to crop requirements. While manure application based on crop nitrogen requirements can achieve optimum crop yield, it will result in the build-up of phosphorus in soils (Olson et al. 2006). He recommended that the application of manure based on crop phosphorus requirements, in combination with supplemental nitrogen fertilizer, can also produce optimum crop yield, while reducing environmental concerns. There are many tools to assist with nutrient budgeting (Kryzanowski et al. 2001), including calculators specific to Alberta conditions such as the MMP and AFFIRM, as discussed previously.

Manure spreading. Although appropriate rates of manure application may be determined based on crop phosphorus requirements, there are significant challenges that need to be addressed before such management can occur. Application of solid manure at annual agronomic phosphorus rates is currently not possible in Alberta because the manure spreading technology does not exist to deliver such low rates with uniform application. Injection of liquid manure at annual crop phosphorus rates is also limited, because the technology of the distribution manifold on liquid injectors prevents low application rates. However, the technology to inject agronomic phosphorus rates has been developed in Europe and in a few years it is also expected to be available in Alberta (B. Sexton, AAFRD, personal communication). Given the current restrictions in application technology, it is recommended that manure continue to be applied at rates that meet 3 to 4 years of crop phosphorus requirements. Enough manure would be applied in a single year to meet three to four times the annual crop phosphorus requirements, and manure would not be applied the following few years. It is recognized that this approach will increase the short-term risk of phosphorus losses, but would prevent long-term build-up of phosphorus in the soil profile. Accelerated research is required to develop the technologies that will allow producers to apply lower amounts of solid manure to the soil surface.

Commercial manure spreading operation

Besides the rate of application, important considerations for nutrient management are the timing and method of application. Manure application on snow-covered or frozen ground is environmentally unsustainable and should not occur, a policy that is supported by AOPA (except under some specified extenuating circumstances). Surface applied manure should be incorporated as soon as possible to reduce the direct exposure of the manure to surface runoff water. A single pass with a cultivator or double disk immediately following application is effective for reducing phosphorus losses to surface water (Little et al. 2005). Liquid manure should be applied by injection to prevent odours and to reduce contact with surface runoff, and application must be at the appropriate time. Manure injection just prior to freeze-up can result in very high nutrient concentrations in snowmelt runoff (Elliot and Maule 2005). Similarly, manure application or injection during wet periods, or just prior to rainfall, should be avoided if at all possible.

Cultivator incorporation (left) and double disk incorporation (right) of surface applied solid manure

Composting manure. Composting is not a new technology, but should be considered as an alternative to spreading fresh manure. This is particularly true in areas where land availability is limited. Manure composting has the benefits of reducing pathogens, parasites, and weed seeds (Jiang et al. 2003; Major et al. 2005). Similar to fresh manure, compost may enhance soil physical and biological properties, but has the added benefit of suppressing insects and diseases (Alyokhin and Atlihan 2005). Nutrients stabilize during the composting process and are more slowly released than from fresh manure once applied to soil. While greenhouse gas emissions occur during the composting process, emissions from composting are less than either stockpiling or storing manure in slurry (Pattey et al. 2005). Transportation of compost is less expensive than fresh manure, and will not face the same barriers with crop producers as manure. There may even be increased markets for compost in the urban sector for gardening and in the industrial sector for land reclamation.

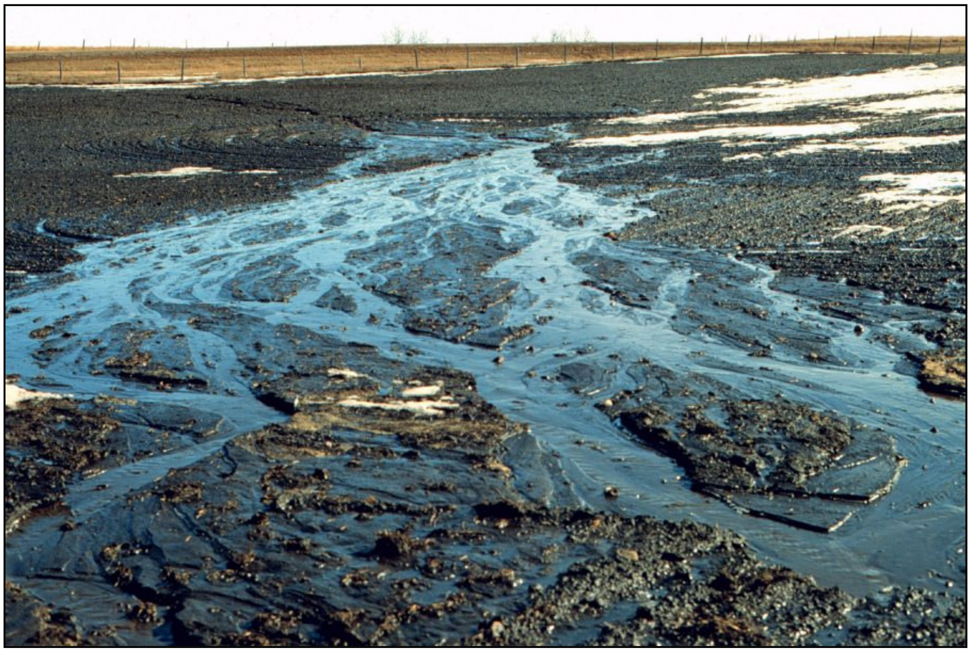
However, composting has some drawbacks. In Alberta, low temperatures may limit composting effectiveness during winter months. Significant land area is required to store the manure during the composting process, and this can be a challenge for large feedlots. Machinery and manpower are also required to turn the compost piles on a regular basis. While nutrients in compost tend to be more stable than in fresh manure, they also tend to be more concentrated, which may result in similar challenges as fresh manure when it comes to spreading. Since compost rates would likely be even lower than manure rates, existing machinery would not be able to spread compost at rates that would not exceed annual crop phosphorus requirements.

Manure composting

Surface Runoff Management

In Alberta, most of the surface runoff from fields occurs during the spring snowmelt period. Agricultural phosphorus losses may be reduced if producers minimize surface runoff from their fields, especially when manure is applied. Incorporation of manure immediately after application is always recommended. In addition, tillage and farming practices that include soil conservation technologies are an important action that producers can take.

For irrigated land, sprinkler application rates should be carefully controlled because irrigation increases antecedent soil moisture, thereby increasing the possibility of surface runoff during precipitation events. The continued development of precision irrigation will contribute to better irrigation water management and help to reduce surface runoff and nutrient leaching (Sadler et al. 2005).



Spring surface runoff

Wetlands. Maintaining low-lying areas, such as wetlands, sloughs, or potholes, in their natural state will also help minimize field runoff. Wetlands act as sponges and are recognized for their ability to naturally improve water quality. A study of 17 wetlands in the cold temperate or boreal climatic zone compared the change in phosphorus from runoff flowing from open streams, culverts or drainage pipes into a wetland. Phosphorus concentrations were measured in the runoff and at the outlet of the wetland. This study found that removal of total phosphorus between the inlet and outlet ranged from 1 to 88% and dissolved reactive phosphorus removal ranged from -19 to 89% (Braskerud et al. 2005). Variation was due to site-specific factors, including wetland size and age. While outlet phosphorus concentrations were often positively correlated with input concentrations, wetland retention often increased as phosphorus concentration increased (Braskerud et al. 2005). Thus, wetlands assist in phosphorus management, and they should be used in conjunction with other BMPs in a watershed.

A southern Alberta research study, which examined the potential for improvement of the quality of manure slurry by diverting it through a constructed wetland, did not provide conclusive results. An 18 000-head beef feedlot used an aeration lagoon, holding pond, and a two-cell constructed wetland to treat the feedlot runoff (Riemersma and Mah 2005). The runoff quality at the outlet varied during the 5-year study, depending on weather and site management. Runoff quality was generally poorer in wet years and in those years when the lagoons were not constantly maintained. The long-term sustainability of the wetlands through drought cycles and wetland performance was uncertain (Riemersma and Mah 2005). In future projects, another type of buffer that is more suitable to a semi-arid climate, such as grass filter strips, may perform better and ease maintenance in dry years.

Natural wetland

Constructed wetland

Buffer zones. Buffers should be considered to reduce the environmental impact of surface runoff from agricultural fields. Buffer species may include grasses, shrubs, and trees. Buffers of 30 m are generally recommended for protection of surface water quality; however, width may vary depending on site slope, soils, and climate (Castelle et al. 1994). Buffers are effective at filtering sediments from surface runoff and may also remove nitrogen, phosphorus, and pesticides (Wenger 1999). However, buffers may become nutrient saturated with time and serve as a source for nutrients and contaminants (Wenger 1999; Riemersma et al. 2004), especially during high precipitation events that result in significant surface runoff.

The effectiveness of buffers is also seasonal. Buffers are much more effective during the growing season than in winter or spring, when frozen or partially frozen ground reduces the filtering capacity of the buffers. Alberta-based appropriate buffer width, type, and long-term retention potential are being examined in the Lower Little Bow River watershed in southern Alberta, as part of the WEBs initiative. Whatever the limitations of buffers in reducing phosphorus losses to water bodies, they are still recommended for a number of other reasons. Buffers help protect the stream banks of streams and rivers, and promote the development of a healthy riparian zone.

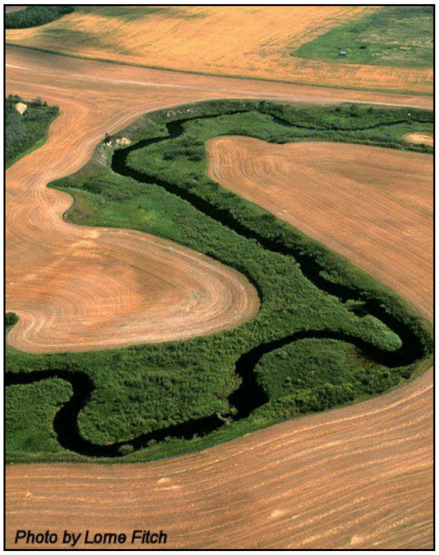


Photo by Lorne Fitch

Buffer zones

Soil Conservation Practices

Soil conservation practices that may be effective at reducing phosphorus movement include reduced tillage, cultivation across the slope, strip and stubble planting, cover crops, and windbreaks. Reducing soil movement will reduce the movement of sediment-bound phosphorus. While soil conservation practices reduce particulate phosphorus movement, the practice may not be effective at reducing dissolved phosphorus losses, particularly in reduced-till fields where organic matter may contribute phosphorus (Riemersma et al. 2006). Despite some ambiguity about the effects of soil conservation practices on phosphorus losses, these practices are highly recommended for overall protection of the soil, and whatever water quality benefits that can be gained.

Conservation tillage

Biogas

In areas where it is impractical to transport manure to un-manured cropland, it may be more feasible to convert the excess manure into energy. The Alberta Research Council and Highmark Renewables have developed the Integrated Manure Utilization System (IMUS) technology that uses anaerobic digestion of manure to create methane gas, heat, bio-based fertilizer, and recycled water (Alberta Research Council 2005). The IMUS technology reduces greenhouse emissions by 70 to 80% when compared to surface application of manure (Row and Neabel 2005). An IMUS demonstration plant was built at Highland Feeders in northeastern Alberta, the fourth largest feedlot in Alberta (and Canada) with 36 000 head of cattle. The technology is being assessed to determine if IMUS is economically feasible for other feedlot operations. Challenges for this new technology include the marketing of the bio-based fertilizer, capital funding, permit requirements for generators, feedlot size, expertise, and awareness and knowledge (Row and Neabel 2000). To date, profit margins are very tight. However, efficiency may be improved and with time the market may help make this technology more profitable. If successful, IMUS may strengthen and diversify the rural economy, and at the same time reduce the environmental impacts of the animal production industry. This technology may have particular application in areas where feedlot density is high, and land area for manure application is limited.

Biodigester – Highland Feeders, Alberta

CHALLENGES TO BMP IMPLEMENTION

The science of understanding and preventing phosphorus loss from non-point sources continues to challenge scientists throughout North America. To date, a single study has shown that BMPs implemented for about 7 years in a Virginian watershed reduced nitrogen and most forms of phosphorus, but were not effective at reducing dissolved reactive phosphorus (Brannan et al. 2000). Thus, while BMPs targeted towards phosphorus control at the farm or watershed scale will be beneficial, policy on agricultural development and infrastructure also needs to be addressed at the regional and national levels to give producers the economic impetus to follow through.

Beneficial management practices are being applied or promoted throughout the agricultural industry because of increasing water quality concerns. Many support programs and financial incentives are available to producers that implement BMPs. However, not all producers readily adopt BMPs, despite their environmental concerns and available assistance programs. Sharpley et al. (2005) identified four reasons for lack of BMP adoption:

(1) A lack of awareness that a problem exists,
(2) Skepticism of BMP effectiveness or legitimacy,
(3) Practicality of implementation,
(4) Economic costs to the producer.

In Alberta, a significant obstacle to BMP implementation may be the lack of science-based testing of BMPs to resolve identified problems in specific geographic regions of the province. Many producers who have expressed interest in implementing BMPs want to know which BMP will be most effective for their situation, what it will cost, and how practical it is to put into practice. To date, widespread testing of BMPs has not been carried out, and as a result, answers to the producers' questions are not available.

Another barrier to BMP adoption may be the inconsistent recommendations and interpretations that occur when there are several objectives for implementing the BMP (Sharpley et al. 2005). Objectives for BMP implementation may include habitat development, soil and water conservation, and water quality protection. The prescribed BMPs will vary depending on their purpose, and in some cases the prescribed BMPs may improve one problem but exacerbate another. For example, manure incorporation is recommended to reduce the risk of phosphorus loss, but in some situations, incorporation may increase the risk of nitrogen leaching and sediment transport (Dampney et al. 2003). Risk assessment must be part of the BMP recommendation process and education programs should ensure that BMP recommendations are clear and concise in their purpose. Based on survey results, Kim et al. (2005) concluded that continued education on BMP implementation had a very important and positive impact on adoption rates. They also found that funding programs are important.

In addition to the challenge of BMP adoption, there are challenges with appropriate implementation. If a research initiative is established to evaluate BMPs, most often researchers implement the BMPs or the researchers greatly assist producers in implementation and maintenance. In these cases, the expert knowledge and amount of time to implement the BMPs help ensure implementation is appropriate, but such a scenario will not be available for most producers. For example, Shepard (2005) conducted a survey to assess the effectiveness of nutrient management plans that were widely implemented, with varying degrees of knowledge and efforts. Slightly more than half of the 127 farmers had nutrient management plans in two Wisconsin watersheds, where nutrient management plans had been extensively promoted. Farmers with nutrient management plans tended to apply fewer nutrients than farmers without a plan. However, even with a nutrient plan, 37% of the farmers still over-applied nutrients (Shepard 2005). Over-application most often occurred because the farmers failed to recognize and account for nutrient inputs from the farm, especially manure. Shepard (2005) concluded that nutrient management plans need to be extended past the initial plan to include on-farm follow ups, plan maintenance, and long-term planning that ensures plans can be modified to accommodate changes in farming practices.

If phosphorus limits are implemented, manure from intensive livestock operations will have to be transported greater distances because of the limited land base that is available for application. If such a scenario developed, transport distances would likely further increase with time, and the additional costs could negatively impact the industry and potentially limit growth. It is recognized that increased transportation costs could negatively impact the economics of Alberta's agricultural industry. Confined feeding operations (CFOs), including hogs, poultry, dairy, and beef cattle, are throughout the agricultural areas of the province, with more concentrated operations in several regions of the province. The greatest concentration of beef feeding operations is in the southern part of the province, especially concentrated near the city of Lethbridge. Many of these operations are less than 1 to 2 km from neighbouring operations. Manure is most commonly applied to areas immediately adjacent to CFOs. Alberta producers who do not have the land base required for manure application may need to develop a manure exchange agreement with non-livestock crop producers.

Manure application to cropland provides many benefits, including nutrients and organic matter. However, in Alberta, convincing crop producers to accept manure from intensive livestock operations is proving to be a challenge. Intensive livestock producers have difficulty finding willing crop producers who will take excess fresh manure, even if the manure is delivered and dumped on their fields. Many crop producers have concerns about weed seeds in the fresh manure, and requirements for additional cultivation management of manured land. More enterprising intensive livestock producers have recently begun to negotiate deals with crop producers who are beginning to appreciate the value of nutrients contained in manure. A typical negotiated deal will involve the intensive livestock producer delivering and dumping the manure free of charge to the fields specified by the crop producers. The crop producer will hire a commercial manure handling company to spread the manure on each field (S. Thiessen, personal communication, 2005).

The Alberta experience with manure exchange is supported by research in the United States. A recent study examined barriers to manure exchange agreements between intensive livestock producers and crop producers (Battel and Krueger 2005). About 50% of the 340 farmers in the Kalamazoo River Watershed, Michigan, responded to a survey about their manure management practices. The study showed that the primary concern in regards to spreading manure was the introduction of weeds. Other major concerns were the cost of transporting manure and odour complaints. The survey revealed that there are different opinions concerning manure exchange.

Interestingly, more livestock producers thought manure was a reliable fertilizer source than non-livestock farmers. Buyers and sellers of manure also had different opinions on the value of their transaction. Sellers believed they were providing valuable fertilizer, while the buyers thought they provided a benefit to help the livestock owner dispose of the waste (Battel and Krueger 2005). The survey showed that as the cost of manure increased, buyers were less interested in purchasing it, even if it was affordable. Manure exchange often does not occur because farmers want to avoid odour complaints from their neighbours. In fact, farmers were more concerned about their neighbours' complaints than they were of environmental concerns (Battel and Krueger 2005). The latter finding supports a previous study that found that rural neighbours were three times more likely to be concerned about manure odour than runoff (Kelsey and Vaserstein 2000).

Education and awareness are required to promote the benefits of manure for many of the soils in Alberta. In addition, further processing of manure (e.g., composting) to eliminate weed problems may make the end product more attractive to buyers.

NUTRIENT MANAGEMENT CASE STUDY

A case study was developed to demonstrate how to manage phosphorus on a farm to protect surface water quality. Recommended BMPs that are appropriate to the operation and will contribute towards environmental sustainability are presented. The case study involves a 2,015-ha (7.75 sections) farm with an 8,000-head feedlot, located on Section 17 (Figure 4).

Annual manure production is 17,280 tonnes (wet weight). During the past 20 years, manure was applied annually on Section 17 at an application rate of about 70 tonne/ha. There is a shallow drainage channel that runs through this section of land. The drainage channel is farmed the same as the rest of the fields.

As a result of the continuous manure applications, the operator has concerns about the level of nutrients in the soil in this part of the farm. Soil testing revealed that soil-test phosphorus was 494 part per million (ppm) in the top 15 cm of soil, a level that is in extreme excess of crop phosphorus requirements. A soil-test phosphorus level of 60 ppm would generally be adequate for optimum crop production (Howard 2006).

The farm operation is located within a central Alberta watershed and most of the farm is within one soil polygon within the watershed. Based on the calculations of Jedrych et al. (2006), the soil phosphorus limit for this soil polygon is 80 ppm in the top 15 cm of soil, when a surface runoff water quality objective of 1 ppm is applied. Given that the soil phosphorus level in the soil is about six times higher than the calculated soil phosphorus limit, this soil is considered a significant risk for phosphorus loss to surface water.

The recommendation and prudent BMP is to stop applying manure to Section 17. Continuous crop removal will slowly reduce the soil-test phosphorus level, but will likely take many years. Growing a relatively high phosphorus uptake crop, such as alfalfa, will help this process, and will also significantly reduce phosphorus losses in surface runoff. If annual crops are grown, seeding the drainage channel to grass may reduce the loss of sediment-rich phosphorus. The ability to harvest the forage from the drainage channel would be helpful to remove nutrients. Because of the high soil-test phosphorus values in the soil, the loss of dissolved phosphorus may continue until the soil-test phosphorus levels are reduced.

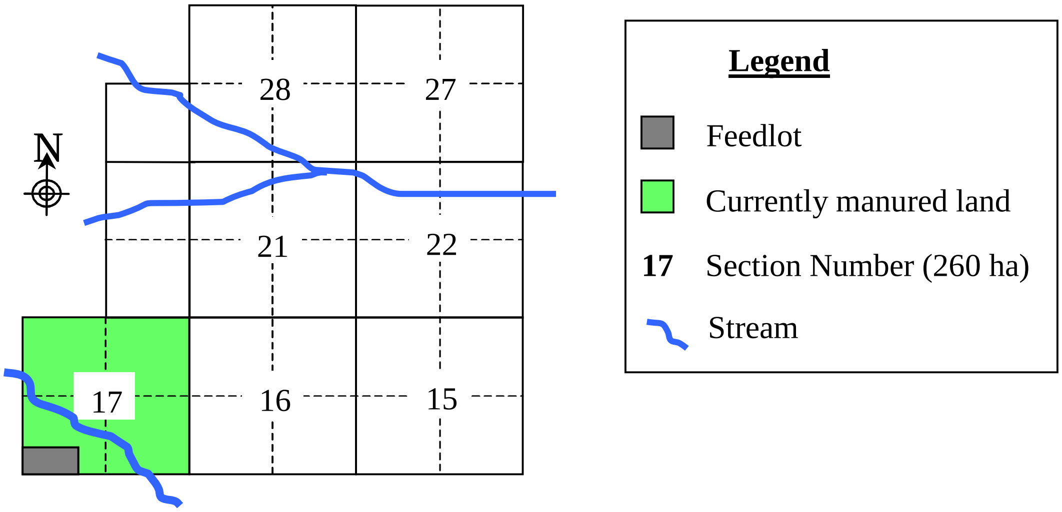


Figure 4. Case study farm.

With Section 17 no longer available for manure application, the remaining 1,755 ha (6.75 sections) of land, which have never received manure, will now have to receive the manure. To avoid the problem of phosphorus accumulation, an alternative would be to apply manure based on crop phosphorus requirements on a 3- to 4-year rotation. This will require the use of a nutrient management plan. Soil testing shows that the soil contains about 18 kg/ha of plant available phosphorus in the upper 15 cm. The fertilizer recommendation for this soil is 22 kg/ha phosphorus. Analysis of manure samples showed the total phosphorus content is 2.16 kg/tonne on a wet-weight basis. Based on this information, a manure application rate can be calculated.

Not all of the total phosphorus in the manure becomes available in the first crop year after application. A reasonable estimate is that about 70% of the total phosphorus becomes available in the first year. Some of the remaining total phosphorus (i.e., the residue) will become available in subsequent years. The crop available phosphorus in the manure is

2.16 kg/tonne x 0.7 = 1.51 kg/tonne

Therefore, the application rate is

22 kg/ha ÷ 1.51 kg/tonne = 14.6 tonne/ha

The amount of land required is

17,280 tonne/year ÷ 14.6 tonne/ha = 1184 ha/year

The amount of land available on this farm is 1,755 ha, which means there is enough land to accommodate manure application based on annual crop phosphorus requirements. If this was not the case, then the producer would have to seek non-owned land to apply manure. To make annual applications on the same land, soil testing should be carried out to account for residual carryover, which may result in some adjustment to the application rate.

The calculated application rate of 14.6 tonne/ha is much lower than the application rate used on Section 17 (about 70 tonne/ha). It is also less than can be applied by existing manure spreading equipment. As a result, it is recommended that manure be applied at rates that provide phosphorus levels that will meet crop requirements for a 3-year period, which is feasible when soil phosphorus levels are relatively low. This would mean that manure would only be applied to the same piece of land once every 3 years. If a multiyear application is used, then it is more appropriate to use the total phosphorus content of the manure in the calculation rather than 70% of the total phosphorus. This will better take into account the residual carryover of phosphorus. If an application rate of three times the annual crop phosphorus requirement is used, then the application rate is

22 kg/ha/year x 3 years ÷ 2.16 kg/tonne = 30.6 tonne/ha

The amount of land required per year is

17,280 tonne/year ÷ 30.6 tonne/ha = 565 ha/year

The total land base required is 1,694 ha (565 ha/year x 3 years). If three times the annual crop phosphorus requirements were applied in a single application of 30.6 tonne/ha, the same land would only receive manure once every 3 years. This may mean accepting a short-term risk of slightly higher soil-test phosphorus levels in the soil, but may solve the practical challenge of applying lower rates of manure. Applying three times the annual crop phosphorus requirement in a single application would mean that about one-third of the available land for manure application (1,755 ha) would receive manure each year on this farm. This would reduce the transportation cost per year rather than having to apply manure to nearly all 1,184 ha each year at a rate of 14.6 tonne/ha.

There are shallow drainage channels running through Sections 20, 21, 22, and 29 as well. Making these into grassed waterways with 30-m buffers on either side would provide additional protection, particularly where annual crops are grown. Manure should not be applied within 30 meters of the drainage channels.

The above case study has been generalized to some degree, but provides a practical option that producers can implement if land availability is not a problem. The main issues of transportation distances and costs need to be considered.

CONCLUSIONS

There are many challenges that must be addressed to economically and practically manage agricultural phosphorus to minimize impacts on surface water. While a number of BMPs and management strategies have been discussed, few have actually been field tested in Alberta. A great deal more research needs to be conducted to understand (1) the effectiveness of BMPs in reducing agriculture's impact on water quality, (2) the practicality of implementing the proposed BMPs, and (3) the costs for implementation and maintenance.

While specific issues related to the implementation of BMPs are still not well understood, there are reasonable recommendations that producers can apply to minimize phosphorus losses from field runoff during spring snowmelt and summer rainfall events. These include actions related to nutrient management, soil conservation, surface runoff management, and riparian area management. The following are the key recommendations.

- Wherever possible, phosphorus application should be according to crop phosphorus requirements, and application should be planned appropriately in relation to timing and location.
- Surface runoff from agricultural land should be minimized as much as possible by using appropriate tillage and irrigation water management, and by maintaining low-lying areas, potholes, and wetlands.
- Application of manure on snow-covered and frozen ground should be avoided at all times.
- Surface applied manure should be incorporated immediately.
- Injection of manure immediately prior to freeze-up or surface application onto snow-covered or frozen ground should be avoided.
- Manure application prior to rainfall or in critical source areas is not recommended.
- Fertilizer should always be banded or applied with the seed.
- Runoff from over-wintering sites must be prevented from entering surface water.
- Livestock should be managed in riparian areas to ensure a healthy ecosystem.
- Off-stream watering systems should be installed to minimize direct access of livestock to surface water.
- Soil conservation practices should always be practiced to reduce soil erosion, which in turn will reduce the movement of particulate phosphorus from the land.
- Buffer strips should be developed, enhanced and maintained around surface water bodies and areas that drain into surface waters.
- Alternative uses of manure in Alberta, such as compost and biogas production, should continue to be explored.

Additional research is required to develop appropriate manure management strategies at the regional scale. Millions of hectares of cropland in Alberta would benefit significantly from manure applications; however, transportation costs and social constraints may continue to prevent the use of excess manure by non-livestock producers. Thus, alternative uses of manure, such as compost and biogas production, should continue to be explored.

Continuing work on BMP implementation and evaluation is also important. Education, funding, and extension program support are required to encourage producer participation in the short and long term. Monitoring and maintenance programs are required to ensure that BMPs are effective now and in the future.

REFERENCES

Agriculture and Agri-Food Canada. 2004a. The Agricultural Policy Framework (APF): An agricultural policy for the 21st century. [Online] Available at http://www.agr.gc.ca/puttingcanadafirst/index_e.php (Posted December 21, 2004; accessed January 10, 2005).

Agriculture and Agri-Food Canada. 2004b. Watershed Evaluation of BMPs (WEBs). Agriculture and Agri-Food Canada, Ottawa, Ontario, Canada. [Online] Available at http://www.agr.gc.ca/env/greencover-verdir/webs_abstract_e.phtml (Posted October, 12, 2004; accessed January 10, 2005).

Agriculture and Agri-Food Canada. 2004c. National Agri-Environmental Health Analysis and Reporting Program. [Online] Available at http://www.agr.gc.ca/env/naharp-pnarsa/index_e.php?page=ind#9 (Posted September 21, 2004; accessed January 12, 2005).

Agriculture and Agri-Food Canada (AAFC) and Alberta Agriculture, Food and Rural Development (AAFRD). 2004. Beneficial management practices: Environmental manual for crop producers in Alberta. Alberta Agriculture, Food and Rural Development, Edmonton, Alberta, Canada. 165 pp.

Alberta Agriculture, Food and Rural Development (AAFRD). 2005a. Agricultural statistics factsheet: Economics and competitiveness. Agdex 853. Statistics and Data Development Unit, Economics and Competitiveness Division, Alberta Agriculture, Food and Rural Development Edmonton, Alberta, Canada.

Alberta Agriculture, Food and Rural Development (AAFRD). 2005b. Alberta manure management planner – 2004. Alberta Agriculture, Food and Rural Development, Edmonton, Alberta, Canada. [Online] Available at http://www1.agric.gov.ab.ca /$department/deptdocs.nsf/all/epw8834 (Posted October 27, 2004; accessed January 10, 2005).

Alberta Agriculture, Food and Rural Development (AAFRD). 2005c. Alberta farm fertilization information and recommendation manager. Alberta Agriculture, Food and Rural Development, Edmonton, Alberta, Canada. [Online] Available at http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/crop10159 (Posted August 26, 2005; accessed January 17, 2006).

Alberta Beef Producers and Alberta Agriculture, Food and Rural Development (AAFRD). 2004. Beneficial management practices: Environmental manual for Alberta cow/calf producers. Alberta Agriculture, Food and Rural Development, Edmonton, Alberta, Canada. 94 pp.

Alberta Cattle Feeders' Association and Alberta Agriculture, Food and Rural Development. 2002. Beneficial management practices: Environmental manual for feedlot producers in Alberta. Alberta Agriculture, Food and Rural Development, Edmonton, Alberta, Canada. 112 pp.

Alberta Egg Producers, Alberta Hatching Egg Producers, Alberta Chicken Producers, Alberta Turkey Producers, and Alberta Agriculture, Food and Rural Development. 2003. Beneficial management practices: Environmental manual for poultry producers in Alberta. Alberta Agriculture, Food and Rural Development, Edmonton, Alberta, Canada. 106 pp.

Alberta Milk and Alberta Agriculture, Food and Rural Development (AAFRD). 2003. Beneficial management practices: Environmental manual for dairy producers in Alberta. Alberta Agriculture, Food and Rural Development, Edmonton, Alberta, Canada. 91 pp.

Alberta Pork and Alberta Agriculture, Food and Rural Development (AAFRD). 2002. Beneficial management practices: Environmental manual for hog producers in Alberta. 107 pp.

Alberta Research Council. 2005. Integrated manure utilization system. Alberta Research Council, Vegreville, Alberta, Canada. [Online] Available at http://www.arc.ab.ca/Index.aspx/ARC/4547 (Accessed January 19, 2006).

Alyokhin, A. and Atlihan, R. 2005. Reduced fitness of the Colorado potato beetle (Coleoptera: Chrysomelidae) on potato plants grown in manure-amended soil. Environ. Entomol. **34**: 963-968.

Battel, R.D. and Krueger, D.E. 2005. Barriers to change: Farmers' willingness to adopt sustainable manure management practices. J. Extension **43**: 12 pp. Article number 4FEA7.

Beegle, D.B., Sharpley, A.N., Weld, J.L., and Kleinman, P.J.A. 2005. Challenges in implementing phosphorus based nutrient management planning. *In* Proceedings of the Symposium State of the Science Animal Manure and Waste Management. San Antonio, Texas, United States. January 5-7, 2005.

Brannan, K.M., Mostaghimi, S., McClellan, P.W., and Inamdar, S. 2000. Animal waste BMP impacts on sediment and nutrient losses in runoff from the Owl Run Watershed. Trans. ASAE **43**: 1155-1166.

Braskerud, B.C., Tonderski, K.S., Wedding, B., Bakke, R., Blankenberg, A.-G.B., Ulen, B., and Koskiho, J. 2005. Can constructed wetlands reduce the diffuse phosphorus loads to eutrophic water in cold temperate regions? J. Environ. Qual. **34**: 2145-2155.

Canada-Alberta Environmentally Sustainable Agriculture (CAESA). 1998. Agricultural impacts on water quality in Alberta: An initial assessment. CAESA Water Quality Committee. Published by Alberta Agriclture, Food and Rural Development, Lethbridge, Alberta, Canada. 95 pp.

Canadian Fertilizer Institute. 2001. Nutrient uptake and removal by field crops: Western Canada 2001. Canadian Fertilizer Institute, Ottawa, Ontario, Canada. 2 pp.

Castelle, A.J., Johnson, A.W., and Conolly, C. 1994. Wetland and stream buffer requirements – A review. J. Environ. Qual. **23**: 878-882.

Dampney, P.M.R., Mason, P., Goodlass, G., and Hillman, J. 2003. Methods and measures to minimize the diffuse pollution of water from agriculture – A critical appraisal. Final report NT 2507. Dep. For. Environ., Food and Rural Affairs, Noble House, London, United Kingdom.

Elliot, J.A. and Maule, C.P. 2005. Influence of hog manure application on snowmelt runoff water quality. Joint International ASA-CSSA-SSSA International Annual Meetings Nutrient Management & Transport, Impact on Water Quality Session. Salt Lake City, Utah, United States. November 6-10, 2005.

Fitch, L., Adams, B., and O'Shaughnessy, K. 2003. Caring for the green zone: Riparian areas and grazing management – Third Edition. Cows and Fish Program, Lethbridge, Alberta. ISBN No. 0-9688541-2-5.

Gilliam, J.W., Osmond, D.L., and Evans, R.O. 1997. Selected agricultural best management practices to control nitrogen in the Neuse River Basin. North Carolina Agric. Res. Serv. Tech. Bull. 311. North Carolina State Univ., Raleigh, North Carolina, United States.

Heathwaite, L., Sharpley, A., Bechmann, M., and Rekolainen, S. 2005. Assessing the risk and magnitude of agricultural nonpoint source phosphorus pollution. Pages 981-1020 *in* T.J. Sims and A.N. Sharpley (eds.), Phosphorus: Agriculture and the environment. Agron. Monogr. 46. ASA, CSSA, and SSSA, Madison, Wisconsin, United States.

Howard, A.E. 2006. Agronomic thresholds for soil phosphorus in Alberta: A review. 42 pp. *In* Alberta Soil Phosphorus Limits Project. Volume 5: Background information. Alberta Agriculture, Food and Rural Development, Lethbridge, Alberta, Canada.

Howard, A.E., Olson, B.M., and Cooke, S. 2006. Impact of soil phosphorus loading on water quality in Alberta. 41pp. *In* Alberta Soil Phosphorus Limits Project. Volume 5: Background information. Alberta Agriculture, Food and Rural Development, Lethbridge, Alberta, Canada.

Jedrych, A.T., Olson, B.M., Nolan, S.C., and Little, J.L. 2006. Calculation of soil phosphorus limits for agricultural land in Alberta. 87 pp. *In* Alberta Soil Phosphorus Limits Project. Volume 2: Field-scale losses and soil limits. Alberta Agriculture, Food and Rural Development, Lethbridge, Alberta, Canada.

Jiang, X., Morgan, J., and Doyle, M.P. 2003. Fate of Escherichia coli 0157:H7 during composting of bovine manure in a laboratory-scale bioreactor. J. Food Prot. **66**: 25-30.

Kelsey, T.W. and Vaserstein, G. 2000. Farming and non farming neighbors: Conflict, coexistence and communication. J. Soil Water Conserv. **55**: 462-466.

Kim, S., J.M. Gillespie, and Paudel, K.P. 2005. The effect of socioeconomic factors on the adoption of best management practices in beef cattle production. J. Soil Water Conserv. **60**: 111-120.

Klotz, R.L and S.A. Linn. 2001. Influence of factors associated with water level drawdown on phosphorus release from sediments. J. Lake Reservoir Manage. **17**: 48-54.

Kryzanowski L., Amrani M., Olson B.M., McKenzie R.H., and Lewis T. 2001. Nutrient management calculators for manure utilization. Pages 103-107 *in* Western Canada Agronomy Workshop Proceedings, Vol. 5. Lethbridge, Alberta, Canada. July 4-6, 2001.

Lemunyon, J.L. and R.G. Gilbert. 1993. The concept and need for a phosphorus assessment tool. J. Prod. Agric. **6**: 483-486.

Line, D.E. and Spooner, J. 1995. Critical areas in agricultural nonpoint source pollution control projects: The rural clean water program experience. Fact Sheet no. 5. NCSU Water Quality Group, North Carolina State Univ., Raleigh, North Carolina, United States.

Little, J.L., Bennett, D.R., and Miller, J.J. 2005. Nutrient and sediment losses under simulated rainfall following manure incorporation by different methods. J. Environ. Qual. **34**: 1883-1895.

Little, J.L., Nolan, S.C., and Casson, J.P. 2006. Relationships between soil-test phosphorus and runoff phosphorus in small Alberta watersheds. 150 pp. *In* Alberta Soil Phosphorus Limits Project. Volume 2: Field-scale losses and soil limits. Alberta Agriculture, Food and Rural Development, Lethbridge, Alberta, Canada.

Major, J., Steiner, C., Ditommaso, A., Falcao N.P.S., and Lehmann, J. 2005. Weed composition and cover after three years of soil fertility management in the central Brazilian Amazon: Compost, fertilizer, manure and charcoal applications. Weed Biol. Manage. **5**: 69-76.

Mallin, M.A. and Cahoon L.B. 2003. Industrialized animal production – A major source of nutrient and microbial pollution to aquatic ecosystems. Population and Environ. **24**: 369-385.

Mausbach, M.J. and Dedrick, D.C.A. 2004. The length we go: Measuring environmental benefits of conservation practices. J. Soil Water Conserv. **59**: 96-103A.

McDowell, R.W., Sharpley, A.N., Condron, L.M., Haygarth, P.M., and Brookes, P.C. 2001. Processes controlling soil phosphorus release to runoff and implications for agricultural management. Nutr. Cycl. Agroecosys. **59**: 269-284.

Meals, D.W. 1993. Assessing nonpoint phosphorus control in the LaPlatte River watershed. Lake Res. Manage. **7**: 197-207.

Oldman Watershed Council. 2005. Oldman River Basin Water Quality Initiative: Five year summary report. Lethbridge, Alberta, Canada. 37 pages.

Olson, B.M. 2004. Switching maximum manure application rates from a nitrogen basis to a phosphorus basis: The issues. Pages 23-28 *in* Agronomy update 2004 conference proceedings. Red Deer, Alberta, Canada. January 13-14, 2004.

Olson, B.M. 2005. Putting theory into practice: A nutrient management planning case study. *In* Manure management planning: The essentials. January 20, Lethbridge Lodge, Alberta, Canada.

Olson, B.M., McKenzie, R.H., Bennett, D.R., Ormann, T., and Atkins, R.P. 2003. Manure application effects on soil and groundwater quality under irrigation in southern Alberta. Alberta Agriculture, Food and Rural Development, Lethbridge, Alberta, Canada. 377 pp.

Olson, B.M., McKenzie, R.H., and Larney, F.J. 2006. Understanding how to use manure or compost to optimize irrigation production. Pages 33-37 *in* Irrigation crop production update 2006 conference. Lethbridge, Alberta, Canada. January 17 2006.

Ontkean, G.R., Chanasyk, D.S., and Bennett, D.R. 2005. Snowmelt and growing season phosphorus flux in an agricultural watershed in south-central Alberta. Water Qual. Res. J. Can. **40**: 401-417.

Osmond, D.L., Spooner, J., and Line, D.E. 1995. Systems of best management practices for controlling agricultural nonpoint source pollution. Fact Sheet no. 6. NCSU Water Quality Group, North Carolina State Univ., Raleigh, North Carolina, United States.

Paterson, B.A., Olson, B.M., Little, J., and Nolan, S. 2004. Phosphorus limits for agricultural lands in Alberta. Pages 103-108 *in* Agronomy update 2004 conference proceedings. Red Deer, Alberta, Canada. January 13-14, 2004.

Pattey, E., Trzcinski M., and Desjardins, R. 2005. Quantifying the reduction of greenhouse gas emissions as a result of composing dairy and beef cattle manure. Nutr. Cycl. Agroecosys. **72**: 173-187.

Pionke, H.B., Gburek, W.J., Sharpley, A.N., and Zollweg, J.A. 1997. Hydrologic and chemical controls on phosphorus losses from catchments. Pages 225-242 *in* H. Tunney, O.T. Carton, P.C. Brookes, and A.E. Johnston (eds.), Phosphorus loss from soil to water. CAB International Press, Cambridge, England.

Province of Alberta. 2001. Agricultural operation practices act. Published by Alberta Queen’s Printer. Edmonton, Alberta, Canada.

Province of Alberta. 2004. Agricultural operation practices act and Regulations. Published by Alberta Queen’s Printer. Edmonton, Alberta, Canada.

Purdue Research Foundation. 2004. Welcome to the manure management planner home page. Purdue University, West Lafayette, Indiana, United States. [Online] Available at http://www.agry.purdue.edu/mmp/ (Posted November 15, 2004; Accessed January 10, 2005).

Riemersma, S., Little, J., Ontkean, G., and Moskal-Hébert, T. 2006. Phosphorus sources and sinks in watersheds: A review. 82 pp. *In* Alberta Soil Phosphorus Limits Project. Volume 5: Background information. Alberta Agriculture, Food and Rural Development, Lethbridge, Alberta, Canada.

Riemersma, S. and Mah, B. 2005. Five years experience with a constructed wetland system designed for feedlot runoff in southern Alberta. Page 154 *in* 42nd Annual Alberta Soil Science Workshop Proceedings. Calgary, Alberta. February 14-16, 2005.

Riemersma, S., Rodvang, J., Little, J., and Olson, B. 2004. Evaluation of buffer zones for surface water and groundwater quality protection and improvement in the Battersea Drain

Watershed, Alberta. Pages 162-168 *in* 41st Annual Alberta Soil Science Workshop Proceedings, Lethbridge, Alberta, Canada. February 17-19, 2004.

Row, J. and Neabel, D. 2005. Integrated manure utilization system life-cycle value assessment – Final report. Pembia Institue, Drayton Valley, Alberta, Canada. 55 pp.

Sadler, E.J., Evans, R.G., Stone, K.C., and Camp, C.R. 2005. Opportunities for conservation with precision irrigation. J. Soil Water Conserv. **60**: 371-378.

Sharpley, A., Foy, B., and Withers, P. 2000. Practical and innovative measures for the control of agricultural phosphorus losses to water: An overview. J. Environ. Qual. **29**: 1-9.

Sharpley, A.N. and Rekolainen, S. 1997. Phosphorus in agriculture and its environmental implications. Pages 1-54 *in* H. Tunney, O.T. Carton, P.C. Brookes, and A.E. Johnston (eds.), Phosphorus loss from soil to water. CAB International Press, Wallingford, Oxon, United Kingdom.

Sharpley, A.N., Weld, J.L., Beegle, D.B., Kleinman, P.J.A., Gburek, W.J., Moore, P.A., and Mullins, G. 2003. Development of phosphorus indices for nutrient management planning strategies in the United States. J. Soil Water Conserv. **58**: 137-152.

Sharpley, A.N., Withers, P.J.A., Abdalla, C.W., and Dodd, A.R. 2005. Strategies for the sustainable management of phosphorus. Pages 1069-1101 *in* J.T. Sims and A.N. Sharpley (eds.), Phosphorus: Agriculture and the environment. American Society of Agronomy Inc., Crop Science Society of America Inc., Soil Science Society of America Inc., Madison, Wisconsin, United States.

Shepard, R. 2005. Nutrient management planning: Is it the answer to better management? J. Soil Water Conserv. **60**: 171-176.

Sims, J.T. and Kleinman, P.J.A. 2005. Managing agricultural phosphorus for environmental protection. Pages 1021-1068 *in* J.T. Sims and A.N. Sharpley (eds.), Phosphorus: Agriculture and the environment. American Society of Agronomy Inc., Crop Science Society of America Inc., Soil Science Society of America Inc., Madison, Wisconsin, United States.

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.

Southern Extension Research Activity 17. 2005. Minimizing phosphorus losses from agriculture: Best management practices factsheets. Cooperative States Research, Education, and Extension Service, United States Department of Agriculture. [Online] Available at http://www.sera17.ext.vt.edu/SERA_17_Publications.htm#BMPPublications (Accessed March 1, 2006).

The Prairie Province's Committee on Livestock Development and Manure Management. (year unknown). Tri-provincial manure application and use guidelines. Alberta, Agriculture, Food, and Rural Development, Edmonton, Alberta; Saskatchewan, Food and Rural Revitalization, Regina, Saskatchewan; and Manitoba Agriculture and Food, Winnipeg, Manitoba. [Online] Available at http://www.agr.gov.sk.ca/docs/livestock/pork/manure_management/tri-provincial_Application_Use_guidelines.asp (Posted; Accessed January 2005).

United States Department of Agriculture. 2004. Conservation Effects Assessment Program. Natural Resources Conservation Service, United States Department of Agriculture. [Online] Available at http://www.nrcs.usda.gov/technical/NRI/CEAP/ (Posted December 12, 2004; accessed January 10, 2005).

Walker, J., Alexander, D., Irons, C., Jones, B., Penridge, H., and Rapport, D. 1996. Watershed health indicators: An overview. Pages 3-18 *in* J. Walker and D.J. Reuter (eds.), Indicators of watershed health: A technical perspective. CSIRO, Collingwood, Victoria, Australia.

Wenger, S. 1999. A review of the scientific literature on riparian buffer width, extent and vegetation. Office of Pubic Service & Outreach, Institute of Ecology, University of Georgia. 59 pp.

West, B. (year unkown). Cattle wintering sites: Managing for good stewardship. Alberta Cattle Commission, Prairie Farm Rehabilitation Administration, Alberta Agriculture, Food and Rural Development, and the Alberta Environmentally Sustainable Agriculture program.

Willms, W.D., Kenzie, O.R., McAllister, T.A., Colwell, D., Veira, D., Wilmshurst, J.F., Entz, T., and Olson, M.E. 2002. Effects of water quality on cattle performance. J. Range Manage. **55**: 452-460.

Withers, P.J.A., Royle, S., Tucker, M., Watson, R., Scott, T., Silcock, P., and Dwyer, J. 2003. Field development of grant aid proposals for the control of diffuse agricultural pollution. R&D Tech. Rep. P2-261/09/TR. Environment Agency, Bristol, United Kingdom.