Spring Snowmelt Impact on Phosphorus Addition to Surface Runoff in the Northern Great Plains

By Tom Jensen, Kevin Tiessen, Esther Salvano, Andrea Kalischuk, and Don N. Flaten

Recent research in Alberta and Manitoba, Canada, confirms that snowmelt runoff is the dominant portion of annual total runoff from agricultural watersheds in the Northern Great Plains (NGP) of North America. The region is character-ized by relatively level landscapes and a dry climate with cold winters and warm summers. Many of the methods used to estimate the risk of P movement into surface streams and lakes were designed for warmer, more humid environments and steeper topography where rainfall runoff is dominant and particulate P associated with soil erosion is the main non-point P source from agricultural land. In the NGP, however, soluble P originating from surface soil, plant residues, and surface-applied manure is a larger proportion of total P runoff than particulate P, especially during the spring snowmelt. Soil erosion control methods that help reduce P loading into surface waters in warmer, more humid climates may be less effective in reducing P losses in the NGP. Recent research in the region also suggests that soil-test P is highly correlated with total P losses in snowmelt runoff. In the NGP, these studies show that P losses in runoff can be most effectively reduced and controlled by avoiding the development of excessively high soil-test P levels.

Movement of nutrients in surface runoff is a natural process in the environment. Under so-called pre-settlement conditions in the NGP, surface runoff naturally moved nutrients from grasslands, parklands, and forests. Nutrients in runoff exist primarily in either dissolved form or particulate form (attached to soil particles). Movement of nutrients in runoff is essential to aquatic ecosystem health as a source of nutrients for microbes, aquatic plants, and aquatic animals.

The movement of nutrients from the landscape to water bodies, however, can be enhanced by human activities including agriculture, forestry, urbanization, industry, and recreation. These activities can promote nutrient loss through land clearing, and the application to land of fertilizers, manures, treated sewage, industrial waste effluents, and sludges. As an example, an 8-year water quality monitoring study of 23 agricultural watersheds in Alberta showed that as agricultural intensity increased, water quality decreased, including increased N and P concentrations in surface water (Lorenz et al., 2008). These additions along with continuing nutrient movement from undisturbed grasslands, parklands, and forests all contribute to the total nutrient loads in surface waters.

Excess P, and N to a lesser extent, can enhance growth of algae (i.e., algal blooms) and other aquatic plants causing eutrophication in freshwater streams, sloughs, and lakes. The growth and subsequent death and decomposition of algal blooms can reduce oxygen content (anoxia) in these surface water bodies. Reduced oxygen content can harm aquatic plants and animals. One example for this concern is the deteriorating water quality in Lake Winnipeg in Manitoba, Canada (the10th largest freshwater lake in the world). The Lake Winnipeg watershed includes most of the southern parts of Alberta, Saskatchewan, and Manitoba. Similar to other water bodies in the NGP, this lake has experienced more frequent and intense algal blooms in recent years, primarily attributed to excess P loading from the watershed (Lake Winnipeg Stewardship Board, 2006).

The actual loading of P in surface waters is dominated by snowmelt runoff in much of the NGP where regular snowfall is received. This is different compared to warmer and more humid areas of the world where loading of P is typically dominated by runoff caused by intense rainfall. Runoff caused by rainfall is often associated with soil erosion, and the majority of total P (TP) entering surface water is particulate P (PP). In contrast, snowmelt runoff is usually less erosive because snowmelt has lower kinetic energy than raindrops and flows over soil that is often still frozen. The majority of P in snowmelt water is dissolved P (DP) rather than PP. Two recent field studies, in Alberta and Manitoba, have shown that the amount of P lost during the snowmelt process is strongly related to the concentration of soil-test P in surface soils (Little et al., 2007; Salvano et al., 2009).

In the study from Alberta, runoff was monitored from eight fieldscale watersheds for 3 years (Little et al., 2007). One of the objectives of this research was to determine the relationships between soil-test P (STP) and the degree of soil P saturation (DPS) with runoff P including TP and dissolved reactive P (DRP). The volume of water and nutrient content of water samples were collected from fieldsized catchments under spring snowmelt and summer rainfall conditions. All eight sites had high runoff potential, uniform management, and no farmyard or non-agricultural influences. The watersheds in the study ranged in size from 5 to 613 acres. The

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Snowmelt runoff in the Northern Great Plains.

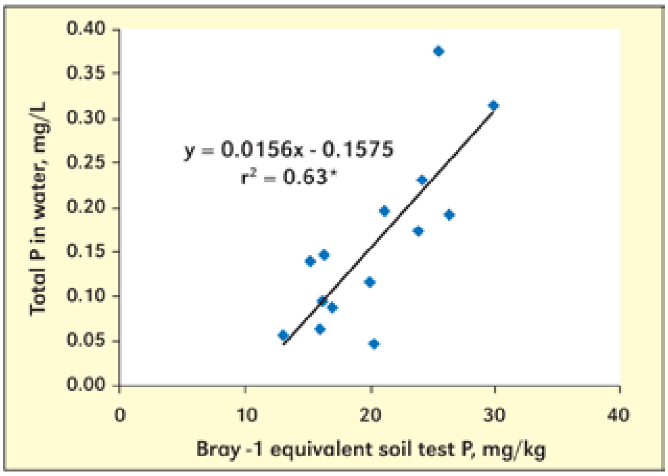

Figure 1. Relationship between overall mean total P in surface water of 14 regional watersheds and Bray-1 equivalent STP concentrations in watersheds.
* Significant at $p < 0.01$. (adapted from Salvano et al. 2009)

majority of runoff (>90% among all sites) was generated from spring snowmelt. Strong linear relationships between STP and P in runoff were determined in this study. Soil-test P accounted for 88% of variation in TP concentrations in the runoff from the watersheds. Reduced levels of STP following the cessation of manure application corresponded directly with reductions in runoff P. Although a number of different STP sampling strategies were examined, a simple average of all soil sampling points was as good a predictor of runoff P concentrations compared to more detailed soil sampling procedures. There were no signiflcant differences among the relationships using different soil sampling depths of 0 to 1 in., 0 to 2 in., and 0 to 6 in. Therefore, it is likely that a common agronomic soil sampling depth of 0 to 6 in. can be used to predict P in runoff from agricultural land in Alberta. Although the DPS holds promise for predicting runoff and leaching losses of P, STP is the standard for agronomic sampling in Alberta and the results suggested that there is no strong reason to use DPS instead of STP.

In the study from Manitoba, Salvano et al. (2009), evaluated the relationship between water quality data for P and three existing P loss risk indicator methods developed to estimate P loss at a regional scale: 1) Birr and Mulla's P Index for Minnesota, 2) the Preliminary P Risk Indicator for Manitoba, and 3) a preliminary version of Canada's National Indicator of Risk of Water Contamination by Phosphorus. Validation of the P loss risk indicators was conducted using long-term water quality monitoring data consisting of TP concentrations collected from 14 watersheds in Manitoba, representing nearly level and rolling landscapes in eastern and western regions of the province, respectively. Water quality data in the watersheds were collected for 11 years from 1989 to 1999. Available STP data for each watershed from 2000 to 2003 were provided by Bodycote Testing Group for fields in each watershed. This was compared to estimated fertilizer P application rates at the regional level using data extracted from the 2001 Census of Agriculture database and Canadian fertilizer consumption recordsSalvano et al. (2009) reported that correlations between the three P risk indicators and P losses to surface waters were poor and generally insignificant. It was thought that the poor correlation was because of the emphasis on soil erosion risk in the risk indicator methods; soil particulate runoff is a low proportion of P in runoff during spring snowmelt, which is the dominate form of runoff. In contrast, STP accounted for 63% ($p<0.01$) of the variation in TP concentrations in water samples (**Figure 1**). Although soil erosion had the most influence on the values generated by the three P risk indicators, STP had the most influence on TP concentrations in runoff water. Therefore, these P risk indicators appear to be too heavily weighted towards soil erosion processes for use under Manitoba conditions.

The extremely poor relationship between erosion and TP concentrations may have implications regarding the value of erosion control measures for reducing P loading in the Manitoba prairie region watersheds. For example, recent studies have determined that P loading to Manitoba waterways is either reduced by only a small degree or even increased by traditional erosion control best management practices (BMPs) such as vegetative buffer strips (Sheppard et al., 2006), and conservation tillage (Glozier et al., 2006), respectively. Therefore, to quantify the risk of P loss and the relative contribution of P loss, Salvano et al. (2009) suggest that research should be conducted that will develop and evaluate BMPs designed to reduce the snowmelt-driven losses of P, mostly in dissolved forms, throughout the nearly level landscapes of the prairie region of southern Manitoba.

Expanding on the report of Glozier et al. (2006), Tiessen et al. (2010) compared the seasonal runoff and nutrient losses from two long-term, adjacent paired watersheds in southern Manitoba. One watershed was 10 acres in size and under conventional tillage (i.e., <30% surface reside after planting, receiving primary and secondary tillage operations followed by a harrowing operation before planting). The other was 13 acres in size and under conservation tillage (i.e., direct seeded or no-till with moderate disturbance and >30% residue from the previous crop remaining on the soil surface after planting) (**Figure 2**). The paired watersheds were monitored between 1993 and 2007, before and after conservation tillage was introduced in 1997 on the 13 acre watershed. Data were separated into three principle time-periods: 1) a 4-year calibration period (1993-1996); 2) a 7-year transitional period (1997-2003); and 3) a 4-year treatment period. The watersheds are 93 miles southwest of Winnipeg, Manitoba.

Yearly runoff patterns at the paired watersheds

Figure 2. Division between the paired watersheds: conventional (on left) and conservation tillage (on right), October 2005.

Table. 1. Four-year average (2004 to 2007) of residue cover and soil-test data at the Manitoba paired watershed study (Tiessen et al., 2010).

Watershed	Residue cover, %	Snow-water equivalent, in.	Nitrate-N 0 to 6 in., lb N/A	Olsen-P 0 to 6 in., mg/kg	Organic matter, 0 to 6 in.,%
Conservation tillage	56 a*	0.32	5.8 b	19.1 a	3.8
Conventional tillage	19 b	0.31	7/4 a	13.1 b	3.5

*Within columns values followed by different letters are significantly different ($p<0.05$).

period (**Figure 3**).

Additionally, of total N and P nutrient export, dissolved nutrients were the dominant form of nutrients compared to particulate nutrients from the two watersheds, in both the spring and summer. The importance of dissolved nutrients was especially evident during the spring snowmelt period when >80% of N and P were exported in the dissolved form (**Figure 3**).

displayed a spring melt peak, typically in March or April, and multiple rainfall event peaks at various times between May and November. This region of the Canadian prairies typically has one snowmelt period lasting several days, if not weeks, and fewer than five rainfall-induced runoff events per year (Tiessen et al., 2010). Data were split into snowmelt and rainfall seasonal periods. Soil samples were collected after harvest in the fall, before the conventional tillage field was cultivated, from both of the watersheds in each year of the 2004 to 2007 study period. Crop residue cover percentage was also determined in the spring after all field operations were conducted. To determine the quantity of water available for runoff within each watershed, snow depth and density were measured in late winter, just before the spring snowmelt (**Table 1**).

Tiessen et al. (2010) report that snowfall accounted for only 25% of total annual precipitation during the study period. However, snowmelt runoff accounted for 80 to 90% of total annual runoff export from these two watersheds. In this study, on average, concentrations of dissolved nutrients in runoff were higher during snowmelt than rainfall events, whereas, concentrations of total suspended sediment (TSS) and particulate nutrients were greatest during rainfall events during the treatment period. However, because snowmelt was the dominant hydrological process, the majority of particulate and dissolved nutrient export occurred during the snowmelt

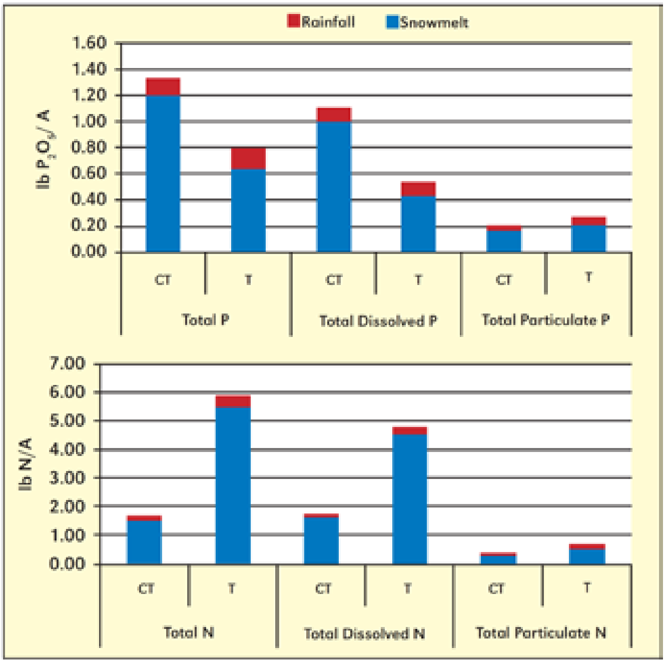

Figure 3. Total, dissolved, and particulate P_2O_5 and N export as annual, snowmelt and rainfall runoff by tillage systems, 4-year average (2004 to 2007). (Note, not controlled for differences in watersheds and seasonal climate variability.)
CT = Conservation Tillage; T = Tilled

The effectiveness of no-till in reducing TSS losses has been well documented (Baker and Laflen, 1983). However, previous studies have reported that no-till reduces total losses of nutrients because of significant decreases in runoff volume and sediment mass. In the study by Tiessen et al. (2010), snowmelt runoff was similar for the two tillage systems at 10,389 and 10,432 ft3/A for conservation tillage and conventional tillage, respectively, while rainfall runoff was about half for conservation tillage compared to conventional tillage (1,143 and 2,472 ft3/A, respectively). These results suggest that under the climatic conditions of subhumid southern Manitoba, conservation tillage can be effective in reducing rainfall runoff, but not snowmelt runoff. One suggested reason is because in this part of the eastern, more humid, portion of the NGP, the snow pack was typically large and premelt snow water equivalent on the conventional tillage and conservation tillage watersheds were almost identical (**Table 1**). In the more arid western part of the NGP, where snowfall can be less and warm Chinook winds occur sporadically during the winter and early spring, there may be differences in snowpack (the magnitude of the snow trapping effect by conservation tillage is expected to be greatest in regions with very little snow), melting, and runoff sessions between conventional and conservation tillage cropping (Pomeroy and Gray, 1995).

Interestingly, Tiessen et al. (2010) report that the two tillage systems affected N and P differently (**Figure 3**). Converting to conservation tillage resulted in lower export of total N (TN), but greater export of TP. After controlling for 1) differences between the two watersheds that existed prior to introducing conservation tillage to one of them, and 2) seasonal and yearly climate and hydrological variability between the two watersheds, particulate P export was determined to have been reduced by 37% after conversion to conservation tillage.

The total dissolved P export, however, increased by 36% after conversion to conservation tillage. Since dissolved P was the dominant form of P export from both watersheds, this increase in dissolved P more than offset any decreases in particulate P export. This increase in P export occurred because the conservation tillage system was more susceptible to losses of soluble P in snowmelt runoff – likely due to the stratification of P at the soil surface (**Table 1**) and the leaching of P from crop and weed residues. Even though the total P losses in this study (i.e., average export of 1.33 lb P_2O_5/A/yr from the conservation tillage watershed from 2004 to 2007) may be minor from an agricultural perspective, they are of ecological significance because as little as 2 to 5 lb P_2O_5/A/yr has been associated with accelerated eutrophication of lakes in the United States (Sharpley and Rekolainen, 1997).

Management practices such as conservation tillage used to improve water quality by reducing sediment and sediment-bound nutrient export from agricultural fields and watersheds in warm, humid regions may be effective for reducing sediment and N losses, but less effective for reducing P losses in cold, dry regions where the nutrient export is snowmelt driven and primarily in the dissolved form. In these situations, it may be more practical to implement management practices that reduce the accumulation of nutrients in crop residues and surface soils. One possible management option raised in the study by Tiessen et al. (2010) is that there may be potential benefits from some tillage operations in the fall prior to freeze-up and snow events. These tillage operations would incorporate a portion of crop and weed residues, as well as any manure applications, so that less soluble P will be at the soil surface and available to be exported from fields during snowmelt runoff. However, further research is required to test this theory.

From a practical viewpoint, all of the studies mentioned above show that STP is a very important factor in the amount of P lost from fields in the NGP, suggesting that P in runoff can be minimized if STP levels are not excessive. The same principles can be applied to N management, in that N additions from manure and inorganic fertilizer sources should be sufficient to supply crop needs, but not excessive to result in unnecessarily high levels of residual inorganic N (NO_3^- and NH_4^+) in topsoil. There needs to be further research determining what STP level guidelines should be, and what management practices can be used to control P losses from fields in cold climate regions of North America.

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Visual Indicators of Phosphorus Deficiency: Selected Crops

Phosphorus deficiency in canola

Phosphorus deficiency in canola