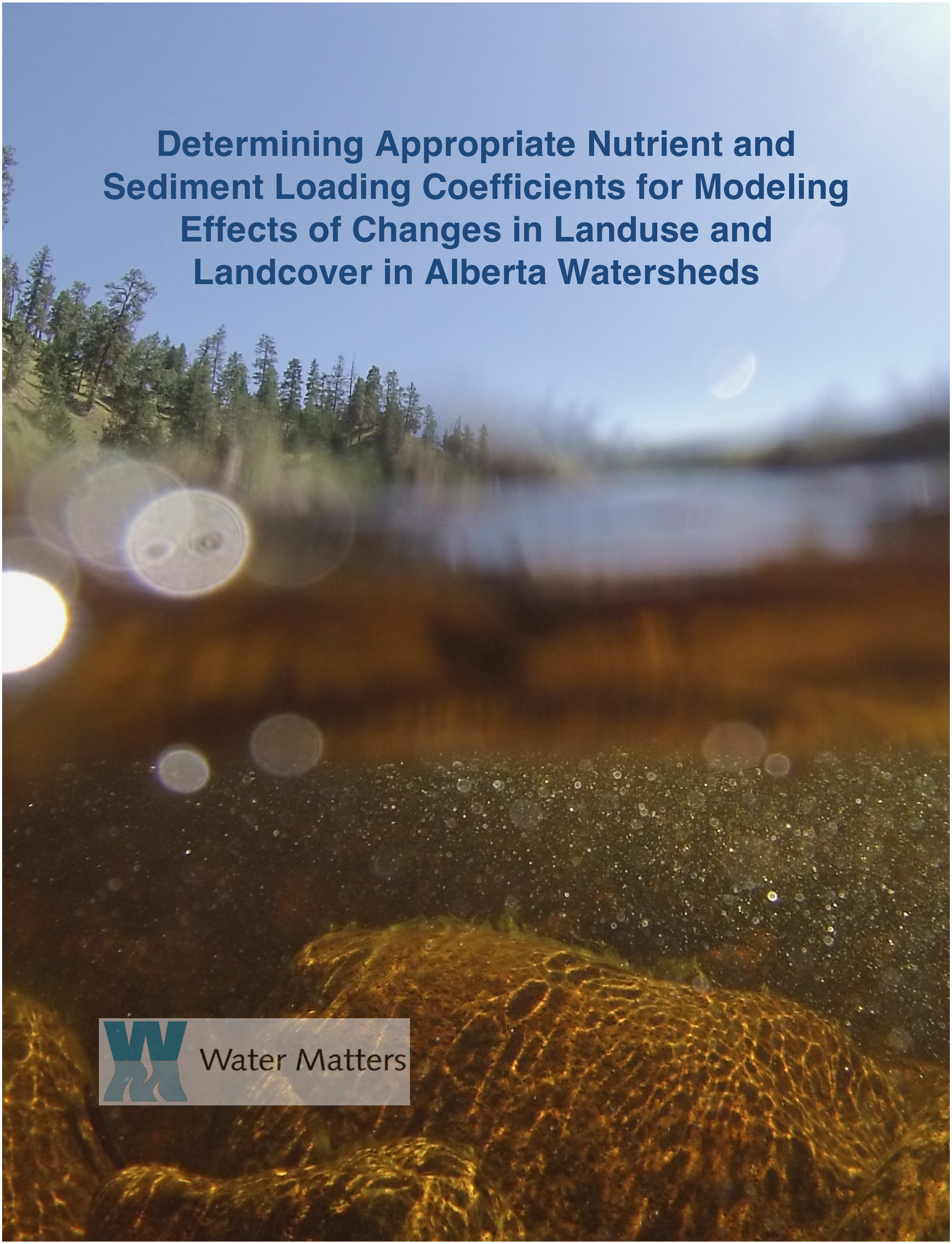
Determining Appropriate Nutrient and Sediment Loading Coefficients for Modeling Effects of Changes in Landuse and Landcover in Alberta Watersheds



Water Matters

Determining Appropriate Nutrient and Sediment Loading Coefficients for Modeling Effects of Changes in Landuse and Landcover in Alberta Watersheds

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Introduction

Alberta is engaged in creating watershed management plans throughout the province, that can be relied upon to provide direction for management of future development and landuse change, while attempting to protect the health of Alberta's rivers and lakes. Because of widespread and growing nutrient enrichment problems and their effect on ecosystem health, and increased downstream water treatment costs, the reduction or avoidance of excess loading of organic matter and nutrients into rivers is a common goal of water resource managers in Alberta and elsewhere. Sources of these deleterious substances include easily identified sources, such as a wastewater treatment plant (point sources), and diffuse non-point sources associated with human landuse and changes in landuse.[1-4] Informed landuse and watershed management that does not harm water quality and freshwater ecosystem health demands an understanding of the effects of landuse change on aquatic systems. Models that link landscape change and changes to water quality or aquatic ecosystem health are therefore relied upon to inform decision-makers, rather than simply tracking changes in water quality, which provides no insight into the sources of various chemicals.

Most commonly, catchment export coefficients and loading rates are modeled to estimate the effects of landuse change on pollutant delivery and water quality, because it is input loads tied to particular sources or landuse change that permit either the avoidance of effects or remediative action to mitigate them. These are generally derived from small-scale field studies, and can range from simple regression models[5] to more complex mechanistic models.[4, 6-12] However, loading rates or export coefficients derived from small-scale catchments are often of limited use in estimating the effects of large-scale land use changes on water quality, or when applied to other locations. Similarly, modeling of export coefficients and pollutant transport based on detailed, site-specific hydrogeological, climatic, and landcover information acquired from field studies is generally not possible because of the exceptional expense and time needed to acquire such data.[13, 14]

Because the utility of coefficients determined somewhere else is uncertain, it is recommended that regional or local pollutant export coefficients be developed for estimation of pollutant loading in water bodies if sufficient landuse, water chemistry, and flow data are available.[11] Unfortunately, in most regions, including Alberta, there has been insufficient environmental monitoring or effort to quantify effects of landuse change on nutrient and sediment export and water quality, in ways that enable land and water managers to make informed decisions to reduce the negative impacts of broad and large-scale landuse change or planning on water quality. Consequently, watershed managers must model estimates of risks of landuse change to aquatic ecosystems from commonly available information, and incorporate the use of loading coefficients developed elsewhere.[3]

In the absence of site- or region-specific studies and export coefficients, modelers and managers must rely on literature-derived export coefficients to assess the costs and benefits of past, current, and future landuse decisions, in terms of the potential for reducing water quality. However, notwithstanding that this necessity is driven by insufficient monitoring and environmental assessment, there often remains resistance to the conclusions of negative impacts of human landuse from the modeling of effects of landuse change on water quality that has been based on export coefficients developed elsewhere.

Many studies elsewhere have provided export coefficients for nutrients and organic matter for forested, agricultural, and urban landscapes.[4, 13, 15-17] The goal of this review is to assess the suitability of literature-based nutrient and sediment loading coefficients for modeling the potential for landuse change to affect water quality in Alberta streams and rivers. In assessing the effects of landuse - or landuse change - on chemical loading in freshwaters, it is important to keep in mind two important caveats that were highlighted by Beaulac and Reckhow (1982)[13]:

- As watersheds shift from natural, undisturbed conditions to increasing levels of human disturbance, the ecological mechanisms controlling nutrient flux become more complex and less understood. Therefore, the ability to accurately quantify or predict interactions between land use and aquatic conditions or responses becomes less precise and more uncertain.
- For management of water resources, the use of nutrient loading coefficients for predicting changes in water quality conditions that follow changing land use is highly subjective. To reduce uncertainty in this use, the user of these coefficients must be familiar with the biogeochemical processes that influence nutrient fluxes.

This is especially the case when there are insufficient local landuse and water quality data to determine loading coefficients. However, because of the breadth of scientific literature on the topic, the absence of local data should not be considered an absolute barrier to estimation of impacts of landuse change on water quality, for the purposes of landuse or watershed planning. This becomes more clear when considering the fact that landuse decisions will proceed whether or not local data are available to inform them definitively about non-point source pollution dynamics. It is arguable that the goal of any environmental modeling exercise is to quantify the nature, scale, and probability of risk, and provide the foundation for reducing environmental risks associated with particular management decisions. Therefore, modeling of non-point source pollution dynamics associated with landuse is a valid and valuable exercise, even in the absence of local data. With that in mind, the approaches and loading coefficients presented here are intended to aid landscape modelers, by providing a starting point for assessing environmental risk and the potential mitigations strategies that may be pursued to reduce them.

Section 1: Export Coefficients and Landuse Change

There are a number of factors that have the potential to influence export rates of nitrogen, phosphorus, and sediments from land to water, including geology, soils, topography, hydrology, climate, land management, and location of nutrient sources in catchments.[12] How these factors are assessed and described numerically also falls in two general classes of literature and techniques: ecological descriptions of export coefficients associated with different landuse changes, in which "universal" coefficients or rates are developed to describe the different non-point source contributions within a catchment; and more dynamic descriptions of non-point source contributions to net loading, such as those based on "event mean concentrations" that consider and incorporate the importance of variation in precipitation or runoff and are typically employed in the context of urban or industrial stormwater management. The degree to which the various factors described above may or have been shown to affect changes in water quality in Alberta, and the potential importance of the two distinct approaches to assessing the spatial and temporal variability of non-point source contributions to loading in freshwater systems, are discussed in more detail below. Summary tables of export coefficients for Alberta's various ecozones, from the scientific literature or derived from methods presented here, are included in the Appendices.

1.1 Geology, Soils, and Topography

Geology is important in to non-point source pollution loading because of its influence on topography, soils, and hydrologic characteristics in a catchment, and the presence and behaviour of underlying aquifers.[12] On a sub-catchment scale, the type and distribution of soils influence its physical structure and intrinsic stability, its permeability to water, and its nutrient retention capacity. Similarly, the steepness of hill-slopes and the presence or absence of floodplains or wetlands are a function of a catchment's topography, and play a significant role in determining the rates of discharge and chemical loading into streams or rivers.[12]

The physical structure and intrinsic stability of soils are closely tied to their hydraulic conductivity or infiltration potential. For example, sandy or gravel soils have generally low nutrient export via runoff, because they do not erode easily, and they have low cation content and high hydrologic infiltration potential (*i.e.*, in sandy soils, water tends to move downward then horizontally via groundwater transport, rather than horizontally via overland flow).[13] In contrast, clay soils tend to have high nutrient runoff via surface runoff because they are relatively impermeable to water, have high cation content (associated with high nutrient adsorption capacity), and are easily eroded. Organic soils also tend to have high nutrient runoff potential, because they have low infiltration, high nutrient content, and limited nutrient retention capacity. Nutrient export from organic soils tends to increase even more when subject to disturbance associated with cultivation, because the soils become highly erodible and decompose rapidly. This is especially the case where fields are left fallow during extended periods, such as over fall and winter.[13]

Anderson *et al.* (1999 at s. 2.4.2) defined runoff potential for surface soils in catchments in much of Alberta according to soil texture and structure that contribute to formation of layers that would restrict infiltration:[18]

- **High runoff potential**: soils with shallow Ah or Ap horizons and fine textures (*i.e.*, silt/clay loam).

Moderate **Table 1.** Distribution of runoff classes based on soil types in 820 catchments across Alberta's ecoregions [from Table 2, Anderson *et al.* (1999)].

	Runoff Potential Based on Soil Type (percent of area)			
Ecoregion	High	Moderate	Low	Unknown
Aspen Parkland	32.8	21.5	38.1	7.2
Eastern Continental Ranges	50.2	0.1	41.8	7.9
Boreal Transition	53.1	18.8	6.5	21.4
Mixed Grassland	58.5	20.5	17.6	3.3
Hay River Lowland	59.0	-	1.4	39.0
Western Alberta Upland	62.0	5.1	7.5	25.1
Mid-Boreal Uplands	62.9	1.9	4.0	31.1
Fescue Grassland	68.3	4.7	23.7	3.3
Northern Continental Divide	68.7	3.4	18.5	9.2
Moist Mixed Grassland	69.4	12.1	14.0	4.4
Cypress Upland	73.1	12.1	12.3	2.4
Wabasca Lowland	73.3	0.2	2.7	23.8
Peace Lowland	79.3	0.6	9.0	11.0
Western Boreal	82.5	0.1	3.0	14.4
Clear Hills Upland	89.2	-	1.2	9.4

- **runoff potential**: soils with moderately deep Ah or Ap horizons and moderately fine textures (loam/silt loam/fine sandy loam).
- **Low runoff potential**: soils with deep Ah or Ap horizons and moderate to coarse textures (loams/sandy loams/sands).

The prevalence of the three classes of soil runoff potential varies among the different ecozones, although for all ecozones other than Aspen Parkland the soils are dominated by those with high runoff potential (Table 1).

In addition to describing runoff potential according to soil type, Anderson *et al.* (1999 at s. 2.4.1) characterized runoff potential according to topographic (or landform) differences in catchments. Similar to soil types, areas of catchments were assigned to three different types of runoff potential, based on common classes of landform including:

- **"Type I" lands**: high runoff potential, with well-developed natural drainages dominated by rolling, undulating, ridged, or inclined landforms and valleys;
- **"Type II" lands**: low runoff potential, with closed, poorly developed natural drainage that trap runoff, and dominated by hummocky landscapes with low relief, potholes, or knob and kettle landforms; and
- **"Type III" lands**: with poor drainage and fine textured soils, typified by flat to low, undulating landforms that are likely to be artificially drained in agricultural areas.

Table 2. Distribution of runoff classes in Alberta's ecoregions, based on landforms [from Table 1, Anderson *et al.* (1999)].

	Runoff Potential Type Based on Landform (percent of area)			
Ecoregion	Type I	Type II	Type III	Unknown
Hay River Lowland	9.8	0.3	70.2	19.7
Wabasca Lowland	9.8	-	88.9	1.3
Mid-Boreal Uplands	40.0	30	21.1	8.9
Boreal Transition	43.7	30.1	19.2	7.1
Peace Lowland	45.2	6.4	44.2	4.2
Western Alberta Upland	47.4	28.5	22.1	2.0
Moist Mixed Grassland	52.8	34.4	7.7	5.1
Aspen Parkland	53.3	32.1	7.5	7.0
Mixed Grassland	57.3	30.4	8.0	4.3
Northern Continental Divide	61.3	30.1	4.3	4.3
Clear Hills Upland	66.7	6.5	24.1	2.7
Fescue Grassland	67.4	20.3	6.9	5.4
Cypress Upland	67.6	29.3	3.0	0.1
Western Boreal	68.0	6.8	21.5	3.7
Eastern Continental Ranges	88.7	8.8	-	2.5

These runoff classes based on topographic differences also were used to describe catchments throughout Alberta (Table 2). As may be expected, based on the definitions of the runoff potential types, the Hay River Lowland and Wabasca Lowland ecozones are dominated by Type III land classes (flat to low, undulating lands that are poorly drained), and the Peace Lowland has approximately equal dominance of Types I and III lands. The Mid-Boreal Uplands and Boreal Transition ecozones have an approximate relative dominance of Types I, II, and III land types of 40:30:20, respectively. As anyone familiar with the topography of the various regions of Alberta would expect, the remaining ecozones - in order of increasing relative runoff potential - are Western Alberta Upland, Moist Mixed Grassland, Aspen Parkland, Mixed Grassland, Northern Continental Divide, Clear Hills Upland, Fescue Grassland, Cypress Upland, Western Boreal, and Eastern Continental Ranges.[i]

The descriptions of soil structure and texture used by Anderson *et al.* (1999) to describe soils with low and high runoff potential are similar to those associated with quantified runoff coefficients presented by Hudson (1993).[19] On the basis of the similarity in these soil descriptions, and the relationships between runoff coefficients and soil texture presented by Hudson (1993), runoff coefficients for soils defined by Anderson *et al.* (1999) as having moderate runoff potential were inferred as intermediate between those for low and high runoff potential that were quantified by Hudson (1993) (Table 3).

Topography and soil type can combine to produce significant differences in runoff coefficients, which in turn would drive differences in chemical export. As described above, runoff coefficients increase substantially as soil sand content decreases and silt and clay loam content increases (illustrated in rows of Table 3). Similarly, as topography shifts from flat, to rolling, to hilly, runoff

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[i] The runoff potential of 820 individual catchments in Alberta's ecoregions, based on soil type and landforms,

Table 3. Runoff coefficients (R_v) associated with different topographies, vegetation, and soil types; from Schwab *et al.* (1981) as presented in Table 13, Hudson (1993).[19, 20] The low, moderate, high, and very high descriptors are borrowed from Anderson *et al.* (1993), on the basis of similarities in descriptions of soil texture. The runoff coefficient values presented in orange for the moderate runoff potential soil types are inferred and intermediate between the low and high runoff potentials presented by Hudson (1993).

Topography & vegetation	Soil Texture			
	Open sandy loam	Silt / fine sandy loam (Inferred)	Clay and silt loam	Tight clay
Soil type	LS/SL		SIL/SICL	C/HC
Runoff potential (from Anderson *et al.* (1999) and Hudson (1993)	Low [18]	Moderate [18]	High [18]	Very high [19]
Woodland				
Flat (0-5% slope)	0.1	0.2	0.3	0.4
Rolling (5-10% slope)	0.25	0.3	0.35	0.5
Hilly (10-30% slope)	0.3	0.4	0.5	0.6
Pasture				
Flat	0.1	0.2	0.3	0.4
Rolling	0.16	0.26	0.36	0.55
Hilly	0.22	0.32	0.42	0.6
Cultivated				
Flat	0.3	0.4	0.5	0.6
Rolling	0.4	0.5	0.6	0.7
Hilly	0.52	0.62	0.72	0.82
	% of area impervious			
Urban areas	30%	40% [21]	50%	70%
Flat	0.4	0.48	0.55	0.65
Rolling	0.5	0.55	0.6	0.8

coefficients increase (illustrated in the columns of Table 3). As can be seen in Table 1, these patterns exist whether a catchment is relatively undisturbed and forested, converted to pasture, subjected to cultivation, or converted to urban uses, although runoff coefficients for any particular soil type also tend to increase as one moves through this continuum of disturbance, from undisturbed to highly disturbed. As an example, forests with sandy soils overlaying granitic igneous rock have approximately one-half the total phosphorus (TP) export of similar forests with loam soils overlaying sedimentary formations.[13]

1.2 Climate

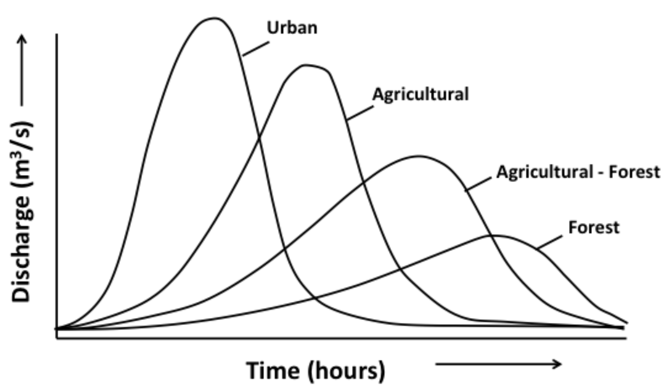
Climate is an important factor to consider in assessing chemical loading in freshwater systems, because it influences soil temperature and freeze/thaw cycles, intensity, seasonality and distribution of precipitation (PPT), and evaporation and evapotranspiration (ET) rates (via wind speed and direction, and temperature).[12] Water yield, *i.e.*, the flow in a stream or river normalized to catchment area and typically expressed in millimeters or centimeters, represents the sum of precipitation, evapotranspiration, and groundwater recharge and discharge inputs to rivers. The southeast corner Alberta has significantly lower precipitation than the rest of the province and generally warmer temperatures and higher winds, resulting in a negative water balance (PPT-ET) and a semi-arid landscape. However, because the remainder of southern Alberta east of the foothills has annual precipitation totals that are similar to those in northern Alberta (~400-450 mm), but much higher ET losses, the south has much less available surface water than the north.[22, 23] Where water yields are low because of low net water balances, loading rates will also be lower than they otherwise would be with higher yields. It is for this reason that dry areas generally have low loading rates, despite that landuse practices or conversions may be the sort that have been demonstrated to contribute to significant increases in loading rates in other ecozones.

1.3 Hydrology

In general, hydrology influences the transport pathways that link land-stream networks, the seasonal variation in the routing of these pathways, and the connectivity of ground- and surface-waters. These hydrologic links also are often highly subject to human alteration, including the introduction of irrigation or physical disturbance of natural pathways.[12] For this reason, human disturbance can act as a multiplier of the effects of hydrologic factors on chemical loading rates.

The hydrodynamics associated with surface runoff events and the differences associated with landcover types are largely responsible for the importance of storm events in delivering nutrients and contaminants to streams or rivers, in both dissolved and particulate form. The influence of landuse on runoff hydrology also plays an important role in establishing the differences in timing and amount of dissolved and particulate nutrient inputs to freshwater systems. As landscapes are increasingly disturbed, water movement tends to become "flashier", with higher peak flow and faster runoff response, post-storm (Figure 1). This is the result of a combination of changes associated with

Figure 1. Hydrographic response of varying land uses to a storm event [from Beaulac and Reckhow (1982)].



increasing degrees of disturbance, including decreased vegetative cover, changes to drainage systems that include channelization of flow to reduce water storage or flooding potential, increased soil compaction and prevalence of impervious surfaces.[4, 13]

Typically, just a few storms in a given year are responsible for the majority of annual catchment nutrient inputs, and in temperate regions like Alberta spring snowmelt can contribute significant portions of annual inputs.[10, 17] During a storm event, the initial increase in runoff typically corresponds with a dilution-driven decrease in the concentration of dissolved N and P, often resulting in the lowest concentrations coinciding with the peak hydrograph. As runoff and flow decrease, concentrations of dissolved nutrients increase to close to pre-storm baseflow levels. In contrast, particulate nutrient concentrations increase quickly with rising runoff, and reach maximum concentrations before the peak in the hydrograph. This "first flush" is the result of the dislodging of particulates from watershed surfaces during the initial runoff stage. Less particulates are thereafter available for transport, and particulate nutrient concentration decreases routinely either precede or coincide with declining flow.[17] Add to these that soluble nutrients may be removed from runoff by vegetative uptake, while nutrients adsorbed to sediments or particulates may be scoured during high-intensity storm events, and the amounts and proportions of dissolved and particulate nutrient inputs into freshwater systems can be highly variable, seasonally and interannually as well as between different sites and landcover types.[13]

1.4 Land Management

Land management practices that can alter natural export rates of chemicals and sediments include land-cover and hydrologic disturbance, timing of fertilizer applications[ii] (including sewage sludge, and animal manures and slurries), cultivation of crops with high residues (*e.g.*, canola) or nitrogen-fixers (*e.g.*, legumes), multiple yearly cropping, stocking of different species or breeds of livestock and at various densities, and use of such practices as intensive or unintensive grazing.[4]

1.4.1 Undisturbed Lands, Forests, Forestry and Fire

In forested catchments, export coefficients typically have a narrow range, and median values have been found to be lower than for all other landuses except pasturing or grazing.[13] Variation in export in forested catchments is usually driven by a combination of factors that include geology, climate (via net water balance), vegetation type, and ecological succession.[13] Where subject to similar climatological factors, runoff and chemical export are generally lower in coniferous softwood forests than in deciduous hardwood forests, because of higher rainfall interception capacity and evapotranspiration rates. For example, annual streamflow reductions of ~20% have been observed up to 15 years after experimental conversion from mature deciduous hardwood forests to white pine.[24, 25]

While conversion of deciduous to coniferous forests can decrease runoff and chemical export, early successional forests tend to have higher runoff and export than older forests, especially where succession results in a substantial decrease in Leaf Area Index (LAI). Forests less than 5 years old tend to have lower evapotranspiration rates and more soil disturbance than mature forests, because of lack of a well-developed canopy that otherwise reduces rainfall impact energy on soil surfaces, which combined result in higher runoff, and greater sediment and phosphorus fluxes.[26]

In addition to forest type and successional stage, climate plays a major role in nutrient export from forests. Generally, warmer climates and higher precipitation results in higher primary productivity,

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[ii] This also applies to pesticides, herbicides, and other classes of chemicals associated with human activities. However, for the purposes of this review, discussion is limited to nutrient and sediment export.

higher stormwater flow, and higher TP export from undisturbed forests. Because TN is often a limiting nutrient in forests and its export is a function of local differences in supply and demand for nitrogen by growing plants, patterns associated with variation in climate are less clear for TN export from forests.[13] In the aftermath of a forest fire, runoff, erosion and nutrient export from undisturbed forests may increase by one or more orders of magnitude – *i.e.*, beyond normal ranges - although this is dependent on the severity of the burn, in terms of both intensity and areal coverage, and whether the fire is a crown fire or restricted to the understory. It also varies with forest type, catchment topography, soil type, and other local conditions.[26] Increases in post-logging or post-fire runoff- and snowpack-generated peak flows have been attributed to reduced water interception loss and transpiration. Further, in the case of intense fire events, combustion of the surface soil organic layer and creation of water-repellant layers at or just below the soil surface that impedes infiltration also can contribute to more intense peak flows.[27] Generally, high-severity fires have a much greater hydrologic effect than low- or moderate-intensity fires.[26]

In British Columbia's and Alberta's boreal forests, pine beetle outbreaks and damage have resulted in large, widespread damage. In 2007, mountain pine beetle attacks of 75% of mature pine stands were predicted to result in 30% increases in annual water yield and 60% increases in peak flows for return periods of 2 to 50 years, because of reductions in evapotranspiration and canopy interception of rainfall or snowfall.[28] In addition to the natural changes in runoff, human responses to wide-spread forest beetle-kills were expected to amplify hydrologic changes. Under a scenario involving post-beetle salvage harvesting of 80% of the catchment area, predicted increases in annual water yields for the same return periods were approximately 50%, and increases in peak flows were predicted to be 90-95%, relative to baseline 1970 conditions.[28] The frequency of flood events also was predicted to increase under the two scenarios, with 20-year flood events under baseline conditions shifting to 4-year frequencies after mountain pine beetle outbreaks, and 3-year frequencies when combined with post-beetle salvage logging. These modeled predictions of water yield played out in 2012, when previous mountain pine beetle infestations and forest fires combined with higher than average snowpacks and heavy rain events to produce substantial flooding in BC's southern interior.[iii]

Similar to natural successional forest changes, forestry activities alone also can result in increase runoff and chemical export from forested landscapes. For example, in a study in mountainous North Carolina, runoff increased by 28% in the first year post-harvest in a deciduous-deciduous/coniferous forested catchment.[iv] Thereafter, runoff declined by 4-6% annually until returning to the normal range by years 5-7.[29] This decline was attributed to decreased evapotranspiration tied to minimal LAI, immediately post-harvest and in the recovering early-successional forest. As LAI and evapotranspiration increase with forest regeneration, streamflow decreased exponentially.[29] Despite increased runoff in early-successional forests, high net primary productivity and sequestration and storage of nutrients in successional vegetation may result in relatively small increases in nitrogen export, which have been observed to peak in year 3, post-harvest (+1.1-1.3 kg/ha, relative to pre-harvest export at or below detection limits), and returning to normal by year 6.[29]

While post-logging runoff increases in deciduous forests may return to pre-logging states relatively quickly, *e.g.*, 5-15 years post-logging, catchments dominated by coniferous forests can experience larger post-logging increases in water yield for much longer periods (*e.g.*, 40-45 years).[30] Jones and Post

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[iii] http://www.cbc.ca/news/canada/british-columbia/story/2012/05/02/bc-pine-beetle-forest-fire-flooding.html

[iv] It must be noted that the North Carolina study site receives substantially more precipitation than Alberta (*i.e.*, 1700-2500 mm, with average annual water yield of 99 cm).

(2004) also found that relative and absolute changes in catchment water yield[v] during the 1-5 and 15-25 year periods post-harvest positively correlated with forest age at the time it was cut. Significant positive changes in spring runoff persisted for up to 35 years post-logging at conifer forest sites with seasonal snowpacks, with increases in spring snow melt of 100 to 200 mm during that time. Interestingly, deciduous basins experienced small declines in spring runoff of 20 to 25 mm for 1-5 years post-harvest, 6 to 8 mm from 6 to 20 years post-harvest, and from 8 to 15 mm from 21 to 40 years post-harvest. During the first 5 years, post-cut, maximum daily areal catchment yield increases were 2 to 3 mm at deciduous forest sites, and 6 to 8 mm at conifer forest sites. During late summer / early fall in years 1-5, streamflow in conifer catchments increased by several hundred percent, but it was more variable in deciduous catchments, increasing from a few tens of percent to 200-300%. In the coniferous catchments, differences in summer streamflow changes, relative to unlogged catchments disappeared by 5 to 10 years, post-logging. However, in both coniferous and deciduous catchments, maximum summer water yield decreased by 30 to 50 percent by 25 to 35 years post-harvest, relative to unlogged catchments.[30]

In general, nitrogen export from forests appears to be closely tied to the nitrogen-status of the forests themselves.[31] That is, other than in N-limited ecosystems, the relationships between ecosystem nitrogen concentrations, fluxes, and leaching are all linear, and losses are controlled by first-order reactions that are linearly dependent on concentrations and/or fluxes.[31] In Finnish forested catchments with varying percentage coverage by peatlands and mean annual runoff of 230-420 mm/yr in which ditching, clear-cutting, scarification, and fertilization affected 2.4% of catchment area per year, 79% of nitrogen export budgets consisted of organic N, and 7.3% was inorganic. Furthermore, nitrate leaching ranged from 28-1,000 g/ha/yr (with total N ranging from 820 to 3000 g/ha/yr) and was strongly associated with (C : organic-N) and N-deposition.[32] In general, total nitrogen export is higher in catchments with a higher proportion of peatlands (*i.e.*, 2.1 and 1.5 kg/ha, respectively, for peatland coverage of > and < 35% of area), and elevated nitrate export corresponds with higher mean annual temperatures, higher N-deposition, and more fertile soils.[32] In mid-Appalachian forests of Pennsylvania, catchment nitrate export rates correlated positively with mean net soil nitrogen mineralization and nitrification rates, and total nitrogen concentrations in the upper 10 cm of mineral soil, and were unrelated to wet and dry atmospheric nitrogen deposition.[33]

In semi-arid, montane pine- and fir-dominated forests in the eastern Sierra Nevada Mountains with low soil-C and -N and intermediate soil-P, fire and post-fire N-fixation were found to be the dominant factors regulating N-cycling[vi], versus other similar forests with high pollution-based N inputs.[34] Direct N-losses due to intense fire in a 100-year-old stand were 300-800 kg N/ha, compared to prescribed burns resulting in losses of 264 kg N/ha. Therefore, averaged on an annualized basis, intense fire losses of N of 3 to 8 kg N/ha/yr are approximately one to two orders of magnitude higher than N losses due to leaching.[34] In that particular ecosystem, however, immediate fire-induced N-export was partially compensated for by high N-fixation rates associated with post-fire regeneration by snowbush (*Ceanothus velutinus*), ranging from 70-100 kg N/ha/yr. It also was predicted that post-fire erosional export of labile P would also be much more important than soil-based export. In addition to fire's role in increased N-mobilization, spring snowmelt pulses in nitrate were also observed, perhaps because of increased below-snow decomposition and the temporal uncoupling of snowmelt N-release

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[v] Annual areal catchment yield, and areal yield associated with snowmelt or the warmer, rainy season.
[vi] Climatic conditions in valley bottoms: 5 °C mean annual T and 700 mm mean annual precipitation, of which ~50% falls as snow.

and biological N-uptake. However, only during drier years was there evidence that NO_3^- released in snowmelt passed through the soil profile or appeared in stream waters.[34]

Along with increasing nutrient export, logging can result in very large, short-term increases of 150% or more in sediment export in the first few years post-harvest, and sustained export for up to 15 years post-harvest (*e.g.*, 50% above pre-disturbance sediment export rates). However, increases in sediment export after clear-cutting are strongly associated with road construction and persistence, and dependent on the intensity of rainfall or runoff events and the degree to which logging roads are permitted to reclaim to grassed or forested cover in the medium- to long-term.[29] As alluded to above in the context of increased runoff, an important difference in the effects of logging and fire involves the development of hydrophobic soil layers and increased surface erosion after intense fires that can also lead to large increases in export of suspended sediment loads. However, the increased sediment export, post-fire, would apply to the entire area burned, rather than be limited to persistent roadway presence that both contributes high sediment loads in runoff and facilitates sediment delivery to aquatic systems.

Section 2: Identifying Loading Coefficients

2.1 Disturbed Lands: Agriculture, Urban, and Industrial

A variety of modeling techniques are typically employed in reconstructing or predicting nutrient and sediment export. Some are based on mechanistic hydrological modeling that determines loading or export coefficients on the basis of relationships between climate data and modeled surface water and groundwater dynamics, including such things as infiltration and runoff, and sediment export. Others may involve statistical assessments of relationships between landcover, land use, and water quality that do not consider small-scale processes or mechanisms at work that facilitate or inhibit export. Both approaches involve a variety of assumptions, such as a reliance on physical rate constants that aren't typically developed for specific catchments of interest. Whichever method is employed, discrete effects of catchment disturbance history on loading or export can also be best illustrated by limiting modeling to the use of long-term mean climate conditions, to avoid swamping predictive power with the effect of great interannual variability in weather and/or runoff or streamflow and on annual catchment export.[35]

As described above, in the discussion on topography and soil types, conversion of landscapes from natural, undisturbed states to agricultural or urban landuses tends to increase runoff, which usually also results in increased chemical loading or export rates. In terms of general patterns in nutrient export among different land covers or landuses, the following patterns have been identified elsewhere (see Table 4):

For total phosphorus (TP): forest < non-row crops < pasture < mixed agriculture < urban < row crops << feedlots & manure storage

For total nitrogen (TN): forest < pasture < urban < non-row crops < row crops < mixed agriculture << feedlots & manure storage

2.1.1 Agriculture

Consistent with the increases in runoff potential described in Table 3, conversion of undisturbed forests to agricultural uses - other than pasture - generally results in significantly higher median TN & TP export, and higher variability in export (Table 4).[13, 19] Increases in nutrient export after conversion of forested lands to agricultural uses are positively correlated with the degree of soil surface disturbance and consequent exposure of soil to the elements. This is usually associated with the method and frequency of tillage. Conventional tillage practices, including leaving exposed ground fallow during non-growing periods and removing crop residues post-harvest, are the primary cause of high nutrient export and erosion associated with crop-based agriculture.[13] As may be expected, conservation tillage or no-till practices reduce nutrient export and sedimentation, and contour planting can reduce export even more. In addition to soil type, crop type also can influence nutrient export. For example, planting of N-fixing crops like canola can approximately double TN export, relative to other cereal crops.[4, 12]

Nutrient export from agricultural lands also is positively associated with the intensity of agricultural activity, and generally a function of the amount of fertilizer or other nutrient forms added or applied to soils, either via grazing animals or chemical or manure applications.[7, 10, 13] As part of

Alberta Environment's and Alberta Agriculture and Rural Development's assessment of effects of agricultural activity on local and regional water quality, the Alberta Environmentally Sustainable Agriculture (AESA) Program was initiated in 1998. Catchments were selected and classified according to the soil and topography characteristics (see Tables 1 and 2, above), and intensity of agricultural activity, as determined according to the per acre manure production, and area-normalized chemical and fertilizer expenses.[18]

The purpose of the AESA program was two-fold: to investigate how stream water quality is affected by low, moderate, and high intensity agriculture, in both dryland and irrigated regions of the province; and to monitor changes in water quality associated with growth of the agricultural industry and changes in agricultural management practices.[10] Based on eight years of monitoring of agricultural watersheds throughout Alberta, researchers concluded that in-stream concentrations of N and P increased and compliance with national and provincial water quality standards decreased with agricultural intensity (Figure 2).[10]

Table 4. Annual TP and TN loading rates for different landuses (from Figures 4 and 5 in Beaulac and Reckhow, 1982).[13] Where the letters following the median loading rates for different landuses or landcovers are the same, there is no statistically significant difference in them; different letters indicate statistically different rates.

	Annual TP loading rate (kg/ha/yr)					
Landuse	**Median[vii]**	**Min**	**Max**	**25%ile**	**75%ile**	**95% confidence intervals (± median)**
Forest	0.22(a)	0.00	0.82	0.06	0.32	0.06
Non-row crops	0.72(b)	0.07	2.86	0.60	1.56	0.44
Pasture	0.80(a,b)	0.10	4.90	0.20	2.66	1.08
Mixed ag	0.90(c)	0.06	3.24	0.44	1.34	0.32
Urban	1.08(b)	0.20	6.23	0.66	2.72	0.70
Row crops	2.25(b,c)	0.17	18.6	0.92	5.34	1.44
Feedlot-manure storage	260(d)	24	795.2	172	426	118

	Annual TN loading rate (kg/ha/yr)					
Landuse	**Median**	**Min**	**Max**	**25%ile**	**75%ile**	**95% confidence intervals (± median)**
Forest	2.5(a)	1.5	6.5	2.0	3.5	0.2
Pasture	5.0(a,b)	1.5	30.85	2.2	10.8	3.5
Urban	5.4(b)	1.5	38.47	3.8	11.3	2.4
Non-row crops	6.0(b)	3.5	8.0	4.1	6.5	1.1
Row crops	9.0(b,c)	2.0	79.6	4.0	22.0	5.7
Mixed ag	14.0(c)	2.8	41.50	9.4	25.7	5.4
Feedlot-manure storage	2950(d)	700	7979.9	1620	3460	1140

[vii] Median TP export from urban landscapes is low because most studies of urban export have been performed in established suburban-residential areas. Where there are significant commercial-industrial areas or significant construction activities, loading rates will likely be higher than other land uses.[13]

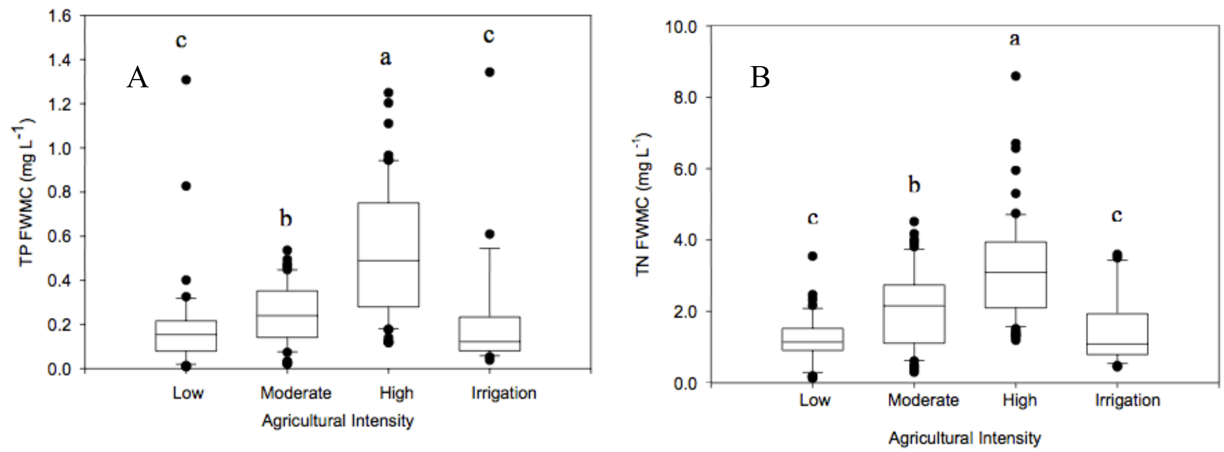

Figure 2. Flow-weighted mean concentrations of (A) TP and (B) TN in four classes of agricultural activity in Alberta [from Tables 3.1 and 3.5, respectively, in Lorenz *et al.* (2008) at p. 3-14 and 3-17]. Significant differences among agricultural intensity categories were observed at the $p<0.005$ significance level with the exception of differences between the moderate and low agricultural intensity watersheds ($p<0.05$). Boxplots stretch from the 25th percentile to the 75th percentile, with the horizontal line in the middle of the box representing the median. Vertical lines represent 1.5 times the interquartile range while dots represent minima and maxima data points.

Meta-analysis of a subset of numerical loading and agricultural intensity data that are available in the literature demonstrates similar patterns of increasing nutrient loading rates to streams with increased agricultural intensity, with the potential for much higher and more variable loading in catchments subject to moderate to high levels of manure application (Figure 3). This meta-analysis was pursued because it permits the investigation of relationships between nutrient loading rates and factors in addition to agricultural intensity, the latter of which was the primary focus of the AESA studies.

As an agricultural landuse, pasture or grazing land is unique, in that nutrient loading rates are not significantly different from undisturbed or forested watersheds (Table 4). This may be because the continuous presence of vegetation reduces the kinetic disturbance of soil, and maintains a relatively high uptake and conversion to vegetation biomass of nutrients from animal waste, while also sustaining relatively high soil infiltration rates and thereby reducing overland runoff.[13] As may be expected, export rates from rotational grazing practices (0-1.5 kg P/ha/yr) are less than from continuous annual grazing or intensive grassland management that includes fertilizer addition (3.0-5.0 kg P/ha/yr).[13] It should be noted, however, that grazing can result in increased runoff and loading. For example, a relatively steep, ungrazed fescue grassland site in Alberta experienced ~1/2 to 1/15th of the runoff of nearby sites that were similarly steep but experimentally grazed at heavy or very heavy intensities.[38] This large

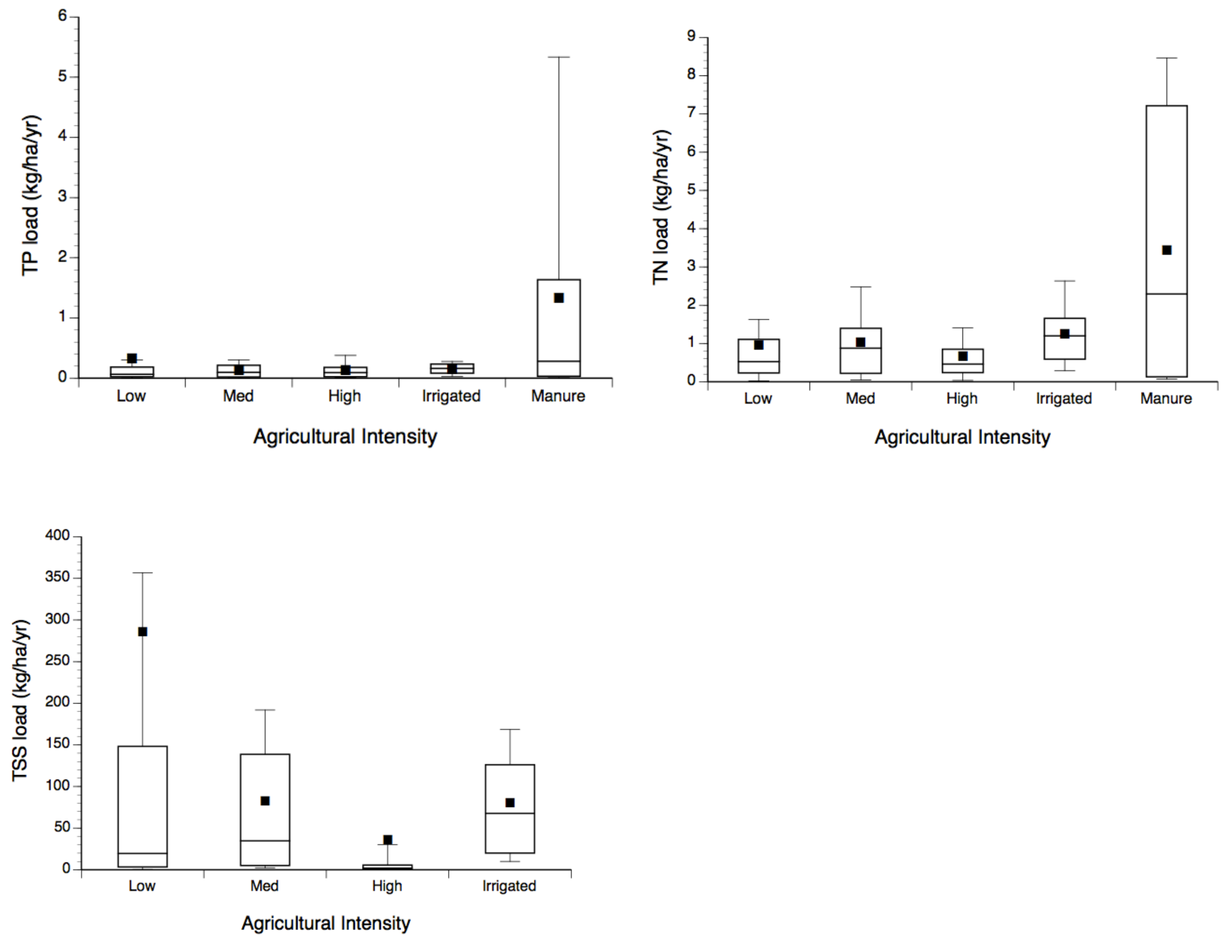

Figure 3. Areal loading coefficients for (A) TP and (B) TN in five classes of agricultural activity in Alberta, calculated from a subset of AESA creek data presented in Casson *et al.* (2006, 2008), Jedrych (2008), and Little *et al.* (2006)[7, 9, 36, 37]]. The "manured" watersheds presented - which are conventionally tilled and receive manure applications to increase N inputs, and include Ponoka Creek and a creek near the Little Bow River - are not AESA study sites. However, they are included here as representatives of a particular type of agricultural landuse prevalent in large parts of Alberta.[viii] Boxplots stretch from the 25th percentile to the 75th percentile with the black square representing the mean and the horizontal line in the middle of the box representing the median. Vertical lines represent the 10th and 90th percentile values.

difference in runoff was attributed to the fact that the ungrazed site had abundant vegetative cover that was more heterogeneous and 5 to 7.5 times greater in areal mass than at the grazed sites.[37]

The variation in the storage and movement of water in a catchment has often been identified as the primary factor in driving the variability or uncertainty in estimates of in-stream pollutant loading rates.[3] This is often because in-stream water chemistry is not monitored through the full spectrum of

[viii] Manure was applied in the Ponoka Creek watershed once or twice per year, and every three years in the watershed of the creek near the Little Bow River.[37]

natural flow rates, from low to peak flood stages, thereby preventing accurate estimation of annual loading rates. The difficulty and expense involved in monitoring surface- and groundwater movement on the catchment and sub-catchment scale to the degree needed to perform site-specific assessments of local or regional impacts of landuse change on water quality highlight the practical importance of using and applying information developed elsewhere in such assessments. This applies equally to the use of monitoring data where it is available, and the use of literature-based loading coefficients or physical and chemical rate constants for detailed mechanistic modeling of hydrology and nutrient or sediment loading in particular catchments, in the absence of sufficient site-specific information.

For assessing loading associated with agricultural landuses in Alberta, AESA loading coefficients and runoff data are useful in demonstrating that there are strong relationships between the amount of runoff or annual precipitation and total annual loading, for various types of agricultural practices and intensities in Alberta (Figure 4). This certainly suggests that using a single coefficient to represent loading from a particular catchment or sub-catchment will not capture the variability in loading caused by inter-annual variation in precipitation/runoff.

However, notwithstanding the clear and strong relationships between runoff and loading rates, there also are clear patterns between landcover / landuse types and loading rates. For example, conventional tillage with moderate to high manure application (Ponoka Creek and Lower Little Bow River; red in Figure 4) resulted in much higher TP loading rates than conventional tillage without manure (Wabash & Grande Prairie Creeks; black), other kinds of tillage (orange), ungrazed grassland, or mixed agriculture operations (Haynes Creek; green).

In addition to differences in tillage and fertilizer application rates, more general patterns in nutrient and sediment loading and agriculture intensity can be described for various ecozones in Alberta (Figures 5 and 6). During dry years with relatively low areal catchment water yield (≤ 3 mm), TP export is lowest in low and medium agriculture intensity catchments in the grassland ecozone (*i.e.*, "low-grassland" and "med-grassland"), followed by low-boreal, med-boreal, and high-Parkland catchments. (Figure 5A). During dry years, the range in P-loading among different agricultural intensities and ecozones was almost two orders of magnitude (from less than 0.0001 to almost 0.01 kg/ha/yr). However, during wet years with much higher areal water yield (20-80 mm), there is little difference in P-loading among catchments experiencing different agriculture intensities or in different ecozones. As might be expected, P-loading rates in irrigated catchments are similar to those observed during wet years in unirrigated catchments. P-loading observed for low agriculture intensity in the Continental Divide ecozone is similar to that seen during moderate to wet years in other ecozones (Figure 5A). However, water yield itself was much higher in the Continental Divide catchment, likely because of a combination of greater slopes, more impermeable soils, and higher total annual precipitation.

Like with P-loading, N-loading in AESA catchments demonstrated strong relationships with runoff/catchment yield, and both variables ranged over approximately three to four orders of magnitude (0.003 to ~ 10 kg/ha/yr, and 0.2 to ~700 mm of runoff; Figure 5B). Although there was much less difference between agricultural intensities and ecozone type than demonstrated for P-loading, moderate to high manure application once again resulted in the highest N-loading, and the Continental Divide catchment was again set apart from other ecozones on the basis of correspondence of comparable loading rates at much high runoff rates.

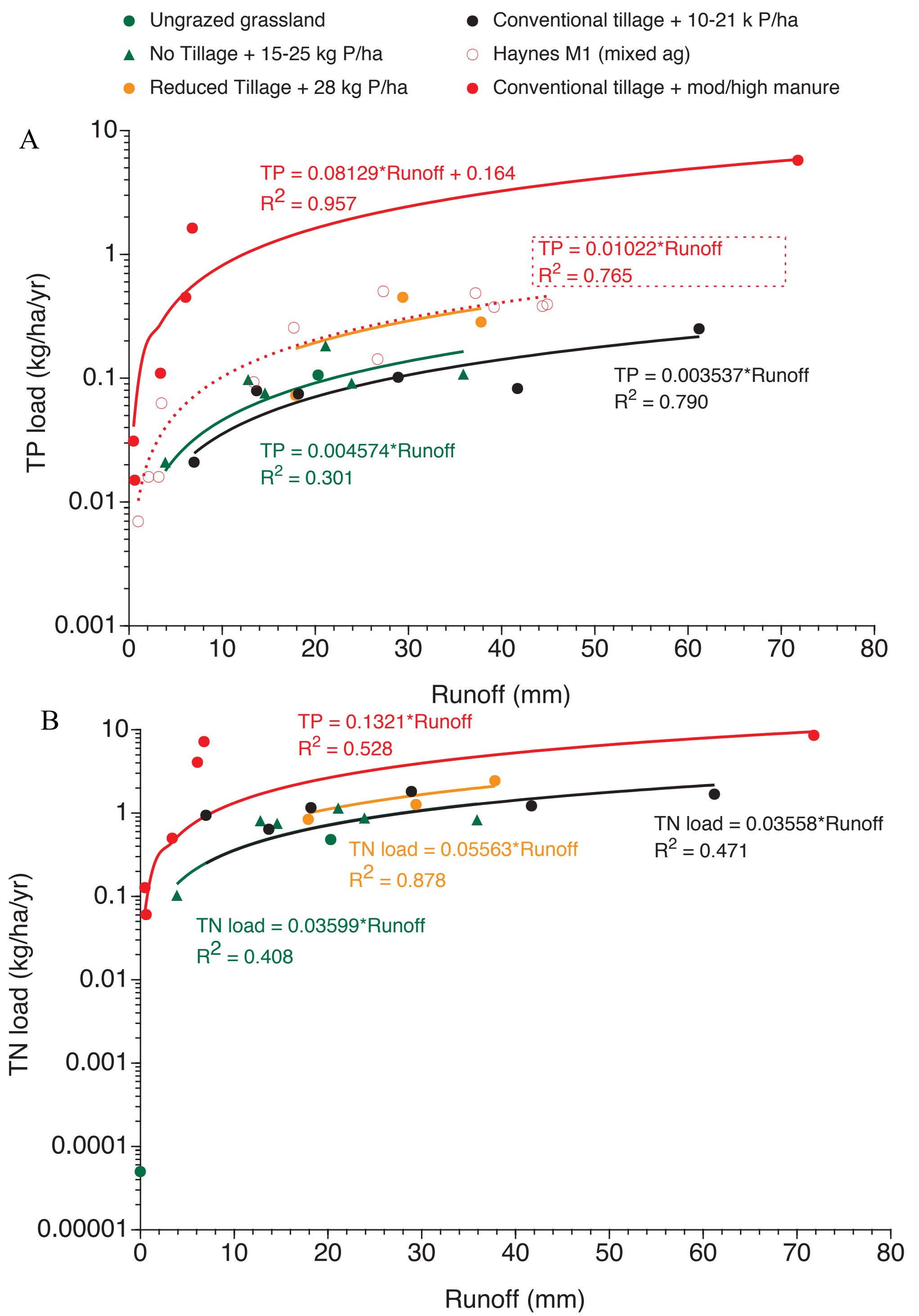

Figure 4. Effects of varying total annual runoff on areal loading coefficients for (A) TP and (B) TN in agricultural catchments in Alberta with different tillage methods, or fertilizer or manure application, calculated from a subset of AESA creek data [7, 9, 36, 37].

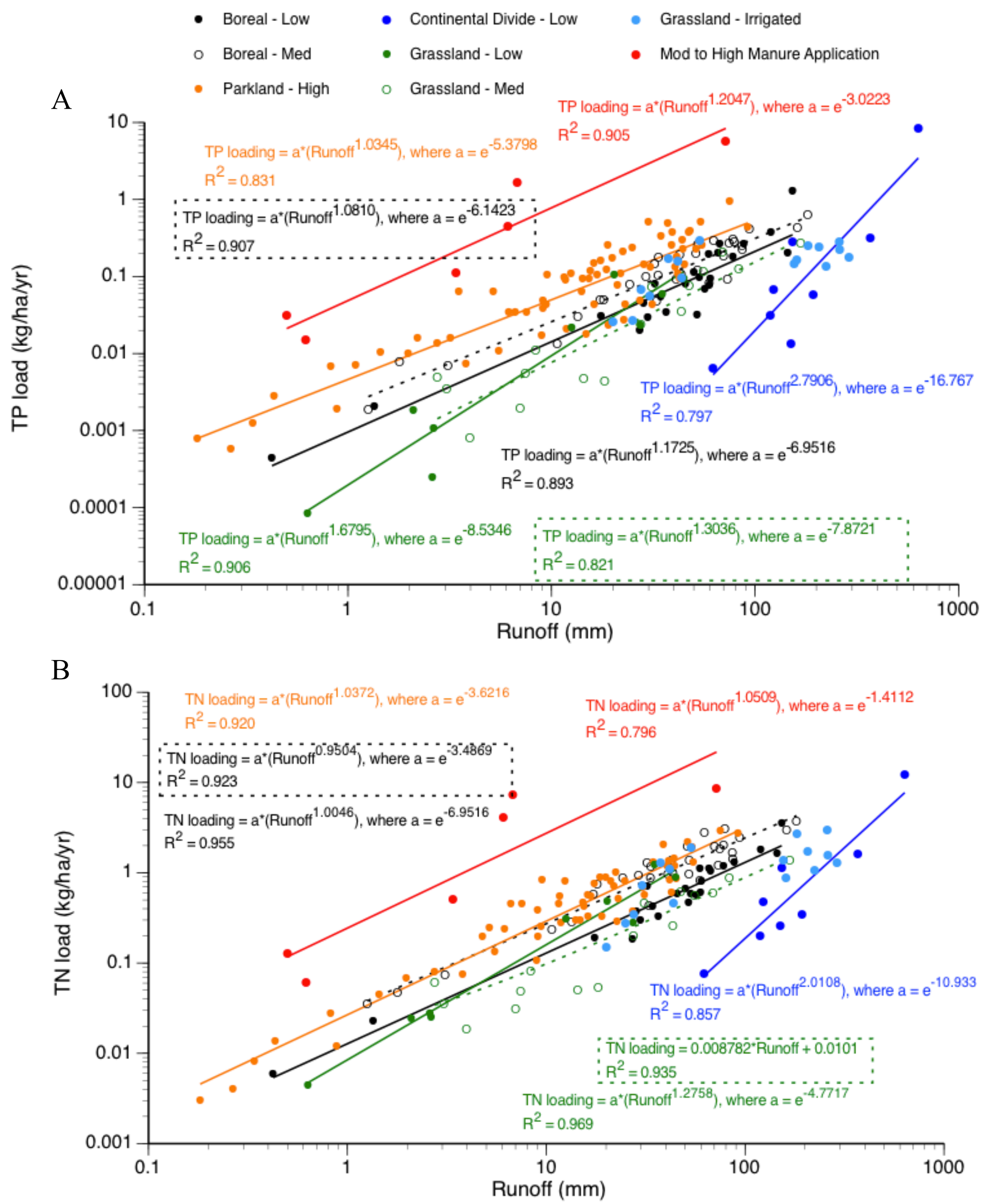

Figure 5. Effects of varying total annual runoff on areal loading coefficients for (A) TP and (B) TN in catchments in Alberta with different intensities of agricultural activity, calculated from AESA loading data Casson *et al.* (2006, 2008), Jedrych *et al.* (2008), and Little *et al.* (2006), and Lorenz, Depoe and Phelan (2008) [7, 9, 10, 36, 37]].

TSS loading among AESA catchments also was highly variable, ranging over almost six orders of magnitude (~0.02 to ~7,000 kg/ha/yr; Figure 6). The lowest values of TSS loading occurred during the driest years in low-boreal, low-grassland, and high-parkland catchments, followed by med-boreal and med-grassland catchments with lowest values approximately one order of magnitude higher. During moderate to wet years, TSS loading was lowest in high-Parkland and low-Grassland catchments, followed by low-Boreal, irrigated-Grassland, med-Boreal, and med-Grassland catchments. Once again, the highest areal catchment water yields in the Continental Divide catchment were associated with loading rates comparable to moderate to wet years in other catchment types, although the highest TSS loading rate also occurred in this catchment (Figure 6).

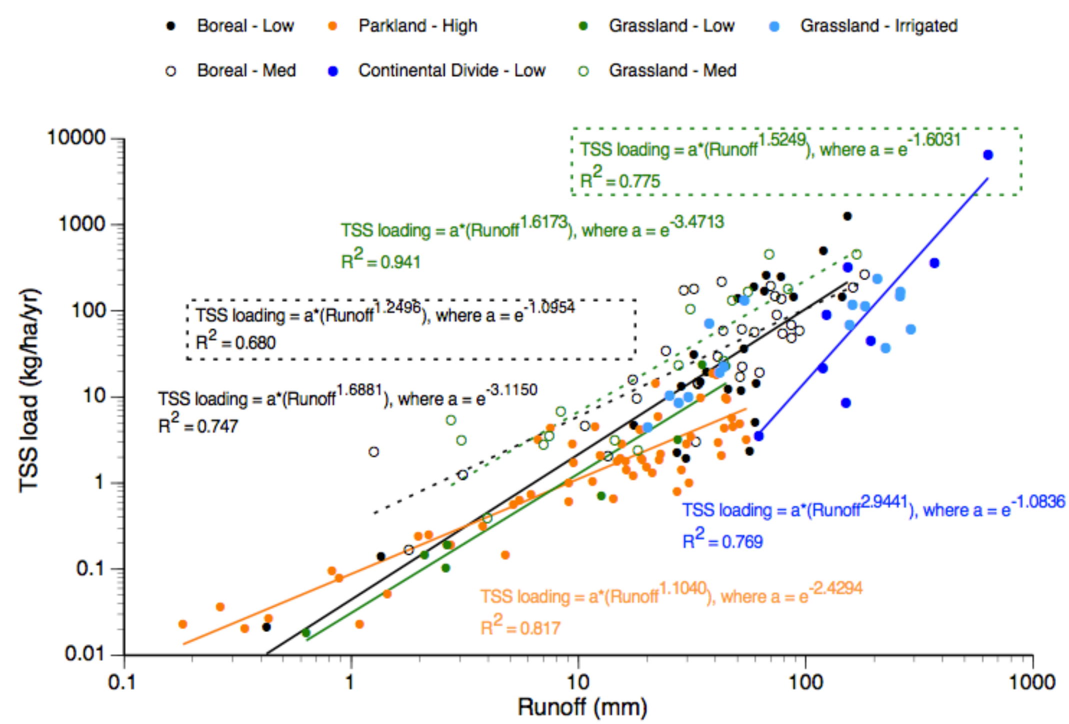

Figure 6. Effects of varying total annual runoff on areal loading coefficients for TSS in catchments in Alberta with different intensities of agricultural activity, calculated from AESA loading data [7, 9, 10, 36, 37].

2.1.2 Urban and Industrial Landuses

As described above, the literature on non-point source pollution loading to aquatic systems is generally divided into two groups: ecological studies that attempt to quantify the loading effects of conversion of natural landscapes to human landuses; and studies in urban water management that generally include more detailed descriptions of impacts of various urban and industrial landuse conversions on water yields and loading rates. The former typically describes loading coefficients derived from water quality and landuse data, and the latter describes areal chemical loading as calculated from urban runoff volumes and event mean concentrations (EMCs), which are flow-weighted concentrations of chemicals or sediments during high-flow. Urban and industrial landuses typically have high chemical loading rates, relative to undisturbed lands, and are discussed in more detail below.

Event Mean Concentrations (EMC) Methods

The determination of urban and industrial loading rates as a function of precipitation or runoff is done according to a series of steps that involves first calculating runoff from urban landuse types and applying EMCs to them. It should be noted that this method is intended to assess and compare relative stormflow pollutant loads related to landuse change, and results in a "general planning estimate of likely pollutant export"; it should not be used to compare the differences between relatively similar development scenarios (*e.g.*, changing a landscape variable by only a few percent).[39] Runoff in urban or industrial landscapes can be calculated via the following formulae:

(1) [39] $$RO_i = Ppt \times Ppt_j \times R_v$$

where: RO_i = annual runoff from surface "i" (mm)
Ppt = annual precipitation (mm)
Ppt_j = fraction of annual rainfall events that produce runoff (usually 0.9)
R_v = runoff coefficient specific to landuse/landcover "v"

Runoff coefficients for different surface types are available in the literature, and range from materials that are impervious to water, including highways, asphalt, and cobblestone (R_v from ~0.75 to 0.95), to highly pervious (*i.e.*, permeable) gravel drainage features or well-drained sandy soil (R_v of ~ 0.1) (see Table 5, below, and Table 3, above). Applying Equation 1 to the runoff coefficients from Tables 3 and 5, and annual total precipitation yields the annual runoff from particular surface types. Another alternative to using literature-based values of runoff coefficients is calculating them, according to Equations 2 or 3, below.

(2) [39][ix] $$R_v = 0.05 + 0.9I_a$$

where: I_a = % area impervious to water that is draining to the structure (in decimal form)

or,

(3) [21] $$R_v = 0.9I_a + 0.2(1 - I_a)$$

Once runoff coefficients are calculated, using one of the approaches described above, the volume of runoff for each land cover type is simply the product of the landuse-specific runoff coefficient and the surface area (Equation 4). The various landuse-specific loading coefficients can then be calculated using EMCs (see Appendix Table A-1) and runoff (Equation 5). The summary equation for the entire calculation is presented in Equation 6, below.

[ix] N = 47; R^2 = 0.71 (McCarthy 2008).

Table 5. Runoff coefficients for different surface types.

Surface Type / Material			R_v	R_v*Ppt_j	Citation
Impervious	Highways		0.87 (0.35-0.95)	0.783	38
	Asphalt, concrete		0.8	0.72	45
	Brick, cobblestone		0.77	0.693	45
Impervious-Pervious	High-density neighbourhood commercial development (70% impervious)		0.69	0.621	21
	Low-density neighbourhood commercial development (50% impervious)		0.55	0.495	21
Pervious	Highly compacted	Unpaved parking, driveway, road shoulder; high automobile & human disturbance, poor drainage	0.50	0.45	45
	Mid-High Compaction	Medium density single family development (~26 units/ha) (35% impervious)	0.45	0.405	21
	Moderate compaction	Low density single family urban development (~ 13 units/ha)(26% impervious)	0.38	0.342	21
	Compacted	Unmaintained sports field, park or playground surface; high human disturbance & poor drainage	0.35	0.315	45
	Unmaintained	Moderate foot traffic & some compaction; foot paths, moderate to poor drainage	0.30	0.27	45
	Turf	Maintained lawn w/ high foot traffic (e.g., golf course, park, lawn, ballfield)	0.25	0.225	45
	Maintained	Landscaped/natural vegetated w/ low foot disturbance/foot traffic	0.20	0.18	45
	Undeveloped	Relatively low foot traffic	0.15	0.135	45
	Drainage feature w/ gravel or other coarse-grained material; porous pavement, asphalt, concrete etc w/ subsurface stone reservoir; well-drained sandy soil		0.10	0.09	45

(4)
$$V_i(m^3) = RO_i(mm) \times \left(\frac{1m}{1000mm}\right) \times SA_i(m^2)$$

where: V_i = Volume of runoff (m^3) from surface area "i"; and
SA_i = surface area generating runoff "I" (m^2)

(5)
$$Load_i = EMC_i \times V_i$$

(6) $$Load_i(mg/ha\cdot yr) = EMC_i(mg/L) \times Ppt(mm) \times Ppt_j \times R_v \times F$$

where "*F*" is the conversion factor:

$$F = (1m/10^3 mm) \times (10^4 m^2/ha) \times (1kg/10^6 mg) \times (10^3 L/m^3)$$

If areal chemical export calculated on the basis of total annual precipitation is desired (*i.e.* "chemical loading factor"; CLF), it can be accomplished by simply rearranging of the formulae described above, yielding Equations 7 and 8:

(7) $$CLF\left(kg/mm\cdot ha\right) = R_v \times Ppt_j \times EMC_i\left(mg/L\right)\left(\frac{m^3\cdot L\cdot kg}{100\cdot mm\cdot ha\cdot m^3\cdot mg}\right)$$

where CLF = chemical loading factor (kg/ha) per mm of total annual precipitation

(8) $$Load\left(kg/ha\cdot yr\right) = CLF\left(kg/mm\cdot ha\right) \times Ppt(mm/yr)$$

where Load = annual areal chemical loading; and
Ppt = total annual precipitation

The chemical load factors for a variety of landuses and landcover types derived by this technique are presented in Table 6, below. Multiplying CLF by annual precipitation (mm) yields the areal loading coefficients for the relevant water quality parameter. As mentioned above, it is best to use long-term mean climate conditions in a comparison of inter-catchment differences or assessment of effects of catchment disturbance history on loading or export, to avoid the likelihood that high interannual variability in weather and/or runoff will overwhelm any attempts to distinguish between spatial or temporal differences in catchment export.[35]

Average annual precipitation is highly variable among the different natural regions in Alberta, with the highest average annual precipitation in the Rocky Mountain region and the lowest in the Canadian Shield and Grassland regions (Table 7). Using the EMC-based approach described here, loading coefficients for many different natural and human landuses can be calculated for the various natural regions in Alberta. Of course, the resulting loading coefficients for particular catchments or subcatchments within the natural regions may differ from "real" loading rates, and will have to be compared to actual water quality data or runoff quality/quantity. It also is important to note that the loading rates determined this way may be considered loading "potential" for delivery of sediments or nutrients to streams, rivers, or lakes, and are not necessarily reflective of in-stream concentrations of nutrients or sediment because they do not account for in-stream removal processes, such as sedimentation or physiological uptake.

Table 6. Annual chemical load factor (CLF; load per mm of total annual precipitation; kg/mm•ha) for different landuse and footprint types, using runoff coefficient and EMC values from Tables 5 and A-2. Sources are as presented in Table A-2.

		Loading factor (CLF; kg/mm•ha)			
Transportation		TKN	TN	TP	TSS
Soft Roads (gravel)					
Hard Roads (paved)			0.09825	0.00314	0.41330
Trails (motorized)			0.01440	0.01211	2.88900
Trails (non-motorized)			0.00780	0.00447	1.06635
Industrial					
Industrial Plants		0.01218	0.01426	0.00184	1.08731
Transmission Lines			0.00346	0.00134	0.36043
Seismic Lines			0.00259	0.00101	0.27032
Wellpads			0.01368	0.00689	1.93873
Pipelines			0.00519	0.00201	0.54065
Processing Plants			0.01296	0.00168	0.98846
Feedlots			1.62012	0.32423	4.99275
Surface Mines - undisturbed			0.00202*	0.00013*	0.07153*
Surface Mines - disturbed			0.00531	0.00068	0.42273
Construction - Clearing, grubbing, grading of former wooded/ag land		0.00340	0.01215*	0.00135	10.99665
Construction - Installation of roads, storm drainage & housing		0.01792	0.00791*	0.00088	4.57695
Recreation					
Recreational Features (golf courses)		0.01541	0.02159*	0.00241	0.45450
Recreational Features (ski areas)			0.005247	0.000343	0.18598
Recreational Features (campgrounds)			0.00689	0.00286	0.68398
Residential					
Urban (City Core)		0.00859	0.01436	0.00178	0.62382
Urban (Suburban)		0.01336	0.00779	0.00161	0.34922
Rural Residential (farm yard)			0.49410	0.08316	2.65140
Rural Residential (acreage yard)			0.00316	0.00026	0.06309
Rural					
Wooded		0.00967	0.00340	0.00061	0.55350
Open space / grass		0.00097	0.00202	0.00013	0.07153
Pasture - native	Flat	0.00623	0.00287	0.00236	0.88920
	Rolling	0.00810	0.00373	0.00307	1.15596
	Hilly	0.00996	0.00459	0.00378	1.42272
Pasture - modified	Flat		0.00913	0.00085	0.29718
	Rolling		0.01187	0.00110	0.38633
	Hilly		0.01461	0.00135	0.47549
General Ag	Flat		0.01121	0.00096	0.27041
	Rolling		0.01419	0.00122	0.34251
	Hilly		0.01755	0.00151	0.42363

* CLFs for TN in red are inferred from the correlation between TN and TP for the literature-based values ($CLF_{TN} = 8.967 \cdot CLF_{TP}$; $R^2 = 0.614$).

Table 7. Average total annual precipitation for Alberta's natural regions. Values were inferred from a combination of Figure 3-9 and Table 3-1, in "Natural Regions and Subregions of Alberta" (Alberta Environment: 2006), Natural Regions Committee, compiled by D.J. Downing and W.W. Pettapiece. These values of average annual precipitation – or measured, annual values – can be multiplied by the chemical loading factors (CLF) presented in Table 6, to estimate annual chemical loading.

Natural Regions	Average annual ppt (mm)		Average annual Ppt (mm)
Rocky Mountain	798	Alpine	990.8
		Subalpine	754.6
		Montane	585.9
Foothills	603	Upper Foothills	633.4
		Lower Foothills	585.9
Grassland	374	Dry Mixedgrass	332.8
		Mixedgrass	392.6
		Northern Fescue	381.9
		Foothills Fescue	469.3
Parkland	447	Foothills Parkland	516.9
		Central Parkland	441.7
		Peace River Parkland	449.4
Boreal Forest	469	Dry Mixedwood	458.6
		Central Mixedwood	475.5
		Lower Boreal Highlands	492.3
		Upper Boreal Highlands	535.3
		Athabasca Plain	426.4
		Peace-Athabasca Delta	377.3
		Northern Mixedwood	386.5
		Boreal Subarctic	512.3
Canadian Shield	380	Kazan Uplands	377.3

2.2 TSS Export Estimation

There have been a number of studies of total suspended solids (TSS) export in Alberta, including in the Ghost River basin[40], the Little Bow River basin[41], and the Upper Elbow River basin[42]. However, they have generally assessed catchment or sub-catchment loading rates, rather than changes in loading rates linked to changes in landuse. Similarly, Water Survey of Canada has a large historical TSS concentration dataset collected at many of the same sites as daily streamflow data. As with the studies described above, those TSS data are not sufficient to assess landuse-specific TSS loading rates without detailed, catchment-specific landcover and landuse information.

Unpaved roads are one of the major sediment sources in forested catchments. This is especially the case in wet, mountainous terrain, where roads can increase the undisturbed landslide erosion rate by 10 to 300 times, and road surface erosion can increase catchment sediment production rates by an order of magnitude or more.[43] Sediment delivery from roads to streams occurs mainly at road-stream crossings, but also via road-induced gullies. While there are a variety of approaches for estimating areal sediment production for roads, they generally involve estimates of annual export mass of sediment per kilometer of roadway, adjusted for an estimate of delivery of sediment to aquatic systems.[44, 45] As can be imagined, TSS loading rates from paved roads are substantially lower than from unpaved roads, although the latter is highly dependent on the volume of traffic on the unpaved road (Table 8).

Table 8. Annual sediment loading for paved and dirt roads [44], and off-highway vehicle trails (OHV) [45]. Stream connectivity is assumed to be 14% for roads and 24% for OHV trails [45], although it can also be calculated using Equation 9.

Road Type	Use intensity[x]	Linear TSS export (T/road km/yr)	Linear width (m)	Footprint area (ha/km)	Sediment production (kg/ha)	Sediment delivery (kg/ha road)
Paved road		2.1	10	1	2,100	294
Dirt roads	heavy use	500	10	1	500,000	70,000
	moderate use	41	10	1	41,000	5,740
	light use	3.8	6	0.6	6,333	887
	unused	0.5	6	0.6	833	117
OHV trails		4.0	2.1	0.21	19,048	4,571

The amount of sediment produced by different types of unpaved roads and trails is typically measured in close proximity to the road or trail, and depends on whether road runoff is regularly dispersed along the roadway or instead concentrated in a single drainage outlet.[43] Where runoff is dispersed along the length of a road or trail, sediment from erosion of road surfaces rarely travels more than 30 meters on vegetated downhill slopes.[46-48] However, where roadway runoff is concentrated as a single drainage location, the gully formation that may ensue can result in sediment transport traversing downhill slopes by distances up to three or four times further than when roadways are designed to disperse runoff.[47, 48] Therefore, annual sediment production from roads does not necessarily reflect the amount of sediment delivered to nearby streams via gullies formed by frequent high volumes of roadbed runoff. The sediment flux from roads and trails therefore must be adjusted for the connectivity of roads and trails to streams.

The degree of road-stream connectivity for the delivery of sediment export is a simple function of annual precipitation and the presence of engineered drainage structures [43]:

(9) $$C = 12.9 + 0.016Ppt + 39.5M$$ [xi]

[x] For dirt logging roads, heavy use is more than 4 logging trucks per day, moderate use is 1-4 logging trucks per day, and light use is only light vehicle traffic.[44]

[xi] $R^2 = 0.92$, $P < 0.0001$.

where C = percent of road length connected to stream channel network;
Ppt = mean annual precipitation (mm); and
M = binary of 0 (roads with drainage structures) or 1 (roads without drainage structures)

2.3 Calculated Export Coefficients

The approaches described here may be used to estimate nutrient and sediment loading coefficients via two methods: the effects of various types or intensities of agricultural activity and areal water yield on nutrient and sediment export rates, based on the AESA dataset; and the effects of landcover types and human landuses and variation in annual precipitation on loading rates, based on determination of event mean concentrations (EMCs) and chemical loading factors (CLFs). Comparisons between the various methods described here yield reasonably consistent values for export coefficients. For example, TSS annual export for paved roads determined according to CLFs are comparable to those determined via areal loading coefficients and road-stream connectivity calculations (*e.g.*, 330 and 539 kg/ha/yr for the Rocky Mountain Natural Region). Similarly, CLF-based TSS loading from motorized trails is approximately an order of magnitude greater than from paved surfaces, and loading from OHV trails based on areal loading coefficients and road-stream connectivity calculations are about twice as high again, all consistent with patterns observed in the literature.

In terms of values for export coefficients determined using EMCs and CLFs, and average annual precipitation values for Alberta's various ecozones (Appendix C), the loading coefficients determined for TN, TP and TSS from forested catchments are very similar to average export coefficient values for a number of literature-based values from different studies for similar forest types to those in Alberta (*e.g.*, 2.72 versus 3.32 kg N/ha/yr, respectively; 0.49 versus 0.51 kg P/ha/yr; 442 versus 380 kg TSS/ha/yr). The added benefit of the EMC/CLF approach is that temporal and spatial variation in loading also can be assessed, by using annual precipitation values available in a variety of provincial and federal government databases.

To specifically address the degree to which consideration of interannual variability and long-term average loading on agricultural lands in different natural regions compares to loading calculated simply on the basis of average annual areal runoff yields, Monte Carlo simulations was performed (n=1000, matching mean, median, min, max, and stdev for flow distributions presented in actual areal water yield data). In all of Alberta's Natural Regions, mean TP and TN export coefficients based on 1000 simulations with variable annual areal water yield were very similar to export coefficients calculated on the basis of long-term mean values of areal water yield. For example, for the Grassland Natural Region, the loading coefficients for TP, TN, and TSS calculated based on the mean annual areal water yield are basically the same as the mean value of 1,000 Monte Carlo simulations (Table 9). Similar comparisons of loading coefficients for the other Natural Regions in Alberta, based on average areal water yield and Monte Carlo simulations, suggest that using long-term average flow data in calculating loading coefficients according to the methods described here provides an accurate estimate of long-term average loading based on annual water yields (not shown). Consequently, this approach may be useful for assessing large-scale, strategic planning questions related to landuse and its impacts on NPSP loading (that are based on long-term averages), and more detailed assessments that require an understanding of the interannual variation in loading that occurs over a full range of conditions from very dry to very wet years.

Table 9. Comparison of average AESA-based export coefficients for the Grassland Natural Region derived from average areal water yield, and from 1,000 Monte Carlo simulations of areal water yield, the distributions for which matched the distributions of actual catchment flow data (see appendix Table A-3 for runoff distributions).

Agriculture Type	Modeling approach	TN (kg/ha/yr)	TP (kg/ha/yr)	TSS (kg/ha/yr)
Cereal Crop (intensive - manure)	Monte Carlo	1.138	0.147	63.7
	Mean water yield	1.228	0.158	66.7
Cereal Crop (extensive)	Monte Carlo	0.304	0.048	69.2
	Mean water yield	0.313	0.042	53.5
Forage Crop (intensive) alfalfa	Monte Carlo	1.706	0.147	63.7
	Mean water yield	1.842	0.238	66.7
Forage Crop (extensive) alfalfa	Monte Carlo	0.456	0.048	69.2
	Mean water yield	0.469	0.042	53.5

Conclusion

The purpose of modeling non-point source (NPS) pollution is to allow ecosystem managers to most efficiently and effectively anticipate and reduce impacts of human landuse changes related to NSP pollution, whether in the presence or absence of major point sources of pollution in the catchment. However, the main problem with modeling NPS nutrient and sediment export from landscapes to aquatic systems is that, in most cases, there are little or no actual water quality or loading data for the particular ecosystem of interest, and insufficient landuse and landcover data. Even where there are water quality and landuse data, they are typically too coarse, spatially, and are of limited use to managers attempting to identify and manage catchment pollution inputs. Consequently, one is usually left with only two options: use the best available export coefficients presented in the scientific literature for different landuse and land cover types; or derive site-specific export coefficients by expending substantial time and money on mechanistic modeling that requires detailed landuse and landcover data. While the latter approach involves determinations of export coefficients based on site-specific landuse and water quality data, it must be acknowledged that it also typically involves use of standard rate constants, developed elsewhere or imported from the literature, in calculation of such things as runoff, evapotranspiration, infiltration, and ground- and surface water flow rates. For this reason, it is arguable that substantial assumptions are involved in any modeling approach used to determine NPS pollution export coefficients, because it usually relies on rate constants or coefficients that have not been derived for the specific catchment of interest.

Ultimately, the question is whether there is some middle ground between using fixed NPS pollution export coefficients derived elsewhere – perhaps in systems that are very different climatically or biologically – that are not responsive to changes in precipitation or runoff and do not necessarily reflect land or soil types of particular interest, and the work-intensive and expensive mechanistic modeling approach that accounts for hydrologic variability and dynamics and relies on large datasets of site- or catchment-specific information, but may still be limited in accuracy because of a reliance on common rate constants.

The methods I have described here were used to obtain loading coefficients for TN, TP and TSS that respond to hydrologically dynamic systems. The two approaches described also produce comparable export rates, where they have been applied to derive export coefficients for the same landcover or landuse type with Alberta's various ecozones. It must be emphasized that the export rates described here generally reflect water quality in low-order streams. Estimates of nutrient and sediment concentrations in high-order rivers based solely on these export coefficients would likely be too high, because they do not incorporate in-stream nutrient and sediment removal mechanisms and rates. However, at the very least, these methods should be of use for development of strategic watershed management decisions based on estimates of loading potential from different landuses, where insufficient data or resources precludes more detailed mechanistic modeling of loading and water quality. Any deviations between predictions of loading and catchment- or stream-specific data will simply highlight the need to further calibrate and refine the model used and/or perform more detailed monitoring to enable the incorporation of data from the watershed of interest into the modeling approaches used. Ultimately, any modeling effort requires calibration and validation to refine the model output to more accurately reflect the site-specific loading rates and water quality in a particular watershed.

References

1. Duchemin, M.; Hogue, R., Reduction in agricultural non-point source pollution in the first year following establishment of an integrated grass/tree filter strip system in southern Quebec (Canada). *Agriculture, Ecosystems and Environment* 2009, 131, 85–97.
2. Edwards, A. C.; Withers, P. J. A., Transport and delivery of suspended solids, nitrogen and phosphorus from various sources to freshwaters in the UK. *Journal of Hydrology* 2008, 350, 144–153.
3. Hilton, J.; Buckland, P.; Irons, G. P., An assessment of a simple method for estimating the relative contributions of point and diffuse source phosphorus to in-river phosphorus loads. *Hydrobiologia* 2002, 472, 77-83.
4. Johnes, P. J., Evaluation and management of the impact of land use change on the nitrogen and phosphorus load delivered to surface waters: The export coefficient modelling approach. *J. Hydrol.* 1996, 183, (3-4), 323-349.
5. Cohn, T. A.; Caulder, D. L.; Gilroy, E. J.; Zynjuk, L. D.; Summers, R. M., The validity of a simple statistical model for estimating fluvial constituent loads: An empirical study involving nutrient loads entering Chesapeake Bay. *Water Resources Res.* 1992, 28, (9), 2353-2363.
6. Heathwaite, A. L.; Dils, R. M.; Liu, S.; Carvalho, L.; Brazier, R. E.; Pope, L.; Hughes, M.; Phillips, G.; May, L., A tiered risk-based approach for predicting diffuse and point source phosphorus losses in agricultural areas. *Science of the Total Environment* 2005, 344, 225-239.
7. Jedrych, A. T., Predicting phosphorus losses from agricultural areas. Alberta Soil Phosphorus Limits Project, Volume 5: Assessment of Environmental Sustainability in Alberta's Agricultural Watersheds Project. Alberta Agriculture and Rural Development, Alberta, Canada, 2008; p 38.
8. Johnes, P. J.; Heathwaite, A. L., Modelling the impact of land use change on water quality in agricultural catchments. *Hydrological Processes* 1997, 11, 269-286.
9. Little, J. L.; Nolan, S. C.; Casson, J. P., Relationships between soil-test phosphorus and runoff phosphorus in small Alberta watersheds. Alberta Soil Phosphorus Limits Project. Volume 2: Field-scale losses and soil limits. Alberta Agriculture, Food and Rural Development, Lethbridge, AB, Canada, 2006; p 150.
10. Lorenz, K.; Depoe, S.; Phelan, C., Assessment of Environmental Sustainability in Alberta's Agricultural Watersheds Project, Volume 3: AESA Water Quality Monitoring Project. Alberta Agriculture and Rural Development, Alberta, Canada, 2008; p 527.
11. Shrestha, S.; Kazama, F.; Newham, L. T. H., A framework for estimating pollutant export coefficients from long-term in-stream water quality monitoring data. *Environmental Modelling & Software* 2008, 23, 182-194.
12. Johnes, P. J.; Moss, B.; Phillips, G., The determination of total nitrogen and total phosphorus concentrations in freshwaters from land use, stock headage and population data: testing of a model for use in conservation and water quality management. *Freshwater Biology* 1996, 36, 451-473.
13. Beaulac, M. N.; Reckhow, K. H., An examination of land use – nutrient export relationships. Water Resources Bulletin 1982, 18, (6), 1013-1024.
14. Cessna, A. J.; Elliott, J. A.; Tollefson, L.; Nicholaichuk, W., Herbicide and Nutrient Transport from an Irrigation District into the South Saskatchewan River. *J. Environ. Qual.* 2001, 30, 1796–1807.

15. Bartley, R.; Speirs, W. Review and summary of constituent concentration data from Australia for use in catchment water quality models; eWater Cooperative Research Centre, CSIRO: Indooroopilly, Queensland, Australia, 2010; p 58.
16. Lin, J. P., Review of Published Export Coefficient and Event Mean Concentration (EMC) Data. Wetland Regulatory Assistance Program, ERDC, Vicksburg, Mississippi, U. S. A., 2004; p 15.
17. Reckhow, K. H.; Beaulac, M. N.; Simpson, J. T., Modeling phosphorus loading in lake response under uncertainty: A manual and compilation of export coefficients. Clean Lakes Section, U. S. Environmental Protection Agency, Washington, D.C.: 1980; p 161.
18. Anderson, A.-M.; Cooke, S. E.; MacAlpine, N., Watershed Selection for the AESA Stream Water Quality Monitoring Program. In Water Sciences Branch, Alberta Environment and Alberta Agriculture, Food and Rural Development, Edmonton, Alberta, 1999; p 48 + Appendices.
19. Hudson, N. W., Field measurement of soil erosion and runoff. Food and Agriculture Organization of the United Nations: Rome, 1993.
20. Schwab, G. O.; Frevert, R. K.; Edminster, R. W.; Barnes, K. K., Soil and Water Conservation Engineering. 3rd ed.; John Wiley: New York, 1981.
21. Planning Initiatives Ltd. (1996) Section C, Environmental Analysis Report. In: Final Subwatershed Management Plan, Subwatershed Plans #313 and #309, Laurel Creek Watershed, City of Waterloo, p. 59.
22. Sauchyn, D. J.; Barrow, E.; Hopkinson, R.; Leavitt, P. R. Aridity on the Canadian Plains: Future Trends and Past Variability (Summary Document); Prairie Adaptation Research Collaborative Report No. 03-01, 2003.
23. Schindler, D. W.; Donahue, W. F., An impending water crisis in Canada's western prairie provinces. *Proc. Nat. Acad. Sci.* 2006, 103, (19), 7210-7216.
24. Swank, W. T.; Douglass, J. E., Nutrient budgets for undisturbed and manipulated hardwood forest ecosystems in the mountains of North Carolina. In Watershed Research in Eastern North America - A Workshop to Compare Results, Correll, D. L., Ed. Chesapeake Bay Center for Environmental Studies, Smithsonian Institution, Edgewater, Maryland, 1977.
25. Swank, W. T.; Douglass, J. E., Streamflow greatly reduced by converting deciduous hardwood stands to pine. *Science* 1974, 85, 857-859.
26. Committee on Hydrologic Impacts of Forest Management (2008) Hydrologic Effects of a Changing Forest Landscape. National Research Council (ed), p. 180.
27. Moore, R. D.; Richardson, J. S., Natural disturbance and forest management in riparian zones: comparison of effects at reach, catchment, and landscape scales. *Freshwater Science* 2012, 31, (1), 239-247.
28. Forest Practices Board (2007). The Effect of Mountain Pine Beetle Attack and Salvage Harvesting On Streamflows: Special investigation, Government of British Columbia.
29. Swank, W. T.; Voce, J. M.; Elliott, K. J., Long-term hydrologic and water quality responses following commercial clearcutting of mixed hardwoods on a southern Appalachian catchment. *Forest Ecology and Management* 2001, 143, 163-178.
30. Jones, J. A.; Post, D. A., Seasonal and successional streamflow response to forest cutting and regrowth in the northwest and eastern United States. *Water Resources Res.* 2004, 40, W05203.
31. Tietema, A.; Beier, C.; de Visser, P. H. B.; Emmett, B. A.; Gunderson, P.; Kjønaas, O. J.; Koopmans, C. J., Nitrate leachingin coniferousforest ecosystems: The European field-scale manipulation experiments NITREX (nitrogen saturation experiments) and EXMAN (experimental manipulation of forest ecosystems). *Global Biogeochemical Cycles* 1997, 11, (4), 617-626.

32. Kortelainen, P.; Saukkonen, S.; Mattson, T., Leaching of nitrogen from forested catchments in Finland. *Global Biogeochemical Cycles* 1997, 11, (4), 627-638.
33. Williard, K. W. J.; DeWalled, D. R.; Edwards, P. J.; Schnabel, R. R., Indicators of nitrate export from forested watersheds of the mid-Appalachians, United States of America. *Global Biogeochemical Cycles* 1997, 11, (4), 649-656.
34. Johnson, D. W.; Susfalk, R. B.; Dahlgren, R. A., Nutrient fluxes in forests of the eastern Sierra Nevada mountains, United States of America. *Global Biogeochemical Cycles* 1997, 11, (4), 673-681.
35. Aber, J. D.; Driscoll, C. T., Effects of land use, climate variation, and N deposition on N cycling and C storage in northern hardwood forests. *Global Biogeochemical Cycles* 1997, 11, (4), 639-648.
36. Casson, J. P.; Bennett, D. R.; Nolan, S. C.; Olson, B. M.; R., O. G.; Little, J. L., Degree of phosphorus saturation thresholds in Alberta soils. In Alberta Soil Phosphorus Limits Project. Volume 3: Soil sampling, manure application, and sorption characteristics. Alberta Agriculture, Food and Rural Development, Lethbridge, AB, 2006; p 40.
37. Casson, J. P.; Olson, B. M.; Little, J. L.; Nolan, S. C., Nitrogen loss in surface runoff. In Alberta Soil Phosphorus Limits Project. Volume 4: Assessment of Environmental Sustainability in Alberta's Agricultural Watersheds Project. Alberta Agriculture and Rural Development, Lethbridge, AB, 2008; p 71.
38. Mapfumo, E.; Willms, W. D.; Chanasyk, D. S., Water quality of surface runoff from grazed fescue grassland watersheds in Alberta. *Water Quality Research Journal of Canada* 2002, 37, 543-562.
39. McCarthy, J., New Hampshire Stormwater Manual, Vol. 1: Stormwater and Antidegradation. U. S. Environmental Protection Agency and New Hampshire Department of Environmental Services, 2008; p 109.
40. Andrews, D. Water Quality Study of Waiparous Creek, Fallentimber Creek and Ghost River; Alberta Environment: Edmonton, AB, 2006.
41. Sosiak, A., Water Quality Sampling of the Little Bow River and Mosquito Creek in 1999. Alberta Environment. Edmonton, AB, 2000; p 22 + Figures & Appendices.
42. Sosiak, A.; Dixon, J., Impacts on Water Quality in the Upper Elbow River. Alberta Environment. Calgary, AB, 2004; p 88.
43. MacDonald, L. H.; Coe, D. B. R. In Road sediment production and delivery: processes and management. First World Landslide Forum; International Consortium on Landslides: United Nations University, Tokyo, Japan, 2008; pp 385-388.
44. Cederholm, C. J.; Reid, L. M.; Salo, E. O., Cumulative effects of logging road sediment on salmonid populations in the Clearwater River, Jefferson Country, Washington. In Salmon-Spawning Gravel: A Renewable Resource in the Pacific Northwest?, Seattle, WA, 1980.
45. Welsh, M. J. Sediment Production and Delivery from Forest Roads and Off-Highway Vehicle Trails in the Upper South Platte River Watershed, Colorado. Colorado State University, 2008.
46. Brake, D.; Molnau, M.; King, J. G., Sediment transport distances and culvert spacings on logging roads within the Oregon Coast Mountain Range. In *American Society of Agricultural Engineers, Annual International Meeting*, Minneapolis, MN, 1997; Vol. Paper No. IN-975018, p 11.
47. Coe, D. B. R. Sediment production and delivery from forest roads in the Sierra Nevada, California. Colorado State University, Fort Collins, CO, 2006.
48. Megahan, W. F.; Ketcheson, G. L., Predicting downslope travel of granitic sediments from forest roads in Idaho. *Water Resources Bulletin* **1996,** *32*, (2), 371-382.
49. Stormwater Monitoring Report: 1998-1999; http://dpw.lacounty.gov/wmd/NPDES/9899TC.cfm

50. Harper, H. H., Stormwater Chemistry and Water Quality: Estimating Pollutant Loadings and Evaluation of Best Management Practices for Water Quality Improvements. *Proceedings of the 1999 Stormwater Management: A Designer's Course, Florida Engineering Society, Orlando, Florida, August 26-27* **1999**.
51. Kim, L.-H.; Kayhanian, M.; Zoh, K.-D.; Stenstrom, M. K., Modeling of highway stormwater runoff. *Science of the Total Environment* **2005,** *348*, 1–18.
52. Whitney, S. S. Modeling total suspended solids in the rogue River Watershed (Michigan) for future buffer implementation projects. University of Florida, 2010.
53. Babin, J.; Mitchell, P.; Allan, D.; Trew, D. *A summary of atmospheric deposition measurements for nutrients in Central Alberta (1982-86)*; Alberta Environment: Edmonton, AB, 1989.
54. Chambers, P. A.; Dale, A. R. *Contributions of Industrial, Municipal, Aricultural and Groundwater Sources to Nutrient Export, Athabasca, Wapiti and Smoky Rivers, 1980-1993*.; Northern River Basins Study: Edmonton, Alberta, 1997.
55. Walsh, M. J. Sediment Production and Delivery from Forest Roads and Off-highway Vehicle Trails in the Upper South Platte River Watershed, Colorado. Colorado State University, 2008.
56. 2nd Nature LLC. Load Reduction Planning Tool (LRPT): A Methodology for Estimating Water Quality Benefits of Redevelopment Projects in the Lake Tahoe Basin; 2009; p 35.
57. Rahman, A.; Rahman, S.; Cihacek, L., Efficacy of vegetative filter strips (VFS) installed at the edge of feedlot to minimize solids and nutrients from runoff. *Agric. Eng. Int.* **2012,** *14*, (4), 9-21.
58. Prairie Farm Rehabilitation Administration (PFRA, 2001), Feedlot runoff treatment demonstration project; http://www.prairiewaternews.ca/water/vol12no1/story10.html.
59. Simons, D. B.; Li, R. M.; Schall, J. D.; Peterson, M. R.; Anderson, B. A.; Summer, R. M.; Fullerton, W. T., Section 3, Hydrological Analysis. In *Surface Mining Water Diversion Design Manual*, Office of Surface Mining, U. S. Department of the Interior: 1982; p 380.
60. Winter, J. G.; Dillon, P. J., Export of nutrients from golf courses on the Precambrian Shield. *Environmental Pollution* 2006, 141, 550-554.

Appendix A: EMCs and Runoff Coefficients for Different Landuse and Footprint Types

Table A-1. Event Mean Concentrations for difference landuse and footprint types (EMCs; mg/L) [16], **used in calculating chemical loading factors (CLFs) shown in Table 6, above.**

	TKN			TN			TP			TSS		
Footprint Types	**Mean**	SD	N	**Mean**	SD	N	**Mean**	SD	N	**Mean**	SD	N
Transportation												
Hard Roads (paved)				12.040		2	0.385		2	50.65		2
Industrial												
Industrial Plants	2.460	0.932	4	2.880	1.541	3	0.373	0.088	5	219.66	117.33	6
Surface Mines				1.180		1	0.150		1	93.94		1
Recreation												
golf courses	6.850		1				1.070		1	202.00		1
Residential												
Urban (City Core)	1.735	0.092	3	2.900	0.099	3	0.360	0.068	5	126.03	106.97	5
Urban (Suburban)	3.907	1.962	4	2.278	0.110	3	0.471	0.204	6	102.11	73.45	6
Rural Residential (acreage yard)				1.755		2	0.145		2	35.05		2
Construction												
Clearing, grubbing, grading of former wooded/agri land	1.080		1				0.430		1	3491.00		1
Installation of roads, storm drainage & housing	5.690		1				0.280		1	1453.00		1
Rural												
Wooded	3.580		1	1.261		2	0.227	0.120	3	205.00	244.57	3
Pasture (native)	3.460		1	1.593		1	1.311		2	494.00		2
Pasture (modified)				5.074	2.281	3	0.470	0.097	3	165.10	82.70	3
General Agriculture				4.150		2	0.357		2	100.15		2
Open space	0.720		1	1.495		2	0.098	0.040	3	52.99	42.92	3
Aquatic												
Wetland				1.490		2	0.135		2	8.10		2
Open water/lake				1.315		2	0.095		2	4.55		2

Table A-2. Runoff coefficients and EMCs for different landuse and footprint types used in calculating CLFs in Table 6. Values in red are inferred, according to assumptions indicated by the superscript numeral, and listed below the table.

			EMC$_i$ (mg/L)				
	R_v	R_v*Ppt_j	TKN	TN	TP	TSS	Source
Transportation							
Soft Roads (gravelled)	0.50	0.45					2nd Nature LLC 2009
Hard Roads (paved)	0.91	0.816		12.040	0.385	50.650	Department of Public Works, LA County 1999, Harper 1999, Planning Initiatives Ltd. 1996, Kim et al. 2005, Lin 2004, McCarthy 2008[16, 21, 39, 49-51]
Trails (motorized)	0.50	0.45		3.2	2.69	642	Edwards and Withers 2008, 2nd Nature LLC 2009
Trails (non-motorized)[1]	0.35	0.315		2.478	1.418	338.525	2nd Nature LLC 2009
Industrial							
Industrial Plants	0.55	0.495	2.460	2.880	0.373	219.658	Planning Initiatives Ltd. 1996, Lin 2004
Transmission Lines[2]	0.20	0.18		1.9213	0.7458	200.24	2nd Nature LLC 2009
Seismic Lines[2]	0.15	0.135		1.9213	0.7458	200.24	2nd Nature LLC 2009
Wellpads[3]	0.50	0.45		3.04	1.5313	430.829	2nd Nature LLC 2009
Pipelines[2]	0.25	0.225		1.9213	0.7458	200.24	2nd Nature LLC 2009
Processing Plants	0.50	0.45		2.880	0.373	219.658	2nd Nature LLC 2009
Feedlots (dairy cow yard)	0.50	0.45		360	72.05	1109.5	Edwards and Withers 2008, 2nd Nature LLC 2009
Surface Mines undisturbed[4]	0.15	0.135	0.72	1.495	0.098	52.987	Simons et al. 1982
disturbed	0.5	0.45		1.180	0.150	93.940	Lin 2004, Simons et al. 1982
Recreation							
Golf courses	0.25	0.225	6.850		1.070	202.000	Lin 2004, 2nd Nature LLC 2009
Ski areas[4]	0.15	0.135	0.72	1.495	0.098	52.987	2nd Nature LLC 2009
Campgrounds[5]	0.35	0.315		2.1885	0.9085	217.135	2nd Nature LLC 2009
Residential							
Urban (City Core)	0.55	0.495	1.735	2.900	0.360	126.025	Planning Initiatives Ltd. 1996, Lin 2004
Urban (Suburban)	0.38	0.342	3.907	2.278	0.471	102.111	Planning Initiatives Ltd. 1996, Lin 2004
Rural Residential (farm yard)	0.30	0.27		183	30.8	982	Edwards and Withers 2008, Lin 2004
Rural Residential (acreage yard)	0.20	0.18		1.755	0.145	35.050	Lin 2004, 2nd Nature LLC 2009

<u>Assumptions for inferred runoff coefficients:</u>

1. 50% motorized trail & 50% acreage yard
2. 25% motorized trail + 75% open space
3. 50% industrial plant & 50% motorized trail
4. Presumed to be same as undisturbed open space
5. 30% motorized trail + 70% acreage yard

Table A-2 (cont'd). Runoff coefficients and EMCs for different landuse and footprint types.

				EMC$_i$ (mg/L)				
		R_v	R_v*Ppt$_j$	TKN	TN	TP	TSS	Source
Construction								
Clearing, grubbing, grading of former wooded/ag land		0.35	0.315	1.080		0.430	3491.000	Lin 2004, 2nd Nature LLC 2009
Installation of roads, storm drainage & housing		0.35	0.315	5.690		0.280	1453.000	Lin 2004, 2nd Nature LLC 2009
Wooded		0.3	0.27	3.580	1.261	0.227	205.000	Hudson 1993, Lin 2004
Pasture - native	Flat	0.2	0.18	3.460	1.593	1.311	494.000	Hudson 1993, Lin 2004
	Rolling	0.26	0.234	3.460	1.593	1.311	494.000	Hudson 1993, Lin 2004
	Hilly	0.32	0.288	3.460	1.593	1.311	494.000	Hudson 1993, Lin 2004
Pasture - modified	Flat	0.2	0.18		5.074	0.470	165.100	Hudson 1993, Lin 2004
	Rolling	0.26	0.234		5.074	0.470	165.100	Hudson 1993, Lin 2004
	Hilly	0.32	0.288		5.074	0.470	165.100	Hudson 1993, Lin 2004
General Ag	Flat	0.3	0.27		4.150	0.357	100.150	Hudson 1993, Lin 2004
	Rolling	0.38	0.342		4.150	0.357	100.150	Hudson 1993, Lin 2004
	Hilly	0.47	0.423		4.150	0.357	100.150	Hudson 1993, Lin 2004
Grassland	Flat	0.25	0.225		0.193	0.042	31.792	Back-calculated from Stavely site measured values
	Rolling	0.31	0.279		0.193	0.042	31.792	
	Hilly	0.37	0.333		0.193	0.042	31.792	
Wetland					1.490	0.135	8.100	Lin 2004
Open water/lake					1.315	0.095	4.550	Lin 2004
Open space		0.15	0.135	0.72	1.495	0.098	52.987	Lin 2004

Table A-3. Statistical distributions for TP, TN, and TSS loading rates in AESA catchments in the different Natural Regions of Alberta. "Runoff" is areal water yield from 1 March to 31 October, in mm, and all export coefficients are in kg/ha/yr.

	Boreal - Low Ag Intensity				Boreal - Med Ag Intensity			
Export (kg/ha/yr)	Runoff	TP	TN	TSS	Runoff	TP	TN	TSS
Average	56.7	0.16	0.81	137.79	53.0	0.18	1.37	72.41
Median	52.7	0.08	0.59	19.58	43.4	0.14	1.20	51.68
Min	0.4	0.00	0.01	0.14	1.3	0.00	0.04	0.17
Max	152.8	1.26	3.55	1220.68	181.5	0.63	3.69	266.45
StDev	38.7	0.25	0.75	265.69	41.6	0.15	0.95	76.49
N		24	24	23		32	32	30
	Parkland - High Ag Intensity				Continental Divide - Low Ag Intensity			
Average	21.8	0.14	0.66	35.93	225.6	1.13	2.05	1053.51
Median	16.5	0.09	0.46	1.99	151.7	0.06	0.41	87.96
Min	0.2	0.00	0.00	0.02	62.2	0.01	0.08	3.47
Max	92.2	0.94	2.94	650.16	634.6	8.30	12.24	6540.15
StDev	19.1	0.16	0.65	122.70	188.3	2.90	4.16	2423.94
N	66	70	59	66		8	8	7
	Grassland - Low Ag Intensity				Grassland - Med Ag Intensity			
Average	15.9	0.03	0.35	7.26	36.9	0.06	0.33	103.80
Median	7.6	0.01	0.15	0.71	22.9	0.02	0.14	23.22
Min	0.6	0.00	0.00	0.10	2.7	0.00	0.02	0.39
Max	44.7	0.09	1.24	23.74	167.7	0.27	1.38	454.99
StDev	17.4	0.03	0.47	11.00	43.0	0.08	0.39	155.29
N		8	8	7		16	16	15
	Grassland - Irrigated				Moderate to high manure application			
Average	126.2	0.16	1.25	80.42	14.9	1.33	3.43	126.2
Median	104.8	0.16	1.20	67.78	4.8	0.28	2.29	104.8
Min	20.1	0.03	0.15	4.49	0.5	0.02	0.06	20.1
Max	290.0	0.29	3.00	233.73	71.8	5.75	8.60	290.0
StDev	100.4	0.09	0.82	68.36	28.0	2.25	3.80	100.4
N		16	16	15		6	6	

Appendix B: Nutrient and TSS Export Coefficients for Different Landuse and Footprint Types in Alberta's Ecozones

Table B-1. Export coefficients for difference landuse and footprint types – Rocky Mountain Natural Region (kg/ha/year). Values include those from NPSP literature, those calculated from ELFs listed and **average annual precipitation** according to methods described above (Tables 6 and 7), from relationships derived from AESA data, the from literature (in red).

Average Annual precipitation (mm)	798	798	798
Average runoff (1 Mar - 31 Oct; mm)	226	226	226
Landscape Types	**Nitrogen (TN) kg/ha/yr**	**Phosphorus (TP) kg/ha/yr**	**Sediment (TSS) kg/ha/yr**
Conifer-dominated Forest	3.320[17]	0.514[17]	380[20, 43]
Hardwood-dominated Forest[xii]	2.656[13, 17]	0.411[13, 17]	433
Wooded (based on +36% over wooded EMCs)[xiii]	2.717[16, 19]	0.490[16, 19]	442[16, 19]
Shrubland[1]	3.695[16, 52]	0.666[16, 52]	601[16, 52]
Native Grassland[1]	0.512[9, 16, 37]	0.111[9, 16, 37]	84[19, 20]
Natural Unvegetated Flat (rock/ice/sand)[xiv]	2.950[53, 54]	0.200[53, 54]	N/A
Natural Unvegetated Steep (rock/ice/sand)	2.950[53, 54]	0.200[53, 54]	N/A
Natural Unvegetated Flat (rock/ice/sand) - oilsands region	N/A	N/A	N/A
Natural Unvegetated Steep (rock/ice/sand) - oilsands region	N/A	N/A	N/A
Cereal Crop (intensive - manure)[xv]	72.54[37]	33.58[9]	170[1]
Cereal Crop (extensive)[2]	0.967[37]	0.194[9]	170[1]
Forage Crop (intensive) alfalfa[2]	108.8[13, 37]	0.194[9, 13]	170[1]
Forage Crop (extensive) alfalfa[2]	1.451[13, 37]	0.194[9, 13]	170[1]
Native Grazing - Flat (0-5% slope) [1]	2.288[16, 19]	1.883[16, 19]	710[16, 19]
- Rolling (5-10% slope) [1]	2.975[16, 19]	2.448[16, 19]	922[16, 19]
- Hilly (10-30% slope) [1]	3.661[16, 19]	3.013[16, 19]	1,135[16, 19]
Intensive Grazing - Flat (0-5% slope) [1]	7.289[16, 19]	0.675[16, 19]	237[16, 19]
- Rolling (5-10% slope) [1]	9.475[16, 19]	0.877[16, 19]	308[16, 19]
- Hilly (10-30% slope) [1]	11.66[16, 19]	1.079[16, 19]	379[16, 19]
General Agriculture – Flat [1]	8.942[16, 19]	0.769[16, 19]	216[16, 19]
- Rolling [1]	11.33[16, 19]	0.974[16, 19]	273[16, 19]
- Hilly [1]	14.01[16, 19]	1.205[16, 19]	338[16, 19]

[xii] For hardwood forests, sediment export is 14% higher than for conifer-dominate forests.

[xiii] Calculated from CLFs and average annual precipitation (Tables 6 and 7).

[xiv] Nutrient loading from unvegetated rock/ice/sand is the equivalent of atmospheric deposition.

[xv] Calculated from AESA data and average seasonal areal water yield (i.e., "runoff"): TP loading = $5.23 \times 10^{-8} (Runoff^{2.791})$, $R^2=0.797$; TN loading = $1.79 \times 10^{-5} (Runoff^{2.011})$, $R^2=0.857$; TSS loading = $2.25 \times 10^{-5} (Runoff^{2.923})$, $R^2=0.758$. Intensive forms of agricultural activity involve manure application, where TP loading = $0.04869 (Runoff^{1.2047})$, $R^2=0.905$; TN loading = $0.2439(Runoff^{1.0509})$, $R^2=0.905$.

Table B-1 (cont'd).

Footprint Types	Rocky Mountain Natural Region: Nitrogen (TN) kg/ha/yr	Phosphorus (TP) kg/ha/yr	Sediment (TSS) kg/ha/yr
Transportation			
Soft Roads (gravel/dirt) - heavy use, assuming 10 m wide, drainage structures[1]			128,300[55]
Soft Roads - heavy use, assuming 10 m wide, no drainage structures[1]			325,800[55]
Soft Roads - moderate use, 10 m wide, drainage structures[1]			10,520[55]
Soft Roads - moderate use, 10 m wide, no drainage structures[1]			26719[55]
Soft Roads - light use, 6 m wide, drainage structures[1]	11.49[1, 2, 16]	9.660[1, 2, 16]	1,626[55]
Soft Roads - light use, 6 m wide, no drainage structures[1]			4,127[55]
Soft Roads - unused, 6 m wide, drainage structures[1]			214[55]
Soft Roads - unused, 6 m wide, no drainage structures[1]			543[55]
Hard Roads (paved) [1]	78.40[16, 21, 37, 47-49]	2.507[16, 21, 37, 47-49]	330[16, 21, 37, 47-49]
Hard Roads (paved; 10 m wide, drainage structures)			539[16, 21, 39, 49-51, 55]
Trails (motorized) [1]	11.49[1, 2, 16]	9.660[1, 2, 16]	2,305[1, 2, 16]
Trails (OHV)			4,440[55]
Trails (non-motorized) [1]	6.228[16, 56]	3.563[16, 56]	851[16, 56]
Industrial			
Industrial Plants[1]	11.38[16, 21]	1.471[16, 21]	868[16, 21]
Transmission Lines[1]	2.760[16, 56]	1.071[16, 56]	288[16, 56]
Seismic Lines[1]	2.070[16, 56]	0.803[16, 56]	216[16, 56]
Wellpads[1]	10.92[16, 56]	5.499[16, 56]	1,547[16, 56]
Pipelines[1]	4.140[16, 56]	1.607[16, 56]	431[16, 56]
Processing Plants[1]	10.34[16, 56]	1.338[16, 56]	789[16, 56]
Feedlots (loading coefficient kg/ha/yr)	100-1,600[16, 19]	10-620[16, 19]	
- based on EMCs, runoff, etc[1]	1,293[1,2, 56-58]	259[1,2, 56-58]	3,984[1,2, 56-58]
Surface Mines[1]	4.237[16, 59]	0.539[16, 59]	337[16, 59]
Construction 1 - Clearing, grubbing, grading of former wooded/ag land[1]	9.692[16, 56]	1.081[16, 56]	8,775[16, 56]
Construction 2 - Installation of roads, storm drainage & housing[1]	6.311[16, 56]	0.704[16, 56]	3,652[16, 56]
Recreation			
Recreational Features (golf courses) [1]	17.23[16, 56]	1.921[16, 56]	363[16, 56]
Recreational Features (ski areas) [1]	4.187[56]	0.274[56]	148[56]
Recreational Features (campgrounds) [1]	5.501[56]	2.284[56]	546[56]
Residential			
Urban (City Core) [1]	11.46[16, 21]	1.422[16, 21]	498[16, 21]
Urban (Suburban) [1]	6.216[16, 21]	1.285[16, 21]	279[16, 21]
Rural Residential (farm yard) [1]	394.3[2, 16]	66.36[2, 16]	2,116[2, 16]
Rural Residential (acreage yard) [1]	2.521[16, 56]	0.208[16, 56]	50[16, 56]

Table B-2. Export coefficients for difference landuse and footprint types – Foothills Natural Region (kg/ha/year). Values include those from NPSP literature, those calculated from ELFs listed and **average annual precipitation**, according to methods described above (Tables 6 and 7), those calculated from relationships derived from AESA data ("medium agriculture intensity" and catchments with manure application), and those calculated from equations from the literature (in red). References are the same as listed in Table B-1, unless as indicated.

Average Annual precipitation (mm)	603	603	603
Average runoff (1 Mar - 31 Oct; mm)	37	37	37
Landscape Types	**Nitrogen (TN) kg/ha/yr**	**Phosphorus (TP) kg/ha/yr**	**Sediment (TSS) kg/ha/yr**
Conifer Dominated Forest	3.320	0.514	380
Hardwood Dominated Forest	2.656	0.411	433
Wooded (based on +36% over wooded EMCs)[xvi]	2.053	0.370	334
Shrubland[1]	2.792	0.503	454
Native Grassland[1]	0.324	0.070	53
Natural Unvegetated Flat (rock/ice/sand)	2.950	0.200	N/A
Natural Unvegetated Steep (rock/ice/sand)	2.950	0.200	N/A
Natural Unvegetated Flat (rock/ice/sand) - oilsands region	N/A	N/A	N/A
Natural Unvegetated Steep (rock/ice/sand) - oilsands region	N/A	N/A	N/A
Cereal Crop (intensive - manure)[xvii]	10.819	3.789	53.5
Cereal Crop (extensive)[2]	0.334	0.042	53.5
Forage Crop (intensive) alfalfa[2]	16.23	3.789	53.5
Forage Crop (extensive) alfalfa[2]	0.501	0.042	53.5
Native Grazing - Flat (0-5% slope) [1]	1.729	1.423	536
- Rolling (5-10% slope) [1]	2.248	1.850	697
- Hilly (10-30% slope) [1]	2.766	2.277	858
Intensive Grazing - Flat (0-5% slope) [1]	5.508	0.510	179
- Rolling (5-10% slope) [1]	7.160	0.663	233
- Hilly (10-30% slope) [1]	8.812	0.816	287
General Agriculture – Flat [1]	6.757	0.581	163
- Rolling [1]	8.558	0.736	207
- Hilly [1]	10.59	0.911	255

[xvi] Calculated from CLFs and average annual precipitation (Tables 6 and 7).

[xvii] Calculated from AESA data and average seasonal areal water yield (i.e., "runoff"; 1 Mar – 31 Oct). For the medium agricultural intensity Grassland AESA catchment in the Foothills Fescue Natural Region, average "runoff" was 37 mm. TP loading = 0.000381 ($Runoff^{1.3036}$), R^2=0.821; TN loading = 0.008782 (Runoff)+0.0101, R2=0.935; TSS loading = 0.232 ($Runoff^{1.508}$), R^2=0.792. Intensive forms of agricultural activity involve manure application, where TP loading = 0.04869 ($Runoff^{1.2047}$), R^2=0.905; TN loading = 0.2439 ($Runoff^{1.0509}$), R^2=0.905.

Table B-2 (cont'd).

Footprint Types	Foothills Natural Region Nitrogen (TN) kg/ha/yr	Phosphorus (TP) kg/ha/yr	Sediment (TSS) kg/ha/yr
Transportation			
Soft Roads (gravel/dirt) - heavy use, assuming 10 m wide, drainage structures[1]			112,700
Soft Roads - heavy use, assuming 10 m wide, no drainage structures[1]			310,200
Soft Roads - moderate use, 10 m wide, drainage structures[1]			9,245
Soft Roads - moderate use, 10 m wide, no drainage structures[1]			25440
Soft Roads - light use, 6 m wide, drainage structures[1]	8.683	7.299	1,428
Soft Roads - light use, 6 m wide, no drainage structures[1]			3,929
Soft Roads - unused, 6 m wide, drainage structures[1]			188
Soft Roads - unused, 6 m wide, no drainage structures[1]			517
Hard Roads (paved) [1]	59.24	1.894	249
Hard Roads (paved; 10 m wide, drainage structures)			474
Trails (motorized) [1]	8.683	7.299	1,742
Trails (OHV)			4,440
Trails (non-motorized) [1]	4.706	2.692	643
Industrial			
Industrial Plants[1]	8.596	1.112	656
Transmission Lines[1]	2.085	0.809	217
Seismic Lines[1]	1.564	0.607	163
Wellpads[1]	8.249	4.155	1,169
Pipelines[1]	3.128	1.214	326
Processing Plants[1]	7.815	1.011	596
Feedlots (loading coefficient kg/ha/yr)	100-1,600	10-620	
- based on EMCs, runoff, etc[1]	977	196	3,011
Surface Mines[1]	3.202	0.407	255
Construction 1 - Clearing, grubbing, grading of former wooded/ag land[1]	7.324	0.817	6,631
Construction 2 - Installation of roads, storm drainage & housing[1]	4.769	0.532	2,760
Recreation			
Recreational Features (golf courses) [1]	13.017	1.452	274
Recreational Features (ski areas) [1]	3.164	0.207	112
Recreational Features (campgrounds) [1]	4.157	1.726	412
Residential			
Urban (City Core) [1]	8.656	1.075	376
Urban (Suburban) [1]	4.697	0.971	211
Rural Residential (farm yard) [1]	297.9	50.15	1,599
Rural Residential (acreage yard) [1]	1.905	0.157	38

Table B-3. Export coefficients for difference landuse and footprint types – Grassland Natural Region (kg/ha/year). Values include those from NPSP literature, those calculated from ELFs listed and **average annual precipitation**, according to methods described above (Tables 6 and 7), those calculated from relationships derived from AESA data ("medium agriculture intensity", or irrigated catchments), and those calculated from equations from the literature (in red). References are the same as listed in Table B-1, unless as indicated.

Average Annual precipitation (mm)	374	374	374
Average runoff – Medium Intensity Ag (1 Mar - 31 Oct; mm)	37	37	37
Average runoff – Irrigated Ag (1 Mar - 31 Oct; mm)	126	126	126
Landscape Types	**Nitrogen (TN) kg/ha/yr**	**Phosphorus (TP) kg/ha/yr**	**Sediment (TSS) kg/ha/yr**
Conifer Dominated Forest	1.875	0.048	380
Hardwood Dominated Forest	2.360	0.219	433
Wooded (based on +36% over wooded EMCs)[xviii]	1.273	0.230	207
Shrubland[1]	1.732	0.312	282
Native Grassland[1]	0.162	0.035	27
Natural Unvegetated Flat (rock/ice/sand)	7.000	0.219	N/A
Natural Unvegetated Steep (rock/ice/sand)	7.000	0.219	N/A
Natural Unvegetated Flat (rock/ice/sand) - oilsands region	N/A	N/A	N/A
Natural Unvegetated Steep (rock/ice/sand) - oilsands region	N/A	N/A	N/A
Cereal Crop (intensive - manure)[xix]	1.228	0.158	66.7
Cereal Crop (extensive)[2]	0.334	0.042	53.5
Forage Crop (intensive) alfalfa[2]	1.842	0.238	66.7
Forage Crop (extensive) alfalfa[2]	0.501	0.042	53.5
Native Grazing - Flat (0-5% slope) [1]	1.072	0.883	333
- Rolling (5-10% slope) [1]	1.394	1.147	432
- Hilly (10-30% slope) [1]	1.716	1.412	532
Intensive Grazing - Flat (0-5% slope) [1]	3.416	0.316	111
- Rolling (5-10% slope) [1]	4.441	0.411	144
- Hilly (10-30% slope) [1]	5.466	0.506	178
General Agriculture – Flat [1]	4.191	0.360	101
- Rolling [1]	5.308	0.457	128
- Hilly [1]	6.565	0.565	158

[xviii] Calculated from CLFs and average annual precipitation (Tables 6 and 7).

[xix] Calculated from AESA data and average seasonal areal water yield (i.e., "runoff"; 1 Mar – 31 Oct). "Extensive" cropping is represented by the medium agricultural intensity AESA catchment in the Foothills Fescue Natural Region, with average "runoff" was 37 mm. TP loading = 0.000381 ($Runoff^{1.3036}$), R^2=0.821; TN loading = 0.008 ($Runoff^{1.016}$), R^2=0.848; TSS loading = 0.232 ($Runoff^{1.508}$), R^2=0.792. "Intensive" cropping is represented by the irrigated Grassland AESA catchments, with "runoff" of 126 mm: TP loading = 0.01 ($Runoff^{0.571}$), R^2 = 0.541; TN loading = 0.06 ($Runoff^{0.624}$), R^2=0.551; TSS loading = 0.676 ($Runoff^{0.949}$), R^2=0.606.

Table B-3 (cont'd).

Footprint Types	Grassland Natural Region Nitrogen (TN) kg/ha/yr	Phosphorus (TP) kg/ha/yr	Sediment (TSS) kg/ha/yr
Transportation			
Soft Roads (gravel/dirt) - heavy use, assuming 10 m wide, drainage structures[1]			94,420
Soft Roads - heavy use, assuming 10 m wide, no drainage structures[1]			291,900
Soft Roads - moderate use, 10 m wide, drainage structures[1]			7,742
Soft Roads - moderate use, 10 m wide, no drainage structures[1]			23,937
Soft Roads - light use, 6 m wide, drainage structures[1]	5.386	4.527	1,196
Soft Roads - light use, 6 m wide, no drainage structures[1]			3,697
Soft Roads - unused, 6 m wide, drainage structures[1]			157
Soft Roads - unused, 6 m wide, no drainage structures[1]			486
Hard Roads (paved) [1]	36.744	1.175	155
Hard Roads (paved; 10 m wide, drainage structures)			397
Trails (motorized) [1]	5.386	4.527	1,080
Trails (OHV)			4,440
Trails (non-motorized) [1]	2.919	1.670	399
Industrial			
Industrial Plants[1]	5.332	0.690	407
Transmission Lines[1]	1.293	0.502	135
Seismic Lines[1]	0.970	0.377	101
Wellpads[1]	5.116	2.577	725
Pipelines[1]	1.940	0.753	202
Processing Plants[1]	4.847	0.627	370
Feedlots (loading coefficient kg/ha/yr)	100-1,600	10-620	
- based on EMCs, runoff, etc[1]	606	121	1,867
Surface Mines[1]	1.986	0.252	158
Construction 1 - Clearing, grubbing, grading of former wooded/ag land[1]	4.542	0.507	4,113
Construction 2 - Installation of roads, storm drainage & housing[1]	2.958	0.330	1,712
Recreation			
Recreational Features (golf courses) [1]	8.074	0.900	170
Recreational Features (ski areas) [1]	1.963	0.128	70
Recreational Features (campgrounds) [1]	2.578	1.070	256
Residential			
Urban (City Core) [1]	5.369	0.666	233
Urban (Suburban) [1]	2.913	0.602	131
Rural Residential (farm yard) [1]	184.8	31.10	992
Rural Residential (acreage yard) [1]	1.181	0.098	24

Table B-4. Export coefficients for difference landuse and footprint types – Parkland Natural Region (kg/ha/year). Values include those from NPSP literature, those calculated from ELFs listed and **average annual precipitation**, according to methods described above (Tables 6 and 7), those calculated from relationships derived from AESA data ("high agriculture intensity" and catchments with manure application), and those calculated from equations from the literature (in red). References are the same as listed in Table B-1, unless as indicated.

Average Annual precipitation (mm)	447	447	447
Average runoff (1 Mar - 31 Oct; mm)	22	22	22
Landscape Types	**Nitrogen (TN) kg/ha/yr**	**Phosphorus (TP) kg/ha/yr**	**Sediment (TSS) kg/ha/yr**
Conifer Dominated Forest	1.875	0.048	380
Hardwood Dominated Forest	2.360	0.219	433
Wooded (based on +36% over wooded EMCs)[xx]	1.522	0.274	247
Shrubland[1]	2.070	0.373	336
Native Grassland[1]	0.194	0.042	32
Natural Unvegetated Flat (rock/ice/sand)	2.950	0.219	N/A
Natural Unvegetated Steep (rock/ice/sand)	2.950	0.219	N/A
Natural Unvegetated Flat (rock/ice/sand) - oilsands region	N/A	N/A	N/A
Natural Unvegetated Steep (rock/ice/sand) - oilsands region	N/A	N/A	N/A
Cereal Crop (intensive - manure)[xxi]	6.232	2.013	4.7
Cereal Crop (extensive)[2]	0.661	0.122	4.7
Forage Crop (intensive) alfalfa[2]	9.348	2.013	4.7
Forage Crop (extensive) alfalfa[2]	0.991	0.122	4.7
Native Grazing - Flat (0-5% slope) [1]	1.282	1.055	397
- Rolling (5-10% slope) [1]	1.666	1.371	517
- Hilly (10-30% slope) [1]	2.051	1.688	636
Intensive Grazing - Flat (0-5% slope) [1]	4.083	0.000	133
- Rolling (5-10% slope) [1]	5.308	0.491	173
- Hilly (10-30% slope) [1]	6.532	0.605	213
General Agriculture – Flat [1]	5.009	0.431	121
- Rolling [1]	6.344	0.546	153
- Hilly [1]	7.847	0.675	189

[xx] Calculated from CLFs and average annual precipitation (Tables 6 and 7).
[xxi] Calculated from AESA data and average seasonal areal water yield (i.e., "runoff"; 1 Mar – 31 Oct). For the high agricultural intensity Parkland AESA catchments, average "runoff" was 22 mm. TP loading = $0.005*(Runoff^{1.035})$, $R^2 = 0.831$; TN loading = $0.027*(Runoff^{1.037})$, $R^2=0.920$; TSS loading = $0.0779*(Runoff^{1.328})$, $R^2=0.620$. Intensive forms of agricultural activity involve manure application, where TP loading = $0.04869*(Runoff^{1.2047})$, $R^2=0.905$; TN loading = $0.2439*(Runoff^{1.0509})$, $R^2=0.905$.

Table B-4 (cont'd).

Footprint Types	Parkland Natural Region Nitrogen (TN) kg/ha/yr	Phosphorus (TP) kg/ha/yr	Sediment (TSS) kg/ha/yr
Transportation			
Soft Roads (gravel/dirt) - heavy use, assuming 10 m wide, drainage structures[1]			100,300
Soft Roads - heavy use, assuming 10 m wide, no drainage structures[1]			297,800
Soft Roads - moderate use, 10 m wide, drainage structures[1]			8,221
Soft Roads - moderate use, 10 m wide, no drainage structures[1]			24,416
Soft Roads - light use, 6 m wide, drainage structures[1]	6.437	5.411	1,270
Soft Roads - light use, 6 m wide, no drainage structures[1]			3,771
Soft Roads - unused, 6 m wide, drainage structures[1]			167
Soft Roads - unused, 6 m wide, no drainage structures[1]			496
Hard Roads (paved) [1]	43.916	1.404	185
Hard Roads (paved; 10 m wide, drainage structures)			421
Trails (motorized) [1]	6.437	5.411	1,291
Trails (OHV)			4,440
Trails (non-motorized) [1]	3.488	1.996	477
Industrial			
Industrial Plants[1]	6.372	0.824	486
Transmission Lines[1]	1.546	0.600	161
Seismic Lines[1]	1.159	0.450	121
Wellpads[1]	6.115	3.080	867
Pipelines[1]	2.319	0.900	242
Processing Plants[1]	5.793	0.749	442
Feedlots (loading coefficient kg/ha/yr)	100-1,600	10-620	
- based on EMCs, runoff, etc[1]	724	145	2,232
Surface Mines[1]	2.374	0.302	189
Construction 1 - Clearing, grubbing, grading of former wooded/ag land[1]	5.429	0.605	4,916
Construction 2 - Installation of roads, storm drainage & housing[1]	3.535	0.394	2,046
Recreation			
Recreational Features (golf courses) [1]	9.650	1.076	203
Recreational Features (ski areas) [1]	2.346	0.153	83
Recreational Features (campgrounds) [1]	3.082	1.279	306
Residential			
Urban (City Core) [1]	6.417	0.797	279
Urban (Suburban) [1]	3.482	0.720	156
Rural Residential (farm yard) [1]	220.9	37.17	1,185
Rural Residential (acreage yard) [1]	1.412	0.117	28

Table B-5. Export coefficients for difference landuse and footprint types – Boreal Forest Natural Region (kg/ha/year). Values include those from NPSP literature, those calculated from ELFs listed and **average annual precipitation** (from all low and medium intensity catchments), according to methods described above (Tables 6 and 7), those calculated from relationships derived from AESA data ("medium agriculture intensity" and catchments with manure application), and those calculated from equations from the literature (in red). References are the same as listed in Table B-1, unless as indicated.

Average Annual precipitation (mm)	469	469	469
Average runoff – Low Intensity Ag (1 Mar - 31 Oct; mm)	57	57	57
Average runoff – Medium Intensity Ag (1 Mar - 31 Oct; mm)	53	53	53
Landscape Types	**Nitrogen (TN) kg/ha/yr**	**Phosphorus (TP) kg/ha/yr**	**Sediment (TSS) kg/ha/yr**
Conifer Dominated Forest	1.875	0.048	380
Hardwood Dominated Forest	2.360	0.219	433
Wooded (based on +36% over wooded EMCs)[xxii]	1.597	0.288	260
Shrubland[1]	2.172	0.392	353
Native Grassland[1]	0.203	0.044	34
Natural Unvegetated Flat (rock/ice/sand)	2.950	0.200	N/A
Natural Unvegetated Steep (rock/ice/sand)	2.950	0.200	N/A
Natural Unvegetated Flat (rock/ice/sand) - oilsands region	11.00	0.200	N/A
Natural Unvegetated Steep (rock/ice/sand) - oilsands region	11.00	0.200	N/A
Cereal Crop (intensive - manure)[xxiii]	16.40	6.105	50.2
Cereal Crop (extensive)[2]	1.391	0.152	50.2
Forage Crop (intensive) alfalfa[2]	24.60	6.105	50.2
Forage Crop (extensive) alfalfa[2]	2.087	0.152	50.2
Native Grazing - Flat (0-5% slope) [1]	1.345	1.107	417
- Rolling (5-10% slope) [1]	1.748	1.439	542
- Hilly (10-30% slope) [1]	2.152	1.771	667
Intensive Grazing - Flat (0-5% slope) [1]	4.284	0.396	139
- Rolling (5-10% slope) [1]	5.569	0.515	181
- Hilly (10-30% slope) [1]	6.854	0.634	223
General Agriculture – Flat [1]	5.255	0.452	127
- Rolling [1]	6.657	0.573	161
- Hilly [1]	8.233	0.708	199

[xxii] Calculated from CLFs and average annual precipitation (Tables 6 and 7).
[xxiii] Calculated from AESA data and average seasonal areal water yield (i.e., "runoff"; 1 Mar – 31 Oct). For the medium agricultural intensity Grassland AESA catchment in the Foothills Fescue Natural Region, average "runoff" was 37 mm. TP loading = $0.002*(Runoff^{1.081})$, $R^2 = 0.907$; TN loading = $0.031*(Runoff^{0.95})$, $R^2=0.923$; TSS loading = $0.343*(Runoff^{1.245})$, $R^2=0.806$. Intensive forms of agricultural activity involve manure application, where TP loading = $0.04869*(Runoff^{1.2047})$, $R^2=0.905$; TN loading = $0.2439*(Runoff^{1.0509})$, $R^2=0.905$.

Table B-5 (cont'd).

Footprint Types	Boreal Forest Natural Region Nitrogen (TN) kg/ha/yr	Phosphorus (TP) kg/ha/yr	Sediment (TSS) kg/ha/yr
Transportation			
Soft Roads (gravel/dirt) - heavy use, assuming 10 m wide, drainage structures[1]			102,000
Soft Roads - heavy use, assuming 10 m wide, no drainage structures[1]			299,500
Soft Roads - moderate use, 10 m wide, drainage structures[1]			8,366
Soft Roads - moderate use, 10 m wide, no drainage structures[1]			24,561
Soft Roads - light use, 6 m wide, drainage structures[1]	6.754	5.677	1,292
Soft Roads - light use, 6 m wide, no drainage structures[1]			3,794
Soft Roads - unused, 6 m wide, drainage structures[1]			170
Soft Roads - unused, 6 m wide, no drainage structures[1]			499
Hard Roads (paved) [1]	46.078	1.473	194
Hard Roads (paved; 10 m wide, drainage structures)			428
Trails (motorized) [1]	6.754	5.677	1,355
Trails (OHV)			4,440
Trails (non-motorized) [1]	3.660	2.094	500
Industrial			
Industrial Plants[1]	6.686	0.865	510
Transmission Lines[1]	1.622	0.630	169
Seismic Lines[1]	1.216	0.472	127
Wellpads[1]	6.416	3.232	909
Pipelines[1]	2.433	0.944	254
Processing Plants[1]	6.078	0.786	464
Feedlots (loading coefficient kg/ha/yr)	100-1,600	10-620	
- based on EMCs, runoff, etc[1]	760	152	2,342
Surface Mines[1]	2.490	0.317	198
Construction 1 - Clearing, grubbing, grading of former wooded/ag land[1]	5.696	0.635	5,157
Construction 2 - Installation of roads, storm drainage & housing[1]	3.709	0.414	2,147
Recreation			
Recreational Features (golf courses) [1]	10.13[60]	1.129[60]	213
Recreational Features (ski areas) [1]	2.461	0.161	87
Recreational Features (campgrounds) [1]	3.233	1.342	321
Residential			
Urban (City Core) [1]	6.732	0.836	293
Urban (Suburban) [1]	3.653	0.755	164
Rural Residential (farm yard) [1]	231.7	39.00	1,244
Rural Residential (acreage yard) [1]	1.482	0.122	30

Table B-6. Export coefficients for difference landuse and footprint types – Canadian Shield Natural Region (kg/ha/year). Values include those from NPSP literature, those calculated from ELFs listed and **average annual precipitation**, according to methods described above (Tables 6 and 7), and those calculated from equations from the literature (in red). References are the same as listed in Table B-1, unless as indicated.

Average Annual precipitation (mm)	380	380	380
Landscape Types	**Nitrogen (TN) kg/ha/yr**	**Phosphorus (TP) kg/ha/yr**	**Sediment (TSS) kg/ha/yr**
Conifer Dominated Forest	6.260	0.309	380
Hardwood Dominated Forest		0.056	433
Wooded (based on +36% over wooded EMCs)[xxiv]	1.294	0.233	210
Shrubland[1]	1.760	0.317	286
Native Grassland[1]	0.165	0.036	27
Natural Unvegetated Flat (rock/ice/sand)	2.950	0.200	N/A
Natural Unvegetated Steep (rock/ice/sand)	2.950	0.200	N/A
Natural Unvegetated Flat (rock/ice/sand) - oilsands region	11.00	0.200	N/A
Natural Unvegetated Steep (rock/ice/sand) - oilsands region	11.00	0.200	N/A
Cereal Crop (intensive - manure)	N/A	N/A	N/A
Cereal Crop (extensive)	N/A	N/A	N/A
Forage Crop (intensive) alfalfa	N/A	N/A	N/A
Forage Crop (extensive) alfalfa	N/A	N/A	N/A
Native Grazing - Flat (0-5% slope) [1]	1.090	0.897	338
- Rolling (5-10% slope) [1]	1.416	1.166	439
- Hilly (10-30% slope) [1]	1.743	1.435	541
Intensive Grazing - Flat (0-5% slope) [1]	3.471	0.321	113
- Rolling (5-10% slope) [1]	4.512	0.418	147
- Hilly (10-30% slope) [1]	5.553	0.514	181
General Agriculture – Flat [1]	4.258	0.366	103
- Rolling [1]	5.393	0.464	130
- Hilly [1]	6.671	0.574	161

[xxiv] Calculated from CLFs and average annual precipitation (Tables 6 and 7).

Table B-6 (cont'd).

Footprint Types	Canadian Shield Natural Region Nitrogen (TN) kg/ha/yr	Phosphorus (TP) kg/ha/yr	Sediment (TSS) kg/ha/yr
Transportation			
Soft Roads (gravel/dirt) - heavy use, assuming 10 m wide, drainage structures[1]			94,900
Soft Roads - heavy use, assuming 10 m wide, no drainage structures[1]			292,400
Soft Roads - moderate use, 10 m wide, drainage structures[1]			7,782
Soft Roads - moderate use, 10 m wide, no drainage structures[1]			23,977
Soft Roads - light use, 6 m wide, drainage structures[1]	5.472	4.600	1,202
Soft Roads - light use, 6 m wide, no drainage structures[1]			3,704
Soft Roads - unused, 6 m wide, drainage structures[1]			158
Soft Roads - unused, 6 m wide, no drainage structures[1]			487
Hard Roads (paved) [1]	37.33	1.194	157
Hard Roads (paved; 10 m wide, drainage structures)			399
Trails (motorized) [1]	5.472	4.600	1,098
Trails (OHV)			4,440
Trails (non-motorized) [1]	2.966	1.697	405
Industrial			
Industrial Plants[1]	5.417	0.701	413
Transmission Lines[1]	1.314	0.510	137
Seismic Lines[1]	0.986	0.383	103
Wellpads[1]	5.198	2.618	737
Pipelines[1]	1.971	0.765	205
Processing Plants[1]	4.925	0.637	376
Feedlots (loading coefficient kg/ha/yr)	100-1,600	10-620	
- based on EMCs, runoff, etc[1]	616	123	1,897
Surface Mines[1]	2.018	0.257	161
Construction 1 - Clearing, grubbing, grading of former wooded/ag land[1]	4.615	0.515	4,179
Construction 2 - Installation of roads, storm drainage & housing[1]	3.005	0.335	1,739
Recreation			
Recreational Features (golf courses) [1]	8.203[60]	0.915[60]	173
Recreational Features (ski areas) [1]	1.994	0.130	71
Recreational Features (campgrounds) [1]	2.620	1.087	260
Residential			
Urban (City Core) [1]	5.455	0.677	237
Urban (Suburban) [1]	2.960	0.612	133
Rural Residential (farm yard) [1]	187.7	31.601	1,008
Rural Residential (acreage yard) [1]	1.200	0.099	24

Appendix C: Riparian Zone Export Multiplication Factors

Table B-7. Riparian Zone Export Multiplication Factors. Nutrient export coefficients may be multiplied by the factors listed below for riparian zones within 50 meters of streambeds, and in catchments with steeper slopes more than 50 meters from streambeds (Johnes 1996).

	Riparian Zone (< 50m from stream)		Steeper catchment slope angles (> 50m from stream)	
Landscape Types	**Nitrogen**	**Phosphorus**	**Nitrogen**	**Phosphorus**
Conifer Dominated Forest	1	1	1	1
Hardwood Dominated Forest	1	1	1	1
Shrubland	1	1	1	1
Native Grassland	2	1.25	1.5	4
Natural Unvegetated Flat (rock/ice/sand)	1	1	1	1
Natural Unvegetated Steep (rock/ice/sand)	1	1	1	1
Cereal Crop (intensive - manure)	2	1.25	0.8 (canola)	0.9
Cereal Crop (extensive)	2	1.25	0.8 (canola)	0.9
Forage Crop (intensive) alfalfa	2	2	1	1
Forage Crop (extensive) alfalfa	2	2	1	1.33
Native Grazing - Flat (0-5% slope)	2	2	2	2
- Rolling (5-10% slope)	2	2	2	2
- Hilly (10-30% slope)	2	2	2	2
Intensive Grazing - Flat (0-5% slope)	2	2	2	2
- Rolling (5-10% slope)	2	2	2	2
- Hilly (10-30% slope)	2	2	2	2