Agricultural Nutrient Management in the Shuswap Watershed for Maintaining and Improving Water Quality: Literature Review and Nutrient Management Strategies

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Executive Summary

Introduction

Water quality monitoring data collected by the Shuswap Lake Integrated Planning Process group (SLIPP) between 2011 and 2013 showed that the Shuswap, Salmon and Eagle Rivers had elevated levels of phosphorus during the spring snowmelt period and the late spring-early summer high water period relative to other lake tributaries. These rivers were found to be contributing a substantial amount of phosphorus to Shuswap and Mara Lakes during this time of year, with the Shuswap River contributing significantly more than either the Salmon or Eagle Rivers. Modelling of the water quality data suggested that agriculture is the largest contributor of phosphorus in these river basins.

As a result of the 2011-2013 water quality data and the data modelling, the Shuswap Watershed Council commissioned a review of current strategies for mitigating the impacts of agricultural-source nutrients, focussing on phosphorus as the nutrient of most concern in most fresh water systems and on watershed-based programs and practices successfully implemented elsewhere. Based on the review of literature, a strategy to address agricultural-source phosphorus in the Shuswap watershed was to be developed tailored to the specific conditions along the three impacted rivers in the watershed. This report presents the results of the literature review, summarizes the types of agriculture along the rivers and the current strategies for phosphorus management in agriculture in B.C. It also contains a discussion of the mechanisms by which phosphorus may be entering surface water from farmland along the rivers, and some mitigation strategies.

The area considered in this report includes sections of three tributaries of Shuswap Lake; the Shuswap River from the outlet at Mabel Lake to the inlet at Mara Lake including Fortune Creek which runs from just north of Armstrong to Enderby; the Salmon River from Westwold to the inlet into Salmon Arm at Salmon Arm and the Eagle River from north of Malakwa to the inlet at Sicamous.

Part A: Review of Literature

The literature review summarizes the current state of knowledge about phosphorus management in watersheds to reduce phosphorus loading of surface water, and is focussed on agricultural-source phosphorus. It looks at current research on reducing phosphorus loading to agricultural land and on reducing the movement of agricultural-source phosphorus into surface water. It summarizes some current research on the effectiveness of traditional best management practices in reducing phosphorus loss to surface water, and some emerging technologies and techniques for managing phosphorus losses. It also contains a review of the results of three watershed-based phosphorus mitigation projects.

Agricultural-source phosphorus has been implicated in surface water quality degradation for several decades. Various freshwater lakes and shallow estuaries throughout the world have experienced water quality degradation ranging from nuisance algal blooms to toxic compounds, linked to nutrient loading of surface water both in tributaries and in the affected water bodies, with phosphorus implicated as the primary nutrient of concern. There have been several sources of phosphorus implicated, including industrial sources, municipal waste water treatment plant effluent and agriculture. Most industrial and municipal point source pollution has been substantially reduced in the past 30 years without a corresponding improvement in surface water quality downstream. Non-point source phosphorus from agriculture has been identified as the source of as much as 50% of the current phosphorus loading to surface water in some areas.

There are many factors contributing to agricultural-source phosphorus loss to surface water. Application of phosphorus fertilizer with the goal of maximizing crop yields has led to soils with a buildup of phosphorus well above natural background levels and above crop requirements in many areas. Application of manure without reference to meeting any specific nutrient goals or to meet crop nitrogen requirements has led to application of more phosphorus than crops can utilize. These two factors have led to enrichment of soils with phosphorus on most intensively-farmed land, termed 'legacy phosphorus' because it can take many years for the soil level to return to normal after cessation of manure and fertilizer application during which soils can continue to contribute phosphorus to surface water. A further source of phosphorus loading of surface water is direct runoff losses of manure from grazing areas or from fields where manure has recently been applied.

Phosphorus can move from farmland into surface water with eroding soil, with surface runoff of manure and water and in subsurface flow. The combination of soils enriched with phosphorus, and runoff and drainage discharge from farmland can lead to discharge of significant amounts of phosphorus into fresh water. Eroding soil carries *particulate phosphorus*, phosphorus that is bound to soil particles and in soil organic matter. Surface runoff and subsurface flow move primarily *dissolved phosphorus*. This form of phosphorus has a very small particle size, is dissolved in the soil solution and can move freely as water moves through the soil. It is also biologically available to aquatic organisms which makes it more damaging in surface water than particulate phosphorus which is not biologically available.

Until recently, the main mitigation strategy was to apply best management practices across the landscape to reduce soil erosion and surface runoff, and to reduce runoff of manure, as these were thought to be the main sources of phosphorus from farmland. Research in the past two decades has pointed to several other contributory factors and this has led to new strategies in phosphorus mitigation. These strategies include: reducing overall phosphorus loading in watersheds to reduce soil levels of phosphorus; identifying 'critical source areas' in the landscape where there is a source of phosphorus as well as a hydrologic route for its transport into surface water; implementing best management practices only on areas of the landscape where phosphorus movement to surface water is occurring, and developing new strategies to prevent and capture phosphorus losses from surface runoff and artificial drainage.

The current strategy for reducing phosphorus movement from agricultural land to surface water is two-fold: the first, source reduction - reducing the loading of phosphorus on agricultural land by balancing phosphorus inputs with outputs on a farm or watershed basis. Current strategies to do this focus on reducing the inputs of phosphorus in fertilizer, feed and manure on a watershed or individual farm basis through nutrient management planning. By reducing phosphorus in livestock feed and improving the digestibility of feed, manure phosphorus levels can be reduced significantly. Chemical fertilizer use can be more carefully matched to crop needs and to existing soil levels, typically resulting in significant reductions in use. Improvements in manure and fertilizer application rate, timing and method can result in significantly less phosphorus moving to surface water in runoff and subsurface flow. In North America, nutrient management programs are mostly voluntary. In the European Union, many member states have imposed limitations on the amount of phosphorus that can be applied to farm land, or have introduced taxation to encourage the farming industry to reduce phosphorus use.

Reducing the transport of phosphorus from farm to surface water is the second major focus of nutrient management programs. Phosphorus can move from agricultural land to surface water by three main routes, soil erosion, surface runoff and subsurface flow. Until recently, soil erosion and runoff of manure and fertilizer were considered the main routes of P loss from farms. Surface runoff was considered a minor route and subsurface flow was considered insignificant. Recent research suggests that on many sites, surface runoff and subsurface flow are significant, particularly because these transport mechanisms preferentially move dissolved phosphorus from the soil into surface water. Because this form of phosphorus is biologically available to aquatic organisms, it has more impact on water quality than particulate phosphorus which moves as part of eroded soil.

Current understanding of phosphorus movement in watersheds is that small areas of the landscape can contribute a disproportionate amount of phosphorus to surface water and in some climates, phosphorus loss occurs during a very short time period such as snowmelt or during one or two large storms, making it critical that mitigation programs are targeted at the areas of the land base where phosphorus is lost and at the climatic events that result in significant loss. Research has shown that in areas where the ground is frozen and snow covered during the winter months, a significant amount of the yearly loss of phosphorus to surface water occurs during the brief snowmelt period. Areas of the landscape at risk of releasing phosphorus should be identified through the use of phosphorus risk assessment tools, and best management practices targeted at these areas.

Traditional best management practices such as conservation buffers, conservation tillage, cover crops and stream bank fencing are very effective but work best in reducing soil erosion and thus reducing losses of particulate phosphorus. There are very few effective best management practices for capturing the dissolved phosphorus that is carried in surface runoff and subsurface flow. Recent research suggests that surface runoff can be captured in conservation buffers and impoundments but that the best strategy for reducing phosphorus loss due to surface runoff is reducing ‘legacy phosphorus’ in soils. There are several phosphorus binding or ‘sorbing’ materials currently being tested for their ability to remove dissolved phosphorus from tile drainage water including alum, gypsum and various industrial residuals. These appear to have promise for remediating subsurface flow water before it is discharged into surface water.

The costs to implement best management practices on farm vary widely. Phosphorus reduction strategies are generally the least expensive to implement. Field management and phosphorus transport loss reduction mitigation measures are more expensive, with conservation tillage and conservation buffers much less expensive than sediment-trapping impoundments and constructed wetlands. Use of phosphorus-sorbing materials to remove phosphorus from tile drainage is mid-range in cost.

Phosphorus mitigation programs have been implemented in several watersheds in the United States in the past three decades. As part of these programs, many different best management practices have been implemented on farm with a resulting decline in the amount of phosphorus being used on-farm in fertilizer and manure. Many programs have shown a reduction in the movement of phosphorus into surface water after implementation of transport-reduction best management practices.

Despite reduction of use of phosphorus and in transport to surface water, there has mostly not been a corresponding improvement in water quality downstream of mitigation projects. This has been attributed to several recently-identified phenomena which are making water quality improvements elusive. Research has shown that legacy phosphorus in soil, and in ditch, stream and lake sediments can continue to contribute phosphorus to water for long periods of time even while phosphorus losses from agricultural land are decreasing, thus masking improvements from best management practices. Some best management practices have not been as effective as anticipated: for example, conservation tillage initially led to water quality improvements by reducing the amount of particulate phosphorus lost to surface water but subsequently caused an increase in the amount of dissolved phosphorus entering water. Subsurface flow has only recently been identified as a significant loss pathway for phosphorus on some sites and there are currently few effective best management practices to mitigate these losses. Some researchers believe there may be a lag time of up to several decades before water quality improvements are seen. This has generated frustration among water managers, farmers and funding agencies who had hoped for rapid improvements in water quality following implementation of phosphorus mitigation programs.

Part B: Nutrient Management Strategy for the Shuswap Watershed

Agriculture in the study area: The land use along the Shuswap, Salmon and Eagle Rivers is primarily agriculture. Agriculture along the lower Shuswap River (downstream of Enderby), lower Salmon River and Fortune Creek is primarily intensive, with approximately 50 dairy farms and 16 commercial poultry operations in the area. Agriculture along the Shuswap River above Enderby, the upper Salmon River and the Eagle River is less intensive, with many beef cow-calf operations and small scale hobby farms and a few dairy and poultry farms.

Much of the land located next to the rivers is planted to high-value forage and silage corn for feed for dairy cattle. These crops are heavily fertilized to ensure optimum yields, and soils also typically receive at least one application of manure per year.

The agricultural areas along the rivers are primarily flat and low-lying. They consist of the flood plains of the rivers, and as such are situated only slightly above the elevation of the rivers and are susceptible to elevated groundwater and flooding during the April through July high water period. The exception to this is the land along Fortune Creek which is slightly higher in elevation and consists of glacial lake-bottom sediments. The land along the three rivers is highly productive for crop production due to the primarily flat topography, access to irrigation water and productive soils. The climate in the study area is moderate with cold winters and long hot summers, making the area only slightly less productive for agriculture than B.C.'s Fraser Valley.

Soils in the study area: The valley bottoms of the three study rivers are dominated by soils derived from fluvial parent materials that were deposited by the post glacial river systems, and to a lesser extent, by glaciofluvial materials deposited from receding flood waters at the end of the last glacial period.

Fluvial and glaciofluvial materials often have high sand content, providing rapid drainage of water through the soil profile and the potential for development of deep root systems, but some glaciofluvial materials contain a more uniform mix of sand silt and clay. The coarse fragment (rocks and stones) content in fluvial and glaciofluvial materials varies, but where it is high, the soils have low water and nutrient holding capacity.

Small areas of organic soils and glaciolacustrine sediments are also found in close proximity to the rivers, especially in Fortune Creek. Organic materials are generally found in low lying portions of the landscape where drainage is poor. Glaciolacustrine materials typically have no coarse fragments, and are characterized by large amounts of silt and clay deposited in the bottom of glacial lakes that occupied portions of the valleys as the glacial ice was melting. Soils derived from glaciolacustrine materials often have high productivity because the silt and clay retain water and nutrients for plant growth, but these soils also tend to have restricted drainage, posing challenges for soil management operations requiring equipment.

Regulations and guidance for phosphorus management on-farm: In B.C., the management and land application of manure and other agricultural waste is regulated by the B.C. Ministry of Environment under the *Agricultural Waste Control Regulation*. The Regulation is part of the *Environmental Management Act*, the primary legislation managing waste and controlling pollution in the province. The associated *Code of Practice* is part of the Regulation, and describes practices for 'using, storing and managing agricultural waste that will result in agricultural waste being handled in an environmentally sound manner'. Producers found to be in violation of the *Agricultural Waste Control Regulation* can be charged under the *Environmental Management Act*. There is no regulation of any aspect of the application of chemical fertilizer in the province.

The B.C. Ministry of Agriculture provides guidance to agricultural producers on the application and use of nutrients on B.C. farms. Guidance applies to nutrients from both manure and fertilizer. This is currently done through a series of nutrient management factsheets. Phosphorus management guidance is contained in the '*Phosphorus Considerations for Nutrient Management'* factsheet. The factsheet contains guidelines to minimize the risk of phosphorus pollution of sensitive receiving environments in B.C. The guidelines generally mirror the recommendations for managing agricultural source phosphorus in the literature. The phosphorus guidelines are voluntary.

B.C's Environmental Farm Plan Program: B.C. has a voluntary, free and confidential Environmental Farm Plan Program, developed by the B.C. Ministry of Agriculture and delivered by the B.C. Agricultural Research and Development Corporation (Ardcorp). The Environmental Farm Plan addresses all aspects of a farm's environmental impact and suggests management changes to mitigate environmental impacts. Due to the voluntary, confidential nature of the EFP program, it is not known how effective it is at mitigating environmental impacts from agriculture. There is no obligation for a producer to implement any of the EFP's recommendations however completion of identified environmental deficiencies allows a producer to apply for provincial cost-shared funding to implement a range of best management practices on farm.

The EFP program contains a nutrient management planning module which suggests that manure application should be phosphorus-based in phosphorus-sensitive fresh water areas and when risk of runoff or erosion of soil is high. Completion of this module is optional based on the recommendation of the EFP planner. It is recommended when the producer's response to nutrient management questions in the EFP indicates the requirement for more in-depth nutrient management planning.

Soil enrichment with phosphorus in the study area: In 2007, the B.C. Ministry of Agriculture and researchers from Agriculture Canada undertook an extensive survey of the nutrient content of soils on commercial agricultural fields in the Okanagan and Similkameen regions of the province, including plant-available and water-extractable phosphorus.

A total of 56 fields were surveyed in the North Okanagan portion of the study area, all located in the area between Mara and Armstrong. Most of the fields surveyed were located in areas that drain into the Shuswap River and Fortune Creek. The fields were cropped to silage corn, cereals, alfalfa and grass, typical crops grown in the area as feed for dairy and beef cattle. Of the 56 fields surveyed, 36% were in the high category (51-100 ppm soil P) and 50% were in the very high category (>100 ppm soil P). Only 8 of 56 fields (14%) were in the low to medium soil P category (<50ppm soil P). A soil level of 20-30 ppm available P is considered adequate to provide phosphorus requirements for one year for crops with a moderate to high requirement for the nutrient.

Of the fields surveyed in the North Okanagan, those cropped to silage corn and cereals contained the highest residual phosphorus, 206 to 237 ppm available phosphorus, which is as much as 10 times the soil level required to supply crop needs. Fields cropped to silage corn also received the most fertilizer phosphorus; on average, 38 kg per hectare per year (as phosphate which is 43% phosphorus) but as high as 67 kg per hectare per year, on fields that already contained sufficient to meet crop requirements for many years.

One of the goals of the soil survey was to assess the risk of loss of phosphorus from area soils to surface water. Soils were assessed for the proportion of available phosphorus that was water soluble as a predictor of the phosphorus that is susceptible to leaching and runoff. Overall, it was determined that soils in the Okanagan region have relatively low capacity to bind phosphorus and, because of the high residual phosphorus in soils in the valley, 96% of fields were considered to pose a potentially high to very high risk of phosphorus leaching or running off to surface water.

Nutrient management in the study area*:* Dairy producers in the study area routinely apply both manure and chemical fertilizer to their high-value crops. Corn silage typically receives the most nutrients but grass and alfalfa crops are also fertilized heavily. Dairy producers typically apply manure to enhance overall soil fertility, although there is some effort made to consider its nutrient content. Fertilizer application rates are usually determined by the fertilizer provider based on the results of soil testing that they conduct for the farmers.

On beef cow-calf operations in the study area, significantly less nutrients are applied to crop land because of the economics of beef production (relative to dairy production). Fertilizer application is limited to the minimum amount necessary to generate reasonable forage yields. Because of this, fields on area ranches are not generally over-supplied with phosphorus; in fact, many may be deficient in this nutrient. The exception to this is ranches that have a feedlot attached; the manure from the feedlot will increase the overall fertility of ranch fields. Livestock overwintering areas can have a significant accumulation of manure which can run off into surface water with spring snowmelt and flooding.

Nutrient management on commercial poultry operations generally involves removing some or all of the manure from their property. Commercial poultry producers in B.C. generally have insufficient land to utilize the nutrients in the manure. This is because they typically do not grow any of their own feed but rather import grains and protein sources that are grown on the prairies. They may apply a small amount of manure to their own land but generally they sell or give away the rest. Despite this general movement of poultry manure off-farm, it is expected that phosphorus levels on land that has routinely received poultry manure will be, in general, very high.

Small holdings are completely unregulated with respect to nutrient management. Nominally they also must adhere to the requirements of the AWCR but in fact, because of their generally small numbers of livestock, there is little oversight. There is the potential for soil buildup of phosphorus on small holdings where there are many animals on a small land base. There is also potential for loss of phosphorus into surface water by all the same mechanisms that can occur on commercial farms.

Recommended nutrient management strategy for the Shuswap watershed: The SLIPP water quality data from 2011 to 2013 does not provide any information about the source of the phosphorus entering Shuswap and Mara Lakes in the Shuswap, Salmon and Eagle Rivers. The water quality data modelling points to agriculture as a major source, but doesn't provide any concrete evidence of agricultural-contribution nor does it identify the mechanisms by which agricultural-source phosphorus may be entering surface water.

Because of this, it is recommended that the Shuswap Watershed Council develops and seeks funding for a long-term water quality monitoring program to identify sources of phosphorus. To ensure that data collected is credible, it is recommended that the water quality program is undertaken by a research institution such as UBC-Okanagan or Thompson Rivers University. The program should have as primary goals to identify the sources of phosphorus in the affected rivers and to identify the mechanisms by which the phosphorus is entering the rivers. It will also be important to identify which areas along the rivers are contributing phosphorus; research suggests that typically, a small area of a watershed can be responsible for a large proportion of the nutrient loading.

The water quality data collected during 2011-2013 by SLIPP suggests that there is both dissolved and particulate phosphorus in the affected rivers and that these two forms are present during different times of year. Based on the conditions along the study rivers, the transport mechanisms most likely for dissolved phosphorus are subsurface flow during freshet and surface runoff during snowmelt. Stream bank erosion and movement of manure into surface water are likely transport mechanisms for particulate phosphorus as well as re-suspension of sediments deposited during low flow in ditches and tributaries.

If it is established that there is a contribution of phosphorus from agriculture along the affected rivers, the most effective long term strategy for reducing phosphorus loading of surface water appears to be to reduce the loading of phosphorus on the land base by reducing use of fertilizer and manure on soils with elevated phosphorus, improving manure management and other phosphorus-reduction strategies. Mitigation strategies to reduce the movement of phosphorus into surface water will have to be developed once transport mechanisms are understood. It is also recommended that an educational program be developed to transfer phosphorus mitigation information to producers in the whole Shuswap watershed, not just the study area. Funding for phosphorus best management practices may be available from the government-funded Growing Forward 2 Fund which is in place from 2013 to 2018. The Alternative Land Use Services (ALUS) program may also be a useful model for funding phosphorus mitigation strategies.

List of abbreviations and definitions

AWCR – Agricultural Waste Control Regulation

BMP – best management practice or beneficial management practice

DP – dissolved P

DRP – dissolved reactive P

E.U. – European Union

FGD gypsum – flue gas desulfurization gypsum

ha - hectare

kg - kilogram

mg - milligram

mg/kg or mg per kg – milligram per kilogram

Mg – 1000 kg or tonne

Micron – micrometre, 1 millionth of a metre

SRP – soluble reactive P

P – phosphorus

PP – particulate P

PO_4 –orthophosphate

PSM – phosphorus sorbing material

SLIPP – Shuswap Lake Integrated Planning Process

SWC – Shuswap Watershed Council

U.S. – United States of America

Contents

Tables and Figures

1. Introduction

Water quality monitoring in and around Shuswap and Mara lakes and along most tributaries was conducted by the Shuswap Lake Integrated Planning Process group (SLIPP) during 2011, 2012 and 2013 to assess the state of water quality in the watershed. SLIPP was a collaborative group made up of representatives of local communities, First Nations and public agencies with an interest in water quality in the Shuswap watershed. Water quality monitoring showed that there were elevated levels of several nutrients including phosphorus (P) entering the lake in the Shuswap, Salmon and Eagle Rivers and several of the smaller tributaries. As a result of the presence of elevated P in these tributaries, SLIPP subsequently engaged Tri-Star Environmental Consulting to review the water quality data and provide some insight into the probable source of the nutrients. The Tri-Star Environmental report concluded that the most likely source of the nutrients was agriculture on the land base immediately adjacent to the river.

As a result of the 2011-2013 water quality data and the Tri-Star Environmental report, the Shuswap Watershed Council (SWC), the current water quality 'watch-dog' group for the Shuswap watershed, commissioned a review of current strategies for mitigating the impacts of agricultural-source nutrients, focussing on phosphorus because of its link to water quality degradation in many other fresh water systems. The specified focus was watershed-based programs and practices successfully implemented elsewhere. A strategy to address agricultural-source P in the Shuswap watershed was to be developed based on the results of the literature review and the specific conditions along the three impacted rivers. This report presents the literature review and discusses the soils and landforms as well as the types of agriculture along the rivers and the current strategies for P management in agriculture in B.C. It also contains a discussion of the possible mechanisms by which P may be entering surface water from farmland along the rivers, and some potential mitigation strategies.

The area considered in this report includes sections of three tributaries of Shuswap Lake (Figure 4); the Shuswap River from the outlet at Mabel Lake to the inlet at Mara Lake, including Fortune Creek which runs from just north of Armstrong to Enderby (Figure 5); the Salmon River from Westwold to the inlet into Salmon Arm at Salmon Arm (Figure 6) and the Eagle River from north of Malakwa to the inlet at Sicamous (Figure 7). Of all the tributaries along these 3 rivers, only Fortune Creek is included in this report because it drains a very significant agricultural area. The land along these rivers is generally flat and low-lying, prone to flooding and high groundwater in spring, and is highly productive for cropping. Most of the land adjacent to surface water is farmed in high-value forage crops for dairy cattle or lower value hay and pasture for beef cattle, horses and other primarily land-based livestock.

The SLIPP water quality data does not provide a direct link for the movement of agricultural-source nutrients from the agricultural land along the impacted rivers to surface water but points to a contribution by agriculture. It also provides little information about which mechanisms are responsible for movement of phosphorus into fresh water. If agriculture is the primary source of phosphorus loading to the study rivers during freshet, additional water quality and soil testing will be required to identify the transfer pathways so that effective mitigation strategies can be implemented.

Part A. The Current State of Knowledge of Phosphorus-based Nutrient Management in Watersheds: Review of Literature

2. Introduction to Literature Review

This review of literature presents current research on phosphorus-based agricultural nutrient management in watersheds. It summarizes the current understanding about how agricultural-source phosphorus (P) moves into surface water and shallow groundwater, the effectiveness of traditional Best Management Practices (BMP)s in reducing P loading to surface water and the success of some farm-based and watershed-based P mitigation programs in improving water quality in the targeted surface water sources. It also discusses ongoing issues and challenges in P mitigation and emerging technologies for P removal from agricultural drainage. It has been prepared to provide background information for development of an agricultural nutrient management strategy for the Shuswap watershed for the Shuswap Watershed Council.

Phosphorus is considered the primary limiting nutrient and therefore the primary cause of nuisance algal blooms and other water quality problems in surface water (Jarvie et al 2013). There are impairments to water quality due to excess loading of surface water with P throughout the European Union (E.U.) (Kronvang et al 2005), in several major watersheds in the United States (U.S.) including Chesapeake Bay, Lake Erie, the Mississippi basin and areas of Florida (Sharpley et al 2013). In Canada, Lake Winnipeg has had recurring algal blooms due to nutrient loading (Tiessen et al 2011) and Lake Champlain in Quebec has been impacted by agricultural-source P. Industry, development and agriculture have been identified as the primary contributors of phosphorus to surface water. Efforts have been underway since the 1970's to reduce point and non-point source loading of P; this has been the primary watershed management tool to control eutrophication in fresh water. Point sources such as waste water treatment plants are easier to control and, due to widespread tertiary treatment of sewage effluent, have largely been eliminated as major sources of P in surface water. Non-point source P inputs from agriculture have been much harder to quantify and control.

This review discusses the many factors contributing to agricultural-source P loss to surface water (Figure 1 and Table 1). Application of phosphorus fertilizer in excess of crop requirements has led to soils with a buildup of P well above agronomic levels in many areas where the land base is used for intensive agriculture. Application of manure without reference to meeting any specific nutrient goals or to meet crop nitrogen requirements generally leads to application of more P than crops can utilize. These two factors have led to enrichment of soils with P on most intensively-farmed land, termed 'legacy P' because it can take many years for the soil level to decline to normal levels, during which soils can continue to contribute P to surface water. A further source of P loading to surface water is direct runoff losses of manure from grazing areas or from fields where manure has been recently applied.

Research has demonstrated that P can move from farmland into surface water with eroding soil, with surface runoff of manure and soil and in agricultural drainage (Figure 1). The combination of soils enriched with P, and runoff and drainage discharge from farmland can lead to the discharge of significant amounts of P into fresh water. Until recently, the main mitigation strategy was to apply BMP's across the landscape to reduce soil erosion losses and runoff losses of P from manure as these were thought to be the main sources of P from farmland. Research in the past two decades has pointed to several other contributory factors and this has led to new strategies in P mitigation. These include: reducing overall P loading in watersheds to reduce soil levels of P, implementing BMP's only on areas in the landscape where P movement to surface water occurs, and developing new strategies to prevent and capture P losses from surface runoff and artificial drainage.

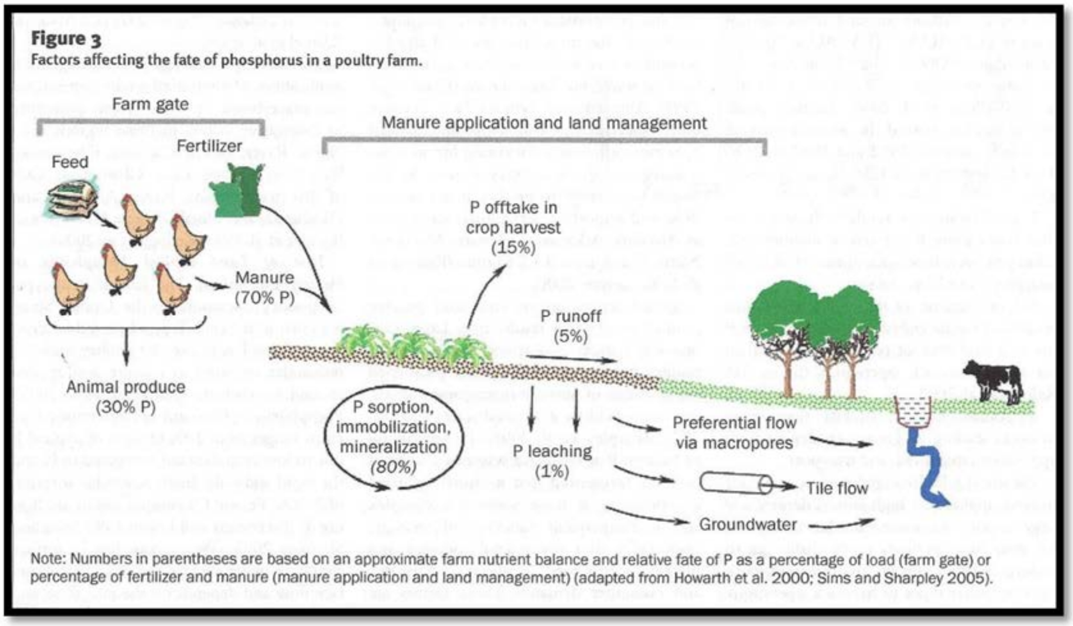
The literature reviewed for this study describes a two-pronged strategy for controlling agricultural non-point source P in watersheds to reduce P loading to surface water: 1. reducing P loading watershed-wide by reducing the amount of P brought into the watershed in livestock feed, chemical fertilizer and manure (source factors), and 2. reducing the opportunities for P to move from agricultural soils to surface water (transport factors). Measures to reduce P loading of the land base are typically applied watershed wide through either an educational program or regulatory measures or a combination of both. Measures to reduce transport of P to surface water are targeted specifically to sites where P movement is likely to occur due to increased risk of runoff, soil erosion or subsurface flow. These sites are increasingly identified through the use of a P-index and BMPs are targeted at sites at most risk of losing P to surface water.

At the end of each section is a short discussion of the relevance of the various P mitigation strategies to the conditions in the study area of the Shuswap watershed.

This literature review is divided into the following sections:

1. Introduction
2. Background information on the various forms of P in soil and surface water, their risk to aquatic organisms and terms used to describe them in the literature.
3. P source factors and BMP's recommended to reduce P loading of farmland.
4. P transport factors – pathways and mechanisms of P movement to surface water
5. A review of traditional BMP's and their effectiveness in reducing P movement to surface water
6. Summary of the results of three watershed-scale nutrient management programs.
7. Ongoing issues and challenges in P mitigation, emerging technologies.

Figure 1. Factors Affecting the Fate of Phosphorus on a Poultry Farm



From: Sharpley et al 2007

Table 1. Sources and Factors Influencing P Loss*

Factors	Description
Application method	P loss increases in this order: subsurface injection, plowed under, and surface broadcast with no incorporation
Application rate	The more P (fertilizer or manure) applied, the greater the risk of P loss
Application source	The P in some fertilizers and manures is more soluble than in others and, thus, more susceptible to runoff
Application timing	The sooner it rains after P is applied, the greater the risk of P loss
Connectivity to stream	The closer the field to the stream, the greater the chance of P reaching it
Erosion	Total P loss is strongly related to erosion
Irrigation runoff	Improper irrigation management can increase P loss by increasing surface runoff and erosion
Proximity of P-sensitive water	Some watersheds are closer to P-sensitive waters than others (that is, point of impact)
Sensitivity to P inputs	Shallow lakes with large surface areas tend to be more vulnerable to eutrophication
Soil P	As soil P increases, P loss in sediment, surface runoff, and subsurface flow increases
Soil texture	Soil texture influences relative volumes of surface and subsurface flow
Subsurface flow	In sandy, organic, and P-saturated soils or soils with preferential pathways, P can leach through the soil
Surface runoff	Water serves as the transport mechanism for P either off or through the soil

*Factors listed alphabetically, not in order of importance.

Adapted from Sharpley et al 2006

3. Assessment of Phosphorus in Soil and Surface Water

Phosphorus exists in many different forms in soil and in water. This section describes briefly the terminology used to describe P in soil and in surface water in this report.

P moving from land into surface water in eroded soil and runoff is divided into two main fractions by size, greater than and less than 45 microns. Soluble or dissolved P is P in forms that are *smaller than 45 microns* in size. Dissolved P is considered to be biologically active because it is a ready food source for aquatic organisms. It is the main form of P lost from agricultural land in surface runoff and subsurface flow. It remains in solution when it enters water.

Particulate P is P found in molecules that are *larger than 45 microns* in size. Particulate P is P that is attached to soil particles or found in organic matter and is therefore not an immediate food source for aquatic organisms but may become one if the P is released into solution. It is the main form of P in eroded soil. It tends to settle on the bottom of stream or lake beds as sediment.

3.1 Soil phosphorus

In agricultural systems, P is an essential nutrient for normal plant growth. Of the total amount of phosphorus in soil, only a small amount is available for plant uptake at any time. Plants take up P as orthophosphate ions (H_2PO_4 and HPO_4). There is a small pool of orthophosphate in the soil at all times and there is constant replenishment of this pool of soil P because P is continually released from organic matter in the soil and from soil particles. Therefore, a soil's ability to provide enough P for a crop over a growing season is determined by the sum of the amount of orthophosphate in the soil at a given time plus the amount of P that will be released into solution over the growing season. Agricultural soil P analytical methods are based on estimating the amount of P that will become available over a growing season using a mild acid to extract some of the P bound to organic matter and mineral soil particles. Therefore, agricultural soil P lab methods measure the amount of orthophosphate, the form that is used by plants, and also estimate the potential release of 'plant available P' over a growing season.

Many different lab methods have been developed to assess the soil's potential to provide sufficient P for growth of a crop including Olsen-P, Mehlich-P, Bray-P and Kelowna-P and there are modifications to all of these methods to improve their predictive ability. They all extract a slightly different amount of P so are not directly comparable however conversion factors can be used which allow comparison between them with reasonable accuracy.

None of these methods determines the amount of orthophosphate in soil. However, research has shown that the soil available P, as measured by these different methods, is a reasonable predictor of the amount of orthophosphate that will move to surface water with runoff or soil erosion (Vadas et al 2005). For example, for a given volume of runoff water, soils with higher available P as measured by these methods will release a proportionally higher amount of orthophosphate into surface water than soils with a lower available P.

3.2 Phosphorus in fresh water

The form of phosphorus that is used as food or 'taken up' by aquatic organisms is the phosphate molecule (PO_4), orthophosphate, the same basic unit taken up by terrestrial plants. The amount of this molecule present in surface water is an indicator of the P food supply for aquatic organisms and is also a predictor of the potential for explosive growth of aquatic organisms that can lead to eutrophication of a surface water source.

Various different lab methods have been developed to estimate the amount of orthophosphate in water. They vary in their accuracy, and are constantly being modified to better estimate the orthophosphate fraction. There are many standard terms in the literature to describe the P fractions captured by the various lab methods. The most common terms in the literature are dissolved P (DP), dissolved reactive P (DRP) and soluble reactive P (SRP).

Dissolved P is simply all of the P in a water sample that will pass through a 45 micron filter. The water sample is filtered through a 45 micron filter. All particles larger than 45 microns are captured on the filter paper and are therefore removed from the sample. The P fraction that passes through the filter is termed *dissolved P*. It consists of dissolved organic P and dissolved inorganic P. Orthophosphate is an inorganic molecule and comprises most of the dissolved inorganic P fraction. The dissolved organic P is P which is smaller than 45 microns but is bound to organic matter and therefore not biologically available. The dissolved P determination overestimates the amount of orthophosphate in a sample by including the dissolved organic fraction. Dissolved and soluble are used interchangeably in describing this P fraction.

Dissolved reactive P and soluble reactive P are lab methods to refine the estimate of orthophosphate by eliminating the organic P fraction and thus leaving inorganic P which is mainly orthophosphate. The 45 micron-filtered water sample is reacted with ammonium molybdate or other similar reagent or reagents. The orthophosphate in the sample reacts with the reagent to produce a strong blue colour which is read colorimetrically. This gives a better estimate of orthophosphate but still can overestimate the actual amount of orthophosphate by one or two orders of magnitude.

Particulate P is the fraction of P in the material that does not pass through a 45 micron filter, primarily soil particles and organic matter. It is calculated as the difference between total P and dissolved P.

Total P is the total amount of P in an unfiltered water sample.

4. P Source Factors and Nutrient Management BMP's to Reduce Source P in Watersheds

P enrichment of soils due to long term fertilization has been identified as one of the main factors that contributes to the amount of P lost to surface water (Sharpley et al 2013). Programs aimed at improving surface water quality on a watershed basis all have as an important component an overall reduction in P loading to the watershed using a mass balance approach: P inputs in feed and fertilizer should not exceed outputs in products exported from the watershed. This involves reducing the amount of P that enters a watershed in all inputs, including livestock feed, fertilizer and manure, until nutrient inputs and outputs are in balance. It also requires better management of the P sources that are applied to the land base to minimize the risk of that P moving to surface water. In North America, with very few exceptions, all programs are voluntary.

Legacy P*:* In many areas of intensive agriculture in North America, Europe and New Zealand, soil available P (as measured by one of the standard soil available P methods) is considerably elevated above the level required to meet crop growth requirements, in some cases up to 10 times or more than the 'agronomic level' (Sharpley et al 2013). This is the result of several factors of which two seem to be most important. The first important factor is that manure applications have for the past 25-30 years been made based on meeting the nitrogen requirement of the crop to be grown (prior to that, based on disposal requirements). When manure is applied to meet the crop's nitrogen requirement, excess P is almost always applied; the excess can be two to four times the crop's P requirement. This is because the ratio of nitrogen to phosphorus in manure is 2:1 to 4:1 while crops take up much more nitrogen than P, with the uptake ratio ranging from 6:1 to 8:1 (Sharpley and Withers 1994). The second factor is that P fertilization rates are typically based on optimizing yield, not on maintaining the soil level within the agronomic range. The result is that many soils in intensively farmed areas have levels of available P that are well above the level required to meet crop requirements. This excess P stored in the soil is termed 'legacy P'.

Depending on the degree of P enrichment in soils, it can take years or decades for soil P levels to decline to the 'agronomic' level even without application of any fertilizer P (Meals et al 2010; Sharpley et al 2013). This soil repository of P can enrich surface water with P for many years even though P loading in a watershed has been significantly reduced, and as a result, can mask or prevent water quality improvements. This is because all surface runoff, subsurface flow or eroded soil will contain more P than if the soil had been maintained at the agronomic level – the level just sufficient to meet crop requirements.

The most common nutrient management strategies on a watershed scale to reduce P loading to the entire watershed are: reducing P in livestock feed to reduce the amount of P in manure, reducing the amount of P fertilizer used and improving the rate and timing of manure and fertilizer application. Figure 2 illustrates some of the nutrient management strategies for reducing P loading on poultry farms but is relevant for livestock operations as well. Table 3 lists P source reduction BMPs.

4.1 Reducing the P content of livestock feed and increasing the digestibility of the feed.

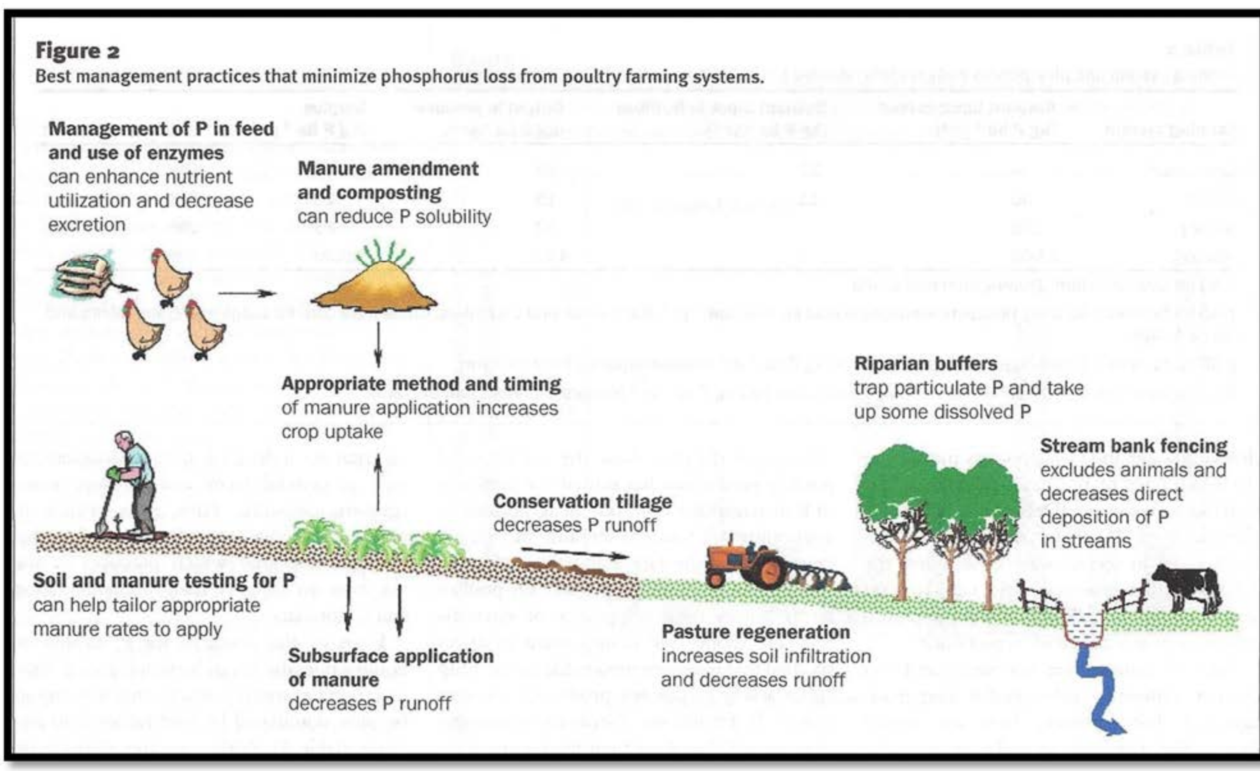
A very important component of P source-reduction programs is improving the efficiency of use of P in livestock and poultry feed. There is a two-pronged problem with livestock and poultry rations. Much of the P in the feedstuffs is relatively undigestible, leading to excretion of much of the P consumed by animals. Rations are often formulated with excess P (above the National Research Council minimum standards) to ensure that there is no risk of a deficiency or to meet some other goal such as enhanced livestock health or production. P mineral supplementation is also common because of the low digestibility of P in livestock feed.

Table 2. Potential for Feed Management Strategies to Reduce Non-point Source P Loss from Agricultural Land

Feeding strategy	P loss reduction
Ruminants and non-ruminants (livestock and poultry)	%
Diet formulated closer to requirement	10 to 15
Growth promotion	5
Protein/carbohydrate enzymes	5
Use of highly digestible feeds	5
Phase feeding	5 to 10
Ruminants (cows, sheep, goats)	
Reduced P in diet	20 to 30
Non-ruminants (swine and poultry)	
Phytase/ low-P diet	20 to 30
Phytase/ low-P diet/high available P corn	40 to 60

Adapted from Sharpley et al 2006

Figure 2. Best Management Practices that Minimize P Loss from Poultry Farming Systems



From: Sharpley et al 2007

Some watershed-wide P mitigation programs have encouraged farmers and feed companies to work together to reduce P in livestock rations and to increase the digestibility of the P. Where implemented, this has resulted in a significant reduction in P entering a watershed. For instance, reduced dietary P in poultry rations was mandated in Maryland as part of the Chesapeake Bay clean-up. This has resulted in a 30 to 40% reduction in the P in poultry rations which will result in a much lower P content in manure (Maguire 2009) with a corresponding reduction in the amount of P applied to farmland in an equivalent volume of manure. Table 2 contains estimates of the potential reduction in non-point source P loss with various P-reducing feeding strategies; P loss reduction is estimated to range from 5 to 60% depending on the feed adjustment.

4.2. Reducing the amount of chemical fertilizer used.

Where the land base has elevated soil P levels, no additional P is required to meet crop requirements because there is sufficient P stored in the soil to meet crop needs. Depending on the degree of P enrichment in the soil, chemical fertilizer can be eliminated altogether with no reduction in crop yield sometimes for many years (Kleinman et al 2011). Soil testing has been found to be an accurate means of identifying fields with elevated P.

Research in Oklahoma on soil with elevated P due to application of high rates of poultry manure demonstrated that crop yield did not decline significantly even after 6 years with no further P application. During that time, soil P levels declined from 258 to 192 mg per kg, still well above the local crop requirements of 20-60 mg per kg which suggests that crop yields would not be negatively impacted for at least several more years (Sharpley et al 2007). Surface runoff P declined steadily from 5.6 kg per hectare per year at the start of the 6-year trial to 0.9 kg per hectare per year at the end of the trial as the soil P level gradually declined. In a study of a sandy coastal plain soil with elevated P due to long term application of manure and fertilizer, it was estimated that it would take 18 years of continuous cropping with no added P in fertilizer or manure to reduce soil levels to the agronomic level of 20 mg/kg Mehlich-3 P from the pre-existing level of 100 mg/kg P (Kleinman et al 2011).

4.3 Changing the method, timing and rate of application of manure and chemical fertilizer to reduce the risk of movement to surface water in runoff.

Significant amounts of P can be lost to surface water by runoff and subsurface flow following the application of manure and chemical fertilizer depending on soil and weather conditions. Nutrient management plans have been the tool of choice to educate farmers about manure application strategies to reduce risk and to provide them with alternative application strategies.

Laboratory-scale research in the U.S. showed that runoff losses of P were significantly higher when manure was applied immediately before heavy rain and declined as the time increased between manure application and rainfall. There was a reduction in the amount of dissolved P in runoff that ranged from 16% to 72% when rain occurred 35 days after application vs. 1 day after application (Sharpley 1997). Research in the U.K. has shown that total and dissolved P loss through tile drains can be significant immediately after application of manure as slurry if fields have not been tilled for a significant amount of time and therefore contain preferential flow channels – cracks, worm and mole tunnels, root channels. Immediately after slurry application, total P in drainage water was measured to be as high as 10 mg per litre, 15 times higher than the surface water quality standard (Smith et al 1998). Withers et al (2001) showed that P release in runoff was minimized when manure and fertilizer were incorporated into the soil.

This research all points to the need to adopt BMP's that reduce P runoff and subsurface flow losses by applying fertilizer and manure when there is lower risk of heavy rain or snowmelt runoff, by tilling manure in to avoid subsurface flow and reduce runoff, and other management strategies to reduce the risk of P movement to surface water. Significant reductions in P loss to surface water can be achieved with environmentally-sound manure and fertilizer management guidelines (Sharpley et al 2006).

Quantifiable results

These P source reduction strategies are the standard measures implemented to reduce P loading in a watershed and thus reduce the amount of P that is available to move into surface water. Part of the appeal of these measures is that they are quantifiable on a watershed level. Goals in terms of reduced loading of P can be set and reductions can be measured in terms of tonnes less fertilizer used, or tonnes less P in manure due to reductions in P in feed. This is in contrast to P losses in runoff, erosion and subsurface flow which are generally extremely difficult to quantify making it difficult to provide assurance to regulators and funding agencies that funds spent are resulting in improvements.

4.4 Limiting P loading– the European strategy

The European strategy to reduce nutrient loading to agricultural land has been somewhat different than the primarily voluntary strategies used in North America. In 1991, in response to increasing levels of nitrates in surface and groundwater throughout the EU, the EU passed into law the *Nitrates Directive*. This law was designed to limit the application of nitrogen in all fertilizing materials including livestock manures and fertilizer with the goal of improving water quality throughout the EU. Because of wide-spread surface water quality degradation, the EU subsequently instituted the Water Framework Directive in 2000 which moved the focus to phosphorus and required the development of a P mitigation strategy for all river basins by 2010 (Kronvang et al 2005). Most EU member states have now, as a result, instituted phosphorus source and transport loss reduction strategies. A brief discussion of P mitigation measures in the Netherlands, Denmark and Germany is presented here; all of these countries have significant areas of intensive agriculture (poultry, swine and dairy production). These countries now have regulations that restrict or discourage application of both nitrogen and phosphorus to agricultural land.

The Netherlands

The Netherlands has had programs in place since 1985 to reduce the excess loading of nitrogen and phosphorus onto agricultural land. The first program, which limited expansion of the pig and poultry industries and capped application rates of phosphorus on agricultural land, and introduced a milk quota system to cap expansion of the dairy industry, resulted in only minor reductions in the nutrient surplus. Further programs have been developed since then and have gradually reduced the allowable application rate of phosphorus in all forms (fertilizer, manure and other) to 41 kilograms per hectare on grassland and 32 kilograms per hectare on arable land per year (95 and 75 kilograms per hectare of phosphate respectively). The government also legislated a reduction in the levels of protein and phosphorus in animal feeds and required the transport of manure from surplus areas to undersupplied areas. As well, there are a number of required nutrient management practices including a ban on application of manure and fertilizer between September 1 and January 31 of the following year (Third Dutch Action Program 2014).

The program resulted in substantial reductions in the use of chemical fertilizer on farms. Reductions in the protein and phosphorus content of animal feed resulted in a 22% reduction in manure nitrogen and a 9% reduction in the amount of phosphorus in manure.

Denmark

Like the Netherlands, Denmark has had nutrient management programs in place since 1987 to address concerns about nitrogen and phosphorus loading of the land base and subsequent pollution of surface and groundwater. Manure and fertilizer management requirements have steadily become more stringent since then. There were several significant improvements to surface water quality from these programs. One significant change is that the amount of phosphorus fertilizer used on farms declined 65% from 40,000 to 18,000 tonnes in the period up to 2005.

The following additional measures were instituted in 2005:

- A tax on phosphorus in livestock feed (4 Denmark Kroner or USD 0.74 per kilogram of P).
- A 10% reduction in standard nitrogen application rates for crops.
- 50,000 hectares of crop-free buffer zones 10 metres wide along lake and river shores to reduce phosphorus runoff from agricultural sites.
- Annual reporting requirements for farms, and random inspections to ensure compliance. Subsidy payments became linked to compliance with nutrient regulations.

Phosphorus application is limited through a two-fold approach. The tax on P in feed brought onto the property encourages feed companies to reduce the level in feed. The system of crop-free buffers between cropped land and surface water is intended to reduce runoff of phosphorus in soil and manure. Unlike many other European jurisdictions, Denmark has not yet limited the application of phosphorus to farm land (Danish Ministry of Environment 2014).

Germany

The following basic information was found on phosphorus limits in Germany. Information is very limited because most information on German nutrient management programs is not available in English.

Phosphorus application to farm land is limited to 9 kg per hectare per year (20 kg per hectare as phosphate, P_20_5) unless soil test results demonstrate that the soil available P content is below stipulated limits (based on standard soil tests in Germany). Soil testing must be conducted every 6 years if a farmer wishes to use more than the 20 kg per hectare limit per year. (From: http://www.gesetze-im-internet.de/bundesrecht/d_v/gesamt.pdf)

4.5 Relevance to local conditions

This section of the literature review covers the importance of reducing P loading to agricultural land as a key way to balance P inputs with outputs and to reduce the amount of 'legacy P' in soils and sediments in a watershed. This is accomplished by applying no more P to the land base than is required to meet crop needs, by allowing soil levels of P to decline if they are elevated, by accounting for the P applied in manure, by manipulating livestock rations to reduce the P content or to increase digestibility, and by improving the timing and placement of manure to minimize the risk of runoff to surface water. These measures are particularly important in regions where soil P levels are elevated due to long term application of P fertilizer and manure *and* where the land base with elevated soil P is linked hydrologically to surface water such that there is a pathway or pathways for the P to move from agricultural land to surface water. In the study area, the land base and agricultural history share many of the characteristics of other areas where agriculture has been identified as a significant contributor of P to surface water. These include:

- Large agricultural land base located immediately adjacent to surface water;
- Significant proportion of land base used to grow high value, highly fertilized crops;
- Elevated soil P on land base (based on results of Okanagan soil study; see section 15);
- Soils with characteristics of soils that are prone to subsurface flow losses of P (high soil P combined with coarse-textured, organic or artificially drained soils) (see section 13.3);
- Land base receiving regular applications of manure, some of that in fall after crop harvest;
- Land base regularly amended with fertilizer P (see section 15).

Based on a large body of research, all of these factors suggest a strong likelihood that there is movement of P from the land base along the study rivers into surface water. Research has shown that the most effective means by which to reduce the amount of P moving into surface water is to reduce the soil level of P on land linked hydrologically to surface water. Therefore, measures to reduce the loading of P on the land base in the study area are likely to be very effective in reducing the loading of P in Shuswap Lake.

Table 3. Phosphorus Best Management Practices – Source BMPs

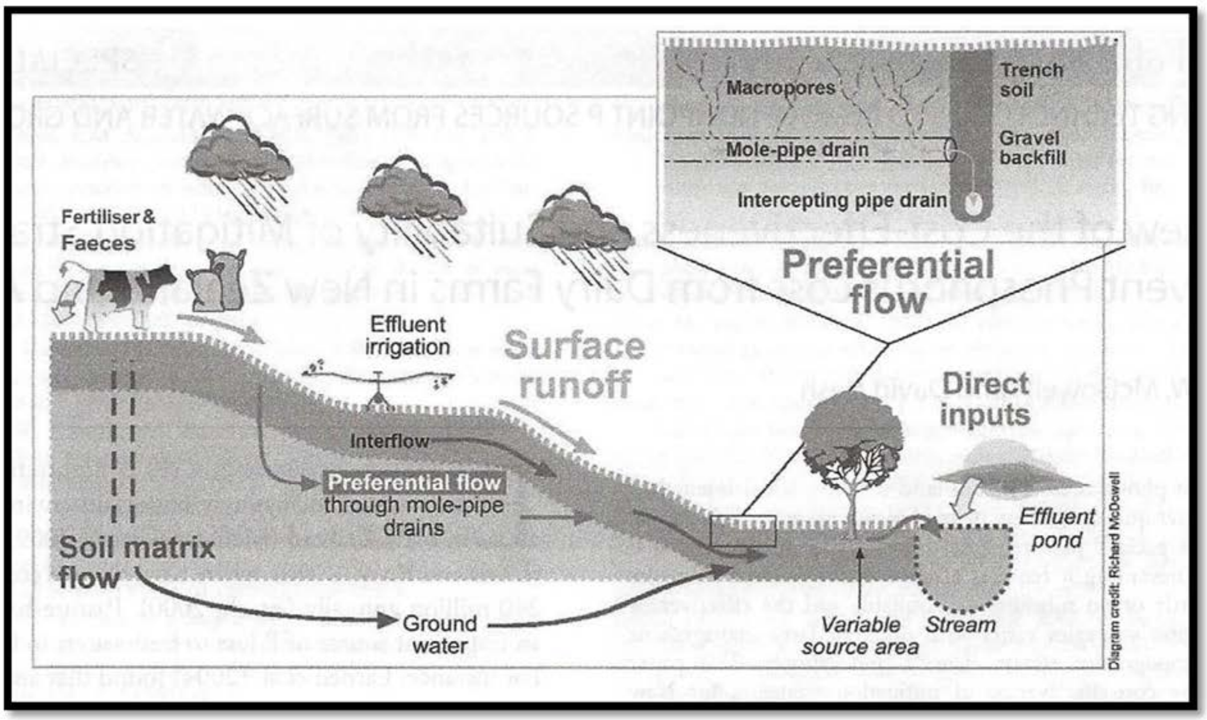
Phosphorus best management practices
Source BMPs-practices that minimize P loss at the origin
1. Balance P inputs with outputs at farm or watershed scale
2. Minimize P in livestock feed
3. Test soil and manure to maximize P management
4. Physically treat manure to separate solids from liquid
5. Chemically treat manure to reduce P solubility, that is, alum, flyash, and water treatment residuals
6. Biologically treat manure, that is, microbial enhancement
7. Calibrate fertilizer and manure spreaders
8. Apply proper application rates of P
9. Use proper method for P application, that is, broadcast, plowed in, injected, subsurface placement or banding
10. Carefully time P application to avoid imminent heavy rainfalls
11. Implement remedial management of excess P areas (spray fields and disposal sites)
12. Compost or pelletize manures and waste products to provide alternate use
13. Mine P from high-P soils with certain crops and grasses
14. Manage urban P use (lawns and gardens)

Adapted from: Sharpley et al 2006

5. P Transport Factors – Movement of Agricultural Source P to Surface Water

The current understanding of P transport from agricultural land to surface water identifies three main pathways by which P moves into surface water: soil erosion, surface runoff and subsurface flow. These are discussed individually in this section, and BMP's to reduce P transport are discussed in the section following. Figures 1 and 3 illustrate the main transport mechanisms of P into surface water.

Figure 3. Transport Processes that Move P from Grazing Land to Surface Water



From McDowell and Nash 2012

5.1 Soil erosion

The most visible transport route for agricultural source P into surface water is via soil erosion. Unchecked, this method of transport has the potential to exceed losses from the other two transport routes. There are several different types of soil erosion, but all result in the movement of soil into surface water. In eroded soil the main form of P entering surface water is particulate P - P which is bound to soil particles and organic matter.

Stream bank erosion: this occurs when natural or anthropogenic activities result in sloughing off of soil along stream banks into surface water. It can occur when riparian vegetation is removed and the integrity of the bank is lost so that erosion increases during periods of high water flow. It can also be the result of livestock trampling of stream banks. It also frequently occurs naturally along streams and rivers during periods of high flow or as the result of non-agricultural activities along the water course.

In the literature, stream bank erosion has been largely ignored as a source of P from agricultural land. Research efforts have focussed on gully or rill erosion from sloping land, and on P losses from surface runoff and subsurface flow. Bank erosion has largely been considered a natural process and the P contributed to surface water during bank erosion a natural background level (Kronvang et al 2012). However, recent research has determined that eroding stream banks can be a significant source of P. Some research suggests that P losses from stream bank erosion can be 2-4 times that lost with surface runoff (Nellesen et al 2011).

Recent research in part of the River Odense watershed in Denmark looked at P losses from stream bank erosion and the factors that contributed to soil and P loss from stream banks (Kronvang et al 2012). The study found that bank erosion contributed 21 to 62% of the annual export of total P from the study area, which consisted of a total of 36 stream reaches, each approximately 100 metres in length. It also determined that there was significantly less bank erosion where there were high buffers along the stream bank (natural trees and shrubs) versus low buffers (grass and herbs). Stream size and channelization did not impact P loss from erosion, nor did the width of buffer strip along the stream bank.

Gully or rill erosion: is soil erosion that occurs on sloping land, and is typically much worse on tilled land than on land in permanent vegetative cover. This type of erosion occurs during snowmelt or during heavy rainfall when the soil's capacity to absorb the runoff water is exceeded, and water running over the soil surface begins to cut into the soil. Gully or rill erosion normally occurs during short but very extreme weather events.

Gully or rill erosion preferentially removes fine soil particles which are more enriched with P than 'bulk soil' which contains a mix of fine and coarse particules. This results in the loading to surface water of more P than if the bulk soil were eroded. Eroded fine particles can have an enrichment ratio of 2:1 to 15:1 over the P concentration of bulk soil (Kleinman et al 2011). As erosion on sloping land worsens during an erosion event, this ratio decreases as larger soil particles are also removed.

5.2. Surface runoff

The second major route of P movement from agricultural land to surface water is through surface runoff. Surface runoff is the movement of water on sloping land over the soil surface and within the top 0.1 to 4 centimetres of soil and subsequently into surface water. Two distinct soil and climate conditions contribute to surface runoff: 'infiltration excess' runoff which occurs when the rainfall rate exceeds the soil's capacity to absorb or infiltrate the water resulting in water flow along the soil surface and within the top few centimetres of soil. 'Saturation excess' runoff occurs when rain falls on saturated soils or when subsurface water returns to the soil surface and subsequently runs off into surface water (Buda and Kleinman 2009).

Surface runoff by either of the two mechanisms described above results in the movement of dissolved P into surface water, not particulate P, because it moves over and through the soil but does not actually erode soil from a site (Buda and Kleinman 2009). The amount of P removed in surface runoff varies with the P loading or 'enrichment' of the soil. This is because soils have a finite capacity to bind P: when soils have *not* been enriched by frequent application of manure and fertilizer, most of the P in the soil will be tightly bound on soil particles and a constant small amount will be released into the soil solution over time. This 'available P' is rapidly used by plants on site such that the amount in solution at any time remains low so there is very little dissolved P present in the soil. In enriched soils, the amount of P in the soil can exceed the soil's capacity to bind it which results in the release of more P into the soil solution than from a soil with no excess P. This P, which is present in the dissolved form, can be picked up and carried by surface runoff. The amount of dissolved P removed in surface runoff will depend on the water flow over and through the soil and the amount of dissolved P in the soil. One study found up to 8 kg P per hectare was lost from a riparian buffer in surface runoff due to enrichment of soils in the buffer with P (Kleinman et al 2011).

There has been a considerable amount of research into runoff losses of P in the last 15 years as researchers have discovered that this can be a significant source of P loading to surface water in sloping landscapes or where sloping land is hydrologically linked to surface water by seasonal runoff channels or creeks. Research has found that the main form of P in surface runoff is DRP which is primarily inorganic P (orthophosphate). Research has also found that the soil available P content (which is used to determine fertilizer requirements for agricultural crops and is based on predicting the amount of P that a soil will release for crop uptake over a growing season), is a good predictor of the potential for a site to release dissolved P in surface runoff (Vadas et al 2005). Soils enriched with P due to frequent fertilization and manure application will contribute more P to surface runoff than non-enriched soils. Standard soil fertility tests for P can be used to predict a site's potential for releasing P during runoff events.

Most of the research into factors contributing to losses of P in runoff have been conducted in humid areas of the U.S. where the climate is quite different than in the interior of B.C. However, there has been some recent research in Alberta and Manitoba looking at runoff losses of P in climates where soils are frozen during the winter and there is low rainfall during the rest of the year, more similar to interior B.C. climatic conditions. Little et al (2007) studied surface runoff losses of P from several sites throughout Alberta for three years. They found that >90% of P loss in surface runoff from all sites occurred during snowmelt when the ground was frozen. In the study, rainfall runoff occurred very infrequently and irrigation runoff occurred at all sites during all three years of the study but represented less than 10% of the total runoff loss of P. The largest concentration of dissolved P in runoff occurred during snowmelt from a site that had been manured the previous fall without incorporation into the soil. A 17-year study in Manitoba found that most of the P lost during snowmelt occurred late in the runoff period, presumably because the ground was beginning to thaw by this time. This allowed the melting snow to interact with the soil causing runoff of soil DP and also some erosion losses of P (Liu et al 2013).

5.3 Subsurface flow

The third route by which agricultural source P can enter surface water is through subsurface flow (leaching). Research has found that, in general, if mineral soils are maintained at agronomic levels of P by limiting fertilizer and manure application of P to the amount expected to be taken up by the crop so that soil levels do not increase over time, the amount of P lost by leaching from soil is minor (Sims et al 1998). However, under certain circumstances losses of P by subsurface flow can be significant:

- In deep sandy soils;
- In soils with a high organic matter content;
- In soils that have enriched levels of P such that the soil's P binding capacity is exceeded;
- In fields with artificial drainage provided by tile drains, mole drains or ditches.

In any of these soil conditions, P can move into surface water through two pathways: by intercepting artificial drainage, and by movement to shallow groundwater which subsequently enters surface water.

Artificial drainage: low-lying fields that are prone to flooding or a seasonal high groundwater table, or poorly drained fields due to fine soil texture can be artificially drained to improve access and crop growth. The most basic form of artificial drainage is a series of drainage ditches strategically placed around a farm to carry off surface runoff water and to lower the water table. If this is insufficient to improve drainage, plastic pipe or mole drainage can be installed at intervals throughout fields to intercept water moving down through the soil and carry it to ditches from where it is discharged into surface water. Perforated plastic pipe is the most common drainage material; historically, wooden or clay pipes were used. Mole drains are simply cylindrical holes formed in heavy clay soil by pulling a cylindrical pipe through the soil at the desired depth. Because clay is solid, the mole drains retain their shape and allow water to move from the soil around them into the drain, from there to ditches and finally to surface water.

Shallow groundwater: P can also move into surface water via shallow groundwater in fields that do not have artificial drainage. In soils that are enriched with P, dissolved P from the soil can move down through the soil and into the subsoil with receding groundwater. Dissolved and particulate P can also move down into the soil through worm holes, root channels and cracks in clay soil. Once in the subsoil, the P can be picked up by groundwater when it is present relatively close to the soil surface. This occurs in low-lying areas prone to flooding or with a high groundwater table in spring. When the water table is at the surface, dissolved P can be picked up and moved as the groundwater recedes from the soil. As the groundwater recedes, it can carry dissolved P with it into nearby surface water because receding groundwater moves not just down in the soil but laterally in the direction of flow, typically towards the nearest surface water.

P losses in artificial drainage and shallow groundwater

Fields with artificial drainage are particularly susceptible to subsurface flow losses of P but P can also move into shallow groundwater and from there into surface water. P moves down through the soil by preferential flow (defined below), is intercepted by tile or mole drains, moves directly through the drain into the adjoining ditch and is discharged into surface water. Preferential flow is the downward movement through the soil of water from snowmelt, rainfall or irrigation containing dissolved P and particulate P via cracks in dry clay soils, worm holes, root channels and other conduits present in the soil (Sims et al 1998). Movement of P to drainage can occur under both perennial forage stands and annually cropped land.

Loss of P in artificial drainage can be particularly high if rainfall occurs on a field with any of the above conditions immediately following manure application; under these conditions, a significant amount of P from the applied manure can move down through the soil and into drains very rapidly (Dils and Heathwaite 1999).

The amount of P lost in artificial drainage increases when soils are saturated such as occurs on low lying lands that flood or have elevated groundwater in the spring. This is because the anaerobic conditions in the soil during saturation promote the release of P from the soil and this dissolved P moves down in the soil and into drainage ditches or shallow groundwater as the groundwater level subsides.

There has been relatively little research on subsurface losses of P from areas with drainage ditches alone (no drain tiles). A study done in the Chesapeake Bay watershed on land that had elevated soil levels of P due to heavy application of poultry manure for many years (up to 10 times the agronomic level) found that there was a significant amount of P lost in drainage water. In 8 ditches where water quality was tested, losses of DRP ranged from 0.6 to 16.6 kg per hectare over one year of monitoring while loss of total P ranged from 2.7 to 25.3 kg per hectare over the same period (Kleinman et al 2007). The highest losses were from ditches that drained areas where poultry manure was stockpiled and represented point source loss of P. The lower range of losses was observed in ditches that drained farm land where there was no farmyard or manure pile runoff contributing to ditch flow.

Ditches themselves can be significant sinks of P. High P sediment which builds up in ditches during periods of low flow can be released to surface water during periods of high flow, contributing a significant amount of P to surface water. In some studies, this has been shown to be a significant source of P loading to surface water (Kleinman et al 2007).

5.4 Summary

The current state-of-knowledge of P transport from agricultural land to surface water identifies three main pathways of movement into surface water: soil erosion, surface runoff and subsurface flow. These transport pathways are summarized in this section; for more detail and references, see Sections 5.1-5.3.

Soil erosion: the most visible transport route for agricultural source P into surface water is through soil erosion. Unchecked, this method of transport has the potential to exceed losses from the other two transport routes. Soil erosion results in the direct movement of soil into surface water. In eroded soil the main form of P entering surface water is particulate P - P which is bound to soil particles and organic matter.

Stream bank erosion occurs when natural or anthropogenic activities result in sloughing off of soil along stream banks into surface water. This type of erosion has been largely ignored as a source of P from agricultural land but recent research in Denmark suggests that it can be responsible for a significant amount of P loading to surface water. Buffers vegetated with trees and shrubs are more effective at reducing stream bank erosion than grassed buffers.

Gully or rill erosion occurs when water running over sloped land begins to erode into the soil which subsequently finds its way to surface water.

Surface runoff: is the movement of water on sloping land over the soil surface and through the top few centimetres of soil and into ditches or surface water. Surface runoff picks up dissolved P from the soil as it moves through the soil but does not cause soil erosion. The amount of dissolved P moved from the soil into surface water with surface runoff is related to two factors: the amount of P in the soil and the hydrologic connectivity of the site with surface water such that the runoff water will reach surface water. On sites where long term application of manure and fertilizer in excess of crop uptake has led to high soil P, relatively more P will move into runoff water than on soils with low P. Research has shown that in typical Canadian conditions of frozen ground and snow-covered soil, most runoff losses of P occur during snowmelt.

Subsurface flow: is the movement of P by leaching from the surface layer of soil into either artificial drainage or shallow groundwater, from where it is discharged into surface water. Dissolved and particulate P can move by this mechanism. It is only relatively recently that it has become clear that significant amounts of P can be discharged to surface water through subsurface flow. The loss of P by subsurface flow is exacerbated in soils with elevated P due to long term fertilization in excess of crop requirements; in these soils, high levels of P can be released into solution and this dissolved P can leach from the surface layer into tile drainage or shallow groundwater. Manure and soil can also move directly into artificial drainage through worm holes, root channels and cracks in the soil.

5.5 Relevance to local conditions

The water quality data collected during 2011-2013 by SLIPP suggest that the bulk of the P entering the Shuswap lake system from the study rivers does so during the peak flow period of May through July. There are three transport mechanisms that move agricultural-source P into surface water: soil erosion, surface runoff and subsurface flow. The likelihood of P loss to surface water in the study area by each mechanism is discussed below.

Soil erosion: Stream bank erosion is occurring along sections of the study rivers which could be contributing a significant amount of P to surface water, especially if the eroding soil contains elevated P from previous nutrient applications. Rill or gully erosion is expected to be minimal in the study area during the months when P level is highest in water because the land base is generally flat and precipitation is generally too low to cause this type of erosion.

Surface runoff: During the months when most of the P moves into the lake system from tributaries, the local snowmelt has finished and there is generally insufficient precipitation in the study area to cause surface runoff. Further, the land base along the river is generally flat and therefore not prone to runoff. It is therefore unlikely that surface runoff is a significant contributor of P to surface water during freshet. It is possible that surface runoff during snowmelt deposits sediment in tributaries or ditches which is subsequently flushed into the river during high water.

Subsurface flow: it is likely that subsurface flow is a significant pathway of P movement from agricultural land to surface water in the study area. Many of the soils located adjacent to the river are of similar texture to soils identified as being prone to leaching P; coarse-textured soils, organic soils, and artificially-drained soils have all been identified as being susceptible to P leaching. The land base along the river is generally farmed intensively with annual applications of manure and fertilizer. The recent Okanagan soil study found that 86% of the fields that were tested in the area had high or very high levels of P (section 13.3), well above the level of P required for crop growth suggesting that there may be excess P in soils which is susceptible to leaching. These factors suggest that there is a high likelihood of movement of agricultural-source P from the land near the river to surface water by subsurface flow.

6. Best Management Practices to Reduce Transport of P to Surface Water – Soil Conservation Measures

Best management practices (BMP's) are soil and water conservation practices, other management techniques and social actions designed for environmental protection (Sharpley et al 2006). Typically, a combination of BMP's is instituted on a farm or in a watershed to address environmental concerns. There are a number of traditional BMP's; this review discusses several of these.

To reduce P transport to surface water, watershed-scale nutrient management projects have to date focussed primarily on the traditional soil conservation BMP's: conservation tillage, conservation buffers and a few others. These BMP's are primarily effective in reducing soil erosion and the transfer of particulate P to surface water. They are less effective at reducing the transport of dissolved P in surface runoff and subsurface flow.

Figure 2 illustrates some BMPs effective at reducing P movement to surface water and Table 5 contains a list of P mitigation transport BMPs. Tables 4, 6, 8 and 9 contain data from different research projects on estimated reduction in P loss to surface water with various BMPs.

6.1 'Critical source areas' and the P risk indicator or 'P-index'

P transport BMP's are management practices that have been demonstrated to reduce the movement of agricultural source P to surface water. When P mitigation programs started, farmers were encouraged to implement BMP's throughout their property (Sharpley and Withers 1994). In the past two decades, with the vast amount of research done on movement of P from agricultural land into surface water, it has become clear that in most watersheds, the majority of the P lost from the watershed (up to 80%) is lost from a very small area of the watershed (20%) and may occur during a very short time. Therefore, some fields or areas on the landscape contribute significantly more P to surface water than other areas. Recent research has also determined that areas of the landscape that contribute P to surface water have a combination of a P source such as elevated P due to long term fertilization or recent manure application, and hydrological connectivity with surface water such that the P can move from the soil to surface water (Sharpley et al 2011). These areas are termed 'critical source areas' and current thinking is that BMP's should be preferentially targeted to those areas (Sharpley et al 2011). The prime mechanism to identify critical source areas is the P-index.

P-indices have been developed and adopted in most states of the U.S.,several Canadian provinces and the Nordic countries with the process beginning in the early 1990's. Indices have become increasingly sophisticated in their ability to identify critical source areas. They are typically applied at the field level and often as part of a Nutrient Management Planning process. They typically consider P source factors (soil P level; rate, method, timing and type of P applied to individual sites) and transport factors (slope, runoff and erosion potential, subsurface flow potential and proximity to streams). The weight given to each source and transport factor varies with climate, site, soil and type of agriculture. Indices continue to be adapted and changed to improve their predictive ability. Many jurisdictions now require that, for farms that are in a P-sensitive watershed (typically a watershed that drains into a sensitive fresh water system or shallow estuary), nutrient management planning includes completion of a P-index to help identify critical source areas.

P-indices are still very much in the development stage. One of the evolving areas is identifying factors that are important predictors of P loss by geographical area: factors important in one area of North America may not be good predictors in other areas. Many Canadian and U.S. jurisdictions are currently conducting research and testing different P-indices to determine the factors that are important for their climate, soil and cropping conditions. Research in Manitoba determined that most P indices developed in the U.S. are not suitable for the climatic conditions on the Canadian prairies. On the prairies, where the climate is characterized by winters where the soil is frozen and snow covered, and summers with little precipitation, most loss of P occurs during spring snowmelt when the ground is frozen. P-indices from the U.S. assume that the main process of P loss from agricultural land is from rainfall-induced erosion from sloping ground. They do not account for the predominately snowmelt-driven losses of soluble P, making them a poor predictor of P loss on the prairies (Salvano et al 2009). Further, because the prairie landscape is primarily flat there is very little erosion loss of P from sloping ground such as occurs in many other areas and therefore, traditional erosion control BMP's such as vegetative buffer strips do not significantly reduce P loss. This points to the need for localized P risk factor tools and research to determine the factors impacting P loss to surface water on a local basis.

6.2 Conservation tillage

Description

Conservation tillage is defined as any tillage system that leaves a minimum of 30% of residues from the previous crop on the soil surface (Tiessen et al 2010). Zero till, minimum tillage, incomplete tillage and reduced tillage are all different forms of conservation tillage. This is in contrast to conventional tillage systems where all crop residues are incorporated into the soil by disking or ploughing prior to seeding. In most P mitigation projects in the U.S. and Canada, conservation tillage has been encouraged and subsequently implemented widely on annually cropped land as a way to reduce erosion losses from bare soil during heavy rain and snowmelt.

Effectiveness

Conservation tillage is very effective at reducing soil erosion and loss of particulate P relative to conventionally-tilled fields, especially on sloping ground. In the Lake Erie watershed study from 1975 to 1995, more than 50% of the annually cropped land in two of the test watersheds was converted to conservation tillage. Between 1975 and 1995 there was an average reduction in total P in watershed rivers and creeks of 40%, and a reduction in dissolved P (SRP) of 55 to 88% (Richards and Baker 2002). Most of this reduction of P in water was attributed to conservation tillage; there was a reduction in the use of P fertilizer during the study period but this was thought to have contributed a small amount of the P reduction observed in surface water.

Tables 6 and 8 contain estimates of P loss reduction with various types of conservation tillage.

Issues

Several studies in the past 15 years have shown that conservation tillage can result in an increase in loss of dissolved P because, in the absence of tillage, all P applied in fertilizer and manure becomes concentrated in the top few centimetres of soil. Therefore, any surface runoff picks up a much higher concentration of P than it would under a conventional tillage system where the P is distributed throughout the plough layer during tillage. This has resulted in an overall increase in total P loss from some conservation tillage sites despite the reduction in loss of particulate P due to control of soil erosion and in some cases a reduction in total P loss but an increase in dissolved P (Sharpley et al 2011; Tiessen et al 2010; Joosse and Baker 2011).

Tiessen et al (2010) measured 12% greater losses of total P from conservation tillage sites than fields under conventional tillage in a paired watershed study in Manitoba due to an increased amount of dissolved P lost from sites. In the same Lake Erie watershed study mentioned above, water monitoring since 1995 when the initial study ended has shown that the concentration of dissolved P has increased in rivers and streams in the study watersheds even though particulate P and total P levels in water have continued to decline (Joosse and Baker 2011). This is partly attributed to concentration of P at the soil surface which has resulted in an increased concentration of P in surface runoff. So, while total P loss has continued to decline in the watersheds, dissolved P, which is more biologically active in water, has increased, leading researchers to question the effectiveness of conservation tillage in reducing P loading to surface water in the long term.

This finding has caused some re-thinking of conservation tillage as an effective BMP for reducing P movement to surface water, particularly under the climatic conditions of the Canadian prairies and the Great Lakes region (Tiessen et al 2010; Salvano et al 2009; Joosse and Baker 2011). Some current research is focusing on how to combine conservation and conventional tillage to get the soil erosion reduction benefits of conservation tillage without the side effect of increased dissolved P.

6.3. Conservation buffers

Description

Conservation buffers are broadly defined as vegetated buffers designed to reduce P loss into surface water. P is retained by conservation buffers through physical retention of soil and particulate P in the buffer, capture of dissolved P in the surface soil in the buffer during infiltration of runoff water and by P uptake by vegetation (Hoffman et al 2009).

Riparian buffers are vegetated strips located along stream and river banks that act both to capture eroding soil and particulate P and stabilize stream banks to reduce stream bank erosion. They can be treed or vegetated with low growing grasses and herbs.

Grassed waterways are areas of permanent vegetation established in runoff channels of sloping fields. They are designed to trap sediment and reduce soil erosion from in-field slopes.

Constructed wetlands are riparian buffers designed to absorb large amounts of runoff or erosive flow in areas where a riparian buffer is insufficient to mitigate flow. They may be natural areas or agricultural fields that are replanted as a riparian buffer.

Effectiveness

Generally, conservation buffers are very effective at retaining P. They are usually more effective at retaining particulate P than dissolved P. Thus, they are more effective when soil erosion is the primary cause of P loading to surface water because soil erosion results in the movement primarily of particulate P into surface water. They are less effective if P loading is primarily due to surface runoff which preferentially moves dissolved P into surface water. In a review of studies of the effectiveness of riparian buffers, it was found that they retained a range of 32 to 93% of total P. Retention of dissolved P was highly variable, ranging from -71% (net release of dissolved P) to 93% (Hoffman et al 2009). Tables 4, 6, 8 and 9 contain estimates of P loss reduction with various types of conservation buffers.

Width of buffer strip: the efficiency of retention of total P improves with width of buffer because there is more time for sediment to settle as runoff moves through the buffer. A buffer width of 16 m appeared to maximize the retention of total P at 95% suggesting that this is the optimum width under some conditions (Hoffman et al 2009). In general, wider buffers appear to be more effective than narrow buffers and constructed wetlands are more effective than riparian buffers due to their typically larger size.

Vegetation in buffer strip: no research was found that compared the effectiveness of the type of vegetation in conservation buffers and particularly the difference in effectiveness between treed and grassed buffers.

Other factors impacting effectiveness of buffer: it appears that soil type and slope also impact the effectiveness of conservation buffers. Buffers in areas with clay soils are less effective than those in sandy soils because of the slower infiltration rate of runoff water. Greater slope in the area feeding the buffer means there is a greater chance that flow into the buffer will be channelized rather than diffuse over the landscape. Buffers are not as effective at capturing sediment and dissolved P in channelized flow.

Issues

Although conservation buffers can be very efficient at capturing P and thus reducing the loading to surface water, they can become net sources of P loading to surface water under certain conditions. Buffers capture particulate P in eroding soil as well as dissolved P. P-containing soil settles on top of the soil in the buffer. Dissolved P moves into the soil with infiltrating water and is bound by the soil in the buffer. Over time, the buffer becomes enriched with P, similar to agricultural soils (Hoffman et al 2009). This P can be released as dissolved P when the buffer's P retention capacity is exceeded. Particulate P can also be released during periods of heavy runoff when the buffer's width is not sufficient to hold eroding soil. In this case, sediment that has settled on the buffer is re-released into surface water. Dissolved P can also be released from riparian buffers established on land that floods periodically because anaerobic conditions promote P release from soil particles and receding floodwaters can carry dissolved P out of the soil and into surface water.

Concerns with establishing riparian buffers and constructed wetlands in flood plains: when riparian buffers are located in flood plains which are flooded for a period of time each spring, these can release P to surface water. When soil is saturated, the anaerobic conditions created during saturation promote release of P from soil. This P is subsequently carried to surface water as the flood waters recede. This can result in the release of a substantial amount of dissolved P into surface water because riparian buffers are typically enriched in P.

This can also occur if riparian buffers or constructed wetlands are established on land that was formerly intensively farmed and is therefore enriched with P. Laboratory-scale research on soil that had been intensively farmed as a dairy operation found that release of a significant amount of dissolved P into surface water may occur if land that was formerly farmed intensively and therefore had an elevated level of soil P was converted to a constructed wetland to act as a riparian buffer (Pant and Reddy 2003).

A study of restored riparian wetlands in Denmark showed that two of four wetlands were net P sinks in that they captured more P than they released while two released more P than they retained (Hoffman et al 2009). This points to the need to choose sites for riparian buffers carefully by estimating potential P release before establishing constructed wetlands on former agricultural land (Hoffman et al 2009).

Table 4. Effectiveness of Buffer Strips in Retaining Total, Dissolved and Particulate P from Overland Flow.

Place/duration	Water source	Slope	Soil type	Width	Vegetation Type	Retention Efficiency		
		%		m		TP %	DRP %	PP %
Virginia, USA (2d)	Simulated feedlot	11	groseclose silt loam	9	mowed grass	80	30	n/a
Virginia, USA (2d)	Simulated feedlot	16	groseclose silt loam	9	mowed grass	57	-51	n/a
Vermont, USA (2yr)	Dairy milkhouse wastewater	2	very fine sandy loam	26	mowed grass	89	n/a	n/a
Iowa, USA (2h)	Bare cropland	5-8	silty clay loam	7 16	grass grass-woody	68 93	44 85	n/a
Georgia, USA (4 yr)	Cultivated field	2.5	loamy sand	8	grass	67	67	80
Ontario, Canada (1-1.5 h)	Sediment-water mixture	2.3 or 5	silt loam with sand and clay (38,54,8%)	2 5 10 15	grass grass grass grass	32 54 67 79	n/a	n/a
S Sweden	Field	n/a	n/a	8 16	grass grass	n/a	65 95	n/a
SE Norway (8 yr)	Field	12	silty loam	5, 10	grass	78-90	n/a	n/a
SW Finland (10 yr)	Spring cereal field	12-18	Typic Cryaquept (>50% clay)	10 10	mowed grass shrubs and grass	41 41	0 -71	n/a
NE Italy (4 yr)	Cropland	1.8	Fulvi-calcaric Cambisol (with a loamy texture)	6	Trees and shrubs with grass	81	83	

Adapted from Hoffmann et al 2009

6.4 Impoundments or sediment basins

Description

Impoundments are small basins or holding ponds that retain P by slowing the flow of runoff water and allowing sediment to settle from the water. As with constructed wetlands, they are more effective at retaining particulate P than dissolved P. They can be constructed anywhere in the landscape where runoff occurs following snowmelt or heavy rain. They are typically designed to hold water for a short time for the purpose of reducing flow rate and thus soil erosion, and to remove sediment and P from runoff water.

Effectiveness

Research on many different types of impoundments suggests that they can be very effective at retaining nutrients. Retention of total P of 20 to 50% has been recorded in the various research projects looking at small dams and sediment basins (Tiessen et al 2011). This research was primarily in warm, humid climates of the U.S. and Europe. However, retention of both particulate and dissolved P can vary significantly between sites and appears to be dependent on the residence time in the basin and possibly on the degree of P enrichment of the soil and sediments on the impoundment bottom.

Most of the research has been on impoundments in warmer climates than exist in most of Canada however Tiessen et al (2011) looked at the effectiveness of small dams in Manitoba to reduce sediment loading and P transport during spring snowmelt which is the primary runoff period. Flows into and out of two small impoundments were measured over 9 years. P loading to surface water was reduced by 9-12% with the use of these impoundments to temporarily hold snowmelt runoff water which suggests they are not as effective as impoundments in warmer climates.

Tables 6 and 9 contain estimates of P retention in impoundments.

Issues

As with riparian buffers, impoundments can be both a sink and a source of P. Sediment enriched with P that has settled in the basin over time can be released during a very large flow event, releasing particulate P to surface water. Dissolved P can be released from sediment which is saturated with P. Research from Finland suggests that if impoundments are built in P-rich agricultural soil, the soil should be removed from the bottom of the impoundment before use or the impoundment may release more P than it retains (Tiessen et al 2011).

6.5 Stream bank stabilization and livestock exclusion fencing

Description

Stream bank stabilization and fencing can reduce erosion of soil and reduce direct deposition of manure into water at the same time. Stream banks are stabilized by establishing riparian buffers along bare areas of river and stream banks, and planting with vegetation. Roots provide stability to the stream bank allowing it to more effectively withstand the erosive power of water. Livestock access to water along streams and rivers can cause extensive trampling of riparian vegetation which can lead to erosion. Livestock exclusion fencing can allow the natural riparian vegetation to regrow which can help to reduce stream bank erosion as well as eliminate direct deposition of manure in surface water.

Effectiveness

Kronvang et al (2012), in a study of the factors impacting stream bank erosion, found that erosion was significantly lower along areas with riparian buffers with high vegetation (trees and shrubs) than along buffers with low vegetation (grasses and herbs) suggesting that the root systems of trees and shrubs are more effective than grasses and herbs in protecting stream banks from erosion. This study also found that stream size, degree of stream channelization and width of riparian buffer strip did not influence bank erosion and P loss.

In a paired watershed study in Vermont, stream bank restoration and livestock exclusion fencing in combination were found to reduce total loading of P to surface water by 30 to 50% (Sharpley et al 2006).

A study conducted in the Salmon River watershed (Interior of British Columbia) compared water quality below a section of river where cattle were fenced out of the river and one where cattle were allowed access to the river and found that while exclusion fencing allowed riparian vegetation to recover quickly, there was no measurable reduction in P concentration in water downstream of the cattle-excluded area (Agriculture and Agri-Food Canada 2012). A similar study conducted in Iowa along a stream where cattle were grazed in pastures with access to water or not found a similar result, that during the 3-year period of the study, there were no significant differences in P loss to surface water from pastures where cattle were excluded or where there was no exclusion fencing (Nellesen et al 2011).

Tables 6 and 9 contain estimates of P loss reduction with stream bank fencing and grazing restrictions.

Issues

Livestock exclusion fencing as a BMP to reduce P loading to surface water appears to have variable effectiveness. Of the three studies reviewed, two found no change in P loading or concentration from stream bank fencing while one study did determine that P loading was reduced. This implies that there are other factors that influence P loading when cattle have access to streams and that before this BMP is implemented on a site, it is advisable to assess whether cattle access is contributing significantly to P loading of surface water.

6.6 Cover crops to protect bare soil from erosion

Cover crops are fast-growing species planted in late summer or fall after harvest of annual crops (such as silage corn) on fields that would otherwise be un-vegetated until the site is seeded the following spring. They are typically fast-growing cereals such as fall rye or barley. They are planted to provide some vegetative cover on fields over winter and also to scavenge excess nitrate-nitrogen remaining in the soil after the growing season. They are effective at protecting the soil surface from erosion during rainfall events or snowmelt. They improve infiltration of rain water relative to rain on bare soil and thus reduce runoff and soil erosion. They do not appear to reduce the amount of dissolved P in runoff as this is largely determined by the concentration of P in soil (Sharpley et al 2006). For this reason, cover crops appear to be primarily effective in reducing erosion losses of soil and therefore losses of particulate P following heavy rain or during snowmelt. Cover crops are estimated to reduce P loss due to soil erosion by 7 to 63% (Table 6).

6.7 Field management practices to reduce erosion and runoff

Strip cropping, contour tillage, terracing and other similar field management practices are designed to reduce soil erosion and runoff from sloping land. Research suggests that in both conventional and conservation tillage systems on annually cropped land, implementation of one or more of these BMP's on sloping land will reduce loss of soluble and total P by 10 to 30% (Devlin et al 2003). Because these methods are primarily effective in reducing soil erosion, they are more effective in reducing loss of particulate P than dissolved P. Other estimates of P loss reduction with these conservation methods are found in tables 6 and 8.

Comparison of fall versus spring ploughing in Norway found that on sites with high and medium erosion potential due to slope and soil type, 66 to 76% less total P was lost from soil erosion when fields were ploughed in spring instead of the previous fall (Kronvang et al 2005). This is significant in Norway because most soil erosion and runoff occurs in the winter months. However, this may not be true under Canada's colder winter climatic conditions where soils are frozen and snow-covered during winter. No similar research was found comparing fall and spring ploughing in an area with a climate similar to Canada's.

6.8 Summary

Best management practices and their effectiveness in mitigating movement of P to surface water are summarized here. For more detail and references, see sections 6.1-6.7.

Best management practices (BMP's) are soil and water conservation practices, other management techniques and social actions designed for environmental protection. Typically, a combination of BMP's is instituted on a farm or in a watershed to address environmental problems.

P mitigation programs have focussed primarily on traditional best management practices such as conservation tillage, conservation buffers and a few others to reduce P movement to surface water. These practices are effective at reducing soil erosion and thus the movement of particulate P into surface water but are less effective at reducing the transport of dissolved P in surface runoff and subsurface flow.

Critical source areas and P risk assessment tools: Research has found that most of the P loss from agricultural land within a watershed occurs from a small area and often within a short time frame such as during snowmelt. P loss also occurs only when there is combination of a source of P such as elevated soil P and site hydrologic connectivity to surface water; P risk assessment tools are being developed to identify such sites so that BMP's can be targeted to these 'critical source areas'.

Conservation tillage, any tillage system that leaves a minimum of 30% of crop residues on the soil surface, has been found to be very effective in reducing soil erosion and loss of particulate P to surface water from sloping land. However, it can result over time in an increase in the loss of dissolved P from areas in conservation tillage. This is because all P applied in fertilizer and manure is concentrated in the top few centimetres of soil which makes it vulnerable to movement in surface runoff. Modified conservation tillage where fields are deeply tilled every few years may solve this problem; current research is working on this issue.

Conservation buffers are vegetated buffers designed to capture P before it can move to surface water. They can be located in riparian areas or in gullies of sloping fields. They can be stream-side buffers or constructed wetlands. They retain P by slowing down the movement of runoff water so that sediment settles out and dissolved P moves into the soil. They can be very effective at retaining P but are generally more effective at retaining particulate P than dissolved P. Conservation buffers become enriched with P over time and can be net sources of P to surface water if this P is released as sediment or as dissolved P.

Impoundments or settling ponds are small basins that can be located anywhere in the landscape to retain runoff from snowmelt or heavy rain and enable the settling of sediment from that water. They can be very effective at reducing the level of particulate P in runoff water but not as effective at retaining dissolved P. As with conservation buffers, they can become enriched with P in sediment and by movement of dissolved P into the surface material on the basin floor. Under heavy flow conditions, they can actually release more P than they retain.

Stream bank stabilization and livestock exclusion fencing can reduce stream bank erosion and reduce manure deposition into surface water. Research has reported variable effectiveness with livestock exclusion fencing in reducing P loading to surface water. High vegetation (trees and shrubs) has been found to be more effective than low vegetation (grasses and herbs) in stabilizing stream banks.

Cover crops are fast-growing species planted in late summer or fall after harvest of annual crops (such as silage corn) on fields that would otherwise be left un-vegetated until the next crop is planted the following spring. They are effective at reducing erosion from rain on bare fields during winter months and during spring snowmelt. They are more effective at reducing loss of particulate P than dissolved P.

Other field management practices such as strip cropping, terracing and contour tillage are effective at reducing erosion from sloping land. Because they primarily reduce erosion, they are more effective at reducing particulate P than dissolved P.

6.9 Relevance to local conditions

In this section of the literature review, the most common best management practices for reducing P movement to surface water were discussed with focus on their effectiveness at reducing movement of agricultural-source P into surface water. The following section presents a 'best-guess' as to which of the BMP's are most relevant to the study area because at this time the P transport mechanisms are not known.

Conservation tillage: is of most use on sloping land to prevent gully and rill soil erosion. This type of soil erosion is not a serious problem in the study area due to primarily flat land and low precipitation.

Conservation buffers: are typically installed next to surface water and are used to slow down the flow of surface runoff resulting from snowmelt or heavy precipitation, allowing sediment and dissolved nutrients to settle in the buffer. In the study area, surface runoff generally occurs only during snowmelt. Runoff can be substantial during the brief period of a few days per year when snowmelt occurs and it is unlikely that a buffer strip will be sufficient to slow down the runoff sufficiently to allow dissolved P to move into the soil and sediment to settle out, particularly if the ground is frozen when snowmelt occurs.

Impoundments and sediment basins: these are effectively very large buffers that slow down runoff water allowing sediment to settle out and filtering out dissolved P. As surface runoff during snowmelt has been identified as being an important transport mechanism for P on the prairies, it is likely also important here. Impoundments have been shown to be effective at reducing total P in runoff water on the prairies. Therefore, it is anticipated that impoundments will be effective at reducing loss of P to surface water here also.

Stream bank stabilization and livestock fencing: stream bank erosion has been identified as one potential pathway for movement of agricultural-source P into surface water in the study area. Therefore, stream bank stabilization projects on eroding reaches should be very effective at reducing P loss to surface water. Livestock fencing, where livestock are either contributing to stream bank erosion or are depositing significant amounts of manure directly into surface water, should also be effective at reducing P loading to surface water.

Cover crops and other field management practices are primarily effective at reducing soil loss due to erosion caused by heavy precipitation on sloping land. Because the land base along the study rivers is primarily flat and local precipitation is low, there is very little soil erosion. It is not expected that these best management practices will be very effective at reducing P loading of surface water in the study area.

Table 5. Best Management Practices to Reduce Transport of Phosphorus

Transport BMPs-practices that minimize the transport of P
15. Minimize erosion, runoff, and leaching
16. Use cover crops to protect soil surface from erosion
17. Terrace to minimize runoff and erosion
18. Practice strip cropping to minimize runoff and erosion
19. Practice contour farming to minimize runoff and erosion
20. Manage irrigation to minimize runoff and erosion
21. Practice furrow management to minimize runoff and erosion
22. Install filter strips and other conservation buffers to trap eroded P and disperse runoff
23. Manage riparian zones to trap eroded P and disperse runoff
24. Install grass waterways to trap eroded P and disperse runoff
25. Manage wetlands to trap eroded P and disperse runoff
26. Manage drainage ditch to minimize erosion
27. Stabilize stream bank to minimize erosion
28. Fence stream bank to keep livestock out of water course
29. Protect wellhead to minimize bypass flow to ground water
30. Install and maintain impoundments to trap sediment and P
Source and transport BMPs-systems approach that minimize P loss
31. Retain crop residues to minimize erosion and runoff
32. Consider reduced tillage systems to minimize erosion and runoff
33. Manage grazing (pasture and range) to minimize erosion and runoff
34. Restrict animals from certain sites
35. Install and maintain manure handling systems (houses and lagoons)
36. Manage barnyard storm water
37. Install and maintain milk house waste filtering systems
38. Practice comprehensive nutrient management planning (CNMP)
39. Install and maintain tailwater return flow ponds
Water body treatment BMPs-practices designed to correct problems associated with excess P in water
40. Remove sediment from water bodies
41. Inactivate sedimentary P (alum and straw)
42. Stimulate aerobic conditions
43. Enhance vegetative growth in littoral zones to decrease water-column mixing
44. Practice vegetative mining of sedimentary P
45. Harvest aquatic vegetation

Adapted from: Sharpley et al 2006

Table 6. Potential Total P Reduction Efficiencies (percent change) in Surface Runoff with Various BMP's

Conservation Practice	Total P reduction %
Source measures	
P rate balanced to crop use vs. above recommended rate	15-47
Subsurface applied P vs. surface broadcast	8-92
Adoption of nutrient management plan	0-45
Transport measures	
No-till vs. conventional tillage	35-70
Cover crops	7-63
Diverse cropping systems and rotations within row cropping	25-88
Contour ploughing and terracing	30-75
Conversion to perennial crops	75-95
Livestock exclusion from streams vs. constant intensive grazing	32-76
Managed grazing vs. constant intensive grazing	0-78
In-field vegetative buffers	4-67
Sedimentation basins	65
Riparian buffers	40-93
Wetlands	0-79

Adapted from Sharpley et al 2009, information summarized from 4 separate sources.

7. Case Studies of Watershed-scale P-based Nutrient Management Programs

7.1 Collaborative efforts to clean up the Chesapeake Bay

Over the past several decades, concerns have grown about the water quality in Chesapeake Bay, a shallow estuary on the eastern seaboard of the U.S. Frequent algal blooms, widespread occurrences of low oxygen conditions in the bay, and reduced overall health of biological communities in the bay have been some of the impacts observed. Excess sediment and nutrients from development and agriculture have been identified as the cause (Lyerly et al 2014).

As a result of the ongoing impaired health of the bay, the USEPA in 2004 mandated a 'pollution diet' for the bay – a Total Maximum Daily Load of nitrogen, phosphorus and sediment. This mandated the maximum loading of each parameter to the bay, which has been divided up among Maryland, Virginia and Pennsylvania whose waters flow into the bay. The result is that water quality managers must work toward achieving the required load reductions by determining where the nutrient load is coming from and then encouraging the implementation of BMP's to achieve the load reduction. Agriculture has been identified as a significant contributor of P loading to the bay; an estimated 45% of P entering the bay is from agriculture; of this, 60% is estimated to come from manure and 40% from inorganic fertilizer (Maguire et al 2009).

The Chesapeake Bay Commission, a tri-state legislative commission formed in 1980 and tasked with improving water quality in Chesapeake Bay, outlined as part of its program six strategies to reduce nutrient inputs to Chesapeake Bay. Four of these were aimed at reducing agricultural-source P input to the bay and were considered cost-effective:

1. Livestock and poultry ration adjustments to reduce dietary P and thus manure P.
2. Nutrient management plans prescribing rate and timing of manure and fertilizer applications to eliminate excess applications.
3. Enhanced nutrient management – compensation for farmers who apply 15% less nutrients than recommended for crop yield.
4. Conservation tillage to reduce soil erosion and loss of particulate P.

A summary of over 40 case studies where agricultural BMP's have been implemented in the watershed at various times since 1985 and effectiveness monitored for varying time periods was published in 2014. Some of the results:

- The upper Pocomoke River, a small watershed in Maryland that feeds into Chesapeake Bay, is a large poultry producing area. From 1998 to 2003, all poultry manure was hauled out of the watershed. Cover crops were planted on all available crop land to reduce soil erosion. Water quality monitoring from 1994 to 2001 showed that total nitrogen in the river declined but total phosphorus remained the same (Lyerly et al 2014).
- In Brush Run creek, a small watershed in Pennsylvania also ultimately draining to Chesapeake Bay, fertilizer and manure applications were reduced significantly resulting in a 57% reduction in P use in the watershed. Total P in water decreased at two of three water quality monitoring stations suggesting that reducing P loading in this watershed resulted in lowering of P in the surface water (Lyerly et al 2014).

- In part of the Corsica River watershed in Maryland, a suite of BMP's were implemented in 2004 to reduce loading of agricultural source P. Cover crops, forested and grassed buffers, manure and fertilizer management, storm water wetland ponds, bio-retention structures and wetland restorations were installed throughout the watershed. No response in water quality was observed until 2007, and from 2007 to 2011 there was a slight reduction in P in two of three monitored streams (Anon 2012).
- Livestock exclusion fencing was installed at many sites around the watershed and resulted in a reduction of nutrients and sediment in streams.

Current status of nutrient management program

As a result of the hundreds of projects initiated around the Bay since 1985, it is estimated that P loads to the Bay decreased 28%, from 12,318 to 8863 tonnes per year between 1985 and 2002. As noted above, there has been improved water quality in terms of N and P in some tributary streams in some watersheds. However, despite the massive reduction in P loading, P-based BMP's have not yet produced measurable ecological improvements in Chesaspeake Bay (Jarvie et al 2013). Reasons given for the lack of improvement range from difficulty getting farmers to implement P-based BMP's, poor understanding of the long-term effects of nutrient reductions on impacted water bodies, legacy sources of P in soil and sediment, and lag time in movement of high-nutrient groundwater to tidal areas.

7.2 Lake Erie Watershed study

Water quality impacts in Lake Erie due to agricultural non-point source pollution were noted and studied first in 1972. Agricultural-source P was identified as the pollutant of main concern in the lake. The first conservation and nutrient management projects were implemented in 1972. During the 1980's several demonstration projects were implemented, education programs were initiated for area farmers and monetary incentives were offered to encourage adoption of BMP's (Forster and Rausch 2002). In 1985, the Great Lakes Water Quality Agreement developed a P reduction strategy for the Lake Erie basin which required a total reduction in P loading to the lake of 1700 tonnes divided amongst the states and provinces bordering the lake. Between 1987 and 1997 numerous programs were developed to address non-point source pollution from agriculture, all voluntary. The programs targeted different geographic areas and involved voluntary adoption of soil and water conservation practices, education, technical assistance, demonstration projects, research and financial incentives.

A large-scale study of two participating watersheds in the Lake Erie basin, the Maumee and the Sandusky, was made during the conservation programs. In these two watersheds, agriculture was predominately annual cropping of corn, soybeans and wheat. The study found that conservation tillage was the most commonly adopted BMP; by the end of the program almost 50% of annually-cropped land had been converted from conventional to conservation tillage versus less than 10% in 1985 when the program started (Forster 2002). Other BMP's adopted in the watersheds included: sediment retention, erosion and water control structures, cover crops, grassed waterways, vegetated buffers and nutrient management planning.

Water quality monitoring during the period 1975 to 1995 showed an average reduction of 40% in total P in four monitored watercourses. Dissolved P in the same watercourses declined between 55 and 90% over the same monitoring period (Richards and Baker 2002). The improvement in water quality was attributed to reduced soil erosion due to the wide-spread adoption of conservation tillage, reduced use of P fertilizer and reduced application of manures. In general, the program was deemed very successful at reducing P loading to surface water and was felt to have achieved good progress.

Follow-up water quality monitoring in the two watersheds revealed a disturbing trend. Even though total P and particulate P continued to decline in the years after 1995, dissolved P began to increase in surface water and has increased steadily since (Joosse and Baker 2011). Dissolved P is more biologically active and bioavailable than particulate P so has a more detrimental impact on water quality in Lake Erie. This has led to an overall further impairment of water quality in Lake Erie despite initial positive results from the nutrient management program.

The rise in loss of dissolved P to surface water in the Lake Erie basin is believed to be the result of several factors. The most important is the movement to conservation tillage which has resulted in the concentration of P added in fertilizer and manure at the soil surface where it is more prone to movement in surface runoff (Joosse and Baker 2011). It is also the result of legacy P, elevated soil P due to long term applications of fertilizer and manure above crop requirements, as well as increased application of manure and fertilizer without incorporation in fall and winter (rather than in spring) (Sharpley 2013). There has also been an increase in tile-drainage throughout the Lake Erie basin which has increased the movement of P through tile drains into surface water.

7.3 South Tobacco Creek, Manitoba paired watershed study

Lake Winnipeg in Manitoba has been experiencing deteriorating water quality, partly attributed to agricultural-source nutrients. A study was initiated in 2005 to look at the ability of multiple BMP's to improve water quality in tributaries of the lake. The study was undertaken in two small sub-watersheds of the South Tobacco Creek watershed in southern Manitoba which drain into Lake Winnipeg; five different BMP's were implemented on one sub-watershed and the second was not treated. Previous watershed-scale studies in nutrient management have been done in warmer, wetter climates where the primary source of P in surface water is particulate P, transported to water by rainfall-induced soil erosion. In colder climates such as Manitoba, P loss to surface water primarily occurs during spring snowmelt and is primarily in the dissolved P form (Li et al 2011).

On the treatment sub-watershed, which was one large farm, the following BMP's were initiated:

- A holding pond downstream of a beef cattle overwintering feedlot
- Riparian zone and grassed waterway management
- Grazing restriction
- Forage conversion
- Nutrient management

All treatments were installed in 2005. No BMP's were initiated in the control sub-watershed. Water quality was monitored in both sub-watersheds from 2005 to 2010.

The results of the study were somewhat inconclusive (Li et al 2011). There were reductions in both loading of P and P concentration in surface water from the treated area after installation of the BMP's. However, there were also reductions in P loading from the control area. Overall, the reductions from the treated area were larger than from the control area. There was also a significant reduction in total P and dissolved P from feedlot runoff due to the holding pond which captured snowmelt and rainfall runoff. It was not possible to determine which of the installed BMP's were responsible for the reductions in P loading to surface water. Research is continuing at the South Tobacco Creek watershed to try to determine which of the BMP's contributed most to water quality improvements so that recommendations can be made to area farmers.

8. Ongoing Issues and Challenges

8.1 Lack of improvement in water quality despite intensive mitigation programs

As has been alluded to throughout this review, many of the mitigation projects undertaken in the U.S. over the past twenty to thirty years have yielded little or no improvement in the quality of the water they were designed to improve. This has occurred despite significant reductions in the total loading of P in many watersheds and resultant water quality improvements early on in some projects which subsequently were reversed. This includes: the Chesapeake Bay watershed, the Lake Erie basin, (both discussed in this review) as well as the Mississippi River basin and Florida's inland and coastal waters (Jarvie et al 2013 and Sharpley et al 2013).

The lack of improvement in water quality has been attributed to several factors (from Jarvie et al 2013):

- Storage and gradual release of 'legacy P' from soil, riparian zones and wetlands, and stream and lake sediments which mask improvements made in P loading and P transport to surface water.
- Inadequate intensity and targeting of source and transport BMP's
- Inadequate monitoring before and after conservation measures are implemented
- Complex and lagged ecological responses arising from multiple (physical, chemical and biological) stressors and feedbacks that make it difficult to differentiate the impacts of nutrient reductions
- A range of 'complicating factors' with increasing scale from the field to the watershed, including the confounding effects of multiple and complex P sources
- Biogeochemical buffering and hydrological damping

One of the most troubling findings from on-going water quality monitoring of P-mitigation projects is that in some instances, even though there has been dramatic reduction in P loading in watersheds resulting in reduction in surface water P, ecological improvements have not occurred. In some instances, algal growth has increased and water quality decreased. There is some concern that some water bodies, once the normal functioning is upset by nutrient overload, may not return to their original condition even when nutrient levels have been lowered to 'normal levels'.

Funding agencies and farmers are increasingly dissatisfied with the lack of response to decades of P mitigation measures. In the U.S. $24 billion was invested in (mainly P based) conservation measures between 2005 and 2010 on agricultural land with no measurable improvement in water quality in the large water bodies that the programs were designed to improve. Farmers are increasingly demanding scientific proof that the BMP's that they are being encouraged to implement and that sometimes put them at a competitive disadvantage are actually going to deliver the water quality improvements that they promise.

Current thinking about P mitigation programs is that there may be a significant lag time between the time the mitigation projects are implemented and when downstream improvements in water quality are observed (Meals et al 2010). The lag time is due to legacy sources of P throughout the system, from P enriched soils to P enriched ditch, stream and lakebed sediments that gradually release P over time and thus mask any immediate improvements in water quality from BMP's implemented on the land base. The lag time may be a few years or several decades depending on the source of legacy P. Examples of lag times reported were summarized by Meals et al (2010) and include a >50 year lag time for river sediments to stop contributing P to surface water in a river basin where land clearing and agriculture has contributed sediment to streams and rivers. For reduction of legacy P in soils, lag times are reported to range from 8 to 28 years. On the other hand, one study found that the lag time to observed water quality improvement following livestock exclusion was less than 1 year. The challenge for watershed managers will be to convince funding agencies and farmers that P mitigation programs are worthwhile even though results may not be measurable for many years.

8.2 Managing soil and sediment legacy P

BMP's such as conservation buffers and conservation tillage are fairly effective at reducing erosion losses of soil and reducing loss of particulate P to surface water. However, these traditional BMP's are not very effective at reducing the losses of dissolved P that occur with surface runoff (as discussed earlier in the review). Loss of dissolved P is particularly problematic in soils that have been enriched with P due to long-term application of manure and fertilizer. This 'legacy P' can be released gradually over time from soils. Sediments in drainage ditches, constructed wetlands, streams and lakes in intensively farmed areas are also frequently enriched with P which can be released over time. Legacy P can mask water quality improvements from P mitigation programs and can take many years to decline. Legacy P is believed to be the reason that, despite significant reductions in loading of P to agricultural land in the various P mitigation projects in past decades, little improvement has been seen in water quality. Legacy P continues to be released from soil and sediment, negating any potential improvement from implementation of BMP's (Sharpley et al 2013).

If the soils and sediment in a watershed contain a significant amount of 'legacy P' and this P is contributing to enrichment of surface water even after conservation measures have been widely instituted on susceptible land, the measures to control loss of this P are much more challenging and at this time are not in wide-spread use. These include:

- Transport manure out of the watershed
- Compost or pelletize manure to provide alternate uses
- Biologically treat manure to reduce P availability
- Reduce use of fertilizer P and other sources of P

These four BMP's simply stop the application of more P on the land base but do nothing to stop the release of P from already-enriched soils. The following BMP's are the subject of current research and have been shown to be effective but are currently either not commercially available or are not considered economically viable.

- Mine P from high P soil using high-P demand crops
- Add P-fixing products to the soil (alum, iron, water treatment residuals, gypsum) to bind P and thus reduce runoff and subsurface losses. Research in New Zealand (McDowell and Nash 2012) and elsewhere has looked at applying alum (aluminum) as a top dressing on pasture land to reduce runoff losses of dissolved P. In the New Zealand study, reduction in runoff losses of P following application of P-fixing products to the soil has been found to range from 0 to 50%.

The issue of legacy P points to the necessity to clearly understand which mechanism and which areas of the landscape are contributing P to surface water before implementing mitigation programs. If the wrong P transport mechanism or site is targeted, the BMP's implemented at potential inconvenience to the farmer will have no impact on surface water quality.

8.3 Removing P from artificial drainage waters using P-sorbing materials

Twenty years ago, the understanding of P loss to surface water from agricultural land was that leaching losses of P were a minor source of P loss. However, extensive research in the past twenty years has shown that subsurface losses can be significant, especially from soils that are enriched in P, in drained fields, under conditions of flooded soil and under several other soil conditions. Traditional BMP's have no impact on reducing the loss of P in drainage water and in shallow groundwater. Recently, some research has been done on capturing the P from ditch drainage and has shown that it can be done very effectively.

Research has been done on several different 'P-sorbing materials' (PSM's) including alum, gypsum, and a range of industrial by-products including acid mine drainage residuals, drinking water treatment residuals and iron-coated sand. Dissolved P becomes strongly sorbed or bound by constituents in the PSM, typically calcium, aluminum or iron, as the ditch drainage water passes through the PSM in a collection tank and the P is thus removed from the ditch water (Penn et al 2007).

Several different PSM's have been used in laboratory and field-scale trials. Groenenberg et al (2013) in a field-scale trial in the Netherlands tested the P-sorbing capacity of iron-coated sand which is a by-product of the production of drinking water from anaerobic groundwater, produced when iron is removed from the groundwater in a sand filter during water treatment. This residual has a very high P-binding capacity. The iron-coated sand was used as an envelope around the tile drain so that drainage water had to pass through the sand filter before discharge. The dissolved P content of the water entering and leaving the iron-coated sand envelope was measured for 15 months. The envelope removed on average 94% of the dissolved P in the tile drainage and was able to reduce the dissolved P concentration in tile drainage from an average of 1.7 mg P per litre to 0.14 mg per litre which is within the Dutch water quality criteria of 0.15 mg per litre P.

This management method appears to have promise as a way to remove dissolved P from drainage water but questions remain about the life-span of the iron-coated sand i.e. how long until its capacity to bind P is saturated, and its performance under submerged conditions. A further concern with this type of system for removing P from drainage waters is that the experimental systems have tended to get overwhelmed when there is a large storm event such that the amount of drainage water increases dramatically. When this happens, a significant amount of the flow bypasses the P-sorbing system altogether (Buda et al 2012). This is problematic because a significant amount of the P lost in drainage water can occur during storm events. More research is required to develop a system that can process drainage from storm events as well as from low-flow conditions. For this type of P-removal system to work under Canadian conditions, it will have to be able to handle storm volumes such as occur during snowmelt when a significant amount of the annual runoff and ditch flow occurs during a very short time period.

Flue gas desulfurization gypsum (FGD gypsum), a by-product of scrubbing sulfur from combustion gases at coal-fired power plants, has been used as a soil amendment to bind P in high P soils and also as a filter to remove P from ditch drainage waters (Watts and Dick 2014). FGD gypsum contains a significant amount of calcium which can efficiently bind P. A filter containing FGD gypsum was placed in a field ditch which drained a 17-ha area of high P soils. Efficiency of removal of dissolved P was monitored for 3 years. It was found that, as with the iron-coated sand envelope, this system was efficient at removal of P during normal flow conditions but was not efficient at removing P during storm flow conditions because much of the storm flow by-passed the filter (Buda et al 2012). Research is continuing towards developing a system that can handle storm flow volumes.

These mitigation methods are currently strictly experimental. They have not yet been adopted in practice. There are potential problems with the use of residuals to treat drainage water including presence of heavy metals in residuals and potential release into water, and disposal of the P-saturated materials once they are removed from the ditch. These mitigative measures are also relatively expensive (Table 9).

8.4 Struvite recovery from animal manure

Introduction

The potential for removing phosphorus from manure and from surface water was investigated as part of the review of literature. Removal of phosphorus from municipal wastewater and from manure in the form of the mineral 'struvite' is in the late development stage and is approaching economic feasibility in Europe. Removal of phosphorus directly from high phosphorus surface water is being done experimentally by binding it to high phosphorus binding residuals but is also not yet economically viable (see Section 8.3).

Research is ongoing on the feasibility of recovering a naturally-occurring mineral called struvite from animal manure in order to reduce phosphorus levels in manure. Struvite (magnesium ammonium phosphate hexahydrate) is a naturally occurring mineral that forms during breakdown of organic material, and is found in manures and municipal biosolids. It requires a reaction between ortho-phosphate, ammonium and magnesium in an approximate ratio of 1:1:1 for formation (Fattah 2012), as well as a pH between 7 and 11 (Burns 2002). A pH in this range ensures the struvite has a decreased solubility, thus enhancing precipitation. If successfully extracted from manure, struvite can be effectively used as a slow-release fertilizer, and applied to meet crop phosphorus requirements. Removal of struvite produces manure that contains a more suitable ratio of nitrogen to phosphorus for crop utilization. Many studies have begun to explore whether struvite can economically be recovered from manure and municipal sludge, and used as an alternative source of phosphorus.

Struvite Formation and Recovery

Struvite formation does not occur consistently in all types of manures. It is also typically not formed naturally; it requires a facilitated process that can only occur when the manure has been treated and chemically altered. To date, experiments with struvite precipitation and removal in animal manure have been done using swine slurries and anaerobically digested dairy manures. These experiments remain at a pilot scale; they are not operational at a full-scale. Struvite formation in livestock manure normally requires the addition of magnesium (for example, as magnesium oxide or magnesium chloride) in order for the solubility reaction between ammonium and phosphate to be successful. There also must be an effective method for pH adjustment if required, as struvite does not form unless it is within a pH range of 7 to 11 (Burns et al.).

Struvite Recovery from Swine Manure

Perhaps the most extensive research on struvite recovery has been conducted on swine manure slurries. A study by Burns and Moody in The Animal Industry Report in 2006 first outlined the technical requirements to recover struvite from manure. The study used a process called the mobile continuous flow reaction (MCFR) to separate the precipitated struvite from the rest of the slurry "using separation methods that take advantage of density differences" (Burns 2006). Because struvite is significantly denser than organic matter in manure, it can be effectively separated this way. This study also piloted hydro-cyclone technology that has proven to be successful in removing precipitate from the waste stream. In this type of system, the liquid slurry enters a hydro-cyclone and is spun in a circular motion. The denser material (in this case the struvite) travels to the bottom of the cone and can then be readily collected. Currently, the extraction of struvite from manure has not reached farm-scale application in North America. Therefore, these methods of struvite extraction are only used experimentally, or on a small scale.

While the precipitation of struvite in swine slurries has not reached full-scale application, there is evidence that it is effective at removing large amounts of phosphorus from the manure. A separate study by Burns et al. (2001) found a 76-90% reduction in soluble phosphorus when 140,000 L of swine slurry was subjected to struvite precipitation. This precipitation occurred successfully with the addition of magnesium chloride $(MgCl_2)$. This study also measured the particle size distribution of the formed struvite to assess the possibility of mechanical removal with sieves. They stated, "the potential for mechanical recovery of the precipitate is very good" (Burns 2001).

Struvite Recovery from Dairy Manure

Research is also on-going in struvite removal from dairy manure, particularly on precipitating struvite from anaerobically-digested dairy manure. It has been found that struvite precipitation was higher in anaerobically-digested manure as compared with undigested manure (NYSERDA 2006). While much research has been done in the area of struvite formation and removal from dairy manure, there are particular challenges to removal from dairy manure. A study in the journal of Water Environment Research states that struvite removal methods for dairy manure are "economically impractical or technically inefficient" (Huchzermeier 2012). It is generally understood that phosphorus removal as struvite is better suited to swine manure. Some of the challenges related to dairy manure are discussed in further detail below.

One of the main challenges associated with struvite precipitation in dairy manure is the high concentration of calcium ions in the manure relative to swine manure (this is due to the high calcium level of dairy cattle rations to meet calcium requirements for milk production). Instead of forming struvite (as occurs in swine manure), the available phosphorus binds with calcium and forms calcium phosphate, leaving little or no phosphorus to bind with ammonium and magnesium (Huchzermeier 2012). A study by Huchzermeier and Tao (2012) suggests that if carbonate were added in significant amounts, it would free up phosphorus for the precipitation of struvite. If enough carbonate was added to the manure or wastewater, it would bind with calcium to form calcium carbonate and leave the available phosphorus free for removal as struvite. Magnesium would need to be added in order to ensure there was the correct ratio of phosphorus, magnesium and ammonium required for formation of struvite.

Experiments on a small-scale to remove phosphorus as struvite from dairy manure have had mixed results. A study by Harris et al. (2008) found that attempted phosphorus recovery from the liquid fraction of separated dairy manure resulted in the formation of calcium phosphate, rather than struvite. The dairy manure used had had the solids removed, which was found to be necessary for optimal phosphorus recovery. The process used a fluidized bed-reactor to aid in the formation of the struvite, a cone-shaped mechanism to which the liquid manure is added, as well as supplementary magnesium (Dangaran 2012). In this process, as the liquid circulates within the reactor, the struvite crystals begin to form and then drop to the bottom of the reactor when they are of sufficient size where they can be collected and removed.

Successful Struvite Removal Operations

While the development of facilities for struvite removal in North America is only at the preliminary stage, a Final Report in 2006 by the New York State Energy Research and Development Authority (NYSERDA) states that “proprietary struvite recovery processes...have been developed both in the Netherlands and Japan” (NYSERDA 2006). These facilities are mainly used for precipitation and removal of struvite from municipal sludge in wastewater treatment plants; however, there is one full-scale system in operation in the Netherlands that treats veal manure. These operations all use various types of reactors to produce the struvite and separate it from the waste stream. The reactors can be very sophisticated, creating pellets of struvite of uniform size to be sold as fertilizer on the commercial market. However, for simple extraction purposes a much less complex reactor can be used such as a simple large rectangular reactor. The liquid manure is added to the reactor and undergoes a mixing process where it is aerated and treated with magnesium salt to aid in the precipitation process. Within the same reactor, the liquid manure moves to an area without mixing where the struvite precipitates and settles to the bottom of the reactor, leaving the liquid waste at the top. After the struvite has formed and settled, it can simply be shovelled or raked out of the tank and collected (NYSERDA 2006).

One specific example of a successful implementation highlighted in the study by the NYSERDA is the Putten plant in the Netherlands which is operated by the non-profit group Mestverwerking Gelderland and which operates four manure treatment plants in the Netherlands. The Putten plant treats about 150,000 cubic metres of veal manure every year (NYSERDA 2006). The manure is first treated “in a biological and denitrification system” (NYSERDA 2006). This process includes solids removal from the manure, conversion of organic phosphorus into ortho-phosphate (the form that reacts with magnesium and ammonium to form struvite) and addition of magnesium oxide in a mix tank before the manure is moved to the first of three reaction tanks. The struvite precipitates and settles to the bottom of the reaction tanks. From the tanks, the manure water “flows to a conventional gravity clarifier” (NYSERDA 2006). Here, the excess liquid at the top is drained and sent to a wastewater treatment plant. The solids are transferred to a separate storage area where it is gravity thickened which produces a material with about 15-20% solids. If a mechanical dewatering process were implemented, total solids content would increase to about 40%. This study estimates that about 95% of the total phosphorus in the manure is removed and incorporated into struvite.

There is little discussion about the end-use of struvite as a fertilizer, or about other uses. Most of the work that has been done is on an experimental level, with pilot-scale projects.

Summary

Struvite (magnesium ammonium phosphate hexahydrate) is a crystalline substance that forms in manures and biosolids because of a reaction between ammonium, phosphate and magnesium in an approximate 1:1:1 ratio. It is most effectively formed at a pH of 7 to 11 (Burns 2002); at this pH, struvite is soluble enough to precipitate. For most manures, precipitation of struvite requires additional treatment such as addition of magnesium, solids separation or pH adjustment.

Phosphorus removal and recovery from animal manures in the form of struvite is a topic with growing interest. There are many technologies in the development stage to aid in the formation and removal of struvite from animal manures, to date used more successfully in swine slurries than dairy manure. Hydro-cyclone technology is used to spin the liquid manure in cones; struvite drops to the bottom and is removed. In the one commercial facility producing struvite in the Netherlands, liquid manure is placed into large tanks with magnesium amendments, struvite forms and settles in the tanks to be raked or shovelled up. Currently, there are few successful large-scale applications of these technologies, though there is increasing interest for such operations to be put in place in North America.

8.5 Relevance to local conditions

Legacy P: much of the land base along the study rivers has been farmed intensively for many years producing high-value forage crops for dairy cattle. The Ministry of Agriculture Okanagan soil study found that 86% of the fields tested in the North Okanagan had high to very high residual soil P, well above the 'agronomic' level (section 13.3). Much of this intensively-farmed land is located next to surface water or is connected to water via drainage ditches and many of the soils in the area have the same characteristics as soils that have been shown to be prone to P leaching (section 15). This suggests that there is a significant pool of 'legacy P' in the study area which may continue to contribute P to surface water even if P loading to the land base is significantly reduced.

P removal from drainage water using P-sorbing materials: as mentioned above, the combination of low-lying land adjacent to surface water throughout the study area and soils that have elevated P and are prone to P leaching suggests that there may be a significant amount of P leached into the study rivers by subsurface flow. If this is found to be the case following more in-depth water quality monitoring, the only effective way at this time to remove this P from drainage water is through the use of P-sorbing materials which is currently an experimental BMP.

Struvite removal for P reduction of manure: struvite removal from manure is unlikely to be an economical means to reduce P in manure for the foreseeable future. Struvite removal is still at the experimental stage and has only been done successfully with liquid swine manure on a trial basis. In the study area, the main types of manure applied to crop land are dairy and poultry. The high calcium in liquid dairy manure makes the precipitation of struvite more difficult than from swine manure. Poultry manure is produced and handled as a solid and therefore can be more easily transported out of the watershed if necessary; already a considerable amount of poultry manure is moved out of the area.

9. Cost of Best Management Practices

This section contains 3 tables with cost estimates for P loss mitigation measures in terms of soil or P saved or cost per acre for implementation. The tables also contain estimates of P loss reduction with the same BMP's. Some of the BMPs are less relevant to Canadian cropping conditions.

While cost estimates are based on different parameters and are therefore difficult to compare, there are some general trends:

- BMPs that reduce P use on farm are generally more cost-effective than field management BMPs and transport BMPs. Maintaining optimum soil test P by soil testing and applying only P crop requirements is highly cost effective and cheaper than most other BMPs to implement.
- Cover cropping and conservation tillage are the least expensive BMP's for reducing erosion losses of P, but are more expensive than reducing P use on farm.
- Conservation buffers are mid-range in cost, more expensive than conservation tillage but much cheaper than dams, sediment traps and constructed wetlands.
- Sediment retention structures (dams, constructed wetlands, impoundments) are the most expensive BMPs to implement, twice or three times the cost of other P loss reduction BMPs
- Use of amendments such as iron-coated sand or flue-gas desulfurization waste to remove P from tile drainage is less expensive than application of amendments to pastures or cropland to bind P (these BMPs are still experimental).
- Use of amendments to remove P from tile drainage appears to be similar in cost to establishment of conservation buffers.

Table 7. Cost Effectiveness of Alternative Soil Loss Reduction Practices, Maumee and Sandusky Watersheds, Lake Erie Watershed, 1987-1997 (USDA Farm Service Agency, 1987-1997) (US$ in 1997)

Practice	Cost of soil saved
	1997$/ tonne
Agricultural Conservation Program best management practices	
Cropland protective cover	1.81
No-till systems	2.72
Permanent vegetative cover on critical areas	6.31
Field windbreak restoration or establishment	11.00
Sod waterways	12.30
Diversions	16.50
Sediment retention, erosion, or water control structures	45.65

From Forster and Rausch 2002

Table 8. BMPs for Conventional Tillage Sites: Cost per Acre for Implementation and P Retention

Best Management Practice for Conventional Tillage	Cost/Acre ($)	Nutrients	
		Soluble Phosphorus	Total Phosphorus
		(percent reduction in runoff by adopting BMP)	
Preplant incorporate into the top two inches of soil prior to the first runoff	7.15	60	20
Band nitrogen and phosphorus on the soil surface prior to or at planting; typically 30 percent surface area, weeds between rows controlled with cultivation	3.40	20	20
Subsurface apply phosphorus or nitrogen fertilizer	3.50	60	30
Crop rotations	0	25	25
Establish vegetative buffer strips	[1]	25	50
Do not apply nutrients within 100 feet of streams or near where runoff enters a stream	[2]	25	25
Conservation tillage farming (>30 percent residue cover following planting)	0	0	35
No-till farming	0	0	40
Contour farming (without terraces)	6.80	20	30
Terraces with tile outlets	[3]	10	30
Terraces with grass waterways (with contour farming)	[4]	30	30
Soil sampling and testing	1.00	0-25	0-25
Sound fertilizer recommendations	0	0-25	0-25

[1] Establishment cost of $100 per acre plus an annual cost equal to the average per acre land rental rate for the acreage within the vegetative buffer strip

[2] Annual cost equal to the average per acre land rental rate for the acreage where nutrients are not applied (i.e., acres within 100 feet of streams or before runoff enters a stream)

[3] One-time installation cost of $40 per acre plus an annual cost of $13.60 per acre

[4] One-time installation cost of $30 per acre plus an annual cost of $13.60 per acre (all crop acres in the field) plus an annual cost equal to the average per acre land rental rate for the acreage within the grass waterways

Adapted from Devlin et al 2003

Table 9. Summary of Efficacy and Cost of Phosphorus Mitigation Strategies for Pasture-based Dairy Farms in New Zealand.

Strategy	Main targeted P form(s)	Effectiveness (% total P decrease as compared to control)[1]	Cost, range ($ per kg P conserved)
Management			
Optimum soil test P	dissolved and particulate	5-20	highly cost-effective[2]
Low solubility P fertilizer	dissolved and particulate	0-20	0-20
Stream fencing	dissolved and particulate	10-30	2-45
Restricted grazing of cropland	particulate	30-50	30-200
Greater effluent pond storage/application area	dissolved and particulate	10-30	2-30
Flood irrigation management[3]	dissolved and particulate	40-60	2-200
Low rate effluent application to land	dissolved and particulate	10-30	5-35
Amendment			
Tile drain amendments	dissolved and particulate	50	20-75
Red mud (bauxite residue)	dissolved	20-98	75-150
Alum to pasture	dissolved	5-30	110 to >400
Alum to grazed cropland	dissolved	30	120-220
Edge of field			
Grass buffer strips	dissolved	0-20	20 to >200
Sorbents in and near streams	dissolved and particulate	20	275
Sediment trap	particulate	10-20	>400
Dams and water recycling	dissolved and particulate	50-95	(200) to 400[4]
Constructed wetlands	particulate	-426 to 77	100 to >400[5]
Natural seepage wetlands	particulate	<10	100 to >400[5]

[1] Numbers in parentheses represent net benefit, not cost. Data is taken as midpoint for average farm in Monaghan et al. (2009a).

[2] Depends on existing soil test P concentration

[3] Includes adjusting clock timings to decrease outwash <10% of inflow, installation of bunds to prevent outwash, and releveling of old borders.

[4] Upper bound only applicable to retention dams combined with water recycling

[5] Potential for wetlands to act as a source of P renders upper estimates for cost infinite

Adapted from McDowell and Nash 2012

10. Conclusions – Literature Review

Programs with the goal of reducing the movement of P to surface water from agricultural land must have a clear understanding of where and by what mechanism the P is moving into surface water. In general, P source reduction measures appear to be more effective at reducing the loading of P to surface water, are less expensive to implement and are more quantifiable than measures aimed at reducing the movement of P into surface water. However, implementation of BMPs to reduce the transport of P into water are also important. Traditional BMP's, effective at reducing soil erosion losses of P and to a lesser extent dissolved P losses, are not effective at preventing movement of dissolved P into water via subsurface flow; emerging technologies are being developed to more effectively deal with these P loss pathways.

Based on the current knowledge of nutrient management in watersheds, the following is a list of elements of an effective P mitigation program:

1. Prevent further buildup of soil P on farmland through a policy of reducing P loading by reducing chemical fertilizer use, and reducing manure P by reducing feed P. Improve manure and fertilizer management on the land to prevent direct movement to surface water.
2. Determine which areas of the landscape are contributing phosphorus to water and what mechanism is transporting the phosphorus – erosion, surface runoff or subsurface loss - through water quality monitoring, soil testing and the use of P risk assessment tools.
3. Target BMP implementation to critical source areas in the landscape (areas where there is both elevated soil P and a hydrological link between agricultural land and surface water).
4. Do not expect quick results due to legacy P sources in soil, ditches, streams and lakes. Educate funding agencies about this.
5. Acknowledge that land management under a previous paradigm may impact water quality for many years and it is not always the current land owner's fault or responsibility. Stakeholders must work together to address the problem.
6. Continue to monitor water quality during and after the program as this is the only credible way to measure the impact of P mitigation programs on downstream water quality.

Part B. Water Quality and Agriculture in the Shuswap Watershed

11. Shuswap Watershed 2011-2013 Water Quality Testing Results and SLIPP Source of Nutrients Study

In 2008, the Shuswap Lake Integrated Planning Process (SLIPP) developed a Strategic Plan that, among other things, recommended long-term water quality monitoring around the lake and its tributaries to monitor water quality trends. This was partly the result of concerns about minor changes to water quality in the lake and also the result of algal blooms in 2008 in Shuswap Lake and 2010 in Mara Lake.

Water quality in various tributary rivers and streams was monitored in 2011, 2012 and 2013. The results from the 2011 water monitoring indicated that nutrients including phosphorus and nitrogen were elevated in some rivers and streams at certain times of year (NHC 2013a), and as a result of these results, monitoring in 2012 and 2013 focussed on the Shuswap, Salmon and Eagle Rivers which appeared to contribute the bulk of the nutrients entering the lake from tributaries.

11.1 Shuswap River

The Shuswap River between Mabel Lake and Mara Lake was found to be the largest contributor of both total phosphorus and total nitrogen to Shuswap Lake (NHC 2014). Phosphorus loading to Mara Lake from the Shuswap River begins to rise in March corresponding with snowmelt, is high from May through July, peaks in June and declines significantly in August. Phosphorus loading to the lake is low from September through February. In 2012, total phosphorus loading from the river ranged from 374 to 772 kg per day throughout May, June and July (NHC 2014). In 2013, nutrient loading from the river peaked at 1336 kg per day on May 14 and remained above 400 kg per day between May 14 and July 9 (NHC 2013b).

In all three years, water quality monitoring was done at five monitoring stations along the river to provide additional information about phosphorus sources:

- at the outlet from Mabel Lake
- at the Trinity Valley bridge
- at Enderby
- at Grindrod
- upstream from the inlet into Mara lake at Mara

In all 3 years of monitoring, it was observed that total phosphorus concentration in river water increased at each monitoring station moving down the river. Total phosphorus concentration in water averaged 3-4 ug/L at the outlet from Mabel Lake and 14.6 to 20 ug/L at the outlet into Mara Lake. The largest single increase occurred between Grindrod and Mara Lake in each year (Figure 5, monitoring point NL 12). Most of this increase was in particulate phosphorus; there was only a small increase in dissolved phosphorus along the length of the river (NHC 2013b).

Water quality was also monitored in Fortune Creek during February, March and April of 2011 at four sites along the creek between the Highway 97 rest stop and Enderby. Fortune Creek drains a highly developed agricultural and urban area between Armstrong and Enderby. The levels of total and dissolved phosphorus in the creek were very high during this period of relatively low flow with all but a few samples exceeding the water quality standard of 10 ug/L total phosphorus. Moving downstream, at each monitoring station the concentration of phosphorus, both dissolved and total, increased. Between 70 and 90% of the phosphorus was present in the dissolved form in contrast to the Shuswap River where approximately half is in the dissolved form and half as particulate phosphorus (NHC 2013a).

11.2 Salmon River

After the Shuswap River, the Salmon River is the second largest contributor of nutrients to the Shuswap Lake system. The Salmon River originates in the plateau above Westwold B.C. and runs through Westwold and down the Salmon River Valley to Salmon Arm (Figures 4 and 6). It discharges approximately half of the phosphorus as does the Shuswap River. In the Salmon River, phosphorus begins to increase in March, peaks in May and declines to normal levels by mid-July. This is approximately one month earlier than the peak of phosphorus levels in the Shuswap River and appears to be related to the earlier snowmelt in the headwaters of the Salmon River. Phosphorus loading peaked at 188 kg per day total phosphorus in 2013, and ranged from 95 to 110 kg per day between early April and the end of May. This contrasts with 400 kg per day during the approximate same period in the Shuswap River (NHC 2014). Phosphorus loading was low from mid-July to early March.

11.3 Eagle River

The Eagle River is the third largest contributor of phosphorus to the Shuswap Lake system. It enters Shuswap Lake at Sicamous (Figures 4 and 7). Phosphorus levels in this river increase in May, peak in June and return to normal levels in late July similar to the Shuswap River. In 2012, phosphorus loading in the river peaked at 478 kg of total phosphorus per day in June, and averaged 108 kg per day in May and 177 kg per day in July (NHC 2014). Phosphorus levels were low from August through April.

11.4 Dissolved versus particulate phosphorus

The 2011 water quality monitoring program looked at both dissolved and total phosphorus in the Shuswap and Salmon Rivers. The monitoring data showed that in April, in early freshet but before peak flows, 35-43 % of phosphorus is in the dissolved form in the Shuswap and Salmon Rivers respectively. In June and July during peak flows, that proportion drops to 18 to 20% of the total P respectively indicating that during high flow, significantly more particulate phosphorus is present in the rivers. No causal factors were discussed.

11.5 SLIPP nutrient loading report 2014

In 2013, SLIPP contracted Tri-Star Environmental Consulting to estimate loadings from the various contributory nutrient sources based on the water quality data generated during the 2011-2013 monitoring period. The report concluded that the majority of the nutrients entering Shuswap and Mara Lakes from the Shuswap, Salmon and Eagle Rivers originated from agriculture on the land-base in the immediate vicinity of the rivers and tributaries. Up to 78% of the phosphorus entering from these tributary rivers was estimated to originate from livestock-based agriculture along the rivers (Tri-Star Environmental Consulting 2014).

Figure 4. Overview Map of Study Areas of the Shuswap, Salmon and Eagle Rivers

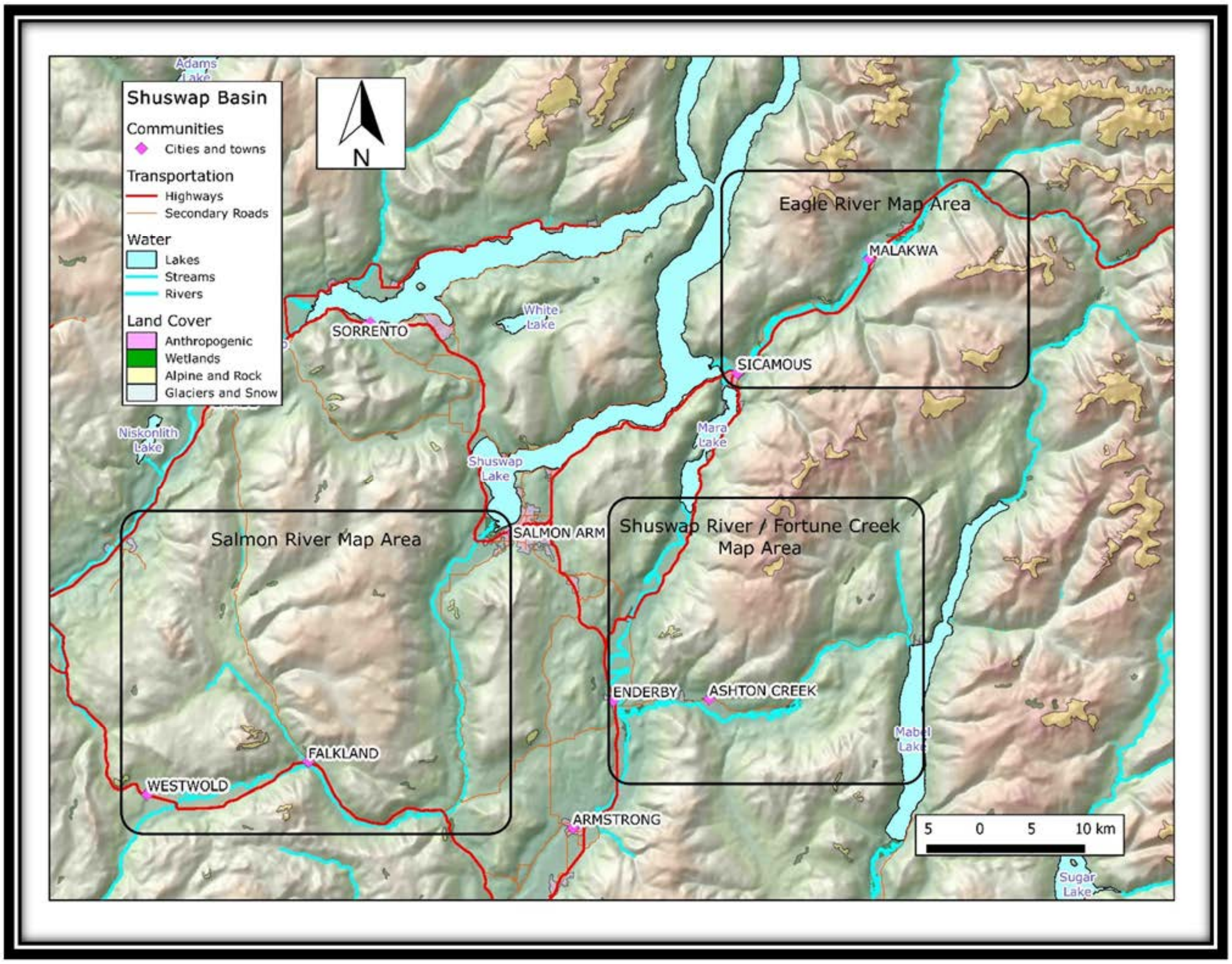


Figure 5. Land in Agricultural Use along the Shuswap River from Mabel Lake to Mara Lake and Fortune Creek

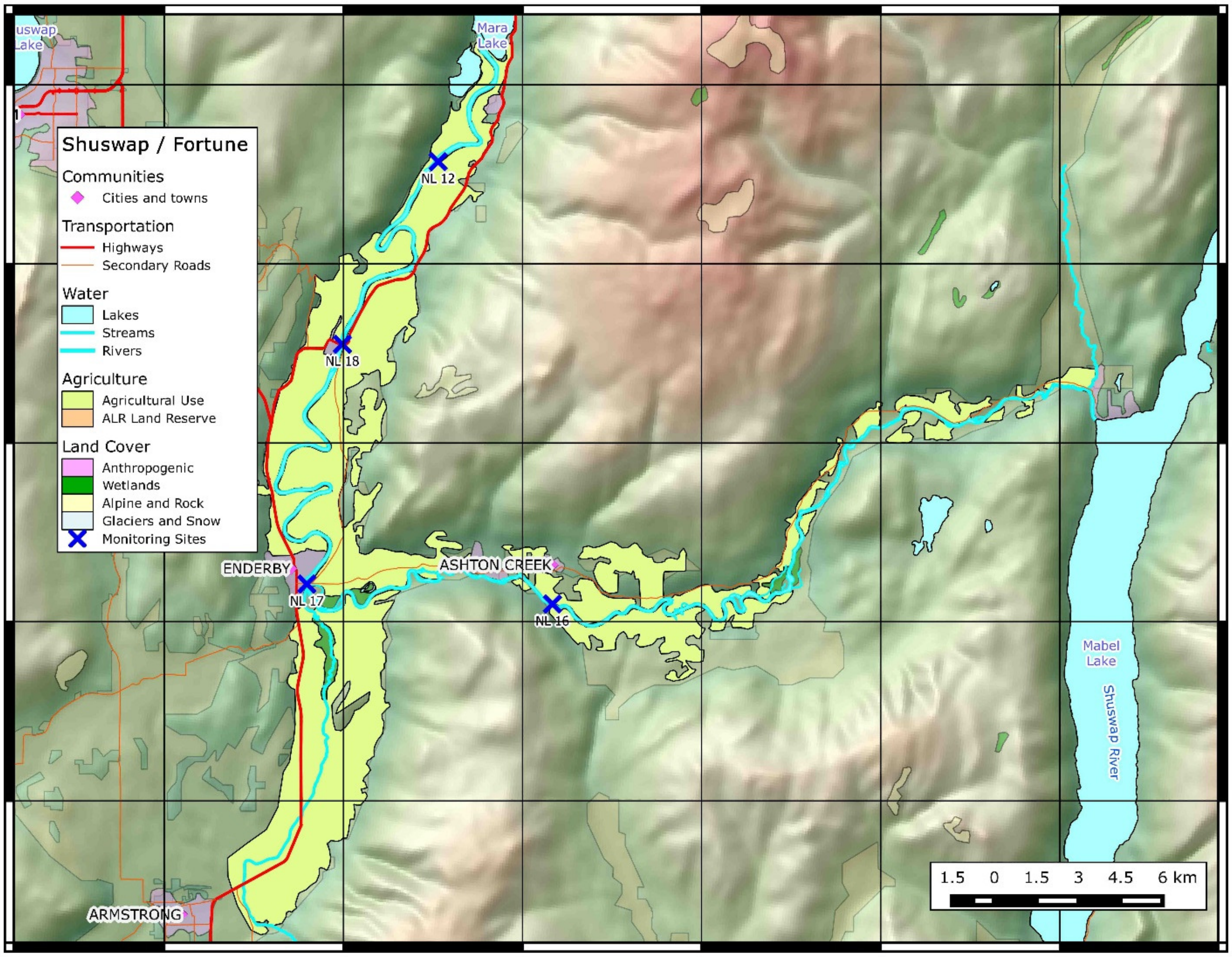


Figure 6. Land in Agricultural Use along the Salmon River from Westwold to Shuswap Lake

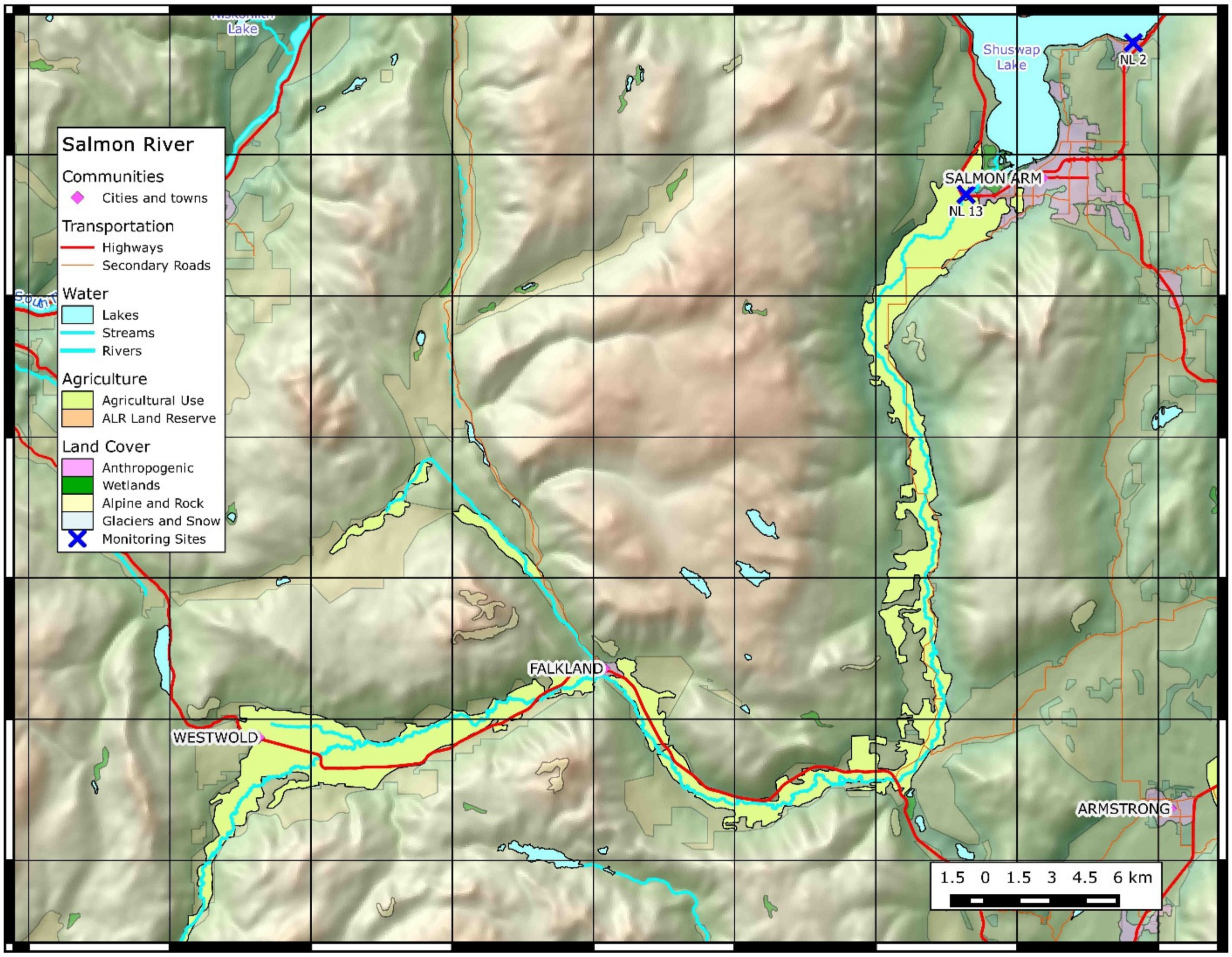
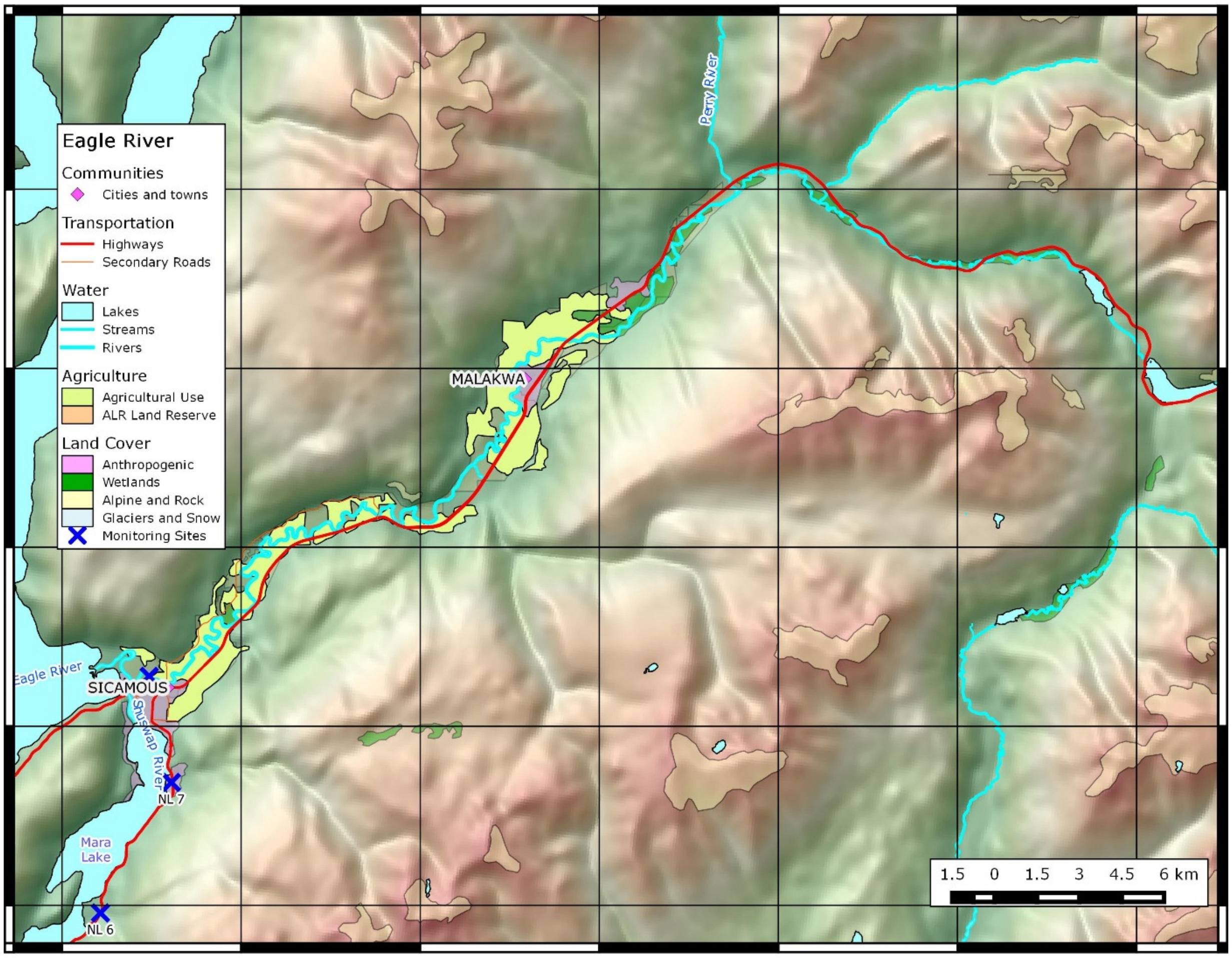


Figure 7. Land in Agricultural Use along the Eagle River from Upstream of Malakwa to Sicamous



12. Agriculture on the Shuswap, Salmon and Eagle Rivers and Fortune Creek

Figures 5, 6 and 7 show the land in agricultural use along the study sections of the Shuswap, Salmon and Eagle Rivers and Fortune Creek, as well as the land in the B.C. Agricultural Land Reserve. The primary land use along these watercourses is agriculture.

Agriculture in the watersheds of the study rivers can be broadly divided into two main types: intensive agriculture where livestock and poultry production occurs primarily in enclosed areas or barns, and the land base is used for the production of high-value crops for feed. The main commodity groups of this type in the area are dairy and poultry production (broilers and eggs), with a smaller number of beef feedlots. The second main type of agriculture in the region is land-based consisting of some large beef cow-calf operations as well as many small holdings with beef cattle, horses, sheep and llamas. On this type of operation, the land base is used to graze livestock and produce alfalfa and grass hay for winter feed.

As part of this project, a rough land use survey was conducted along the three rivers to identify dairy farms, poultry operations and other large livestock operations. This was done by conducting a drive-by survey along the rivers and tributaries and visually identifying dairy and poultry operations. This may not have identified all operations as some may not have been visible from the road however it gives a reasonable estimate of the amount of intensive agriculture in the study area. It was more difficult to identify large beef cow-calf operations which are land based, and impossible to determine the number of small-scale hobby and horse farms of which there are hundreds in the study area.

12.1 Lower Shuswap River, lower Salmon River and Fortune Creek

The land use in the area adjacent to the Shuswap River from just above Enderby downriver to Mara where the river enters Mara Lake, and along the Salmon River from Silver Creek to the inlet at Salmon Arm is primarily crop production for feed for dairy cattle (Figures 5 and 6). The land base along Fortune Creek, which extends from just north of Armstrong to the City of Enderby and drains into the Shswap River at Enderby, is also primarily used to produce high-value forage for dairy cattle feed. There are also of course many small holdings along these water courses but much of the land base owned by small-holders is leased by dairy farmers or beef feedlot owners and is used to grow high-value forage and silage corn.

There are an estimated 62 dairy farms in the study area, approximately 51 of those located along the lower Shuswap (Enderby to Mara and Fortune Creek) and the lower Salmon River (Silver Creek to Salmon Arm) (Table 10). Each dairy farm crops approximately 1 acre per milking cow (0.4 hectare), and at an average size of 135 milking cows per farm (BC dairy farm average size), the dairies in the area crop at least 3350 hectares (8375 acres) of land, most of it the highly productive land on the river floodplains and along Fortune Creek. Dairy farmers typically own some of the land required to grow feed for their livestock but they also lease a significant amount of land in the area when they don't own sufficient for feed production. This is typically land that is owned by people who do not wish to crop it; there is a significant amount of this type of land in the North Okanagan owned by 'hobby' farmers or retired farmers.

Land owned and leased by dairy farmers is used to grow several high-value crops: silage corn, grass and alfalfa for silage and hay, and cereals harvested before maturity and preserved as silage. The crops are fertilized with chemical fertilizer to maximize crop production, and most land also receives some dairy manure. Some land also receives poultry manure as there are a number of commercial poultry operations in the study area, and some of that manure goes onto land used for dairy cattle feed.

There are an estimated 17 commercial poultry operations in the study area, of which 16 are located along the lower Shuswap and Salmon Rivers and along Fortune Creek (Table 10). Poultry operations typically have a very small land base, insufficient to utilize all their manure and they typically do not produce any of their own feed (there are exceptions to this in the study area). Some of the poultry manure is hauled out of the watershed but much of it is used to enhance the fertility of crop-producing land, some of it on dairy farms. Some of the poultry manure is used on-site.

There are also at least three beef feedlots in the study area. Feedlot owners also own and lease land on highly-productive river bottom lands and grow high-value corn silage and forages to feed to the finishing cattle in their feedlots. This land base receives feedlot manure and may also receive some poultry manure.

Table 10. Estimated Number of Dairy and Poultry Farms in the Study Area

	Dairy	Commercial poultry
Shuswap River		
Upper section - Mabel Lake to Enderby	5	0
Lower - Enderby to Grindrod	14	4
Lower - Grindrod to Mara	9	0
Fortune Creek – Armstrong to Enderby	15	7
Total – Shuswap River and Fortune Creek	**43**	**11**
Salmon River		
Upper -Westwold to Silver Creek	3	1
Lower - Silver Creek to Salmon Arm	13	5
Total – Salmon River	**16**	**6**
Eagle River	**3**	**0**
Total in study area	**62**	**17**

12.2 Upper Salmon River, upper Shuswap River and Eagle River

The agricultural land along the Shuswap River upstream of Enderby, along the Salmon River upstream of Silver Creek and from the mouth of the Eagle River upstream to just past Malakwa is characterized by a mix of beef cattle ranches and diverse hobby farms ranging from sizeable horse farms to small holdings with 1-2 cows or a few sheep, interspersed with a few large-scale intensive agriculture operations (11 dairy farms and 1 commercial poultry operation). The land base used by dairy farmers in these areas is cropped to high-value silage corn and forages, while the land base used by beef cattle ranchers and small-holders is used for hay production and for grazing. This land base (aside from the area used by dairy farmers) is fertilized much less intensively because the crops produced are of much less value than those produced for dairy feed. The land base is less likely to receive manure other than that deposited by grazing livestock. On the other hand, land near the river may be used for cattle winter feeding or spring calving grounds resulting in an accumulation of manure on the field which may run off during early spring snowmelt. Flooding may also move nutrients from livestock high-use areas into water.

13. Climate, Landforms and Soils along the Shuswap, Salmon and Eagle Rivers and Fortune Creek

13.1 Climate

The Shuswap region is centrally located between Vancouver BC, and Calgary AB. It is a large land area that contains multiple climate zones which include semi-arid parts around Falkland, Westwold and Monte Creek, temperate continental near Shuswap Lake and Salmon Arm, and sub-alpine in mountainous regions. In the areas near Salmon Arm and the Shuswap Lake, there is an average rainfall of 487 mm per year, with approximately 150 days of rainfall per year (Environment Canada). There is also an average snowfall of 182 cm per year, with a recorded average of 58 days of snowfall per year (Environment Canada). The first frost in this region usually occurs at the end of September, and the last frost occurs in the middle of May; there is an average of 139 frost-free days throughout the year. In the more semi-arid regions around Monte Creek, Westwold and Falkland, the average annual number of days with rain is 129 per year, with an average of only 287 millimetres of rain per year. The snowfall also decreases to about 72 centimetres per year, with just less than 28 days of snowfall every year.

The soil in the Shuswap watershed is frozen or snow-covered normally during the months of December, January and February, and part of March. In most years, the ground begins to freeze in November and is frost-free by April. Typical settled snowfall accumulation in the region varies from 15-30 cm in the more arid areas of the watershed to 1 metre or more in wetter areas. Snowmelt normally occurs in mid-March but can occur during any winter month. Snowmelt can occur very quickly during one or two unseasonably warm days during which there can be considerable runoff, or it can occur more slowly over several weeks when there is more opportunity for melting snow to infiltrate the soil.

In all areas of the Shuswap watershed, there is a seasonal moisture deficit for most agricultural crops. This deficit is more extreme in the more arid areas of the watershed (Westwold-Falkland) and less in the Enderby-Mara area. Some crops such as cereals can be grown without irrigation. To achieve optimum yields of silage corn and forages, irrigation is required.

13.2 Topography

The agricultural areas along the Lower Shuswap River (Mabel Lake to Mara), the Salmon River (Westwold to Salmon Arm) and Eagle River (Malakwa to Sicamous) are primarily flat and low-lying. They consist of the flood plains of the rivers, and as such are situated only slightly above the elevation of the rivers and are susceptible to elevated groundwater and flooding during the April through July high water period. The exception to this is the land along Fortune Creek which is slightly higher in elevation and consists of glacial lake-bottom sediments. In this area, Fortune Creek has carved a channel through the ancient clay-rich lake sediments. There is a small amount of agricultural land along Fortune creek which is susceptible to elevated groundwater and flooding but most of the agricultural land is at a higher elevation. The detailed map series included as separate digital file shows the approximate extent of the floodplains along the study river basins.

13.3 Soils in the southern portion of the Shuswap Basin

Soils in close proximity to the major drainages leading into the southern sections of Shuswap Lake were identified and described from soil survey reports and geographic datasets available from the Ministry of Environment (2014) and Agriculture and Agri-Food Canada (2014). Tables 11-14 contain quantitative and descriptive information about the most common soil types in each river basin, and Tables 15 and 16 explain the abbreviations found in the soil tables. A set of detailed maps has been prepared to accompany this report showing the soil types for the sections of the Shuswap, Salmon and Eagle Rivers discussed in this report as well as for the agricultural areas of Fortune Creek. These are available as a separate digital file.

The soil characteristics described in this section reflect the natural geomorphic and soil forming processes that have operated on the landscape for thousands of years. The distribution of soil parent materials and types was determined by the balance of these natural processes, and they continue to operate today. The distribution of materials and the specific soil characteristics at a particular site significantly affect the potential land uses and the environmental effects of management, and they also constrain the options and opportunities available to mitigate environmental problems.

The valley bottoms of the three major rivers (Shuswap, Salmon, and Eagle) are dominated by soils derived from fluvial parent materials that were deposited by the modern (post glacial) river systems, and to a lesser extent, by glaciofluvial materials deposited from receding flood waters at the end of the last glacial period.

Fluvial and glaciofluvial materials often have high sand content, providing rapid drainage of water through the soil profile and the potential for development of deep root systems, but some glaciofluvial materials contain a more uniform mix of sand silt and clay. The coarse fragment (rocks and stones) content in fluvial and glaciofluvial materials varies, but where it is high, the soils have low water and nutrient holding capacity.

Small areas of organic soils and glaciolacustrine sediments are also found in close proximity to the rivers, especially in Fortune Creek. Organic materials are generally found in low lying portions of the landscape where drainage is poor. Glaciolacustrine materials typically have no coarse fragments, and are characterized by large amounts of silt and clay deposited in the bottom of glacial lakes that occupied portions of the valleys as the glacial ice was melting. Soils derived from glaciolacustrine materials often have high productivity because the silt and clay retain water and nutrients for plant growth, but these soils also tend to have restricted drainage, posing challenges for soil management operations requiring equipment.

Soil development reflects the combined effects of climate and vegetation on the original soil parent material, and these effects are strongly influenced by topography. The most common soil development condition close to the major rivers in the Shuswap area is Regosol, which is a soil with organic matter accumulation in the surface but little colour change in the subsoil. These soils commonly occur where fresh sediments are continually being deposited by floods, and in areas prone to erosion. Lesser, but significant amounts of Brunisolic, Gleysolic and Luvisolic soils are also present adjacent to the river channels. Gleysolic soils occupy low lying areas where the water table is close to the surface while Brunisolic and Luvisolic soils both occupy well-drained landscape positions. Luvisols develop where the parent materials contain clay that can be carried through the soil profile in percolating waters, while the Brunisols form on sandy parent materials or where rainfall is limited. Minor amounts of Organic soils, Podzols and Chernozems are also found in portions of the valley bottoms leading into Shuswap Lake.

13.3.1 Shuswap River Soils

The most abundant soil types in the Shuswap River area are Mara, Nisconlith and Mabel. All three of these soils derive from fluvial parent material, but differ significantly in their properties and classification (Table 11). Mara is classified as a Gray Luvisol, is found in moderately well drained slope positions and contains significant amounts of clay. Nisconlith is derived from similar parent materials, but is found lower in the landscape where the water table is close to the surface. Nisconlith is classified as a Gleysol. Mabel is derived from a fluvial material with very little clay, and has a high content of coarse material. Small amounts of glaciolacustrine materials (Broadview) and organic deposits (Waby and Okanagan) are also found in close proximity to the Shuswap River.

13.3.2 Fortune Creek Soils

The three most abundant soil types in the Fortune Creek area are Nisconlith, Okanagan and Bessette (Table 12). Nisconlith and Bessette are both poorly drained soils formed in fluvial material, with Nisconlith containing more clay than the Bessette (33 and 28 percent respectively). Okanagan soil is an organic soil, meaning it has a very high carbon content, and contains very little sand or clay. None of these soils contain significant amounts of coarse fragments. There are also significant areas of gladiolacustrine material in the areas adjacent to Fortune Creek. The soils on these deposits vary in classification but all contain considerable amounts of silt and clay. Of the major valleys within the overall study area, the Fortune Creek area has the highest proportion of soils with fine texture (high in silt and clay) and poor drainage (Gleysol soil development).

13.3.3 Salmon River Soils

The Salmon River area is the longest section of river within the overall study area. The three most abundant soil types in the Salmon River area are Falkland, Lumby and Glenemma, and account for almost approximately 2/3 of the soils adjacent to the river, Appendix 1 and Table 13). All of these soils have a high sand content to 100 centimetres, and low clay content. Falkland soil contains no coarse fragments, while Lumby (30%) and Glenemma (29%) contain high quantities of coarse fragments. Falkland and Glenemma are Regosolic soils found on active areas of deposition and erosion immediately adjacent to the river, while Lumby occupies more stable sites some distance away where Brunisolic soil development has occurred over a longer period of time. A large number of associated soils are present in the Salmon River valley. Overall, in the Salmon River valley, Regosols are the dominant soil type, with lesser but significant amounts of Brunisolic and Gleysolic soils, and small amounts of other soils.

13.3.4 Eagle River Soils

The most abundant soil adjacent to the Eagle River is Solsqua, a medium textured Gray Luvisol with a high silt content (Table 14). The Mabel Complex and Yard soil together occupy the same area as Solsqua, and have higher sand content with less clay. In general, the soils adjacent to the Eagle River tend to be coarse to medium textured, with only small areas occupied by soils rich in clay. Mabel Complex and Yard are both Regosolic soils, as is the fourth most common soil, Rumball. Overall, Regosolic soils are dominant in the vicinity of the Eagle River, reflecting the narrower valley with a relatively smaller area of flood plain where the later stages of soil development can occur. Gray Luvisols and Brunisols also occupy a large proportion of the area adjacent to the Eagle River, with comparatively lower proportions of the Gleysol and organic soils typical of flood plains and low lying areas. The Eagle River also contains some Podzolic soils, reflecting increased rainfall that occurs in this portion of the study area.

Table 11. Shuswap River Soil Information

Soil Name	Area (ha)	Code	Parent Material	Soil Type	Carbon 50cm (kg/m^2)	Sand 100cm (%)	Clay 100cm (%)	Coarse Fragments 100cm (%)
Mara	1014	MAR	FLUV	O.GL	7	14	29	0
Nisconlith	691	NTH	FLUV	O.HG	14	33	28	0
Mabel	347	MBL	FLUV	O.R	4	88	3	46
Duteau	291	DUA	FLUV	O.G	14	54	9	8
Hupel	189	HUP	FLUV	O.DYB	3	82	3	49
Gardom	87	GDM	FLUV	R.G	21	10	54	0
Grindrod	63	GND	FLUV	O.R	11	75	6	19
Broadview	42	BDV	GLLC	O.GL	15	2	78	0
Waby	24	WAY	FNPT	T.M	28	--	--	12
Okanagan	3	OKG	FNPT	CU.H	94	--	--	0

Note: Tables 15 and 16 explain soil abbreviations.

Table 12. Fortune Creek Soil Information

Soil Name	Area (ha)	Code	Parent Material	Soil Type	Carbon 50cm (kg/m^2)	Sand 100cm (%)	Clay 100cm (%)	Coarse Fragments 100cm (%)
Nisconlith	110	NTH	FLUV	O.HG	14	33	28	0
Okanagan	105	OKG	FNPT	CU.H	94	--	--	0
Bessette	84	BES	FLUV	O.HG	11	68	6	0
Broadview	77	BDV	GLLC	O.GL	15	2	78	0
Coldstream_OK	65	CSO	GLFL	O.LG	15	45	17	0
Spallumcheen	39	SLC	GLLC	O.BLC	17	9	45	0
Duteau	38	DUA	FLUV	O.G	14	54	9	8
Hullcar	18	HLC	GLLC	O.DBC	8	24	18	0
Enderby	16	EBY	GLLC	E.EB	7	4	13	0

Note: Tables 15 and 16 explain soil abbreviations.

Table 13. Salmon River Soil Information

Soil Name	Area (ha)	Code	Parent Material	Soil Type	Carbon 50cm (kg/m2)	Sand 100cm (%)	Clay 100cm (%)	Coarse Fragments 100cm (%)
Falkland	2212	FKD	FLUV	GL.R	8	64	6	0
Lumby	1628	LBY	FLUV	O.EB	9	70	5	30
Glenemma	1305	GMM	GLFL	O.R	9	82	6	29
Nisconlith	636	NTH	FLUV	O.HG	14	33	28	0
Kalamalka	347	KAK	FLUV	O.DGC	11	57	10	19
Bolean	261	BOL	FLUV	GL.R	4	31	17	0
Rumball	249	RBL	FLUV	GL.R	4	52	23	0
Mabel	211	MBL	FLUV	O.R	4	88	3	46
Stepney	179	SPY	GLFL	E.EB	4	80	40	0
Pillar	161	PIL	GLFL	O.EB	3	88	3	0
IDA	123	IDA	FLUV	E.EB	14	58	7	0
Grindrod	89	GND	FLUV	O.R	11	75	6	19
Wallenstein	67	WLI	FLUV	GL.GL	8	18	28	0
Gardom	26	GDM	FLUV	R.G	21	10	54	0
Enderby	19	EBY	GLLC	E.EB	7	4	13	0
Marl	7	$MA	UNDM	GL.R	13	3	22	0
Rabie	3	RBI	FNPT	T.H	75	--	--	0

Note: Tables 15 and 16 explain soil abbreviations.

Table 14. Eagle River Soil Information

Soil Name	Area (ha)	Code	Parent Material	Soil Type	Carbon 50cm (kg/m2)	Sand 100cm (%)	Clay 100cm (%)	Coarse Fragments 100 cm (%)
Solsqua	682	SQU	FLUV	O.GL	4	50	14	0
Mabel Cpx	322	MBL	FLUV	O.R	4	88	3	46
Yard	286	YRD	FLUV	O.R	2	82	6	2
Rumball	270	RBL	FLUV	GL.R	4	52	23	0
Legerwood	200	LRW	FLUV	R.G	19	25	20	0
Sitkum	183	SKU	FLUV	O.HFP	17	83	5	34
Hupel	175	HUP	FLUV	O.DYB	3	82	3	49
Shuswap	141	SWP	GLFL	O.SB	6	83	4	3
Duteau	128	DUA	FLUV	O.G	14	54	9	8
Okanagan	111	OKG	FNPT	CU.H	94	--	--	0
Malakwa	63	MKW	GLFL	E.DYB	2	86	6	35
Wap	57	WAP	GLFL	O.HFP	4	84	5	35
Grindrod	46	GND	FLUV	O.R	11	75	6	19
White	28	WHT	FLUV	O.EB	14	64	7	35

Note: Tables 15 and 16 explain soil abbreviations.

Table 15. Parent Material Abbreviations

Parent Material Types	
FLUV	Fluvial
FNPT	Fine Peat
GLFL	Glaciofluvial
GLLC	Glaciolacustrie
UNDM	Undifferentiated Material

Table 16. Soil Development Abbreviations

Soil Development	
O.DYB	Orthic Dystric Brunisol
E.DYB	Eluviated Dystric Brunisol
O.EB	Orthic Eutric Brunisol
E.EB	Eluviated Eutric Brunisol
O.SB	Orthic Sombric Brunisol
O.BLC	Orthic Black Chernozem
O.DBC	Orthic Dark Brown Chernozem
O.DGC	Orthic Dark Grey Chernozem
O.G	Orthic Gleysol
R.G	Rego Gleysol
O.HG	Orthic Humic Gleysol
O.LG	Orthic Luvic Gleysol
O.GL	Orthic Gray Luvisol
GL.GL	Gleyed Gray Luvisol
CU.H	Cumulic Humisol
T.H	Terric Humisol
T.M	Terric Mesisol
TY.M	Typic Mesisol
O.HFP	Orthic Ferro-Humic Podzol
O.R	Orthic Regosol
GL.R	Gleyed Regosol

14. B.C. Regulations and Guidance for Phosphorus Management On-farm

In B.C., the management and land application of manure and other agricultural waste is regulated by the Ministry of Environment under the *Agricultural Waste Control Regulation*. There is no regulation of any aspect of the application of chemical fertilizer in the province. The B.C. Ministry of Agriculture provides guidance to agricultural producers on the application and use of nutrients on B.C. farms which applies to nutrients from both manure and fertilizer. This is currently done through a series of nutrient management factsheets.

14.1 B.C. Ministry of Environment Agricultural Waste Control Regulation and Code of Agricultural Practice for Waste Management

Agricultural waste is regulated in B.C. under the *Agricultural Waste Control Regulation* (AWCR) and the *Code of Agricultural Practice for Waste Management.* The Regulation is part of the Environmental Management Act, the primary legislation managing waste and controlling pollution in the province. The Code of Practice is part of the AWCR, and describes practices for 'using, storing and managing agricultural waste that will result in agricultural waste being handled in an environmentally sound manner' (B.C. Ministry of Environment 1992). The AWCR has been in force since 1992. Agricultural producers in B.C. are required to comply with the AWCR; compliance with the Regulation excludes them from the requirement for a permit to discharge agricultural waste. Producers found to be in violation of the AWCR can be charged under the Environmental Management Act.

Two sections of the Code of Practice are relevant to on-farm management of phosphorus and control of phosphorus movement to surface water.

Part 5, the Application and Composting of Agricultural Waste contains a number of provisions designed to limit soil buildup of nutrients from manure and to prevent losses of manure to surface water:

- Agricultural waste must not be directly discharged into a watercourse or groundwater.
- Agricultural waste must be applied to land only as a fertilizer or a soil conditioner.
- Agricultural waste must not be applied to land if, due to meteorological, topographical or soil conditions or the rate of application, runoff or the escape of agricultural waste causes pollution of a watercourse or groundwater.

The following conditions are considered unfavorable to application of agricultural waste but waste application is not forbidden under these circumstances. Agricultural waste must not be applied during these conditions *if* runoff or escape of the waste causes pollution of a watercourse or groundwater or if the waste goes beyond the farm boundary:

- On frozen ground
- In diverting winds
- On areas having standing water
- On saturated soils
- At rates of application that exceed the amount required for crop growth.

The other relevant section of the regulation is Part 9, Feeding Areas and Access to Water. This section outlines requirements for seasonal feeding areas and livestock access to water.

The Code contains the following provisions that are relevant to management of manure on ranches and small holdings:

Access to water

- *Grazing areas*: livestock within a grazing area may have access to watercourses, provided that the agricultural waste produced by that livestock does not cause pollution.
- *Seasonal feeding areas* (overwinter feeding areas): livestock in a seasonal feeding area may have access to watercourses provided that the access is located and maintained as necessary to prevent pollution.

Siting and management of seasonal feeding areas

- Seasonal feeding areas for livestock must be operated in a way that does not cause pollution and have berms where necessary to prevent agricultural waste runoff from causing pollution
- Feeding locations within seasonal feeding areas must be at least 30 m from watercourses and be distributed throughout the area to prevent accumulation of manure that causes pollution.

14.2 B.C. Ministry of Agriculture recommended management practices for phosphorus in B.C.

The B.C. Ministry of Agriculture is responsible for providing guidance to agricultural producers about nutrient management. Phosphorus management guidance is contained in the 'Phosphorus Considerations for Nutrient Management' factsheet (Poon and Schmidt 2010). The factsheet contains guidelines to minimize the risk of phosphorus pollution of sensitive receiving environments in B.C. The guidelines are not enforceable. Guidelines are summarized here.

The guidelines are directed towards farms with high phosphorus soils in phosphorus-sensitive areas of B.C. which are defined as areas:

- Where streams and drainage systems empty into lakes
- Where there is opportunity for soil P transport from the fields to surface waters
- Where fields have subsurface drainage systems that empty ultimately into a lake system

Management practices to minimize transport losses of phosphorus

The following management practices are recommended to minimize phosphorus loss by erosion and runoff:

- Do not apply manure or fertilizer when there is risk of surface runoff from rain or snowmelt into the stream
- Establish well-vegetated buffer strips between the stream and field to catch eroded material
- Do not apply manure or fertilizer in the buffer strips
- Avoid over-applying phosphorus in manure and fertilizer to keep soil concentrations in the optimum range
- Improve irrigation and drainage management to minimize erosion and runoff
- Plant cover crops where practical to reduce erosion in fields with high soil phosphorus
- Direct surface runoff to retention/settling ponds

The following management practices are recommended to minimize phosphorus loss from drainage systems:

- Till tile-drained fields before manure or fertilizer application in spring to break up cracks and macropores
- On fields in perennial forage where tillage is not possible, apply manure in several small applications throughout the growing season.

Management practices to maintain or reduce soil phosphorus level

The factsheet contains guidance on acceptable soil phosphorus levels based on the Kelowna extraction method which is the standard analytical method in B.C. for soil available phosphorus. The following manure management practices are recommended to maintain or reduce soil phosphorus concentrations:

- Test soil to identify high phosphorus fields and apply manure and or fertilizer P only if required using the following guideline for soil P.
- Fields with low to medium P (<40 ppm available P) can receive manure to meet the crop P requirement
- Fields with optimum soil P (41 to 75 ppm) do not require either manure or fertilizer P for at least 1 year.
- Fields with high to excess soil P (>75 ppm) do not require either manure or fertilizer P for 1 to 2 years until soil levels decline.

Long term strategies for high phosphorus soils

The guideline also mentions several long term strategies to deal with soils with elevated phosphorus, including ration manipulation to reduce phosphorus in manure, exporting manure from the farm, and struvite extraction from manure.

14.3 The B.C. Environmental Farm Plan Program

B.C. has a voluntary, free and confidential Environmental Farm Plan Program, developed by the Ministry of Agriculture and delivered by the B.C. Agricultural Research and Development Corporation (Ardcorp) (Ardcorp 2014). The Environmental Farm Plan addresses all aspects of a farm's environmental impact and suggests management changes to mitigate environmental impacts. Due to the voluntary, confidential nature of the EFP program, it is not known how effective it is at mitigating environmental impacts from agriculture. There is no obligation for a producer to implement any of the EFP's recommendations but funding for eligible BMP's is linked to completion of recommendations. The EFP process does educate producers about areas of their operation that may be negatively impacting the environment.

The EFP program contains a nutrient management planning module which suggests that manure application should be based on P in P-sensitive fresh water areas or when risk of runoff or erosion of soil is high. Completion of this module is optional based on the recommendation of the EFP planner. It is recommended when the producer's response to nutrient management questions in the EFP indicates the requirement for more in-depth nutrient management planning.

Soil testing is not mandatory when completing an EFP so fields with elevated P due to excess nutrient application would not be identified. Other environmental impacts such as inappropriate timing, rate and method of manure application would be identified.

15. B.C. Ministry of Agriculture Okanagan Agricultural Soil Study – Soil P Levels in Region

In 2007, the B.C. Ministry of Agriculture and researchers from Agriculture Canada undertook an extensive survey of soils on commercial agricultural fields in the Okanagan and Similkameen regions of the province. The study looked at many parameters in the soil, among them *plant-available phosphorus*, which is used to predict whether the amount of phosphorus in the soil can meet crop requirements, and *water-extractable phosphorus*, considered a good indicator of risk for phosphorus loss from soil by leaching and surface runoff (Kowalenko et al 2009).

A total of 56 fields were surveyed in the North Okanagan portion of the study area, all located in the area between Mara and Armstrong. Most of the fields surveyed were located in areas that drain into the Shuswap River and Fortune Creek. The fields were cropped to silage corn, cereals, alfalfa and grass, typical crops grown in the area as feed for dairy and beef cattle.

15.1 Soil plant-available phosphorus content

Soil available phosphorus was determined by the Kelowna P method, the standard method used in the interior of B.C. for this parameter. The resulting soil phosphorus levels were compared with a standard agronomic rating for soil available P by the Kelowna method (Table 17). Of the 56 fields surveyed, 36% were in the high category (51-100 ppm soil P) and 50% were in the very high category (>100 ppm soil P). Only 8 of 56 fields (14%) were in the low to medium soil P category (<50ppm soil P). A soil level of 20-30 ppm available P is considered adequate to provide phosphorus requirements for one year for crops with a moderate to high requirement for the nutrient. Soils in the high category contain residual P levels 2.5 to 5 times crop requirements, while soils in the very high category (50 % of fields surveyed) contain more than 5 times crop requirements.

Of the fields surveyed in the North Okanagan, those cropped to silage corn and cereals contained the highest residual phosphorus, 206 to 237 ppm available P, which is 10 to 12 times the soil level required to supply crop needs (Table 18). Research suggests that, when soil levels are very elevated, it can take 10 or more years of cropping without application of any P in manure or fertilizer to allow soil P levels to decline to the agronomic level and that these highly elevated P fields can be significant contributors of P to surface water. Fields cropped to silage corn also received the most fertilizer P; on average, 38 kg per hectare per year (as phosphate which is 43% phosphorus) but as high as 67 kg per hectare per year, on fields that already have elevated levels (Table 18). In contrast, fields cropped to alfalfa and grass contained the lowest residual soil P (70 to 74 ppm soil P), still well above the agronomic level of 20-30 ppm but not as elevated as fields planted to silage corn and cereals.

15.2 Risk of P loss to surface water

One of the goals of this soil survey was to assess the risk of loss of P from area soils to surface water. Soils were assessed for the proportion of available P that was water soluble as a predictor of the P that is susceptible to leaching and runoff. Overall, it was determined that soils in the Okanagan region have less capacity to bind phosphorus than Fraser Valley soils with the result that, because of the high residual P in soils in the valley, 96% of fields were considered to pose a potentially high to very high pollution risk (risk of P leaching or running off to surface water)(Table 18).

The study concluded that because of the high residual soil P and the limited P binding capacity of valley soils, Okanagan agricultural fields are at high risk for P loss to surface water and 'soil P amendment rates need re-evaluation and management practices to minimize transport of soil P …are necessary' (Kowalenko et al 2009).

Table 17. Soil Phosphorus Status of Okanagan Soils According to Agronomic Criteria for Crops with Moderate to High Phosphorus Requirement

Agronomic Rating	Armst-rong	Vernon	Kelowna	Summer-land	Oliver	Similka-meen	All
(mg kg^{-1} Kelowna P)	*Number of fields*						
Low (0-20)	5	1	0	1	0	6	13 (7%)
Medium (21-50)	3	7	3	1	6	12	32 (18%)
High (51-100)	20	11	8	7	4	6	56 (31%)
Very High (100+)	28	18	17	4	7	5	79 (44%)
mg kg^{-1} Kelowna P (0-15 cm depth)							
Average	149	111	117	80	91	58	111

From Kowalenko et al 2009

Table 18. Mean Residual Kelowna Extractable Phosphorus Contents (0-15 cm depth) in 180 Fields that Represent Crops Grown in Six Regions of Okanagan-Similkameen Valleys of British Columbia in Comparison to Reported 2007 Soil Applied P.

Factor	Kelowna Extraction	Soil applied in P in 2007[x]		
		Mean	Minimum	Maximum
Crop Group	mg P kg^{-1}	kg P_2O_5 ha^{-1}		
-Apple	122	3	0	26
-Cherry	106	23	0	154
-Other tree fruit	83	14	0	60
-Grape	94	18	0	78
-Alfalfa	122	13	0	116
-Alfalfa/grass or barley mix	74	19	0	82
-Grass (cultivated or natural)	70	24	0	110
-Forage corn	237	38	0	67
-Cereal	206	23	0	116
-Vegetable	105	28	0	64
Management	mg P kg^{-1}	kg P_2O_5 ha^{-1}		
-Conventional	115	17	0	116
-Organic	102	20	0	154
-Transitional	107	32	0	94
-Unknown or other	75	31	0	62
[x] Data for only 165 of these fields were available for reported P applications				

From Kowalenko et al 2009

16. Agricultural Nutrient Management Strategies in the Shuswap Watershed

For livestock and poultry operations in the study area, nutrient management includes managing nutrients from manure and other agricultural wastes, and nutrients from chemical fertilizer. In general, producers in the study area manage manure and other agricultural wastes based on the requirements of the *Agricultural Waste Control Regulation* (AWCR) and associated *Code of Practice* (see section 14.1 for more information). This mainly involves ensuring that manure does not run off into water or off the property and cause pollution. In terms of manure application rate, most producers apply manure roughly based on providing crop nitrogen requirements, or supplementing crop nitrogen requirements. They typically do not consider the contribution of other nutrients in manure to meeting crop requirements.

The application of nutrients in chemical fertilizer is not regulated in B.C. There are no regulations or environmental guidelines for timing, location, method or rate of application of chemical fertilizer. Because of the cost of chemical fertilizer, it is assumed that producers use only what is required to meet crop requirements.

16.1 Dairy

Dairy producers in the study area routinely apply both manure and chemical fertilizer to their high-value crops. Corn silage typically receives the most nutrients but grass and alfalfa crops are also fertilized heavily. Dairy producers typically apply manure to enhance overall soil fertility, although there is some effort made to consider its nutrient content. Fertilizer application rates are usually determined by the fertilizer provider based on the results of soil testing that they conduct for the farmers.

Phosphorus starter fertilizer: On silage corn, fertilizer companies (as well as the Ministry of Agriculture) frequently recommend a small amount of phosphorus fertilizer at planting (20-30 kg phosphate per hectare) to kick-start plant growth even if the soil contains sufficient to meet crop requirements. This is because, on annually cropped land early in the growing season, phosphorus is sometimes released from soil more slowly than the growing crop requires it with the result that a temporary deficiency results. Research suggests that crop yields overall are not usually affected by this; the crop catches up once sufficient soil P becomes available later in the spring. However, fertilizer companies are reluctant to eliminate ‘starter-P’ and farmers are also reluctant to risk a yield loss. This results in phosphorus application to many fields that do not need it and a general exacerbation of the residual phosphorus problem.

Fields used to produce high-value crops, particularly annual crops, typically receive an annual application of manure which provides some phosphorus which is not accounted for by the producer, and also receive some fertilizer P with the result that P application in manure and fertilizer generally exceeds crop uptake. The result of this is that soil levels have gradually increased over time so that it is expected that most fields in the North Okanagan/Shuswap region that have been farmed intensively have elevated levels of soil P.

Under the AWCR, in the Interior of the province manure can be applied at any time of the year provided that there is no movement of the manure into surface water as a result of the application. There is a considerable amount of manure applied to farm land in the fall in order to empty manure pits for the over-winter storage period. If applied to low-lying land susceptible to flooding, fall-applied manure can move into surface water with flood waters the following spring because there typically is insufficient crop growth overwinter to assimilate the nutrients from the manure.

16.2 Beef

On ranches in the study area, significantly less nutrients are applied to crop land because of the economics of beef production (relative to dairy production). Fertilizer application is limited to the minimum amount necessary to generate reasonable forage yields. Because of this, fields on area ranches are not generally over-supplied with phosphorus; in fact, many may be deficient in this nutrient. The exception to this is ranches that have a feedlot attached; the manure from the feedlot will increase the overall fertility of ranch fields.

On beef cattle operations, manure is deposited around the land base by grazing animals, and almost half of the manure produced by the herd is deposited on rangeland far removed from the valley bottom fields. On most fields, manure is not present in sufficiently high quantities to impact surface water. The exception to this is winter feeding and calving areas where there can be a substantial accumulation of manure which can lead to phosphorus-containing runoff (and other nutrients) during snowmelt and to manure movement into surface water during flooding of low-lying land.

Ranchers have been encouraged to fence streams from cattle access and thus to reduce direct deposition of manure in surface water, and damage to riparian vegetation and stream banks. Many have done this however many have been reluctant to do so. The AWCR permits livestock access to surface water on range and grazing land.

16.3 Poultry

Nutrient management on commercial poultry operations generally involves exporting some or all of the manure off their property. Commercial poultry producers in B.C. generally have insufficient land to utilize the nutrients in the manure. This is because they typically do not grow any of their own feed but rather feed grains and protein sources that are grown on the prairies. They may apply a small amount of manure to their own land but generally they sell or give away the rest. Some producers compost their manure and sell it to home gardeners. Despite this general movement of poultry manure off-farm, it is expected that phosphorus levels on land that has routinely received poultry manure will be, in general, very high because poultry manure contains significantly more phosphorus than livestock manures and it is produced and handled in solid form which is much more concentrated than the liquid manures produced by dairy farms. What seems like a low application rate of poultry manure will in fact contribute a substantial amount of phosphorus and other nutrients to the soil.

On a positive note, educational efforts on the part of the Ministry of Agriculture over the past 25 years have contributed to a new awareness of the nutrient value of manures and this has led to demand for poultry manure for use on dairy farms, organic farms and fruit growing operations. This has taken the pressure off the small land base typically owned by poultry producers.

16.4 Small holdings

Small holdings are completely unregulated with respect to nutrient management. Nominally they also must adhere to the requirements of the AWCR but in fact, because of their generally small numbers of livestock, there is little oversight. There is the potential for soil buildup of phosphorus on small holdings where there are many animals on a small land base. There is also potential for loss of phosphorus into surface water by all the same mechanisms that can occur on commercial farms.

17. Recommendations for a Nutrient Management Strategy for the Shuswap Watershed and Cost Estimates for BMPs

17.1 Identification of source or sources of phosphorus in the Shuswap, Salmon and Eagle Rivers.

The water quality data compiled and presented in the 2011, 2012 and 2013 SLIPP Shuswap Watershed water quality reports suggests that the primary source of P entering the Shuswap Lake system is the tributaries in the southern half of the watershed, mainly the Shuswap River, the Salmon River and the Eagle River. Of these three rivers, the Shuswap River apparently contributes twice as much P to the lakes as do either the Salmon or Eagle River. The concentration of P in the Shuswap River increases steadily from the outlet at Mabel Lake to the inlet at Mara Lake, with the largest increase observed in the area between Enderby and Mara. Smaller amounts of P enter the lakes in the Adams and Seymour Rivers and in the smaller tributaries.

The SLIPP water quality data does not provide any information about the source of the phosphorus entering Shuswap and Mara Lakes in the Shuswap, Salmon and Eagle Rivers. The water quality data modelling done by Tri-Star Environmental Consulting points to agriculture as a major source, but there is currently no data confirming that there is agricultural contribution nor does the data identify the mechanisms by which agricultural-source P may be entering surface water. There are a significant number of dairy farms using the land base along the affected rivers and there are also a large number of beef cow-calf operations and small holdings as well as some commercial poultry operations. It is likely that, if agriculture is contributing to the P loading in the lakes, all of these types of agriculture contribute to it.

It is therefore recommended that the Shuswap Watershed Council develops and seeks funding for a long-term water quality monitoring program to identify sources of phosphorus. To ensure that data collected is credible, it is recommended that the water quality program is undertaken by a research institution such as UBC-Okanagan or Thompson Rivers University. The program should have as primary goals to identify the sources of phosphorus in the affected rivers and to identify the mechanisms by which the phosphorus is entering the river. It will also be important to identify which areas along the rivers are contributing P; research suggests that typically, a small area of a watershed can be responsible for a large proportion of the P loading.

The water quality data collected and compiled during 2011-2013 by SLIPP suggests that there is both dissolved and particulate P in the affected rivers and that these two forms are present during different times of year in the river. If there is contribution of P to the affected rivers from agricultural land along the river, the likely mechanisms by which this is occurring will differ between dissolved and particulate P.

***Probable transport mechanisms of dissolved P*:** dissolved P (a measure of ortho-P, the biologically available fraction) appears to predominate during the early spring runoff period (March and April) when P loading begins to increase in affected rivers. Dissolved P moves from agricultural land to surface water by two mechanisms, surface runoff and subsurface flow. In the North Okanagan and Shuswap, surface runoff typically only occurs during the very brief early spring period when snowmelt occurs. Research suggests that snowmelt runoff can contribute a significant amount of P to surface water, particularly from fields that contain elevated levels of P such as are found throughout the region. Subsurface flow could also be substantial from the land base along the river. In the dairy farming areas of the Shuswap and Salmon Rivers, the land adjacent to the river is flat, low-lying, and prone to flooding and/or elevated groundwater during spring freshet. Many of the soils located adjacent to the rivers are coarse-textured and thus prone to subsurface loss of P. Some of the finer-textured soils are drained with ditches and artificial drainage to lower the groundwater table to allow the fields to be worked earlier in the spring, a condition that also promotes subsurface flow of P, especially considering the elevated phosphorus level in area soils. The small amount of water quality testing conducted along Fortune Creek suggested that there is a large contribution of dissolved P entering along the length of the creek; this may be an area where dissolved P sources can be identified.

***Probable transport mechanisms of particulate P*:** according to the water quality data in the 2011, 2012 and 2013 SLIPP reports, particulate P (P attached to soil or manure, not biologically available) makes up more than half of the P in the affected rivers during the May through July period when the local snowmelt is finished but water levels are high because of snowmelt at higher elevations. Particulate P moves from agricultural land to surface water by soil erosion, stream bank erosion and also by runoff of manure from low-lying areas that flood during high water. On the land base along the affected rivers, there is not likely to be soil erosion from fields because in general, during the May through July period, there is not sufficient precipitation in the region to produce runoff or erosion and the land base is primarily flat. There is likely some stream bank erosion which may contribute a significant amount of P to the rivers especially if the eroding land has elevated P. There is also likely some movement of manure into water from flooded areas from beef cattle and from fall-applied dairy or poultry manure on land close to the rivers or tributaries. There may also be a significant amount of re-suspension of sediment during freshet, sediment that is deposited in ditches, sloughs, streams and in the affected rivers during low flows from August through March of every year; this may be partly responsible for the predominately particulate phosphorus observed, for example, in the lower Shuswap River during freshet. It is possible that much of the phosphorus originates as sediment which is deposited in waterways during low flow periods of the year.

The P source research program should identify the sources of both forms of P in the river; the particulate P because it is being added to the lakes is large amounts and can become biologically available over time, and the dissolved P because it is immediately biologically active.

17.2 Education and dialogue

If the SWC wishes to engage with the commodity groups located in the study areas, the following strategies are recommended:

1. Maintain communications with KODA and consider establishing communications with local cattlemen's association and poultry producers. Engage them around existing water quality data and the potential for P loss from farm land to surface water.
2. Implement educational programs aimed at agricultural producers who own or lease land adjacent to surface water in the watershed. Effective educational programs include:
   - Seminars and workshops with local and industry experts covering a range of topics relevant to P mitigation on-farm such as: impact of P in surface water, managing manure application for P vs. N; how P moves into surface water and how to minimize the risk of P movement into water;

reducing P content of feed; fertilizing based on soil test results.
- Newsletters with information on P mitigation strategies, P management on farm, results of P mitigation research.
- Demonstration trials and field days to educate producers about fertilizing based on soil test results, and the potential for reducing or eliminating use of P fertilizer.

17.3 Implementation of P mitigation practices

Reduce P loading to the land base along lake tributaries

If it is established that there is a contribution of P from agriculture along the affected rivers, the most effective long term strategy for reducing P loading of surface water appears to be to reduce the loading of P on the land base.

Based on the findings of the literature review and the existing conditions in the area, the most important tool to begin to reduce phosphorus movement to surface water is to reduce the amount of phosphorus applied to area soils in chemical fertilizer, dairy manure and poultry manure to stop the increase in soil phosphorus and eventually to allow soil levels to decline. This type of strategy would be best aimed at the dairy industry in the area as dairies are heavy users of nutrients, and the poultry industry to a lesser extent because they produce a large volume of manure on a small land base. This would best be accomplished through on-farm nutrient management planning and an industry-wide education program for all dairy producers and poultry farms located in P-sensitive watersheds in the province.

Develop strategies for reducing P movement to surface water based on the transport mechanisms active on agricultural land in the study area

If further water quality testing establishes that there is a contribution of P from agriculture along the affected rivers, and if the P transport mechanisms are identified, mitigation strategies can be put in place to reduce P movement from agricultural land to surface water. At this time it is not possible to identify a P mitigation strategy without knowing which transport mechanism or mechanisms are most important in moving P into surface water.

The most likely transport mechanisms for dissolved and particulate P during the early spring runoff period (March and April) are surface runoff during snowmelt and subsurface flow. The most likely transport mechanisms for dissolved and particulate P during the May to July high water period are manure runoff, subsurface flow, stream bank erosion and re-suspension of sediments. Mitigation measures will differ for each of these transport mechanisms and each will require implementation of a unique set of best management practices. In the case of mitigation of P in subsurface flow from agricultural land via drainage ditches or shallow groundwater flow, there are not currently any economically viable mitigation measures available.

17.4 Relative cost of P mitigation practices

Source reduction strategies

P source reduction management practices are considered the most cost-effective BMPs. Source reduction strategies include:

- Soil testing to identify fields with excess P

- Reducing or eliminating chemical fertilizer use
- More closely matching chemical fertilizer use to crop requirements
- Optimizing placement of P fertilizer to optimize crop uptake
- Applying manure to fields with low soil P
- Optimizing manure application timing, location, rate to minimize risk of movement into surface water

All of these strategies are very cost-effective because they are typically no more expensive and may be less expensive than the management practices currently in use. The exception to this is farms where all of the land base has elevated P and is considered at risk of P movement to surface water; in this case, the cost to handle manure may increase if it has to be hauled off the farm.

Transport reduction strategies

Without knowing the mechanisms by which P moves to surface water from agricultural land in the Shuswap watershed, it is difficult to provide cost estimates for BMPs. The cost of BMPs is largely irrelevant because there are typically only one or two options for control of P transport for each mechanism. For instance, if subsurface flow to ditches is contributing a significant amount of P to surface water along the affected rivers, the options for control will include tile drain amendments or constructed sediment basins, both of which are very expensive. Conservation buffers will have no impact on subsurface flow. If stream bank erosion is a significant contributor of particulate P, stream bank stabilization with riparian vegetation, with livestock exclusion fencing if required, is the only BMP that will effectively reduce P loss by this transport mechanism. If snowmelt runoff is a large P contributor, large sediment basins or very wide buffer strips will be required in susceptible areas, both of which will be very expensive.

In general, the cost of BMPs increases from lowest cost to highest cost as follows:

1. conservation tillage – zero or low till, contour farming, terraces, cover cropping
2. conservation buffers – riparian buffers, grassed waterways
3. soil or tile drain amendments to capture P - alum applied to pasture land to bind P, tile drainage installations using residuals to capture and bind P in drainage water
4. sediment retention structures – constructed dams, sediment ponds, constructed wetlands, natural seepage wetlands

18. Funding Programs for Phosphorus Mitigation on Agricultural Land

18.1 Beneficial Management Practices funding through the Growing Forward 2 Fund

Funding is available for on-farm implementation of beneficial management practices through the Growing Forward 2 fund. This is a $3 billion federal, provincial and territorial fund to support agriculture from 2013 to 2018 which funds innovation and adaptability in agriculture, and part of the funding is allocated for agriculture sustainability which encompasses the type of programs needed to enhance water quality. The program is delivered by the B.C. Agricultural Research and Development Corporation (Ardcorp). Ardcorp also administers the Environmental Farm Plan program. It is aimed at providing funds to individual producers to implement BMP's on farm, and not at research or demonstration-type projects (Ardcorp 2014).

The main relevant funding category under the Growing Forward 2 fund is Sustainable Agriculture Management. There are two programs available in this category, Environmental Farm Plans (EFP) and Beneficial Management Practices (BMP).

In order to access BMP funds, a farm must have a completed Environmental Farm Plan. This is a free service provided by the Ministry of Agriculture. With a valid (less than 5 year old) EFP, producers can access cost-shared funds from Growing Forward 2 to make improvements identified in the EFP. Eligible projects fall under the following categories:

- Waste management
- Soil riparian integrity
- Water quality

Cost sharing ranges from 30 to 100% of the cost of implementation of the BMP and is capped at $1000.00 to $70,000.00 depending on the type of BMP.

The following are a few categories of BMP that are eligible under this program:

- Manure application equipment and technology
- Farmyard runoff control/storm water management
- Livestock wintering site management
- Riparian area management
- Riparian erosion control structures
- Nutrient management planning

Potential to reduce P movement to surface water in the study area

This program has excellent potential to reduce P movement to surface water provided that the BMP implemented on farm is targeted at a known P transport mechanism.

18.2 Alternative Land Use Services (ALUS)

The Alternative Land Use Services program (ALUS) was started to support farmers by compensating them for removing non-viable farmland from production which could then be used to preserve and reconstruct natural areas and fragile ecosystems. It was formed in Manitoba in 2006 as a result of a collaboration between Keystone Agricultural Producers (KAP), which is the largest farm organization in Manitoba, and the Delta Waterfowl Foundation (ALUS 2014). Since 2006, Ontario, Saskatchewan, Prince Edward Island and Alberta have all adopted ALUS, and several projects are underway in those provinces.

The main goal of ALUS is to support farmers and ranchers and promote cooperation between communities and farmers to create landscapes that sustain agriculture, wildlife and natural spaces (ALUS 2014). ALUS programs are developed and run by the communities and the farmers. Farmers can enrol with ALUS, and provide land that is inefficient or unproductive as farmland, or land that requires environmental protection. This could include highly erodible fields, steep slopes, or fields that are susceptible to flooding. ALUS determines the best use for the land through site visits and consultations, and the project is developed with the help of the farmer and ALUS staff. An audit by a government body is also mandatory. The land provided is used to create and retain natural spaces including wetlands, native grasslands and critical habitat for wildlife.

ALUS programs are funded by a variety of organizations including provincial and federal governments, private foundations, councils and environmental groups (ALUS 2014). Most of the funding is from corporations and community groups within each individual province, not from the national ALUS organization. ALUS pays farmers the equivalent land rental rates for their area when they enrol and agree to an ALUS program. A typical conservation agreement between ALUS and farmers is 3-5 years in length.

There have been successful examples of ALUS programs implemented on farms in many small communities in Canada. One example is the work done in Norfolk, Ontario. Van Meer Farms grow 8,000 acres of field corn and soybeans (ALUS 2014). They developed an ALUS program to grow native grasses around the edges of the fields where productivity was very low. This encouraged biodiversity by encouraging growth of native species, but it also reduced gully erosion when there was surface run-off to nearby ditches. Another example is the Trent Selte Farm in Alberta. They have initiated projects to preserve important ecosystems by protecting several wetlands on the property.

Potential to reduce P movement to surface water in the study area

This program appears to be primarily used to enhance wildfowl and fish habitat by removing marginal farmland from production and compensating farmers for loss of production. The program could be effective at reducing P movement to surface water provided that the conservation measures were developed based on a known transport mechanism of P from agricultural land to water. This would have to be based on water quality and soil loss monitoring to determine the mechanisms by which P is moving into surface water, and implementing practices that are aimed at reducing P movement by those mechanisms. The types of projects that have been completed to date have been aimed at reducing soil erosion on sloping land; the land along the Shuswap, Salmon and Eagle rivers is primarily flat and therefore not subject to erosion except during the very short window of snowmelt.

19. Conclusions

- Extensive research in the U.S, the E.U., Canada and New Zealand in the past 30 years has found a significant contribution by agriculture of P to surface water, primarily in areas of intensive agriculture. Agricultural-source P has been implicated in water quality degradation in many areas of the world. On-going P mitigation programs have been focussed on reducing the amount of P used in agriculture in susceptible areas, and on reducing the amount of P moving into surface water.
- Water quality monitoring in the Shuswap watershed between 2011 and 2013 by SLIPP found elevated P in the Shuswap, Salmon and Eagle rivers during freshet. The Shuswap River was found to contribute twice as much P to the Shuswap Lake system as the Salmon or Eagle rivers. In the Shuswap River, the area from Enderby to Mara was found to contribute a significantly larger amount of P than the area above Enderby.
- No source of the elevated P was identified by water quality testing although agriculture was identified as a potential major contributor by the modelling completed under SLIPP (Tri-Star Environmental Consulting 2014).
- The land base along the Shuswap, Salmon and Eagle Rivers is primarily used for agriculture, mainly for feed for dairy and beef animals.
- Agriculture along the Shuswap River from Enderby to Mara and along Fortune Creek, as well as along the lower Salmon River is primarily intensive, mainly dairy and poultry operations.
- Agriculture along the Shuswap River upstream of Enderby to Mabel Lake, along the upper Salmon River and along the Eagle river is primarily land-based, mainly beef cow-calf operations and small holdings.
- The soil levels of P were found in a Ministry of Agriculture study in 2007 to be elevated on intensively farmed fields throughout the Okanagan, and the report concluded that, due to the high available P and low P binding capacity of area soils, soils were at high risk for runoff and leaching losses of P.
- Based on these conditions in the areas along the Shuswap, Salmon and Eagle rivers, it is recommended that the Shuswap Watershed Council develop and seek funding for a water quality program to determine the source of P in the study rivers and tributaries, and if there is a contribution from agriculture, to identify the mechanisms by which P is moving from agricultural land into surface water. Based on the results of this water quality monitoring, mitigation measures can be identified to reduce the movement of P into the Shuswap Lake system.

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