, soil polygons, or watersheds. It was decided to focus on the soil polygon scale within watersheds. There are about 28,000 soil polygons in the agricultural regions of Alberta. To run the WEPP model on all soil polygon landscapes, a number of activities had to be carried out including the preparation of data files for the climatic parameters, hillslope and watershed descriptions, and soil information. The climatic data used in this process were obtained from the AESA (Alberta Environmentally Sustainable Agriculture) Soil Quality Monitoring Project. Most of the climatic parameters were in the data set, but a few parameters had to be calculated using various methods. The hillslopes and watershed descriptions and soil information were obtained from AGRASID (Agricultural Region of Alberta Soil Inventory Database).

**Initial watershed assessment study.** In order to develop credible soil phosphorus limits, it was decided to carry out a study in at least one watershed impacted by agriculture. The study provided field data from land and water that were used to compare against modeled phosphorus export from soils containing moderate to high levels of phosphorus. The study furthered our understanding of the linkage between phosphorus export from land and phosphorus in streams.

A subbasin (M1) within the Haynes Creek watershed, which is located near Red Deer, Alberta, was selected for the study (Figure 2). The quality of the water from this subbasin has been monitored for several years. The M1 subbasin is 2514 ha in size, of which 51 percent of the land area is used for annual crops and 28 percent is used for perennial crops or grazing. Cattle and hogs are also present in the subbasin. A survey was used to collect land-use and management information from the landowners. Samples from two depths (0 to 0.05 m and 0 to 0.15 m) were collected from 353 sites within the subbasin. Sampling sites were selected based on landscape classes, and they were located in a series of transects across the subbasin. Each site was georeferenced with a Differential Global Positioning Satellite (GPS) System and descriptive site information was recorded.

Soil extractable phosphorus ranged from 2.5 (half the detection limit) to 453 mg kg$^{-1}$ for the 0 to 0.05-m soil depth, and from 2.5 to 358 mg kg$^{-1}$ for the 0 to 0.15-m soil depth (Olson et al. 2001). A majority of the samples, 78 percent of the 0 to 0.05-m samples and 88 percent of the 0 to 0.15-m samples, contained less than 60 mg kg$^{-1}$ extractable phosphorus. About 21 percent of the 0 to 0.05-m samples and about 10 percent of the 0 to 0.15-m samples contained 60 to 140 mg kg$^{-1}$ extractable phosphorus. About one percent of the samples from either depth contained more than 140 mg kg$^{-1}$ extractable phosphorus.

The measured STP values were used to predict DIP-FWMC in runoff from the fields. The predicted DIP values were also adjusted using relative Q values provided from the AGRASID-based WEPP modeling to refine the stream DIP estimate based on estimated runoff characteristics. The results showed that the model explained 74 percent of the dissolved phosphorus in the M1 subbasin stream (Olson et al. 2001). Without the scaling factor of 5.9 used in the model, only 13 percent of the dissolved phosphorus found in the stream was explained.
Project Activities - Phase 2

In early 2002, the Soil Phosphorus Limits Project moved into Phase 2. After the completion of the Phosphorus Mobility Study, it was deemed necessary to validate the model by collecting more field data. The Phosphorus Mobility Study collected limited field data, and the M1 subbasin study was on a scale too large to be repeated elsewhere in Alberta. In addition, at this time, the question of relative contributions of phosphorus from various locations and activities within watersheds was raised and discussed.

Two projects were started in Phase 2, of which one has been completed. The first was a literature review on phosphorus sources and sinks in watersheds. The second was to carry out an extensive micro-watershed field study to validate the EFPEM.

Literature review of phosphorus sources and sinks in watersheds. The purpose of the literature review was to (1) identify phosphorus sources and sinks that may impact water resources, (2) identify their individual contributions, (3) assess attempts to integrate phosphorus fluxes on a watershed scale, and (4) identify implications of the information on the Soil Phosphorus Limits Study (Riemersma et al. 2002). The review covered terrestrial phosphorus losses from cultivated land, grasslands, irrigated land, forested land, urban sources, industrial sources, septic systems, and atmospheric contributions. Phosphorus flux within aquatic environments was covered, including groundwater, wetlands, riparian areas, in-stream processes, lakes, and reservoirs. The review also described several specific watershed-scale case studies.

The following are some highlights from the review carried out by Riemersma et al. (2002).
1. A common aspect to all studies was the inherent variability of phosphorus flux and its dependency on local conditions.
2. Each land-use activity has a variety of factors that can affect the availability and transport of phosphorus.
3. The phosphorus cycle in receiving water bodies is complex, and aquatic systems act as a source and sink for phosphorus.
4. Because of the inherent variability in watersheds, the phosphorus in runoff water is site specific, and this results in a large range of export coefficients for each source.
5. Few studies have attempted to link small-scale plot work with large-scale watersheds. Researchers that have attempted this linkage of different scales have found that a large proportion of soluble phosphorus from land is attenuated in-stream through adsorption or dilution.
6. Researchers that have studied large, multiple land use water studies have found it difficult to account for phosphorus from specific sources.
7. There is some evidence that internal loading may contribute more to phosphorus concentration in surface water than from surrounding land.
8. Soil test phosphorus and the relationship between soil test phosphorus and dissolved phosphorus in runoff, alone, will not provide the appropriate basis for developing soil phosphorus limits in Alberta.
9. Particulate phosphorus must also be included in the assessment of phosphorus loss from land to water.
10. Targeting management practices within critical source areas may be the most effective way to reduce phosphorus loss.
11. A better understanding of in-stream processes may help to identify the contributions of phosphorus from terrestrial or aquatic environments.
12. Groundwater/surface water interactions, as well as atmospheric deposition may be important sources.

**Micro-watershed field study.** The EFPEM is based primarily on laboratory rainfall simulations with modification based on very limited field data (i.e. the scaling factor adjustment). The Haynes Creek M1 Subbasin study was the first attempt to assess the model on a watershed scale. Following a review workshop in July, 2001 and a more intensive peer review of the Phosphorus Mobility Study results in early 2002, it was decided that a province-wide micro-watershed study should be carried out to validate the EFPEM.

Eight sites were selected and instrumented (Figure 3). The micro-watersheds were located within the three main ecological zones in Alberta; grassland, parkland, and boreal. Seven sites are cultivated agricultural fields. One site (Stavely) is under ungrazed, native grass. Two of the agricultural sites (Ponoka and Lower Little Bow) have received significant amounts of livestock manure. The micro-watersheds range in size from 22 to 330 ha.

Digital elevation models were obtained based on aerial photographs, and the digital elevation models were used to determine wetness index, landform elements, and distance to outlet for each micro-watershed. Based on this information, about 30 soil-sampling sites were selected within each micro-watershed. Sites were selected on the basis of proximity to the outlet and landscape topography. The location of each site was recorded with the GPS. A metal frame (19 by 50 cm) was pressed into the soil surface and shovels were used to excavate the soil to three depths (0 to 0.025 m, 0.025 to 0.05 m, and 0.05 to 0.15 m). The samples were dried, ground (2-mm sieve), and analysed for soil test phosphorus using the Modified-Kelowna extraction procedure. Soil samples were collected in the fall of 2002.

Each site was instrumented to collect water samples and measure flow. Two of the sites (Stavely and Ponoka) were existing sites and were instrumented with H-flumes. The other six sites were instrumented with circular flumes and float potentiometers (Samani and Magallanez 2000). The circular flumes were either attached to culverts or inserted in constructed berms. The sites were also instrumented with rain gauges, thermisters, ISCO™ automatic samplers, and RomComm™ telecommunication systems. The
RomComm™ technology provide the means, through the cellular telephone system, pagers, and the Internet, to have real-time data for flow events and automatic water sampling. Water samples are submitted to the laboratory within 24 hours. Samples are analysed for total phosphorus and dissolved inorganic phosphorus.

At the time of this writing, spring runoff in 2003 has occurred at five of the eight sites. The monitoring and sampling collection system has worked well during the first season of the study.

**SUMMARY AND CHALLENGES**

Several factors influenced the need to develop science-based tools and information to manage soil phosphorus for the purpose of protecting surface-water quality in Alberta. The Soil Phosphorus Limits Project was initiated in 1999, with the overall objective of developing phosphorus limits for all agricultural land in Alberta. Phase 1 of the project (1999 to 2002) focused on obtaining background information and supporting the Phosphorus Mobility Study to gather experimental data to develop the relationship between phosphorus in Alberta soils and phosphorus in runoff water. Phase 1 resulted in the development of the Edge-of-Field Phosphorus Export Model (EFPEM), which is based primarily on laboratory data and limited field data.

After intensive consultation and peer review, it was decided that more field data were required to validate, and if required, modify the EFPEM. Phase 2 of the study began in 2002 with the initiation of a province-wide micro-watershed study. Eight micro-watershed sites were selected and instrumented in

![Figure 3. Location of the eight micro-watershed sites in Alberta.](image-url)
2002. Baseline soil samples were collected in late 2002 and the first runoff water samples were collected in spring 2003.

The Soil Phosphorus Limits Project has made significant progress during that past three years. However, several challenges remain to overcome as outlined below.

- There is a realization that a potential implication of EFPEM is that soil test phosphorus may need to be quite low to meet water quality objectives, particularly in medium- to high-risk areas. For example, the current form of the STP/DIP relationship in EFPEM (i.e. Equation 2) would suggest that to meet a 0.05 mg L$^{-1}$ water quality objective, STP would have to be no more than 17 mg kg$^{-1}$. Higher water quality objectives such as 0.1, 0.5, and 1.0 mg L$^{-1}$, would yield STP values of 20, 41, and 69 mg kg$^{-1}$, respectively. These STP values are either at or below agronomic threshold levels considered necessary for optimum crop production.
- A consensus has to be developed on water quality objectives for phosphorus, and at what scale (e.g. edge of field, soil polygon, watershed).
- Depending on what scale that is adopted, an understanding on connectivity and attenuating processes within watersheds need to be taken into account.
- Determine how to include the contribution of particulate phosphorus in a quantitative export phosphorus model.
- Assess the impact of freshly applied and/or surface applied manure (or other phosphorus sources), without incorporation.
- Determine the effectiveness of incorporating phosphorus, particularly from manure sources. Also, decide on a definition of incorporation.
- A framework needs to be developed to deliver the quantitative approach to phosphorus source and transport factors in support of water quality objectives, with direct application to phosphorus-based nutrient management, and with the possibility of inclusion into regulations.

REFERENCES


