Hutchinson

Environmental Sciences Ltd.

Inventory and Evaluation of Non-Point Pollution Sources in the Wapiti River Basin

Milestone Report #3 – Draft Final Report

In Association with

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

Prepared for: Alberta Environment and Parks
HESL Project #: J180002

April 5, 2018

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April 5, 2018 HESL #: J180002

Ms. Alina Wolanski
Alberta Environment and Parks
Suite 111, Twin Atria Building
4999 - 98 Avenue
Edmonton, Alberta T6B 2X3

Re: Inventory and Evaluation of Non-Point Pollution Sources in the Wapiti River Basin – Draft Final Report

Dear Ms. Wolanski;

Please accept our Draft Final Report as our Milestone #3 submission for the "Inventory and Evaluation of Non-Point Pollution Sources in the Wapiti River Basin". This report incorporates analyses of point source loadings, sensitivity of the NPS model, model accuracy, ecological responses and provides a gap analysis, conclusions and recommendations. These materials will be provided in a Power Point format for presentation and discussion on April 6, 2018.

We look forward to discussing our results with you and proceeding to the final project milestone. Please provide any comments at your earliest convenience. Please do not hesitate to contact myself if you have any questions or need any clarifications.

Sincerely,
Hutchinson Environmental Sciences Ltd.

Neil Hutchinson, Ph.D.
President, HESL
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1. Introduction

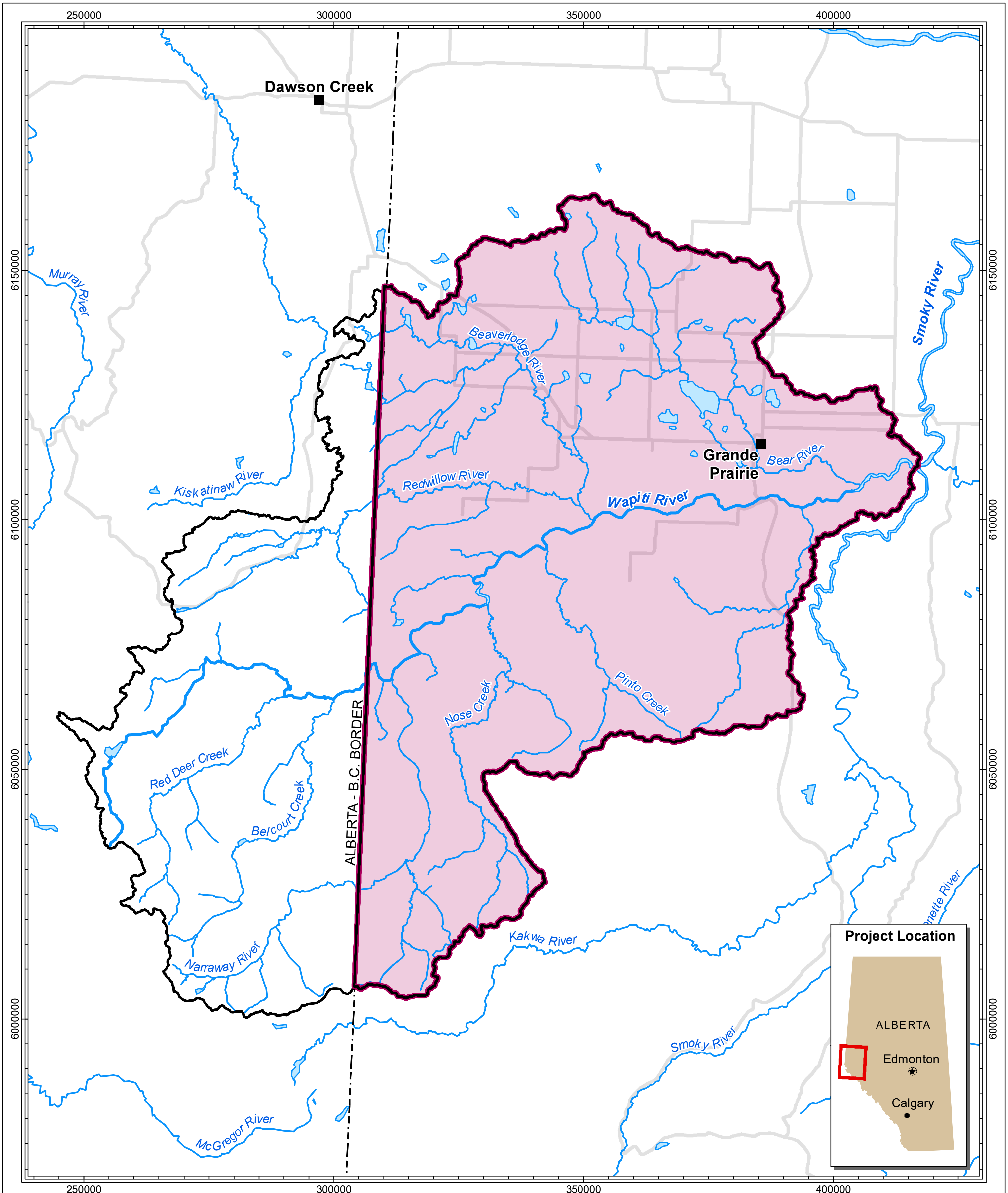
AEP is developing the Wapiti River Water Management Plan (WRWMP) to address cumulative watershed impacts and solutions relating to the stresses associated with increasing human development in the basin, related increases in industrial, agricultural and municipal footprints and impacts to water quality, quantity and aquatic habitat. The Wapiti River shows measurable increases in nutrient concentrations (nitrogen and phosphorus) and associated biological responses (algal growth, benthic invertebrate communities, dissolved oxygen) downstream of the City of Grande Prairie. These changes have been associated with the point source (PS) discharges of treated municipal effluent from the City of Grande Prairie and treated effluent from the International Paper Mill downstream. Although these point source impacts have been well documented, their relative importance compared to other point source discharges in the Wapiti Basin and to non-point source (NPS) nutrient loadings from the landscape is not known. A better understanding of the relative importance of point and non-point sources of nutrients to the Wapiti River is a necessary prerequisite to the development of the Wapiti River Water Management Plan to improve monitoring and management of nutrient sources and maintain water quality.

Accordingly, AEP retained HESL to develop and implement a GIS-based modelling framework to estimate and evaluate point and non-point source loadings of solids, nitrogen and phosphorus to the Wapiti River. The study approach used export coefficients derived by Donahue (2013) for specific Natural Regions of Alberta and land use data housed in an ArcView GIS platform.

1.1 Geographic Description of the Wapiti Watershed

The Wapiti River arises from Wapiti Lake in the Rocky Mountain foothills of west-central British Columbia and flows from there to its confluence with the Smoky River approximately 30 km downstream of the city of Grande Prairie Alberta. The study area includes only those portions of the Wapiti Basin within the Province of Alberta and upstream of its confluence with the Smoky River. Figure 1 shows the entire Wapiti River watershed and highlights that portion within the Province of Alberta.

The Wapiti basin has a very diverse terrain ranging from mountainous to parklands. Summers in the basin are short while the winters are cold and snowy. Standing water and wetlands make up a small portion of the basin area while forest and cultivated lands dominate. Gray Luvisolic soils are typical for the watershed.



Legend

- Wapiti Watershed Boundary
- Study Area
- Populated Place
- Highway
- River
- Lake

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0 10 20 30 40 km

Scale = 1:1000000

N

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Mar 14, 2018

Wapiti River Watershed and Study Area

FIGURE 1

1.1.1 Natural Regions and Subregions of the Wapiti Watershed

Alberta has been classified into six ecozones or natural regions and each of these is subdivided into a total of 21 natural subregions (Figure 2). The natural regions and number of subregions for each are Rocky Mountain (3), Foothills (2), Grassland (4), Parkland (3), Boreal Forest (8) and Canadian Shield (1) (Figure 2). Natural regions are responses to underlying natural features of geology, climate, topography and soils and so represent distinct ecological units of similar natural characteristics which will influence natural cover, water quality, hydrology, human land use and the responses of the natural environment. The Wapiti River basin study area includes seven natural subregions within four natural regions (Figure 3, Table 1).

Table 1. Natural Regions and Subregions in the Wapiti River Study Area

Natural Region	Area (km^2)	Percent
Rocky Mountain - Alpine	22	0.2
Rocky Mountain - Subalpine	469	4.6
Boreal Forest - Central Mixedwood	2305	23
Boreal Forest – Dry Mixedwood	3037	30
Foothills – Upper	977	9.7
Foothills – Lower	2229	22
Peace River Parkland	1096	10.8
Total	10,136	100

The Alpine subregion is defined by its short cold summers, strong winds and high snowfalls. Its made up of mountains, glaciers and snowfields. The severe climate results in very limited tree growth with herbs and shrubs being the dominant plant growth in the subregion. Rivers, lakes and glaciers make up 4% of the subregion. Wetlands in the area are uncommon and small (Alberta Parks 2006).

The subalpine region is characterised by short, cool summers and snowy winters. The subregion is at high elevation below the Alpine subregion. The geology of the subregion is rolling to inclined with limestone, dolomite, quartzite, shale and sandstone bedrock. Vegetation in this subregion is elevation dependent with two separate zones. The upper zone contains Engelmann spruce and subalpine fir forests. The lower zone contains lodgepole pine forests. Soil in this region is Eutric and Dystric Brunisols as well as Regosols and nonsoils. Open water occupies 1% of the subregion area and wetlands occupy 2% (Alberta Parks 2006).

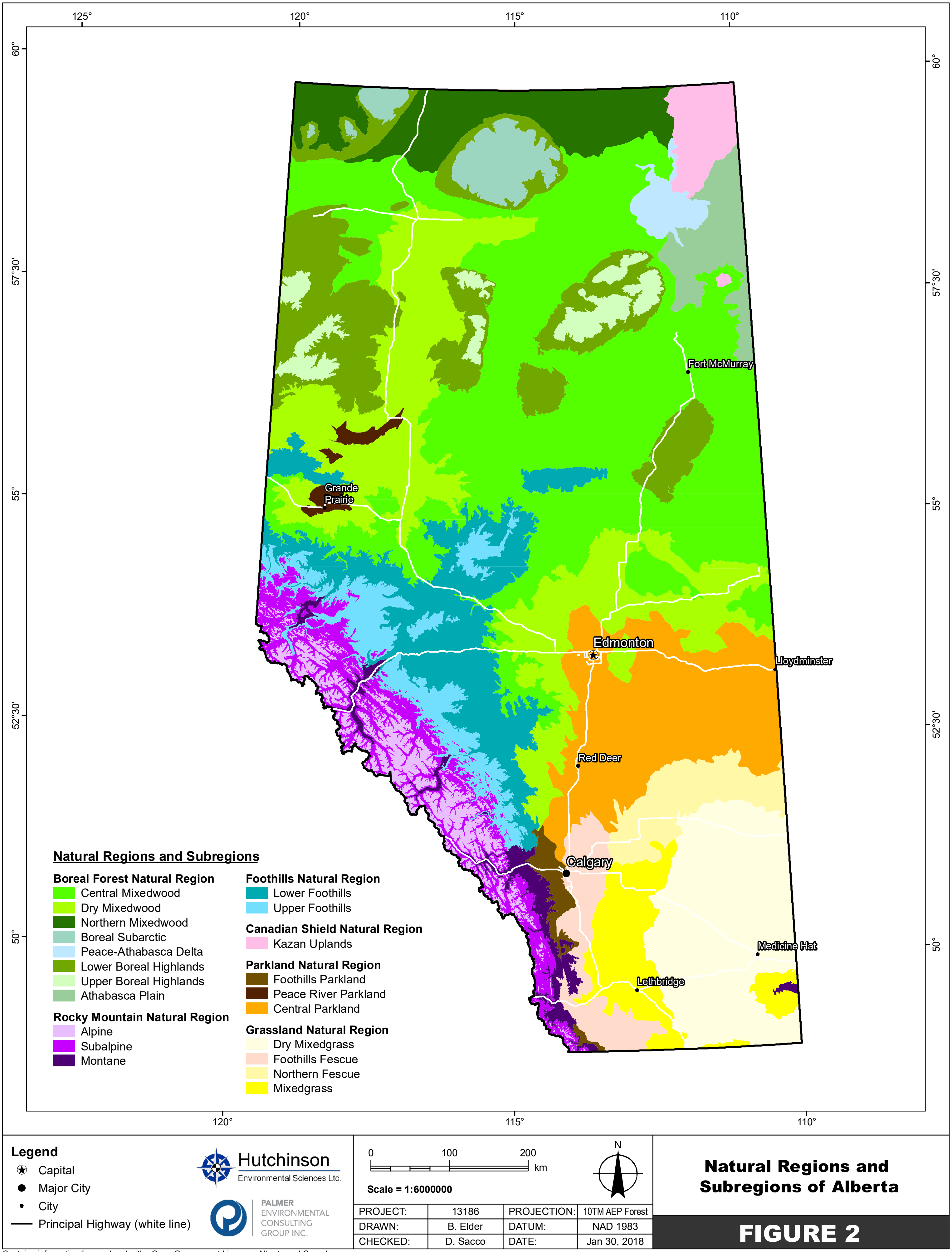
The Central Mixedwood natural subregion is characterised by large stretches of upland forests and wetlands. The landforms are gently undulating plains. Soils and forest stands differ depending on location within the region. At upland sites soils are Gray Luvisolic and tree stands are a mix of aspen, white spruce and jack pine. Central areas contain mostly treed fens and lowland site soils are brunisols on sands and organic. This subregion has short warm summers and long cold winters (Alberta Parks 2006).

Gently rolling plains occur in the Dry Mixedwood natural subregion. The soils in the area are fine textured Gray Luvisols and gleyed subgroups. Vegetation is dominated by aspen forests and cultivated landscapes. Summers are the warmest of the Boreal Natural region and have the highest growing degree-days. Precipitation is intermediate with approximately 70% of the annual precipitation falling as rain between April and August, with the apex occurring between June and July due to intense convective storm events. The land cover for this subregion includes 3% for water (not including Lesser Slave Lake) and 15% for wetlands (Alberta Parks 2006).

The Upper Foothillls subregion experiences short wet summers and cold snowy winters. The geology of the subregion is rolling to steeply sloping with sandstone and mudstone bedrock. The subregion is dominated by forests of lodgepole pine with understories of black spruce. White spruce can be found along river valleys and lower slopes while deciduous and mixedwood stands are found on westerly and southerly slopes. Brunisolic Gray Luvisolic soils are typical for the region. Wetlands cover 10% of the subregion (Alberta Parks 2006).

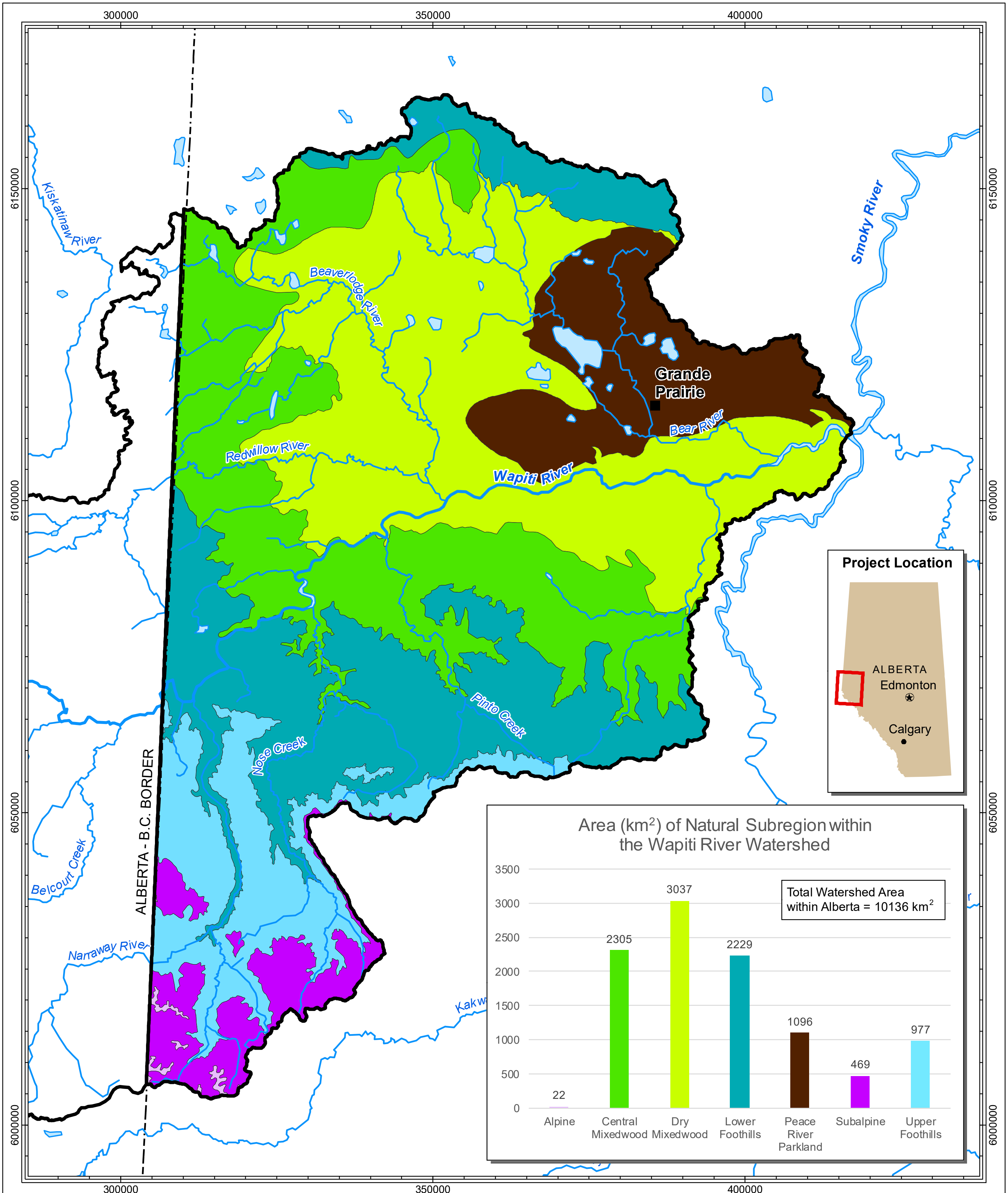
The Lower Foothills subregion is a climate transition zone with cold snowy winters. The geology of the subregion is undulating to strongly rolling with sandstone, siltstone and shale bedrock. The subregion is known for having the most diverse forests in Alberta with regards to forest type and tree species. Tree species found in the subregion include aspen, balsam poplar, white birch, lodgepole pine, black spruce, white spruce, balsam fir and tamarack. Orthic Gray Luvisolic soils dominate the uplands of this subregion. Wetlands are uncommon on the steep slopes but represent 15 to 40% of the area in the valley bottoms and plains (Alberta Parks 2006).

The Peace River Parkland subregion has a similar climate to the Dry Mixedwood subregion, but with fewer growing degree-days and greater precipitation. There are two distinct types or terrain in the region with terrain near Grande Prairie described as gently undulating to rolling plains with non-marine sandstones, mudstones and shales bedrock. The uplands are extensively cultivated. Upland forests are comprised of aspen and white spruce while valley slopes contain grasslands and aspen forests. Upland soils are primarily Solonetzic. Water occupies 2% of the subregion area and wetlands occupy 6% (Alberta Parks 2006).



Natural Regions and Subregions of Alberta

FIGURE 2



Legend

- ■ Populated Place
- River
- Lake
- Wapiti Watershed Boundary

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0 10 20 30 km

Scale = 1:800000

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Natural Subegions within the Wapiti River Watershed

FIGURE 3

1.2 Project Objectives

The following project objectives were confirmed in AEP's February 9, 2018 approval of the study work plan submitted by HESL:

- summarize current knowledge of NPS sources pathways and impacts in the Wapiti basin;
- develop a GIS model to document and provide quantitative estimates of PS and NPS inputs of nitrogen and phosphorus;
- refine the GIS model by including criteria and data to classify and compare the relative potential of different areas and land uses to contribute NPS loadings of N and P using criteria such as erosion rate, slope, sediment yield or drainage to identify priority areas for future management;
- identify areas and pathways most likely to deliver nutrient loads from the landscape to a stream, and ultimately to the Wapiti River;
- estimate the response of the Wapiti River to the loads delivered from NPS loadings; and
- identify missing data and gaps in understanding that can be addressed in subsequent stages, and provide recommendations to guide and improve the development and implementation of the Wapiti River Water Management Plan.

The project objectives were addressed through a review of relevant literature, documentation of known (licensed) point source inputs, the development of an export coefficient model of the Wapiti watershed in a GIS platform to estimate PS and NPS nutrient loadings to the Wapiti River and the use of existing water quality and flow data to assess the relative contributions of PS and NPS loadings to the overall nutrient status of the river. Details are provided in subsequent sections of the report.

1.3 Description and Identification of NPS Pollution

Non point-source (NPS) pollution is pollution derived from many diffuse and widespread sources, unlike point-source pollution which is discharged to the environment from a single point, generally an outfall of treated or untreated effluent. NPS pollution is originates in land use activities such as urbanization or agriculture and is delivered to a waterbody such as a river or lake by the runoff of rainfall or snowmelt and, in some cases, the action of wind or seepage of groundwater. As such, the magnitude of NPS pollution will depend on the nature and intensity of land use, the amount of disturbed land and the amount of precipitation that falls. Steep slopes will accelerate the erosion of soils and the delivery of pollutants and the permeability of the land surface will modify the amount of precipitation that infiltrates or the amount that runs off.

NPS pollution is most commonly related to the transport of solids and adsorbed pollutants such as metals, bacteria, nutrients, organic pollutants (i.e. Polynuclear Organic Hydrocarbons or pesticides in urban and rural environments) but dissolved pollutants, particularly nutrients are also a component of NPS runoff. The importance of particulates means that measurement and control of total suspended solids in runoff is an effective management practice to reduce NPS pollution.

1.4 The need for NPS Estimates for the Wapiti River Basin

The Wapiti River Water Management Plan (WRWMP) is being developed to address cumulative watershed impacts and solutions relating to increasing human development in the basin and the associated increases in industrial, agricultural and municipal footprints. Although the effects of the two largest point source discharges in the watershed (Aquatera Utilities and International Paper) on water quality downstream of the City of Grande Prairie have been well described (Section 2) there has been no systematic estimate made of NPS loading to the watershed. Areas of degraded water quality downstream of Grande Prairie are related to nutrient and bacterial enrichment. Both of these stressors are associated with NPS pollution but the degree of impact in other areas of the watershed is not known. Development of an NPS model for the watershed will identify those areas in which water quality is most likely to be threatened through land uses and natural factors such as terrain. Once identified as potential problems, monitoring efforts can be focussed on key sensitive areas to define the magnitude of any problem and the need for management. Identification of contributing land use activities will inform strategies for mitigating NPS pollution, thus improving watershed health. A better understanding of the relative importance of point and non-point sources of nutrients to the Wapiti River is therefore a necessary prerequisite to the development of the Wapiti River Water Management Plan to improve monitoring and management of nutrient sources and maintain water quality.

2. Current Status of the Wapiti River

2.1 Water Quality

The Wapiti River is a naturally nutrient poor, alkaline system that carries large sediment loads during high flow events.

Two Long-term River Network (LTRN) sites are located within the Wapiti River watershed, in the Wapiti River at Hwy 40 bridge and in the Wapiti River above the Smoky River confluence. These sites are upstream and downstream of the City of Grande Prairie. The Alberta River Water Quality Index (ARWQI) uses measurements taken at the LTRN sites of metals, nutrients, bacteria and pesticide concentrations to assess the quality of the Water. The ARWQI uses four sub-indices (metals, nutrients, bacteria and pesticides) to score the quality of the river as:

- Excellent, received a score between 96-100 indicates that guidelines were almost always met.
- Good, received a score between 81-95 indicates that guidelines were occasionally exceeded, but usually by small amounts.
- Fair, received a score between 66-80 indicates that guidelines were exceeded sometimes by a moderate mount and the quality of the water occasionally departs from desirable levels.
- Marginal, received a score between 46-65 indicates that guidelines were often exceeded, sometimes by large amounts, the quality of the water is threatened and often departs from desirable levels.

ARWQI results indicated that water quality upstream of Hwy 40 was excellent, but declined between Wapiti River at Hwy 40 bridge (score of 98, excellent rating) and Wapiti River above Smoky River confluence (score of 84, good rating) between 2015 and 2016 (AEP 2017, Table 2). The nutrient sub-index and bacteria sub-index were the main reasons for the decrease in water quality downstream of the City of Grande Prairie.

Table 2: Alberta River Water Quality Index Results for the Wapiti River 2015-2016.

	Sub-Index Values (0-100)				Overall Index (average)
Location	**Metals**	**Nutrients**	**Bacteria**	**Pesticides**	
Wapiti River at Hwy 40	100	90	100	100	98
Wapiti River above confluence of Smoky River.	100	80	55	100	84

Note: Data from AEP 2017.

2.1.1 Nutrients

The Wapiti River is naturally nutrient poor, but total phosphorus levels increase seasonally during high-flow events due to elevated sediment transport (HESL 2014). Higher concentrations of total phosphorus in the Lower Wapiti River during low flow events have been linked to wastewater treatment plant (WWTP) and pulp mill effluent discharge (HESL 2012). Bear Creek located, in the Lower Wapiti subwatershed, has also been identified as a potential source of total phosphorus in the Lower Wapiti River based on a monitoring program completed in the Wapiti River in 2017 (C. Geiger, personal communication, March 14th, 2018). Median concentrations of total phosphorus at the LTRN site Wapiti River at Hwy 40 were 0.007 mg/L between 1989 and 2017. Median total phosphorus concentrations at the LTRN site Wapiti River at the confluence with the Smoky River were 0.049 mg/L during the same time period (Table 3). Elevated nutrient concentrations in the Lower Wapiti River have resulted in increased periphyton and lower benthic invertebrate diversity (HESL 2012). Increased productivity measured through biological indicators were confirmed with dissolved oxygen concentrations. Diurnal dissolved oxygen concentrations showed a larger range at a site downstream of the pulp mill effluent discharge and to a lesser extent downstream of the WWTP effluent discharge compared to upstream concentrations based on a data set collected in late summer and fall 2012 (HESL 2014). Concentrations remained above the Alberta Surface Water Quality Guidelines (ABSWQG) for the protection of aquatic life of 6.5 mg/L. However, week-to-week fluctuations in dissolved oxygen concentrations upstream and downstream of the two discharges indicated an upstream influence on dissolved oxygen concentrations (HESL 2014).

Total nitrogen concentrations were also elevated in the Lower Wapiti River with median concentrations of 0.199 mg/L at Hwy 40 compared to 0.553 mg/L at the confluence with the Smoky River (Table 3). A source of nitrite and nitrate was the WWTP discharge where as a source of total Kjeldahl nitrogen was the pulp mill to the Lower Wapiti River during a 2017 monitoring program (C. Geiger, personal communication, March19th, 2018).

Table 3. Summary Statistics on Total Nitrogen, Phosphorus and Suspended Solids in the Wapiti River at Hwy 40 and at the Confluence with the Smoky River.

Sampling Site	Statistic	Total Phosphorus	Total Nitrogen	Total Suspended solids
Wapiti River at Hwy 40	Sample Size	284	282	284
	Median	0.007	0.199	6.8
	25th Percentile	0.004	0.132	1.5
	75th Percentile	0.027	0.314	27
Wapiti River at the confluence with the Smoky River	Sample Size	286	282	284
	Median	0.049	0.553	8
	25th Percentile	0.029	0.325	3.6
	75th Percentile	0.098	0.809	42.3

Note: Based on data collected between 1989 and 2017.

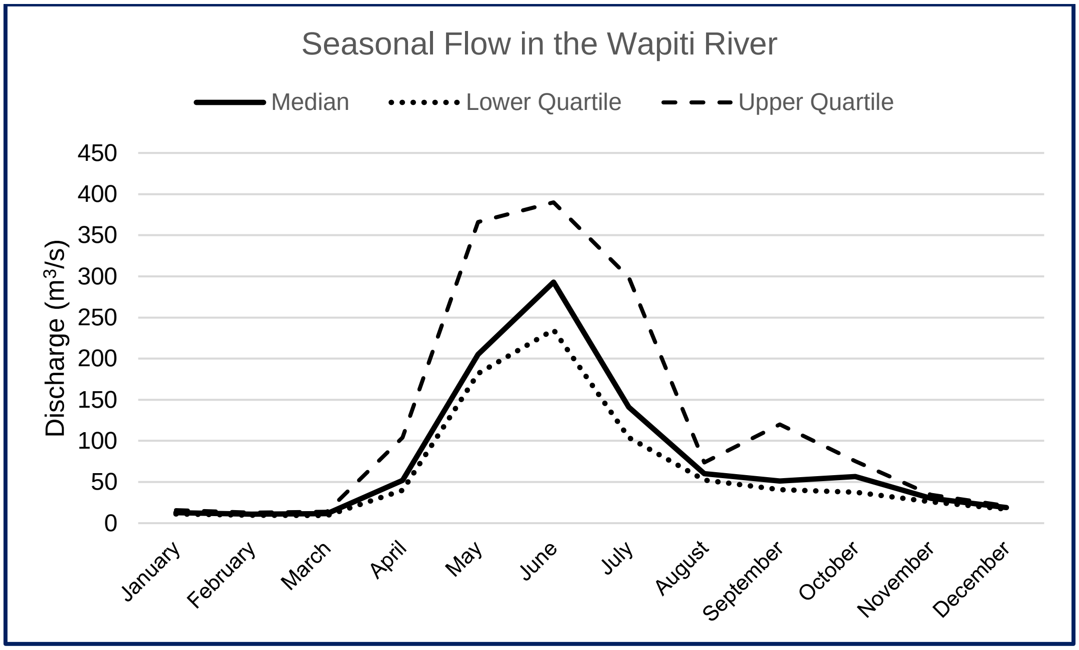
2.1.2 Bacteria

Fecal coliform levels significantly increased in the Wapiti River downstream of the Aquatera WWTP in 2011 from less than 20 to over 80 CFU/100 mL. Concentrations remained elevated throughout the Lower Wapiti River (HESL 2012). Elevated levels of fecal coliforms were measured in Lower Wapiti in Bear Creek at the confluence of the Wapiti River in 2017 with concentrations between 130 CFU/100 mL and 232 CFU/100 mL occurring between August and September (C. Geiger, personal communication, March 14th, 2018). Therefore, sources of bacteria to the Wapiti River include the Aquatera WWTP and Bear Creek.

2.2 Flow Regime

Flow in the Wapiti River displays a typical seasonal pattern as observed in most mountain fed rivers in Alberta (Figure 4). Increases in flow begin in March due to local snowmelt, reaching a maximum in June from mountain snowmelt. Low flows begin in August and continue declining until reaching their nadir in February. Fall precipitation causes small increases in flow in October, but median discharge remains below 60m^3/s. Flow data is from the one Water Survey of Canada site Wapiti River near Grande Prairie (station number 07GE001). Flows in the main stem of the Wapiti River originate from upstream of Pinto Creek (80%), Redwillow River (9.4%), Mountain Creek (~4%), Bear Creek (3.7%), Pinto Creek (2.3%) and several other small tributaries (1%) (Kerkhoven 2014a).

Figure 4. Seasonal Flow in the Wapiti River Near Grande Prairie.



2.3 Known Stressors and Inputs

Known point source stresses on the Wapiti River between the two LTRN sites include stormwater discharge from the town of Grande Prairie into Bear Creek (which flows into the Wapiti River) and the discharges of Aquatera Utilities WWTP and International Paper (IP) bleached kraft pulp mill. Other communities in the watershed discharge sewage lagoon effluent to the river and its tributaries once or twice yearly (Chambers and Dale 1997). Although these intermittent lagoon loads were found to be negligible compared to the continuous discharges of Aquatera's WWTP and IP's pulp mill, the lagoons could result in local decreases in water quality (Chambers and Dale 1997). Point source loadings from all known sources are presented in Section 6.

Other sources of stress in the watershed include changes in land cover. There has been a general decrease in coniferous and deciduous forest, grassland and wetland land cover with a coinciding general increase in bare, crop, pasture and urban land cover. Discussion of current land cover is presented in Section 5.

2.4 Land Use and Human Disturbance

The Wapiti River watershed is divided into seven subregions; Alpine, Subalpine, Central Mixedwood, Dry Mixedwood, Upper Foothills, Lower Foothills and Peace River Parkland. Central Mixedwood (2311 km^2), Dry Mixedwood (3010 km^2) and the Lower Foothills (2205 km^2) account for the majority of the land within the basin. The diverse natural regions within the basin result in an array of human uses of natural resources (HESL 2014). A general description relevant to the Province of Alberta is provided below. Detailed land uses in the Wapiti watershed are provided in Sections 4 and 5.

The Lower Foothills area is known for its timber production; open-pit coal mines; and oil and gas exploration (AEP 2015). The Dry Mixedwood natural subregion has been largely cultivated. Crops grown in the area include oilseeds, wheat, barley and forages (AEP 2015). Other land uses in the natural subregion include; harvesting of aspen for pulp and paper production; oil and gas exploration and hunting and fishing (AEP 2015). Land use activities in the Central Mixedwood natural subregion include; aspen and conifer harvesting; petroleum exploration; domestic livestock grazing and hay crops as well as fishing, hunting and trapping.

Average annual precipitation in each of the natural subregions varies considerably, from 449.4 mm in the Peace River Parkland subregion to 990.8 mm in the Alpine subregion. The effects of alterations to land cover will be influenced by the natural subregion in which those alterations have occurred, as precipitation influences the runoff coefficient.

2.5 Future Projections of Population, Land Use and Climate Change Influences and Implications for NPS

Future predictions for the watershed include continued population growth, but with a decline in the annual rate of growth (Watrecon Consulting 2012). Increases in population are expected to result in a larger human footprint. The average population growth for Grande Prairie is predicted to be 1.4% between 2016 and 2041 (Alberta Government 2017).

Increases in population are also expected to increase agriculture in the area. Annual increases in cattle populations are expected to be between 0.5 to 2.2% and irrigated lands to be between 0.5 to 1% (Alberta Environment 2007).

A watershed specific climate change model has not been completed for the Wapiti River watershed, however Kerhoven (2014c) used historical temperature, precipitation and flow data in conjunction with climate scenarios from the Pacific Climate Impacts Consortium and hydrological predictions for the Upper Peace River Basin to predict temperature, precipitation and stream flow in the Wapiti River Basin. Both temperature and rainfall were predicted to increase over the next century (Kerhoven 2014c). Increases in temperature were predicted at 1.76 ± 0.73°C/100 yr and rain at a rate of 10.5 ± 15.1%/100 yr. No pattern was predicted for snowfall, but higher temperatures would increase the proportion of annual precipitation falling as rain. Flow in the Wapiti River is expected to increase slightly with large interannual variability over the next 100 years. Changes in river flow were predicted to be the result of changes in snow as increases in evaporation due to increases in temperature were predicted to equal the increase in rainfall (Kerhoven 2014c).

3. Export Coefficient Modelling – Source Materials

The project approach linked export coefficient values (in kg/ha/yr) for specific land uses in the Wapiti River watershed to Alberta Government GIS mapping of the same land uses (in ha) to produce estimates of annual export of nitrogen, phosphorus and total suspended solids in kg/yr.

3.1 Export coefficient modelling

Export coefficient modelling is a well-established method of estimating phosphorus or nitrogen export for a specific site, in the absence of measurements made at that site (Dillon *et al.* 1986; Johnes 1996; Winter and Duthie 2000; Chambers et al 2002; Jeje 2006, Donahue, 2013). It can also estimate future changes in export to predict how land use changes and Best Management Practices (BMPs) can alter nutrient export. The export coefficient modelling approach was originally developed in North America to predict nutrient inputs to lakes and streams (Dillon and Kirchner 1975; Beaulac and Reckhow 1982; and Rast and Lee 1983). The export coefficient approach is used where:

- It is not feasible to measure existing nutrient loads through monitoring of surface runoff and water quality with sufficient accuracy to determine absolute values or,
- where remote locations or a large geographic area hinder the ability to monitor.
- it is desirable to forecast nutrient export from a land area prior to a change in land use or prior to implementing BMPs.

The use of export coefficients is based on the knowledge that specific land use types yield or export quantities of nutrients to a downstream waterbody over an annual cycle (Rast and Lee, 1983). The export coefficients are developed from intensive, long-term monitoring programs carried out by academic institutions or government agencies. Using the area of land in a watershed devoted to specific land uses and the quantities of nutrients exported per unit area of these land uses (i.e. nutrient export coefficients), it is possible to estimate total annual nutrient loads to a water body from non-point sources. The modelling procedure is outlined in Johnes (1996), Jones *et al.* (1996), and Reckhow *et al.* (1980).

A simple nutrient export model performed in a GIS platform predicts export from an area as the sum of the export from each nutrient source (or land use) in the area. The model equation is simplified as:

$$L = \Sigma\ E_iA_i$$

where L is the total nutrient export, Ei is the export coefficient selected for the specific land use and Ai is the area of the land use. The export coefficients are expressed as rates (kg/ha/yr) and are derived from previous studies. Land uses and their respective areas are determined from existing spatial data sets derived using GIS mapping for the study area and classification of the land use into categories associated with specific export coefficients.

An export coefficient approach, modelled within a GIS framework, will meet the project objectives specified by AEP, or, as stated in Donahue (2013).

"… 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 land uses, where insufficient data or resources precludes more detailed mechanistic modeling of loading and water quality."

3.2 Ecozone Classification Approach for Wapiti Basin

The project approach is based on the excellent review and synthesis of export coefficients for total phosphorus (TP), total nitrogen (TN) and total suspended solids (TSS) for Alberta in Donahue (2013). That document was prepared for the "Water Matters Society of Alberta" as a literature review to assess the suitability of, summarize and select nutrient and sediment loading coefficients for *"…modeling the potential for land use change to affect water quality in Alberta streams and rivers…".*

While the export coefficient approach offers the merit of ease of application, the available literature provides a wide range of export coefficient values which often range over an order of magnitude for similar land uses. This reflects many factors, most notably, regional variance in geology, soils, hydrology, climate and site-specific variance in slope and land use practices (Lin, 2004) and the time and expense involved in scaling regional export coefficients to smaller scales or to different regions, or to validate or refine export coefficients using local water quality data (Donahue 2013).

Donahue (2013) provides a review of the methods of developing export coefficients and the factors influencing the large range in export coefficient values. Factors such as soil type, landform and topography influence the amount of runoff from land and the nutrient status of runoff, while climate (precipitation amount and seasonality, temperature, evapotranspiration), hydrology (storm intensity and resultant pattern of runoff and nutrient delivery within storm cycles) and land management practices (both land uses and the management of that land use) all determine nutrient runoff and associated export coefficients. The review addresses the types of land use practices and management regimes within each (i.e. tillage and fertilizer practices, form of and intensity of urban development, forest and forest management) and how these influence nutrient export though runoff (permeability of runoff surface) and event mean concentrations (nutrient concentrations in runoff).

Donahue (2013) addresses many of the natural influences on export coefficients by classifying land uses within each of Alberta's 6 Natural Regions (Rocky Mountain, Foothills, Grassland, Parkland, Boreal Forest, Canadian Shield, Figure 2). Natural regions are responses to underlying natural features of geology, climate, topography and soils and so represent distinct ecological units of similar natural characteristics. Natural influences are thus standardized by the Natural Region classification and specific export coefficients developed for land uses and land management practices within each. Export coefficients are then presented that are specific to land uses but which vary between each of Alberta's Ecozones or Natural Regions.

The Wapiti River watershed within Alberta includes four of the six natural regions and two classifications within three natural subregions, for a total of seven distinct ecological classifications (Figure 3, Table 1). These classifications were used as the basis for the export coefficient modelling.

3.3 Export Coefficients from Donahue (2013).

Donahue (2013) provides export coefficients for the six Alberta natural regions. Tables 4 and 5 provide export coefficients for the Boreal Forest Natural Region, the dominant natural region in the Wapiti Basin. Table 4 presents export coefficient values for phosphorus, nitrogen and Total Suspended Solids for natural vegetation and agricultural land uses and Table 5 presents values for transportation, industrial, recreational and urban (residential) land uses. The latter includes classifications for construction activities, which are temporary disturbances and so were not included in the model. Appendix A provides the summary tables for the Boreal Forest, Rocky Mountain, Foothills and Parkland natural regions that were input into the GIS model to estimate NPS runoff of nitrogen, phosphorus and TSS from the GIS land use classifications.

Table 4. Sample export coefficients - Boreal Forest Natural Region.

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 5. Sample export coefficients - Boreal Forest Natural Region – Transportation, Industrial, Recreational and Residential Land Uses.

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

46

4. GIS NPS Model

Table 6 shows the GIS layers needed to complete the NPS model for natural and agricultural land uses and Table 7 for Transportation, Industrial, Recreational and Residential Land Uses using the Donahue (2013) approach**.**

Table 6. GIS layer requirements - Natural and Agricultural Land Uses.

Minimum Requirement	Ideal Requirement or Second Stage Analysis
Annual Precipitation	Annual Runoff
Elevation (Digital Elevation Model - DEM)	
Forest Cover	Conifer, hardwood, wooded, shrubland
Grassland	
Unvegetated (rock, ice or sand)	
Cropland	cereal, forage intensive (manure applied)
Rangeland (native grazing) Use DEM to classify slope as Flat (0-5%), Rolling (5-10%), Hilly (20-30%).	
General agriculture Use DEM to classify slope as Flat (0-5%), Rolling (5-10%), Hilly (20-30%).	

Table 7. GIS layer requirements - Transportation, Industrial, Recreational and Residential Land Uses.

Minimum Requirement	Ideal Requirement or Second Stage Analysis
Road area	Paved and Unpaved
Industrial plant area	Location and we assign area
Transmission line corridors – disturbed area	Linear corridor location and we assign width
Seismic Lines- disturbed area	Linear corridor location and we assign width
Well pads - disturbed area	Location and we assign area
Pipelines	Linear corridor location and we assign width
Processing Plants	
Feedlots	Runoff
Surface mines and quarries	
Recreational Uses – Ski areas, golf courses, camp grounds	
Residential– Urban Core	
Residential – Suburban	
Rural Farmyard	
Rural Residential	

GIS layers were obtained from the Human Footprint Inventory (2014) and the Crop Inventory (2016) to match the land use categories described by Donahue (2013). A detailed description of these layers is presented in Appendix 2. The GIS layers selected for natural land uses (and their corresponding Donahue categories) were:

- 210-Coniferous: for Conifer Dominated Forest
- 220-Broadleaf Forest: for Hardwood Dominated Forest
- 230-Mixed Forest: for Wooded
- 50-Shrubland: for Shrubland
- 110-Grassland: for Native Grassland
- 30-Exposed Land/Barren: for Natural Unvegetated (rock/ice/sand).

Agricultural land uses were assigned to the following GIS layers (with corresponding Donahue categories):

- 132-Cereals, 133-Barley, 136-Oats, 137-Rye, 139-Triticale, and 146-Spring Wheat: for Cereal Crop (Intensive and Extensive)
- 122-Pasture/Forages: for Forage Crop (Intensive and Extensive)- Alfalfa
- ROUGH_PASTURE: for Native Grazing – Flat, Rolling and Hilly

- TAME_PASTURE: for Intensive Grazing – Flat, Rolling and Hilly
- All other crops (147-199): for General Agriculture - Flat, Rolling and Hilly.

Donahue (2013)'s transportation, industrial, recreational and residential land uses were matched with similar GIS layers depicting human influence. We used layers for gravel and dirt unpaved roads for Soft Roads (gravel/dirt) and layers for asphalt and concrete paved roads for Hard Roads (paved). Layers for roadways covered with dirt or low vegetation and those used mainly for ATV activities were used for Trails (motorized and non-motorized).

We used GIS layers related to industrial activities for Donahue's (2013) industrial land uses:

- OIL-GAS-PLANT, MISC-OIL-GAS-FACILITY, CAMP-INDUSTRIAL, FACILITY-OTHER, FACILITY-UNKNOWN: for Industrial Plants
- TRANSMISSION-LINE: for Transmission Lines
- PRE-LOW-IMPACT-SEISMIC: for Seismic Lines
- WELL-ABAND, WELL-CASED, WELL-CLEARED-DRILLED, WELL-CLEARED-NOT-DRILLED, WELL-GAS, WELL-OIL, WELL-OTHER: for Wellpads
- PIPELINE: for Pipelines
- MILL: for Processing Plants
- CFO: for feedlots
- GRVL-SAND-PIT, OPEN-PIT-MINE, BORROWPITS, BORROWPIT-DRY, BORROWPIT-WET: for Surface Mines.

Recreational land uses were represented by golf course and campground layers. Residential land use layers were applied for urban and rural related Donahue (2013) categories:

- URBAN-INDUSTRIAL: for Urban – City Core
- URBAN-RESIDENCE, GREENSPACE: for Urban – Suburban
- RURAL-RESIDENCE, COUNTRY-RESIDENCE: for Rural Residential (farm yard).

Donahue's (2013) Water-Wetlands category was matched with both natural land use layers (20-Water, 80-Wetland; Crop Inventory 2016) and human land use layers (LAGOON, RESERVOIR; Human Footprint Inventory 2014). Similarly, both GIS databases were applied to Donahue's (2013) Construction 1 land use: the Urban/Developed layer from the Crop Inventory (2016) and layers related to human clearings and disturbed road and railway edges from the Human Footprint Inventory (2014).

5. Results – NPS Model

The NPS estimates of nitrogen, phosphorus and TSS loading to the Wapiti watershed were developed in the GIS model for 31 subwatersheds in the Wapiti Basin in two stages. In the first (Section 5.1), the model was used to generate NPS loading of pollutants according to the methods of Donahue (2013). In the second stage (Section 5.2) the model was refined to classify landscape and stream sensitivity to NPS loading as a function of slope, soil type (erosion potential) and drainage density (delivery potential).

5.1 NPS Loading Estimates

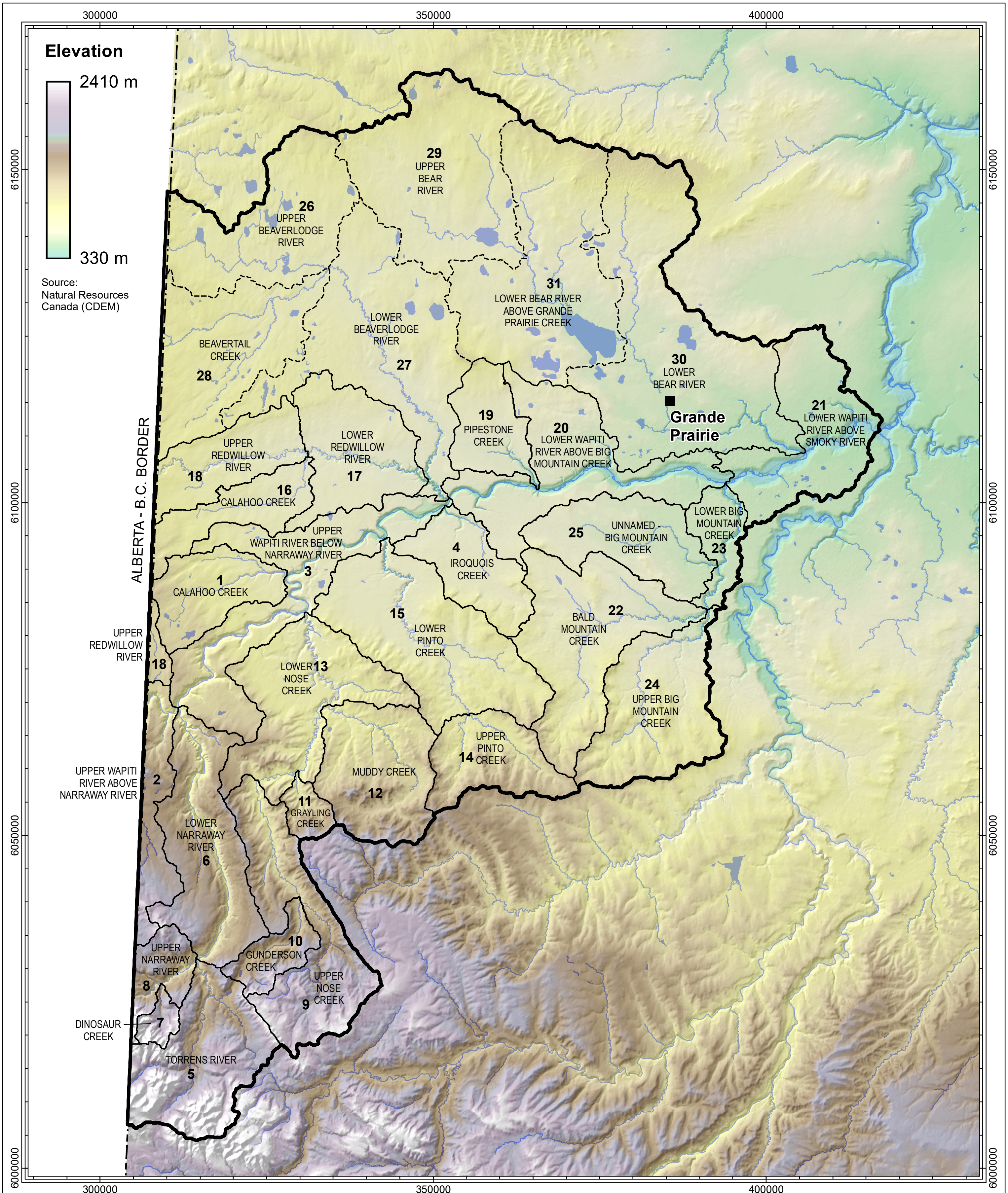
The initial loading estimates are presented as:

- A series of maps showing the Donahue (2013) land use classifications used as input data,
- A series of maps showing NPS export,
- Tables and a narrative discussion of results

5.1.1 Derivation of NPS Loading – Land Use Areas

The model was scaled to 31 subwatersheds (Figure 5, Table 8) corresponding to the Hydrologic Unit Code 10 Watersheds of Alberta classification (https://geodiscover.alberta.ca/geoportal/catalog/search/resource/details.page?uuid=%7B017387ED-2EB1-4D16-868E-B019E3DA12E5%7D). A portion of the study area was not delineated at the Unit Code 10 classification scale. These larger watersheds were subdivided based on topography and drainage. Twenty five subwatersheds were delineated in the Alberta database and six (Table 8; numbers 26-31) were delineated for the study. The total watershed area modelled was 10,136 km^2.

Land uses in the Wapiti basin were classified as "Natural" or "Human Footprint" and mapped as such in Figures 6 and 7. 617,648 ha (61%) of the watershed was classified as natural area and 327,881 ha (32%) as areas of "Human Footprint", of which 267,317 ha (82% of human footprint) were in agricultural use and 60,564 ha(18% of human footprint) in urban or industrial uses (Table 9). The remaining 68,040 ha (7%) of the watershed was classified as surface water or wetland for which no export was calculated.



Legend

- Study Area
- Subwatershed (Unit Code 10)*
- Delineated by PECG

*Source: Hydrologic Unit Code Watersheds of Alberta (2017) - Alberta Environment and Parks, Government of Alberta

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0 10 20 30 km

Scale = 1:750000

N

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Wapiti River Subwatersheds

FIGURE 5

Table 8. Subwatershed identifications and areas.

Watershed Number	Watershed Name	Area (ha)	Area (km2)
1	CALAHOO CREEK	19468	194.7
2	UPPER WAPITI RIVER ABOVE NARRAWAY RIVER	15865	158.7
3	UPPER WAPITI RIVER BELOW NARRAWAY RIVER	44525	445.3
4	IROQUOIS CREEK	19423	194.2
5	TORRENS RIVER	35788	357.9
6	LOWER NARRAWAY RIVER	38031	380.3
7	DINOSAUR CREEK	3605	36.1
8	UPPER NARRAWAY RIVER	9483	94.8
9	UPPER NOSE CREEK	38029	380.3
10	GUNDERSON CREEK	9292	92.9
11	GRAYLING CREEK	5065	50.7
12	MUDDY CREEK	31780	317.8
13	LOWER NOSE CREEK	39120	391.2
14	UPPER PINTO CREEK	21035	210.4
15	LOWER PINTO CREEK	50762	507.6
16	CALAHOO CREEK	16721	167.2
17	LOWER REDWILLOW RIVER	29287	292.9
18	UPPER REDWILLOW RIVER	24028	240.3
19	PIPESTONE CREEK	16064	160.6
20	LOWER WAPITI RIVER ABOVE BIG MOUNTAIN CREEK	43516	435.2
21	LOWER WAPITI RIVER ABOVE SMOKY RIVER	35282	352.8
22	BALD MOUNTAIN CREEK	44806	448.1
23	LOWER BIG MOUNTAIN CREEK	10441	104.4
24	UPPER BIG MOUNTAIN CREEK	36769	367.7
25	UNNAMED - BIG MOUNTAIN CREEK	26768	267.7
26	UPPER BEAVERLODGE RIVER	42609	426.1
27	LOWER BEAVERLODGE RIVER	62067	620.7
28	BEAVERTAIL CREEK	41085	410.9
29	UPPER BEAR RIVER	56114	561.1
30	LOWER BEAR RIVER	80539	805.4
31	LOWER BEAR RIVER ABOVE GRANDE PRAIRIE CREEK	66199	662.0
Total		1013569	10135

Table 9. Land Use Areas – Major Classifications

Classification	Area in ha	Percent of Watershed
Natural Areas	617,648	61
Industrial and Urban	60,564	6
Agriculture	267,317	26
Total Human Footprint	327,881	32
Total Classified Area	945,529	93
Surface Water and Wetland	68,040	7
Total Watershed Area	1,013,569	100

The major land use classifications of "Human Footprint:" and "Natural" were further subdivided into the subclassifications of Donahue (2013) for each subwatershed and the entire Wapiti Basin (Figure 8). Figure 6 shows the "Agricultural" land use areas for the Wapiti Basin, Figure 7 the "Human Footprint" areas, Figure 8 the "Natural" areas and Figure 9 maps all of the Donahue subclassifications for the Wapiti Basin. Table 10 shows the breakdown of areas of the "Natural" subclassifications from Donahue (2013). Table 11 shows the breakdown of agricultural land use areas and Table 12 shows the breakdown for industrial and urban land use classifications.

Table 10. Natural Area Classifications and Areas.

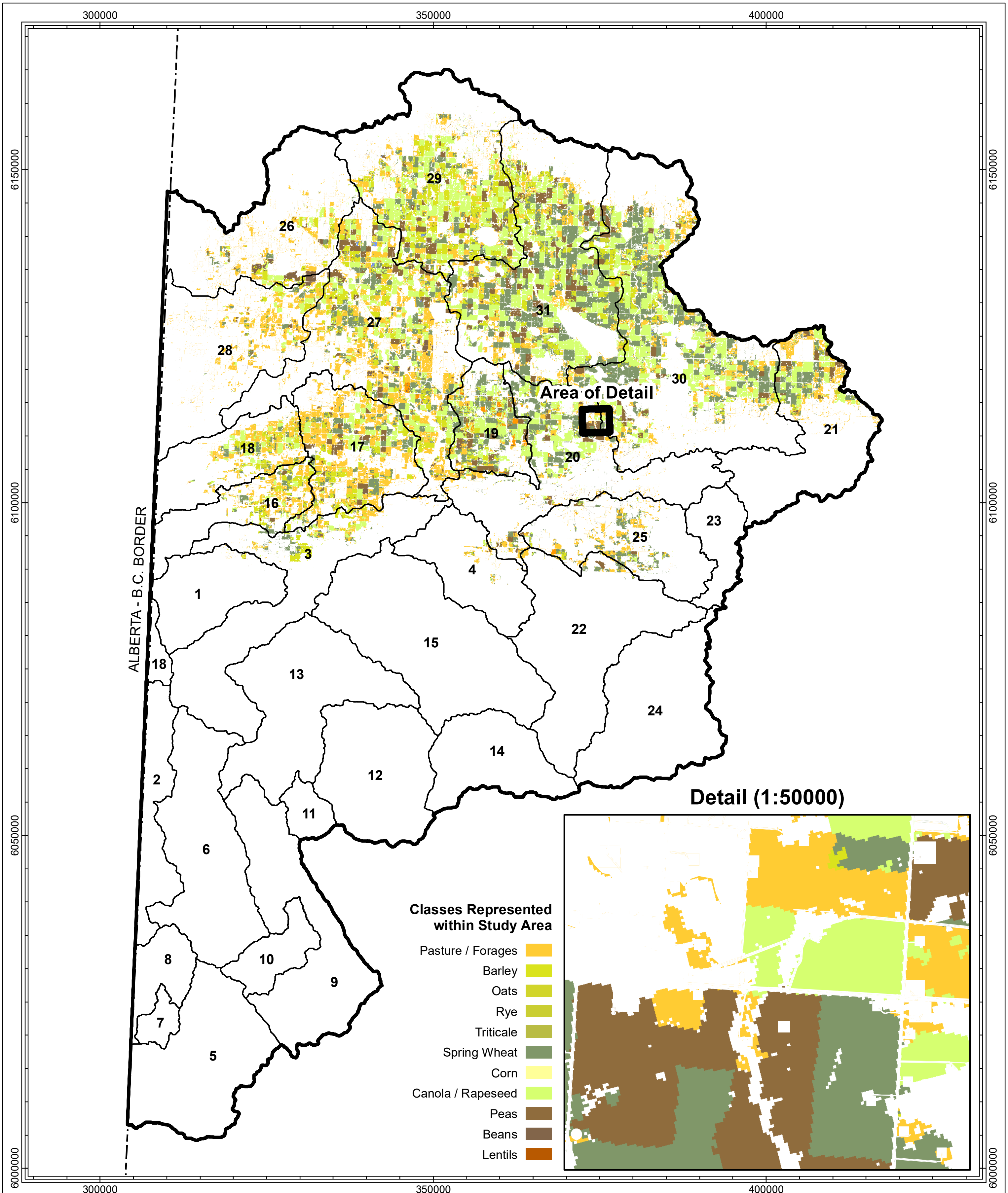
Natural Area	Area in ha	Percent of Natural Area	Percent of Watershed
Conifer Dominated Forest	236,126	38.2	23.3
Hardwood Dominated Forest	322,851	52.3	31.9
Native Grassland	793	0.1	0.1
Natural Unvegetated (rock/ice/sand)	5,542	0.9	0.5
Shrubland	38,564	6.2	3.8
Wooded	13,772	2.2	1.4
Total	617,648		

Table 11. Agricultural Classifications and Areas.

Agricultural Use	Area in ha	% of Human Footprint	% of Watershed
Cereal Crop	76,149	23.2	7.5
Feedlots	196	0.1	0.0
Forage Crop - alfalfa	48,961	14.9	4.8
General Agriculture - Flat (0-5% slope)	75,374	23.0	7.4
General Agriculture - Hilly (10-30% slope)	47	0.01	0.01
General Agriculture - Rolling (5-10% slope)	1,213	0.4	0.1
Intensive Grazing - Flat (0-5% slope)	45,173	13.8	4.5
Intensive Grazing - Hilly (10-30% slope)	75	0.02	0.01
Intensive Grazing - Rolling (5-10% slope)	1,370	0.4	0.1
Native Grazing - Flat (0-5% slope)	8,500	2.6	0.8
Native Grazing - Hilly (10-30% slope)	89	0.03	0.01
Native Grazing - Rolling (5-10% slope)	403	0.1	0.04
Rural Residential (farm yard)	9,769	3.0	1.0
Total Agricultural	267,317	81.5	26.4

Table 12. Urban and Industrial Classifications and Areas.

Urban or Industrial Use	Area in ha	% of Human Footprint	% of Watershed
Construction 1	17,501	5.34	1.73
Hard Roads (paved)	2,370	0.72	0.23
Industrial Plants	1,316	0.40	0.13
Pipelines	7,227	2.20	0.71
Processing Plants	167	0.05	0.02
Recreational - Campgrounds	27	0.01	0.00
Recreational - Golf Courses	65	0.02	0.01
Seismic Lines	6,074	1.85	0.60
Soft Roads (gravel/dirt)	8,586	2.62	0.85
Surface Mines	1,714	0.52	0.17
Trails (motorized)	241	0.07	0.02
Trails (non-motorized)	1,130	0.34	0.11
Transmission Lines	710	0.22	0.07
Urban - City Core	2,544	0.78	0.25
Urban - Suburban	1,910	0.58	0.19
Wellpads	8,982	2.74	0.89
Total Urban and Industrial Lands	60,564	18.6	6.0



Legend

Study Area

Subwatershed

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0 10 20 30 km

N

Scale = 1:750000

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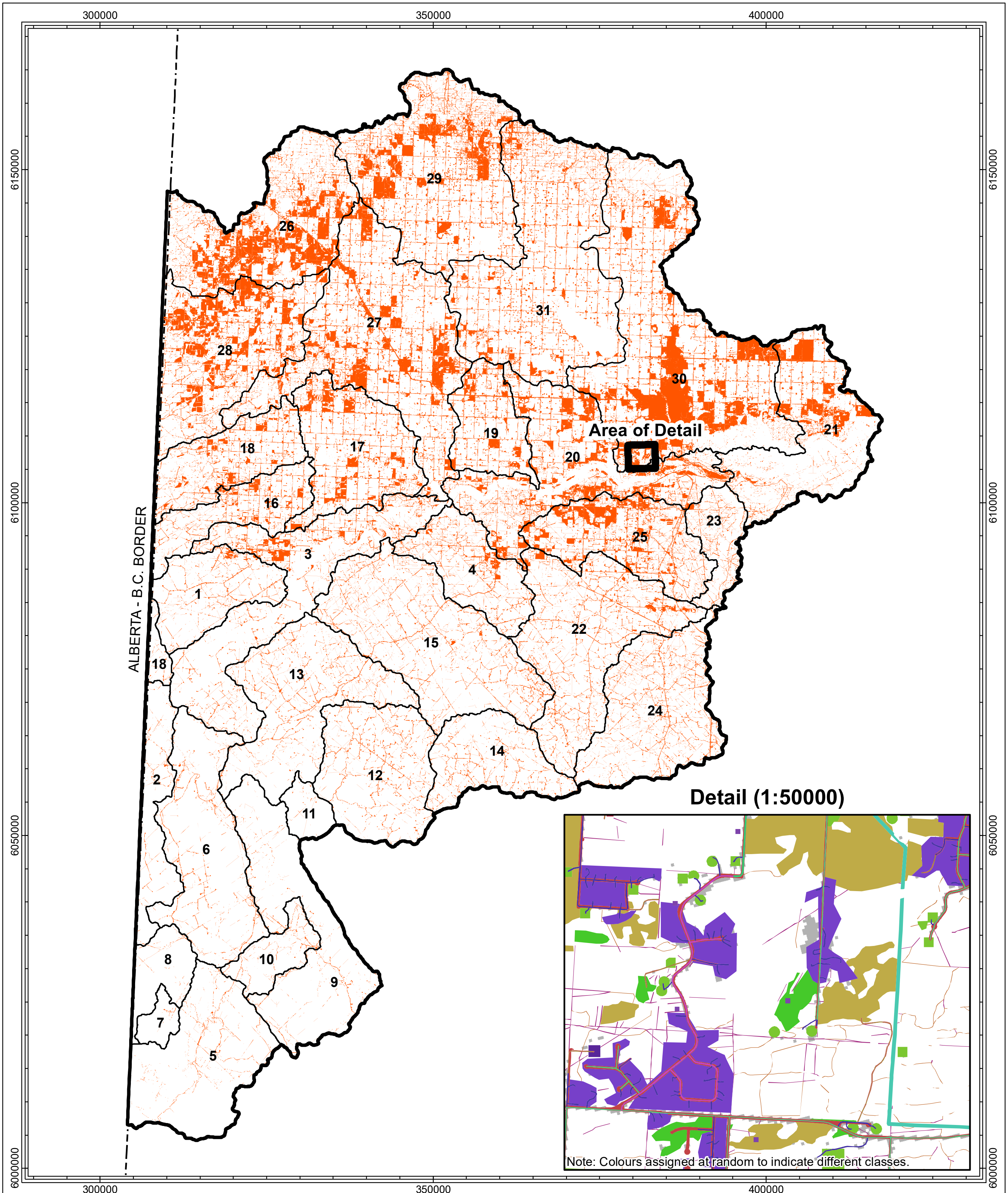
Agricultural Footprint

FIGURE 6

Source: Annual Crop Inventory 2016 - Agriculture and Agri-Food Canada.



Legend

- Study Area
- Subwatershed
- Human Footprint[1,2]

Sources: Human Footprint Index 2014 (AMBI) - main input; Crop Inventory 2016 (AAFC) - infill only.

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0 10 20 30 km

Scale = 1:750000

N

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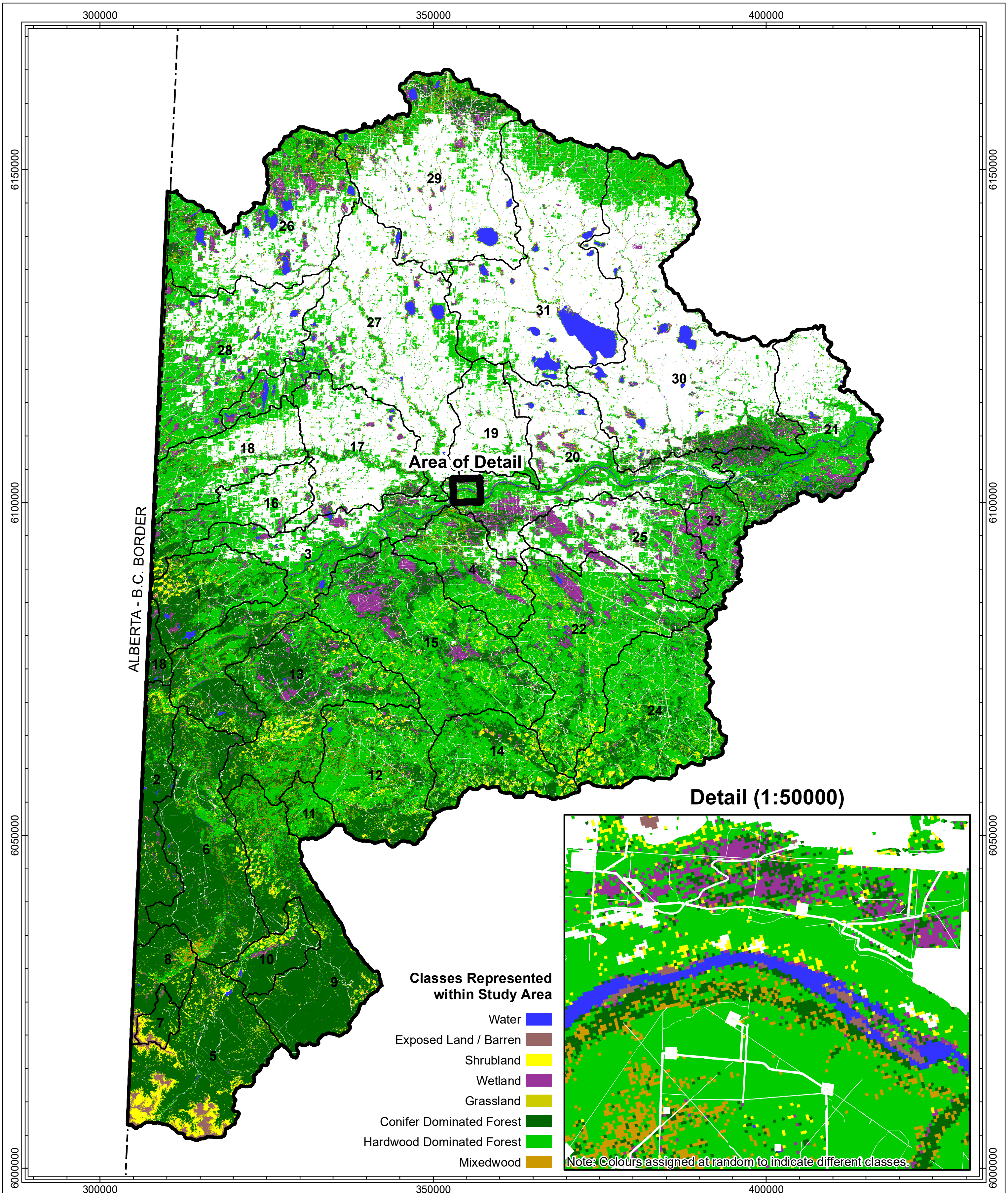
Human Footprint Input Data

FIGURE 7



Legend

Study Area

Subwatershed

Source: Annual Crop Inventory 2016 - Agriculture and Agri-Food Canada.

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0 10 20 30 km

Scale = 1:750000

N

PROJECT:	13186	PROJECTION:	UTM Zone 11N
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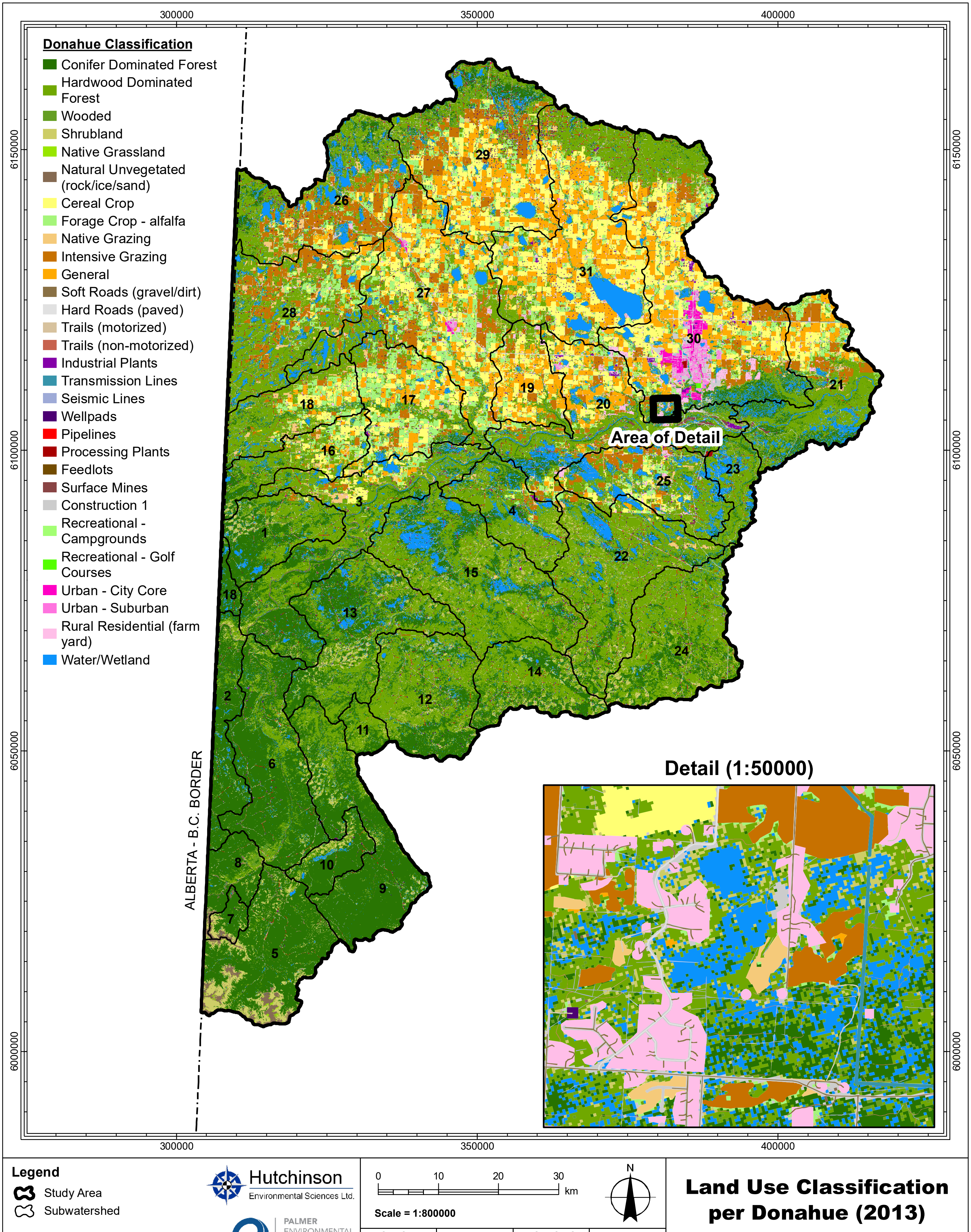
Natural Land Cover Input Data

FIGURE 8



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Land Use Classification per Donahue (2013)

FIGURE 9

5.1.2 Derivation of NPS Loading – Total Annual Pollutant Export Estimates

Estimates of annual loading of nitrogen, phosphorus and solids were derived for all 31 of the sub watersheds in the Wapiti Basin. Land use activities export 5234, 822 and 408,100 tonnes/yr of nitrogen, phosphorus and solids, respectively, to the Wapiti River within the Province of Alberta (Table 13). Annual export from individual subwatersheds is provided in Table 14 The lowest annual export was from the Dinosaur Creek subwatershed and the highest from the Lower Bear River subwatershed and these had the smallest and largest watershed areas, respectively. The mass of nitrogen, phosphorus and solids exported each year was strongly and significantly ($p<0.00001$) related to watershed area, but the relationships for nitrogen and phosphorus were weaker ($r2 \sim 0.65$) than for solids ($r2 = 0.93$) (Figure 10).

Table 13. Total Annual Export of Nitrogen, Phosphorus and Solids in tonnes/yr.

	Nitrogen in tonnes/yr	Phosphorus in tonnes/yr	Solids in tonnes/yr
Total	5234	822	408110
Minimum	12	1.8	1369
Maximum	978	150.5	37636
Average	169	26.5	13165
Median	118	19.1	14435
25th Percentile	57	9.4	7338
75th Percentile	188	29.3	17775

Figure 10. Annual Pollutant Export and Subwatershed Area.

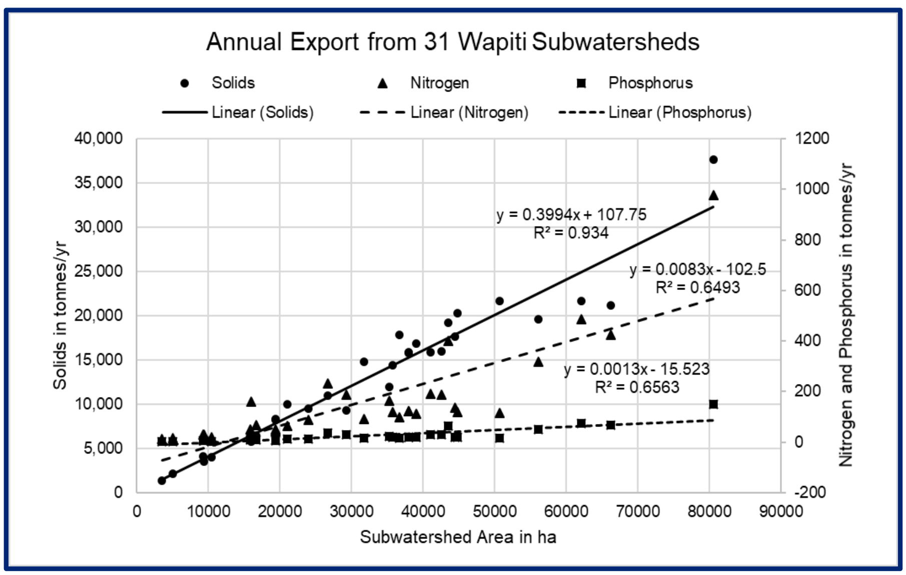
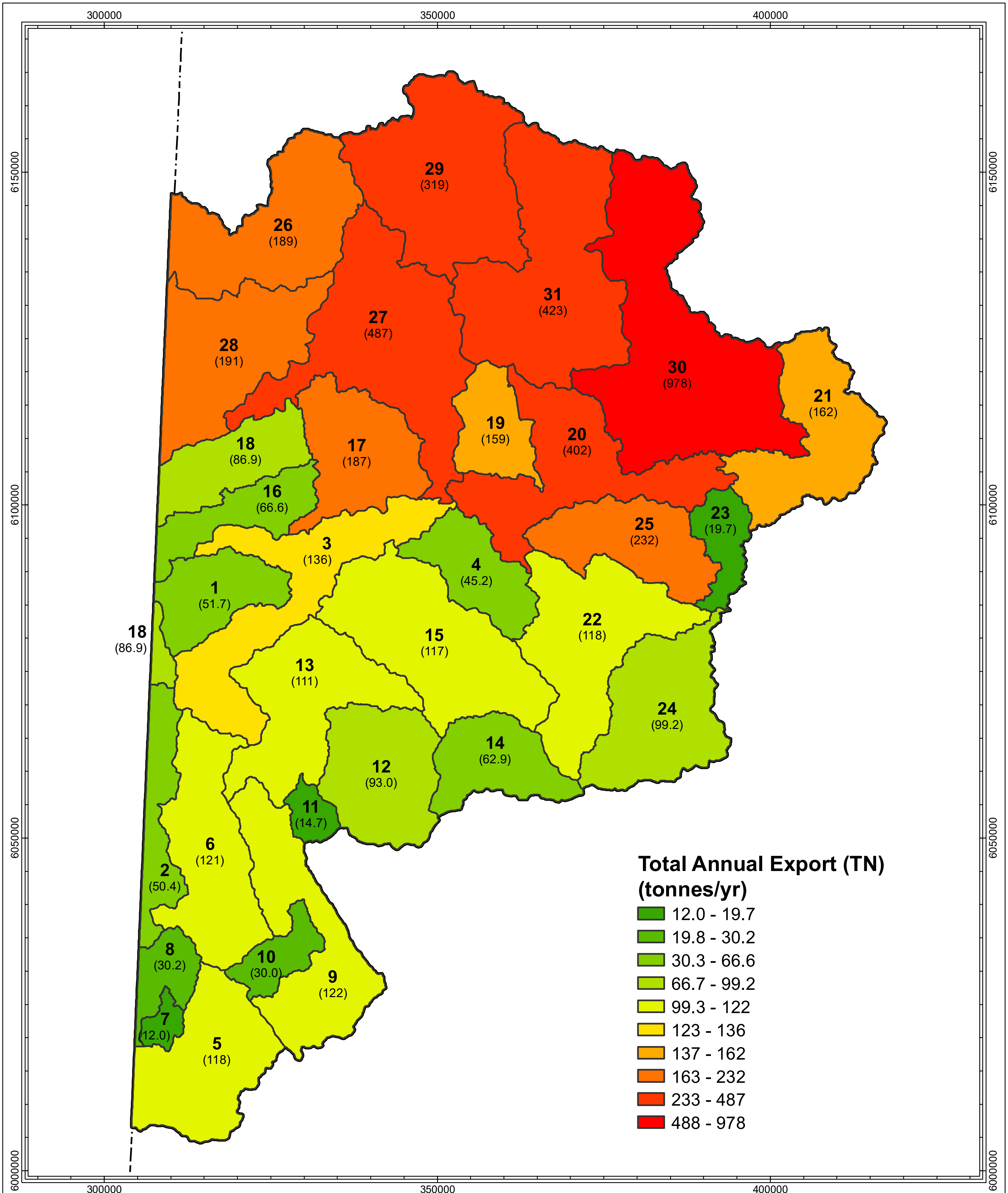


Table 14. Pollutant Export from 31 Wapiti Subwatersheds in tonnes/yr.

Number	Watershed Name	Area (ha)	Nitrogen	Phosphorus	Solids
1	CALAHOO CREEK	19468	51.7	7.87	8,293
2	UPPER WAPITI RIVER ABOVE NARRAWAY RIVER	15865	50.4	8.30	6,201
3	UPPER WAPITI RIVER BELOW NARRAWAY RIVER	44525	135.7	21.02	17,673
4	IROQUOIS CREEK	19423	45.2	6.84	8,188
5	TORRENS RIVER	35788	118.23	19.05	14,435
6	LOWER NARRAWAY RIVER	38031	121.10	20.34	15,881
7	DINOSAUR CREEK	3605	11.95	1.84	1,369
8	UPPER NARRAWAY RIVER	9483	30.21	4.72	3,552
9	UPPER NOSE CREEK	38029	121.66	20.06	15,789
10	GUNDERSON CREEK	9292	30.02	5.31	4,071
11	GRAYLING CREEK	5065	14.67	2.39	2,155
12	MUDDY CREEK	31780	92.98	17.03	14,789
13	LOWER NOSE CREEK	39120	111.22	19.17	16,861
14	UPPER PINTO CREEK	21035	62.89	11.61	9,996
15	LOWER PINTO CREEK	50762	117.17	17.83	21,654
16	CALAHOO CREEK	16721	66.64	10.54	6,488
17	LOWER REDWILLOW RIVER	29287	186.82	28.84	9,300
18	UPPER REDWILLOW RIVER	24028	86.86	13.59	9,487
19	PIPESTONE CREEK	16064	158.88	24.26	5,752
20	LOWER WAPITI RIVER ABOVE BIG MOUNTAIN CREEK	43516	401.75	62.66	19,173
21	LOWER WAPITI RIVER ABOVE SMOKY RIVER	35282	162.14	22.11	11,941
22	BALD MOUNTAIN CREEK	44806	118.39	18.66	20,301
23	LOWER BIG MOUNTAIN CREEK	10441	19.66	2.50	3,981
24	UPPER BIG MOUNTAIN CREEK	36769	99.22	15.51	17,877
25	UNNAMED - BIG MOUNTAIN CREEK	26768	232.45	37.34	10,962
26	UPPER BEAVERLODGE RIVER	42609	188.45	29.69	15,936
27	LOWER BEAVERLODGE RIVER	62067	486.74	75.16	21,660
28	BEAVERTAIL CREEK	41085	190.80	29.88	15,869

Number	Watershed Name	Area (ha)	Nitrogen	Phosphorus	Solids
29	UPPER BEAR RIVER	56114	318.90	51.24	19,615
30	LOWER BEAR RIVER	80539	978.03	150.50	37,636
31	LOWER BEAR RIVER ABOVE GRANDE PRAIRIE CREEK	66199	422.93	66.30	21,224
Total		1013569	5,234	822	408,110

Total annual export of nitrogen, phosphorus and solids is mapped for each subwatershed in Figures 11, 13 and 15. The 25th and 75th percentiles (Table 13) were used to define the ranges of “Low” (1-25th), “Moderate” (26th – 75th) and “High” (>75th) for classification of watersheds and these are provided in Figures 12, 14 and 16.



Legend

Study Area

Subwatershed

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PROJECT:	13186	PROJECTION:	UTM Zone 11N
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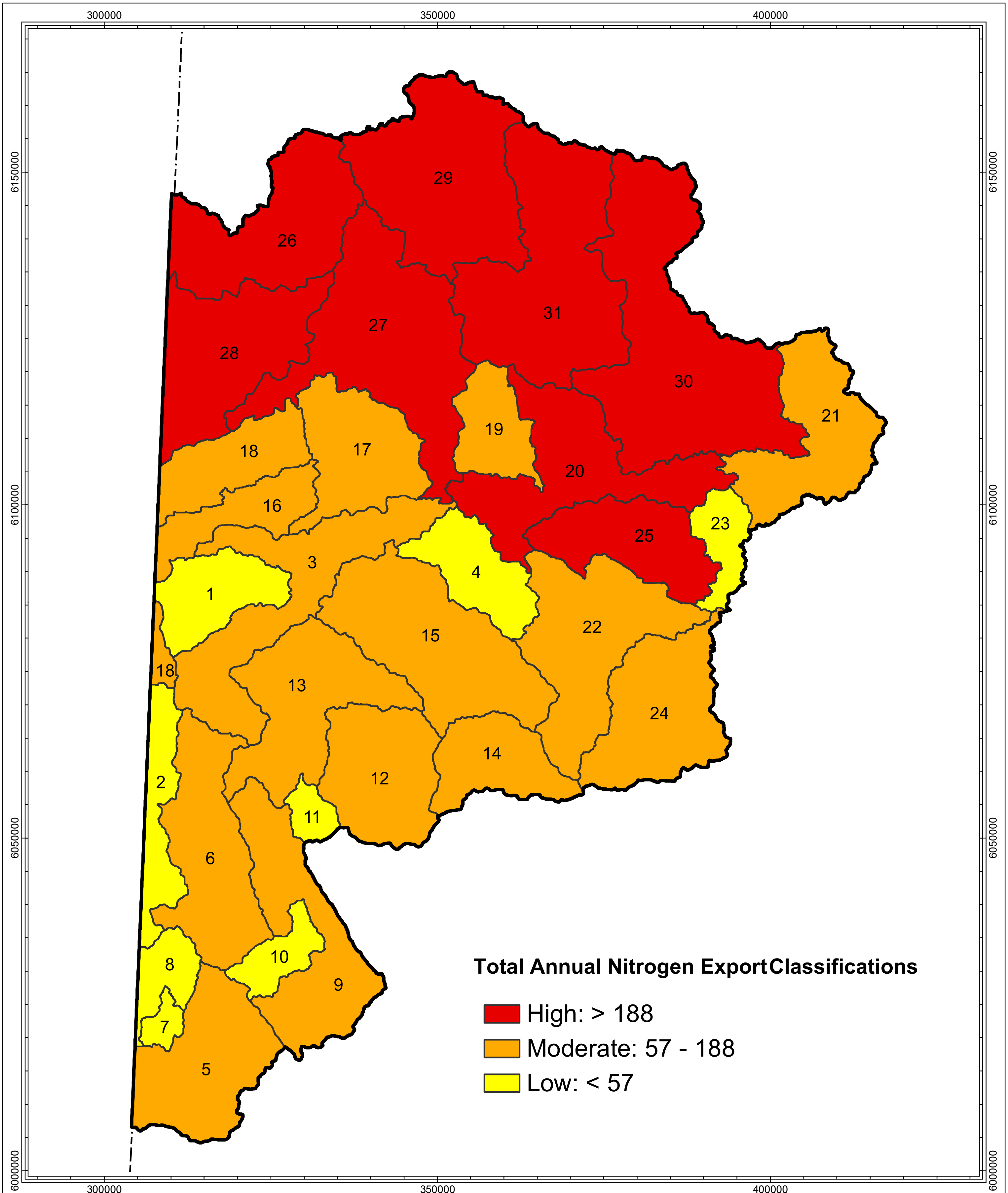
Total Annual Export Nitrogen

FIGURE 11



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Study Area

Subwatershed

Hutchinson Environmental Sciences Ltd.

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

0 10 20 30 km

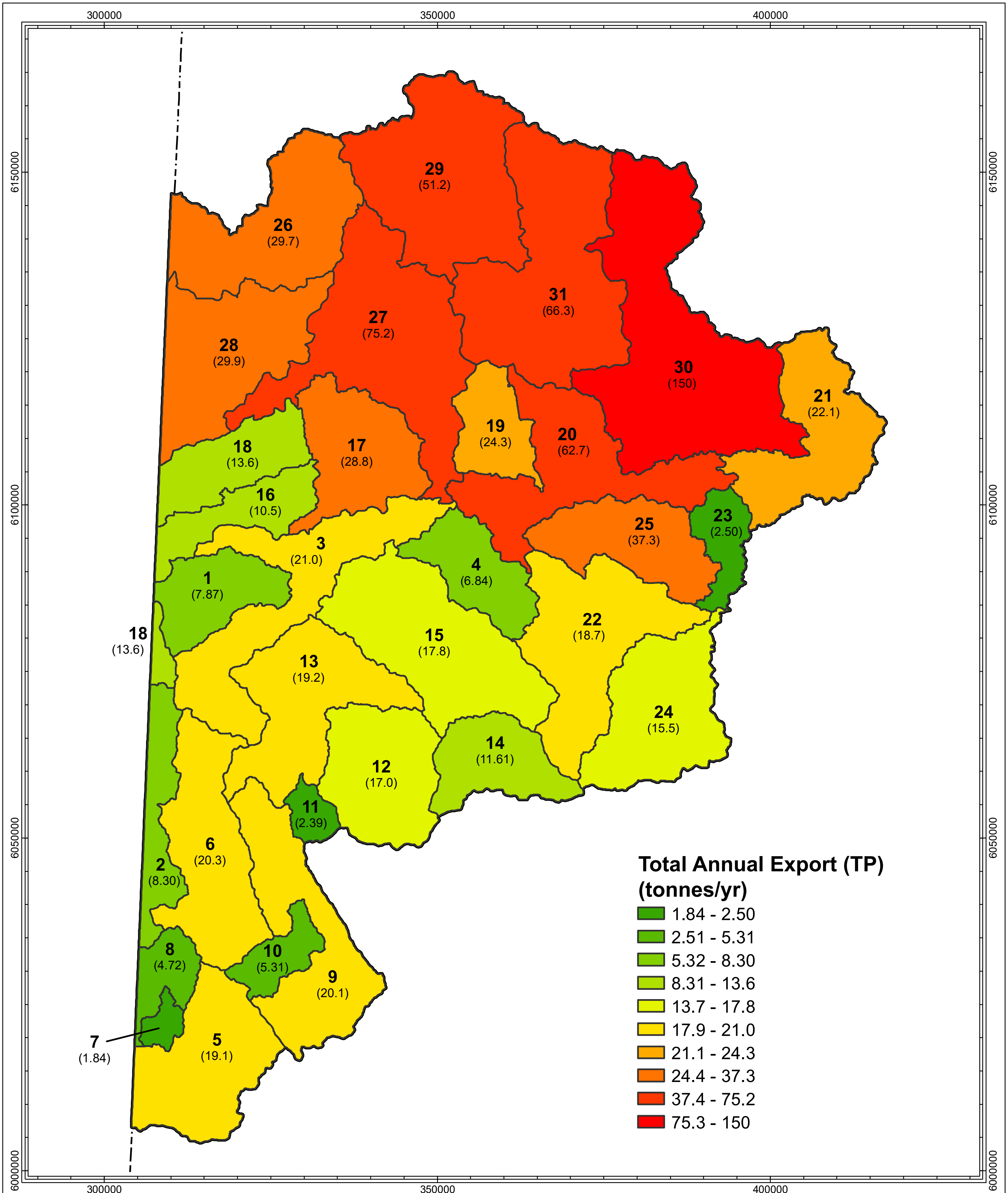
Scale = 1:750000

N

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Mar 29, 2018

Classification of Total Annual Nitrogen Export (tonnes/yr)

FIGURE 12



Legend

Study Area

Subwatershed

Hutchinson Environmental Sciences Ltd.

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

0 10 20 30 km

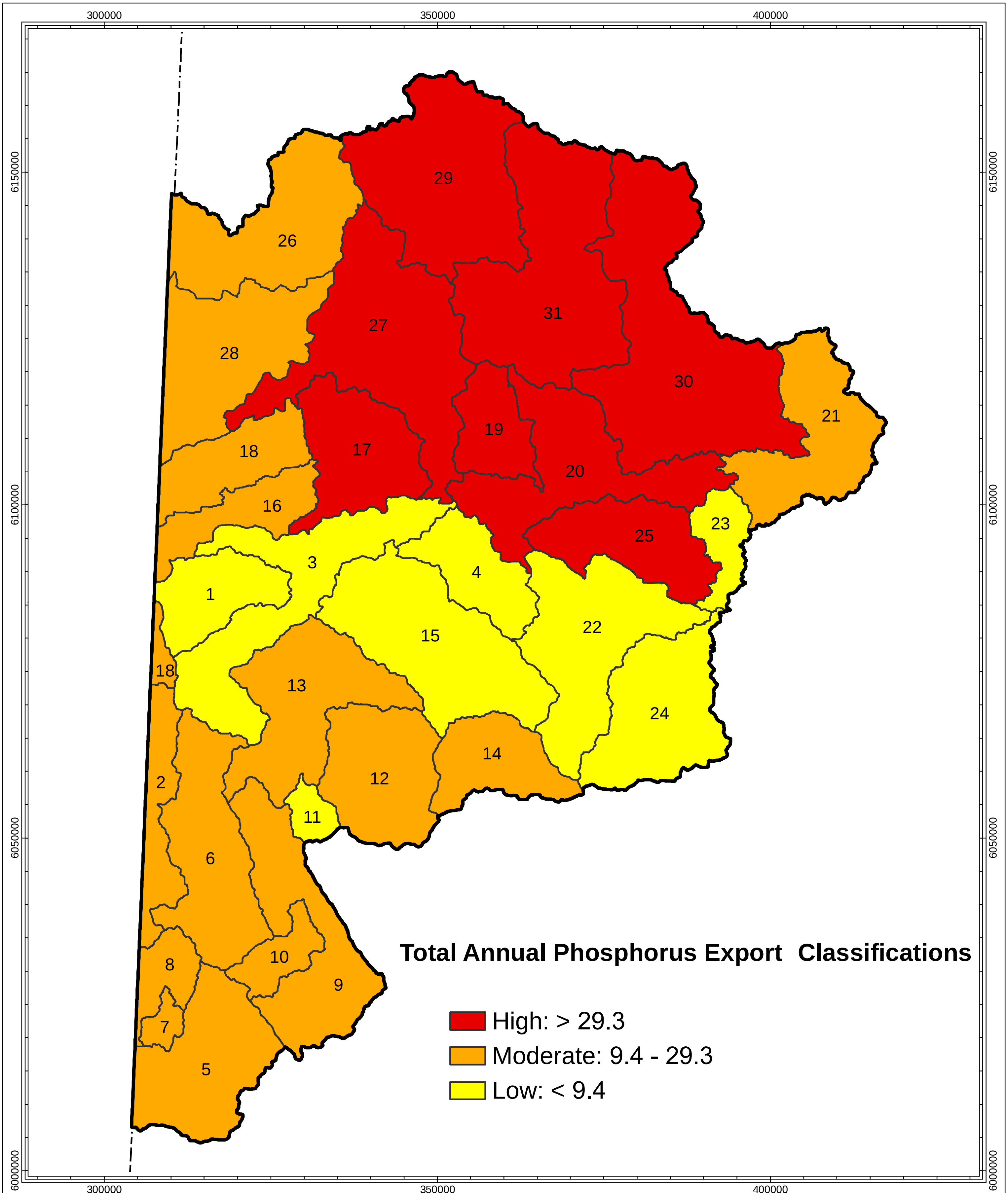
N

Scale = 1:750000

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Mar 09, 2018

Total Annual Export Phosphorus

FIGURE 13



Legend

Study Area

Subwatershed

Hutchinson Environmental Sciences Ltd.

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

0 10 20 30 km

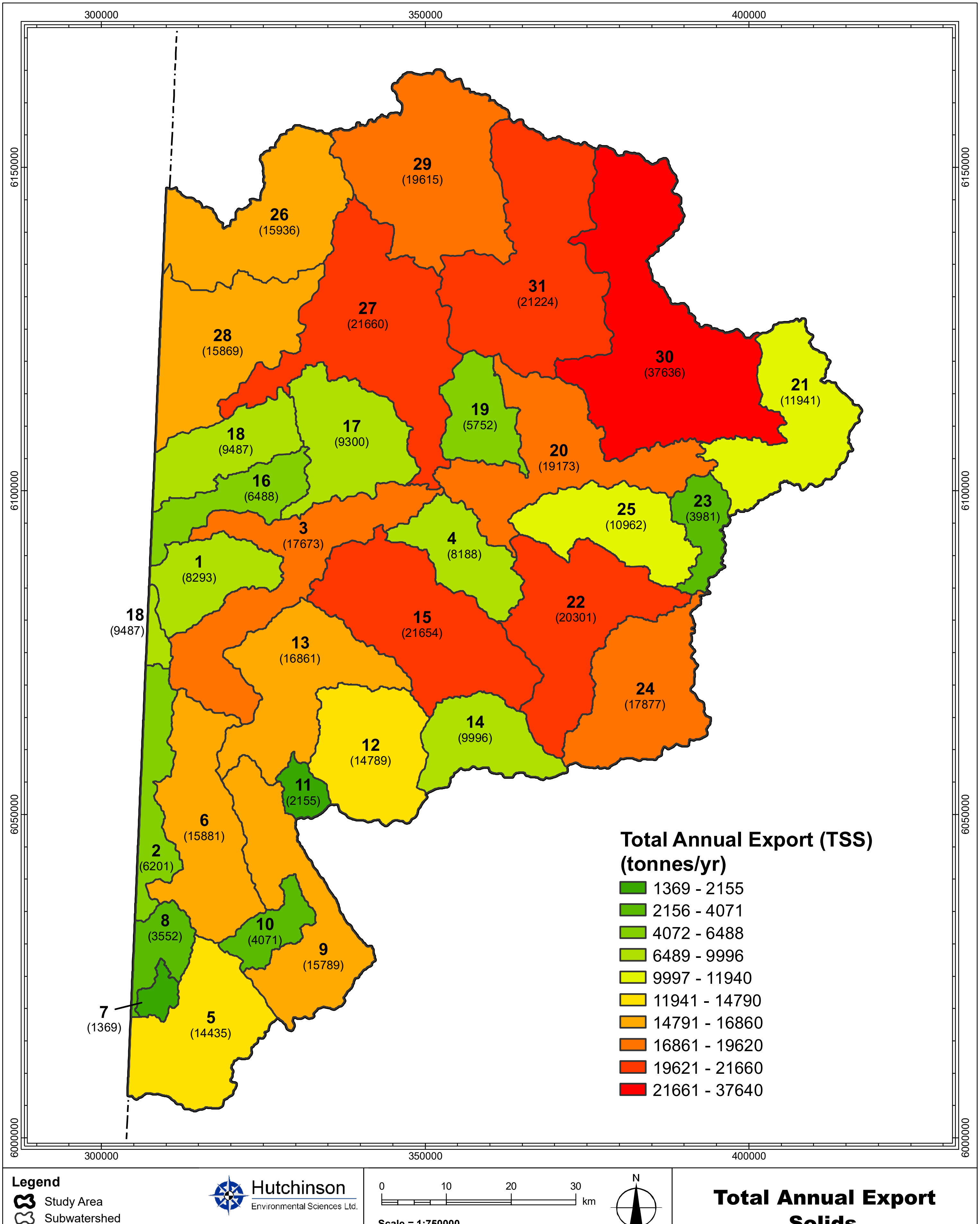
Scale = 1:750000

N

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Mar 29, 2018

Classification of Total Annual Phosphorus Export (tonnes/yr)

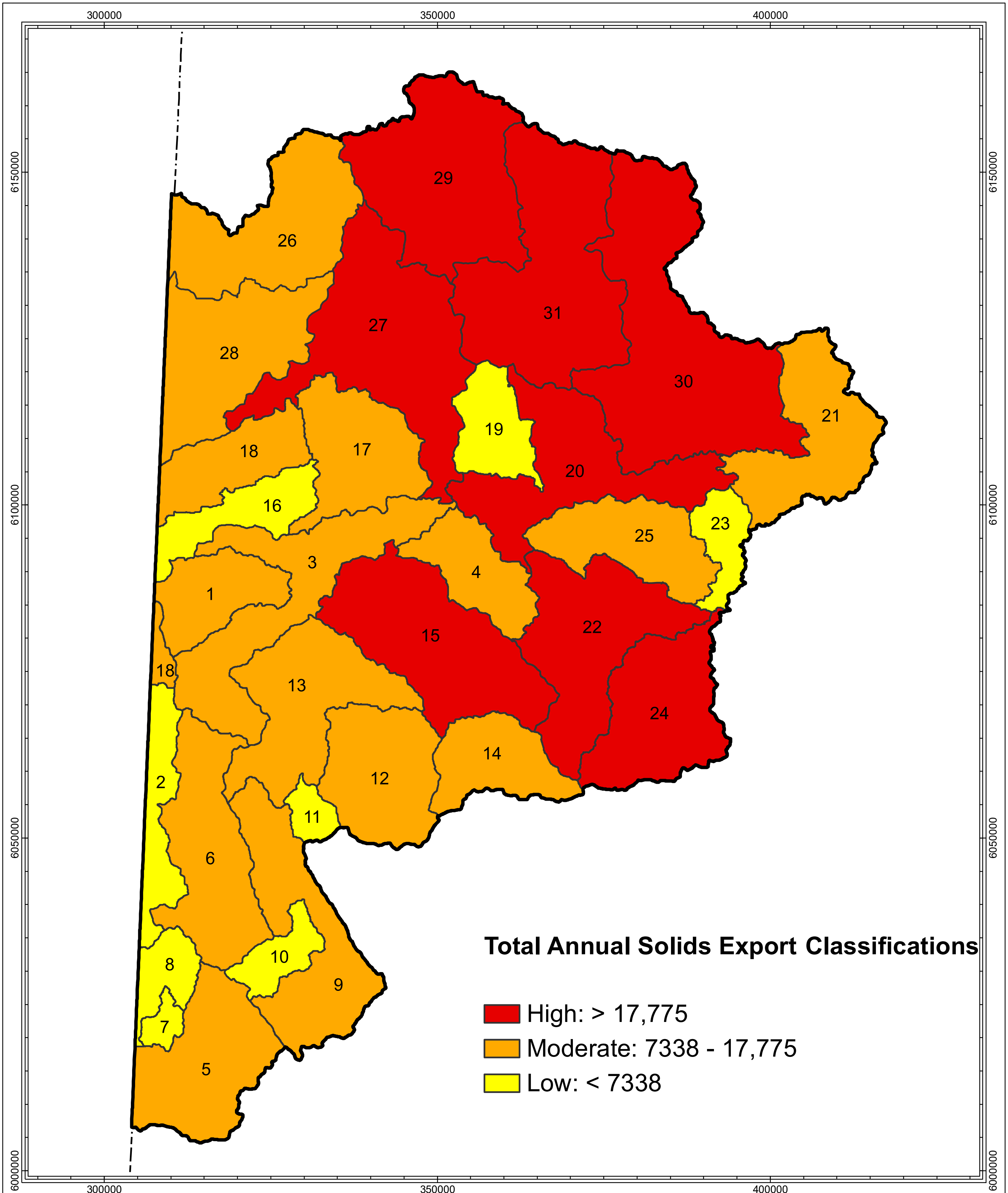
FIGURE 14



PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Mar 09, 2018

Total Annual Export Solids

FIGURE 15



Legend

Study Area

Subwatershed

Hutchinson Environmental Sciences Ltd.

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

0 10 20 30 km

Scale = 1:750000

N

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Mar 29, 2018

Classification of Total Annual Solids Export (tonnes/yr)

FIGURE 16

5.1.3 Derivation of NPS Loading – Average Export Coefficients for 31 Watersheds

Average export coefficients for nitrogen, phosphorus and solids in kg/ha/yr were derived for all 31 of the sub watersheds in the Wapiti Basin (Table 16). Summary statistics are presented in Table 15.

- Average export coefficients for nitrogen ranged from 1.88 kg/ha/yr in Lower Big Mountain Creek (Subwatershed 23) to 12.1 kg/ha/yr in Lower Bear River (Subwatershed 30);
- Average export coefficients for phosphorus ranged from 0.24 kg/ha/yr in Lower Big Mountain Creek (Subwatershed 23) to 1.87 kg/ha/yr in Lower Bear River (Subwatershed 30);
- Average export coefficients for solids ranged from 1.88 kg/ha/yr in Lower Redwillow River (Subwatershed 17) to 486 kg/ha/yr in Upper Big Mountain Creek (Subwatershed 24).

Table 15. Statistical Summary of Average Export Coefficients for 31 Subwatersheds in the Wapiti Basin

	Nitrogen in kg/ha/yr	Phosphorus in kg/ha/yr	Solids in kg/ha/yr
Minimum	1.88	0.24	318
Maximum	12.1	1.87	486
Average	4.49	0.71	403
Median	3.23	0.54	403
25th Percentile	2.91	0.48	377
75th Percentile	5.16	0.82	429

The average export coefficients for nitrogen and phosphorus for each subwatershed were significantly ($p<0.008$) but weakly ($r^2 < 0.23$) related to watershed area (Figure 17) but there was no significant relationship for solids ($p<0.9$). Eight subwatersheds had export coefficients exceeding the 75th percentile values for nitrogen and phosphorus export (Table 17). In two of these, Lower Wapiti River above Big Mountain Creek (#20) and Lower Bear River (#30), solids export exceeded the 75th percentile value, suggesting that solids were an important vector for export of nitrogen and phosphorus. In the remaining six subwatersheds export of nitrogen and phosphorus was not associated with high solids export suggesting that dissolved phases were important in nutrient export. There was no significant relationship ($p>0.27$) between the export coefficients for solids and those for nitrogen and phosphorus across the 31 subwatersheds. Five subwatersheds (highlighted in bold in Table 17) had substantially higher export coefficients for nitrogen and phosphorus compared to solids (Figure 18).

Figures 19, 20 and 21 show the details of export coefficient by land use for the entire study area that were used to derive Figures 11 – 16. Figures 22, 24 and 26 show the average export coefficient values for each of the 31 subwatersheds. The 25th and 75th percentiles were used to define the ranges of “Low” (1-25th), “Moderate” (26th – 75th) and “High” (>75th) for classification of watersheds (Table 15) and Figures 23, 25 and 27 show the resultant classifications for each subwatershed.

Table 16. Average Export Coefficients for 31 Subwatersheds in the Wapiti Basin.

Number	Watershed Name	Area (ha)	Nitrogen	Phosphorus	Solids
1	CALAHOO CREEK	19468	2.657	0.404	426
2	UPPER WAPITI RIVER ABOVE NARRAWAY RIVER	15865	3.178	0.523	391
3	UPPER WAPITI RIVER BELOW NARRAWAY RIVER	44525	3.048	0.472	397
4	IROQUOIS CREEK	19423	2.328	0.352	422
5	TORRENS RIVER	35788	3.304	0.532	403
6	LOWER NARRAWAY RIVER	38031	3.184	0.535	418
7	DINOSAUR CREEK	3605	3.316	0.512	380
8	UPPER NARRAWAY RIVER	9483	3.185	0.498	375
9	UPPER NOSE CREEK	38029	3.199	0.527	415
10	GUNDERSON CREEK	9292	3.231	0.571	438
11	GRAYLING CREEK	5065	2.897	0.472	425
12	MUDDY CREEK	31780	2.926	0.536	465
13	LOWER NOSE CREEK	39120	2.843	0.490	431
14	UPPER PINTO CREEK	21035	2.990	0.552	475
15	LOWER PINTO CREEK	50762	2.308	0.351	427
16	CALAHOO CREEK	16721	3.985	0.630	388
17	LOWER REDWILLOW RIVER	29287	6.379	0.985	318
18	UPPER REDWILLOW RIVER	24028	3.615	0.566	395
19	PIPESTONE CREEK	16064	9.891	1.510	358
20	LOWER WAPITI RIVER ABOVE BIG MOUNTAIN CREEK	43516	9.232	1.440	441
21	LOWER WAPITI RIVER ABOVE SMOKY RIVER	35282	4.595	0.627	338
22	BALD MOUNTAIN CREEK	44806	2.642	0.416	453
23	LOWER BIG MOUNTAIN CREEK	10441	1.883	0.240	381
24	UPPER BIG MOUNTAIN CREEK	36769	2.698	0.422	486

Number	Watershed Name	Area (ha)	Nitrogen	Phosphorus	Solids
25	UNNAMED - BIG MOUNTAIN CREEK	26768	8.684	1.395	410
26	UPPER BEAVERLODGE RIVER	42609	4.423	0.697	374
27	LOWER BEAVERLODGE RIVER	62067	7.842	1.211	349
28	BEAVERTAIL CREEK	41085	4.644	0.727	386
29	UPPER BEAR RIVER	56114	5.683	0.913	350
30	LOWER BEAR RIVER	80539	12.144	1.869	467
31	LOWER BEAR RIVER ABOVE GRANDE PRAIRIE CREEK	66199	6.389	1.001	321
Total		1013569			

Figure 17. Relationship of Export Coefficient to Watershed Size for 31 Subwatersheds in Wapiti Basin.

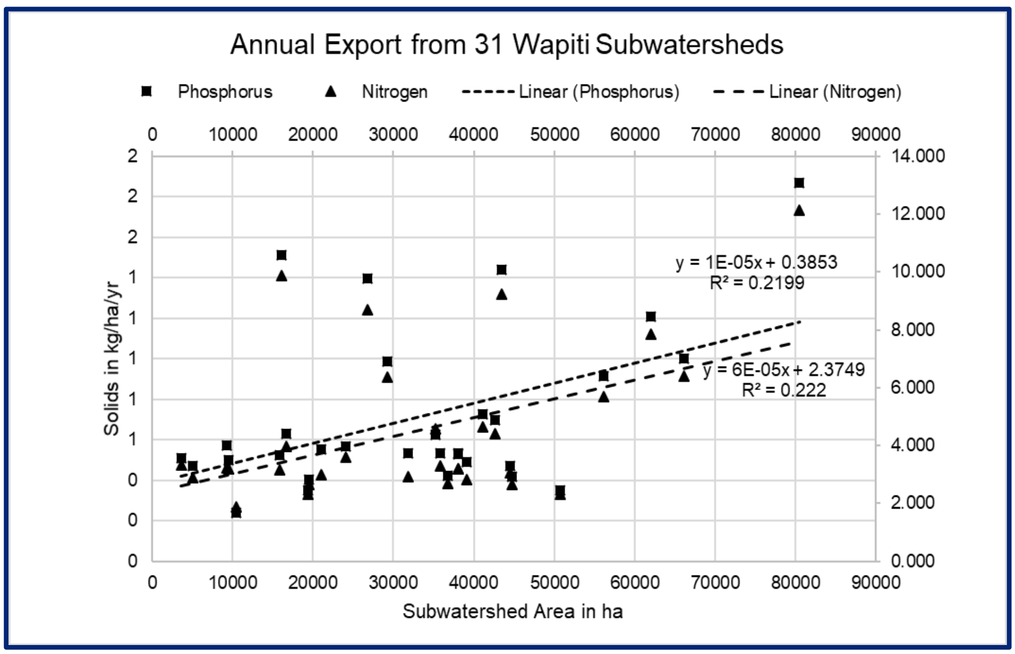
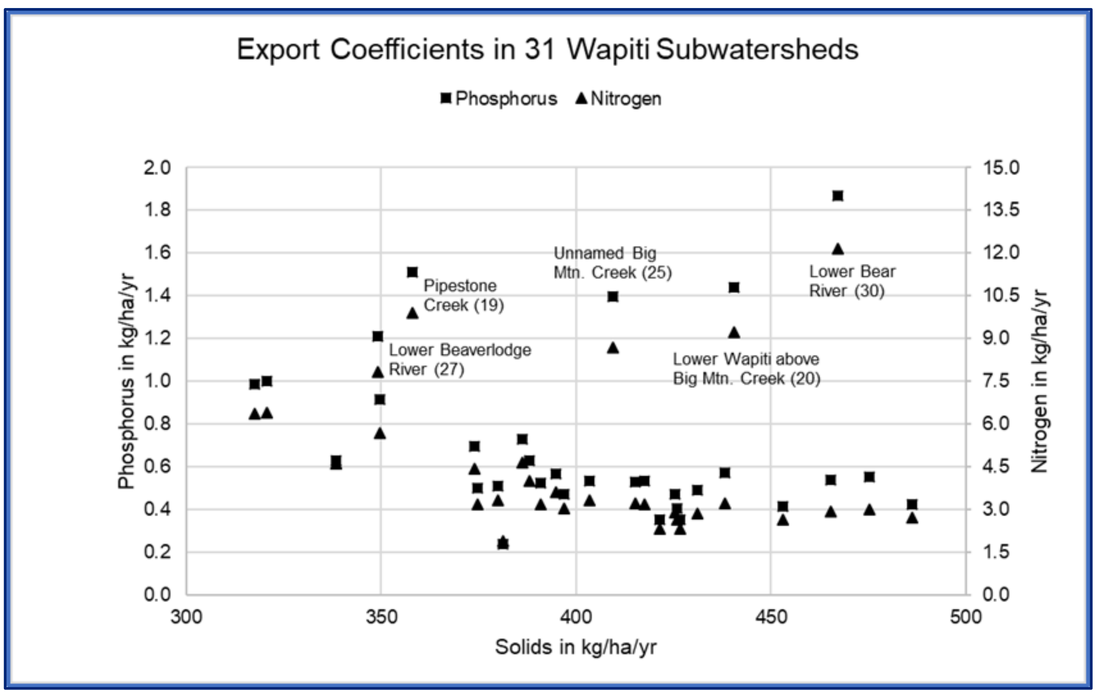
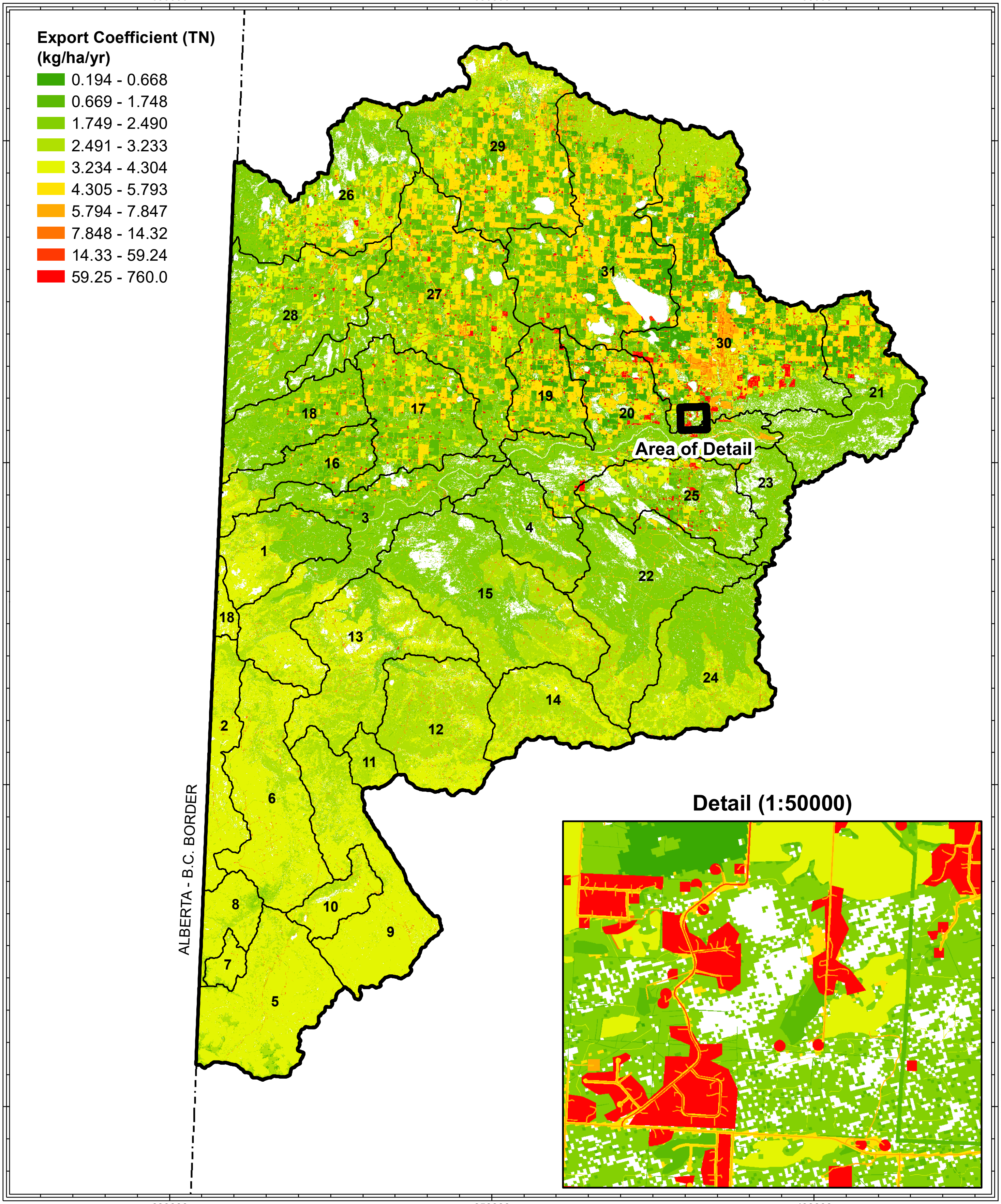


Table 17. Subwatersheds with Export Coefficients Exceeding 75th Percentile.

Number	SubWatershed Name	Nitrogen in kg/ha/yr	Phosphorus in kg/ha/yr	Solids in kg/ha/yr
10	GUNDERSON CREEK			438
12	MUDDY CREEK			465
13	LOWER NOSE CREEK			431
14	UPPER PINTO CREEK			475
17	LOWER REDWILLOW RIVER	6.38	0.98	
19	**PIPESTONE CREEK**	**9.89**	**1.51**	
20	**LOWER WAPITI RIVER**	**9.23**	**1.44**	441
22	BALD MOUNTAIN CREEK			453
24	UPPER BIG MOUNTAIN CREEK			486
25	**UNNAMED - BIG MOUNTAIN**	**8.68**	**1.39**	
27	**LOWER BEAVERLODGE RIVER**	**7.84**	**1.21**	
29	UPPER BEAR RIVER	5.68	0.91	
30	**LOWER BEAR RIVER**	**12.14**	**1.87**	**467**
31	LOWER BEAR RIVER ABOVE	6.39	1.00	

Figure 18. Relationship Between Export Coefficients for 31 Subwatersheds in Wapiti Basin.





Legend
Study Area
Subwatershed

Hutchinson Environmental Sciences Ltd.

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

0 10 20 30 km

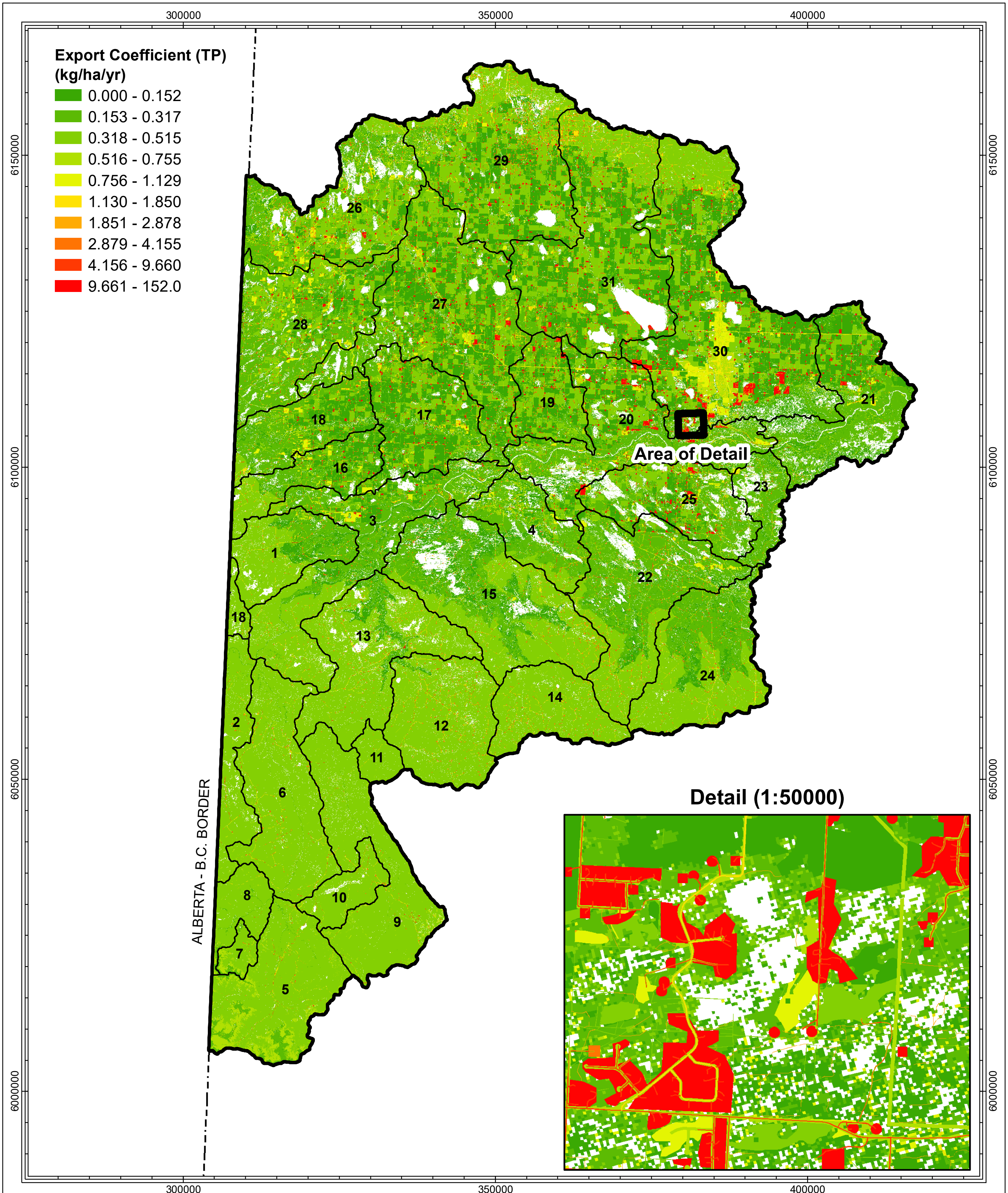
Scale = 1:800000

N

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Mar 22, 2018

Export Coefficients Nitrogen

FIGURE 19



Legend
Study Area
Subwatershed

Hutchinson Environmental Sciences Ltd.

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

0 10 20 30 km

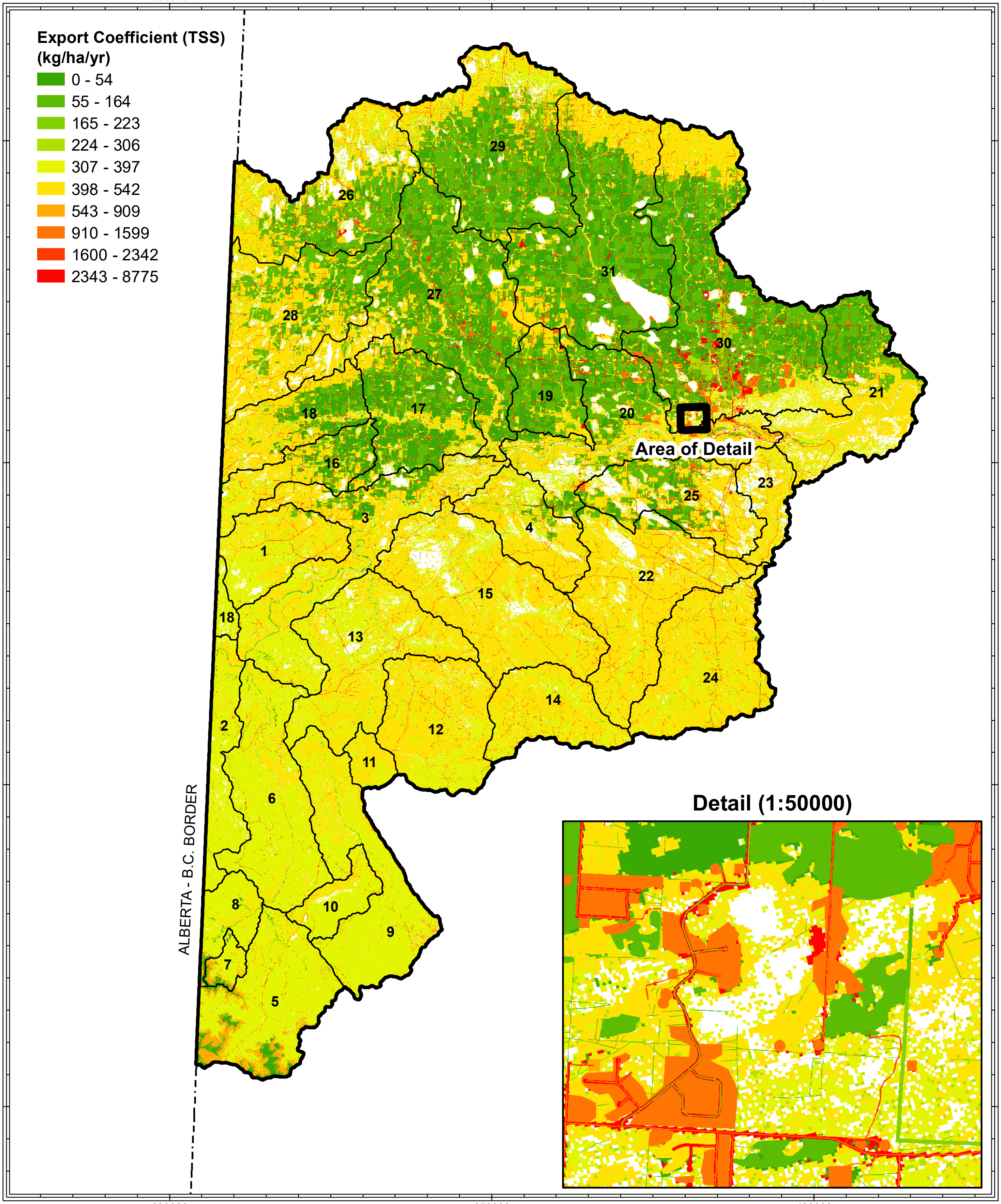
Scale = 1:800000

N

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Mar 22, 2018

Export Coefficients Phosphorus

FIGURE 20



Legend
Study Area
Subwatershed

Hutchinson Environmental Sciences Ltd.

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

0 10 20 30 km

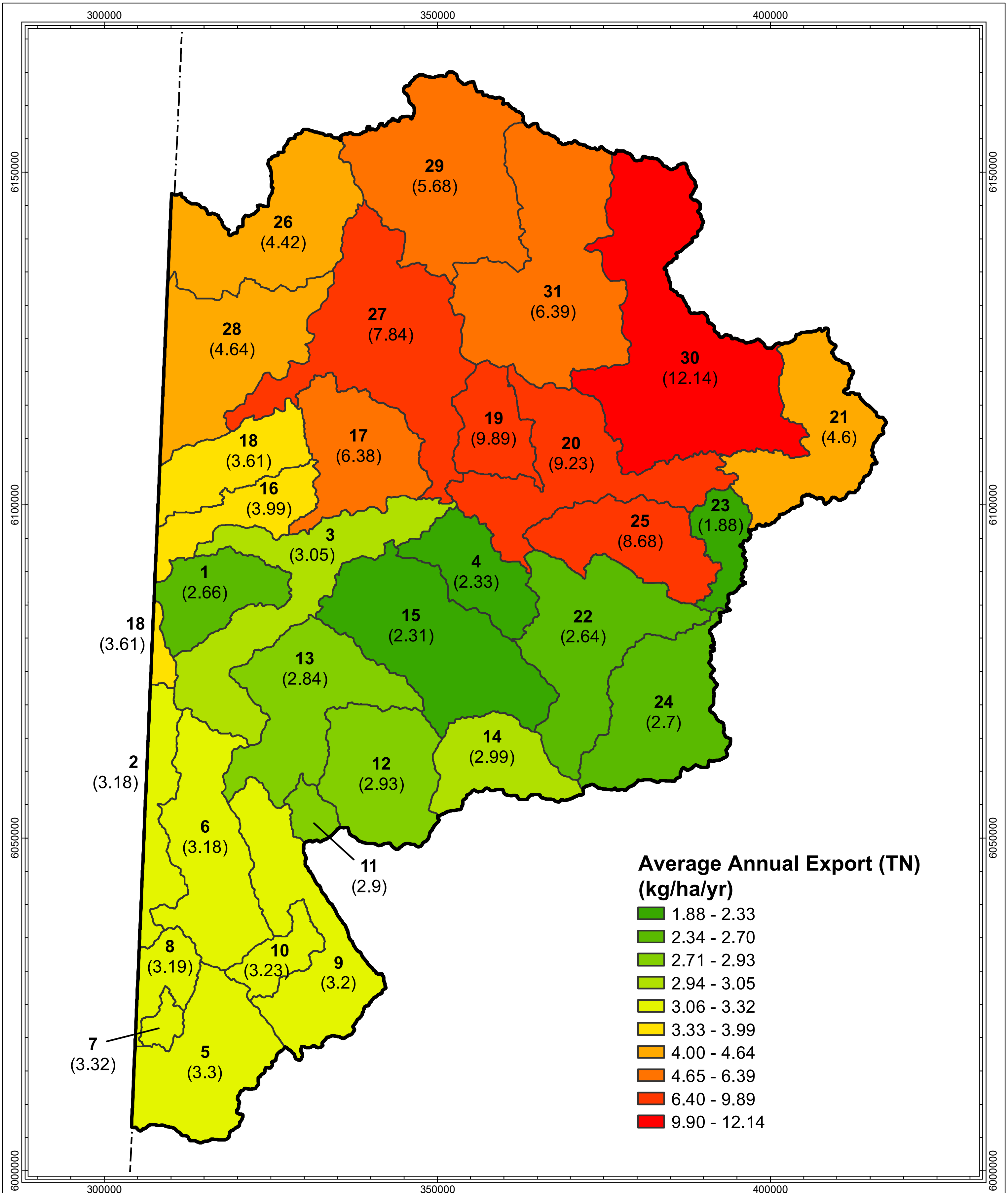
Scale = 1:800000

N

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Mar 09, 2018

Export Coefficients Sediment

FIGURE 21



Legend

Study Area

Subwatershed

Hutchinson Environmental Sciences Ltd.

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

0 10 20 30 km

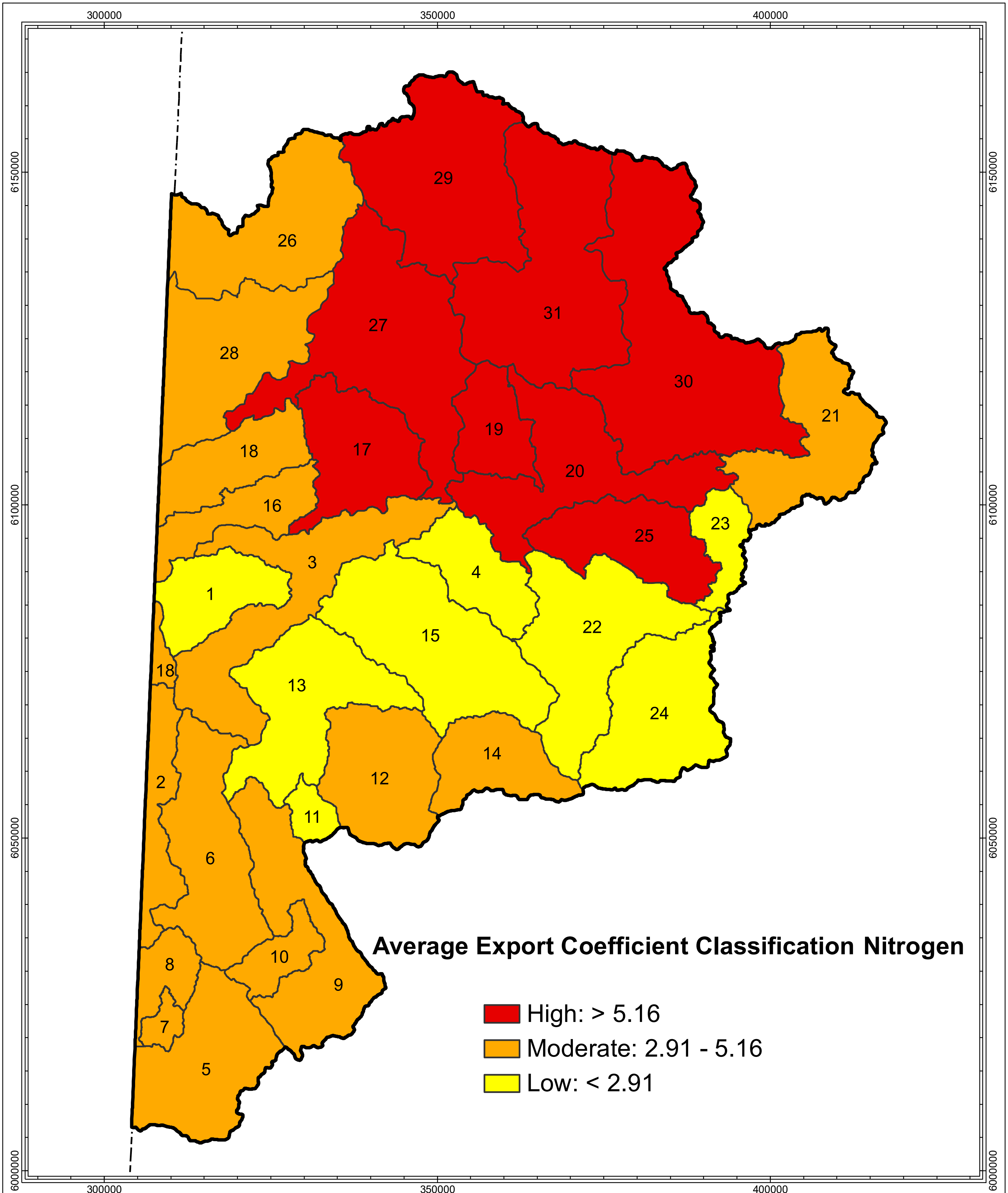
N

Scale = 1:750000

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Mar 08, 2018

Average Annual Export Nitrogen

FIGURE 22



Legend

Study Area

Subwatershed

Hutchinson Environmental Sciences Ltd.

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

0 10 20 30 km

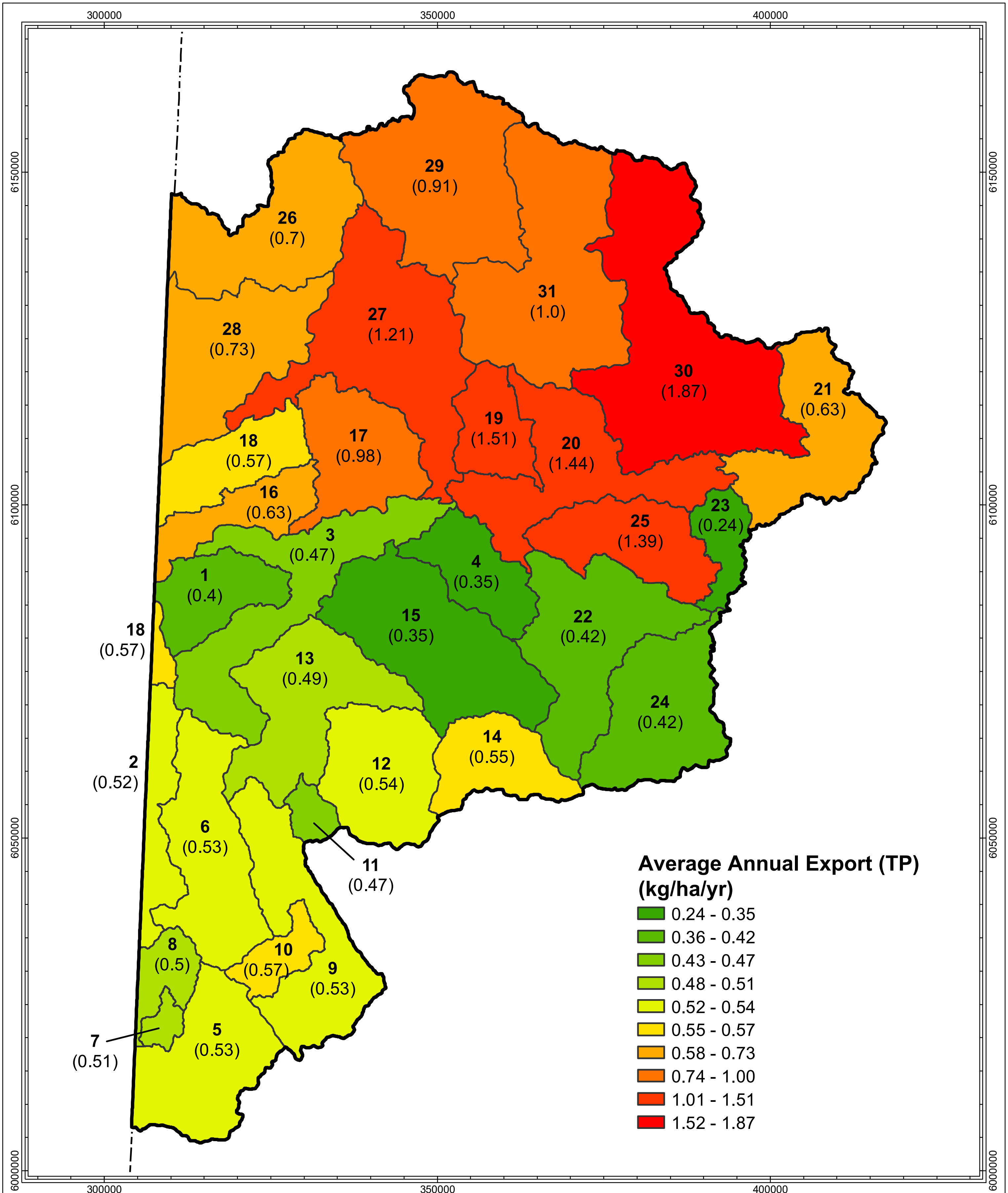
N

Scale = 1:750000

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Mar 29, 2018

Classification of Average Nitrogen Export (kg/ha/yr)

FIGURE 23



Legend
Study Area
Subwatershed

Hutchinson Environmental Sciences Ltd.
PALMER ENVIRONMENTAL CONSULTING GROUP INC.

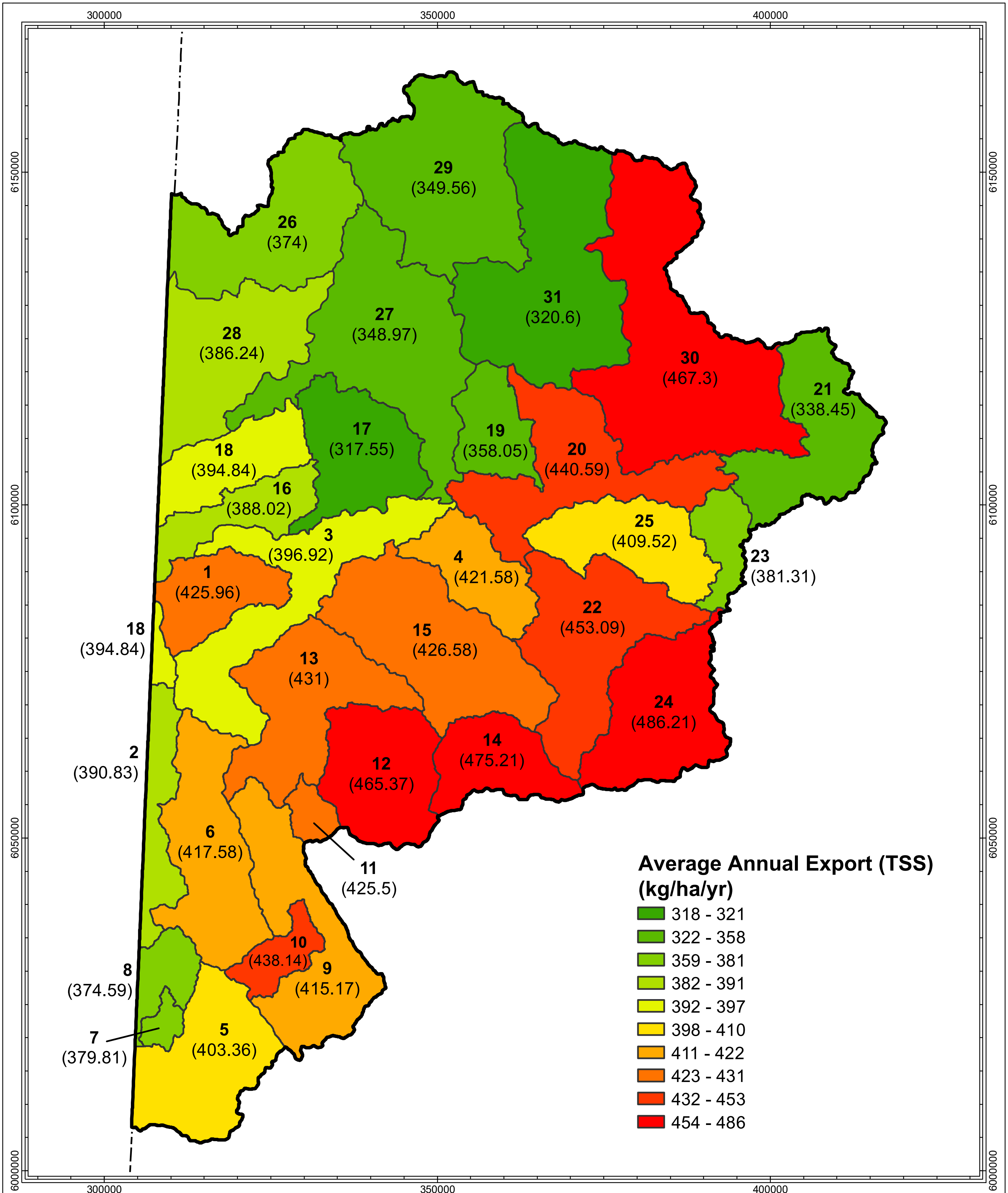
0 10 20 30 km
N

Scale = 1:750000

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Mar 08, 2018

Average Annual Export Phosphorus

FIGURE 24



Legend

- Study Area
- Subwatershed

Hutchinson Environmental Sciences Ltd.

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

0 10 20 30 km

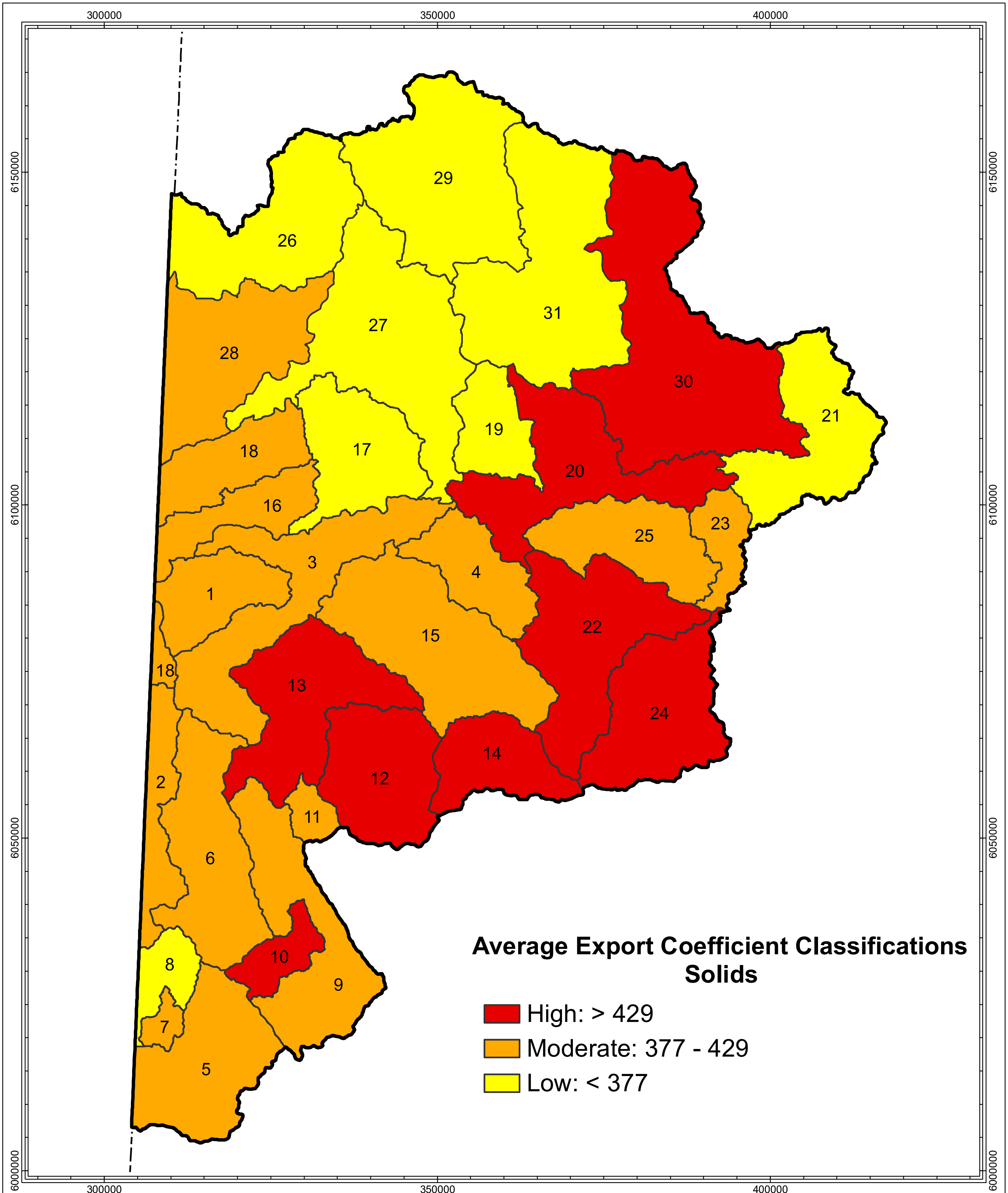
N

Scale = 1:750000

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Mar 08, 2018

Average Annual Export Total Suspended Solids

FIGURE 26



Legend
Study Area
Subwatershed

Hutchinson Environmental Sciences Ltd.

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

0 10 20 30 km

N

Scale = 1:750000

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Mar 29, 2018

Classification of Average Solids Export (kg/ha/yr)

FIGURE 27

5.2 Riparian Zone NPS Model Refinement

Donahue (2013) provided a table of “Riparian Zone Export Multiplication Factors” to account for nutrient delivery to surface water from land uses within 50m of a stream or beyond 50m but where steep slopes could increase delivery of nitrogen and phosphorus to a stream (Table 18).

- Neither Donahue (2013) nor the cited source material (Johnes 1996) define “steep” for the classification in Table 18 and so we classified slopes exceeding 10% as steep slopes,
- Our crop classifications did not distinguish canola from other cereal crops and so the value of 0.8 cited for canola (steep slopes, nitrogen) was used for all cereal crops,
- Our crop classifications did not distinguish intensive from extensive forage crops and so the value of 1.33 for steeper slopes, phosphorus was replaced with a 1 so that all four forage crop categories had the classification of 1 for steeper slopes (note that a value of 2 was used for all four classifications of nitrogen and phosphorus, intensive and extensive, in the <50m classification.)

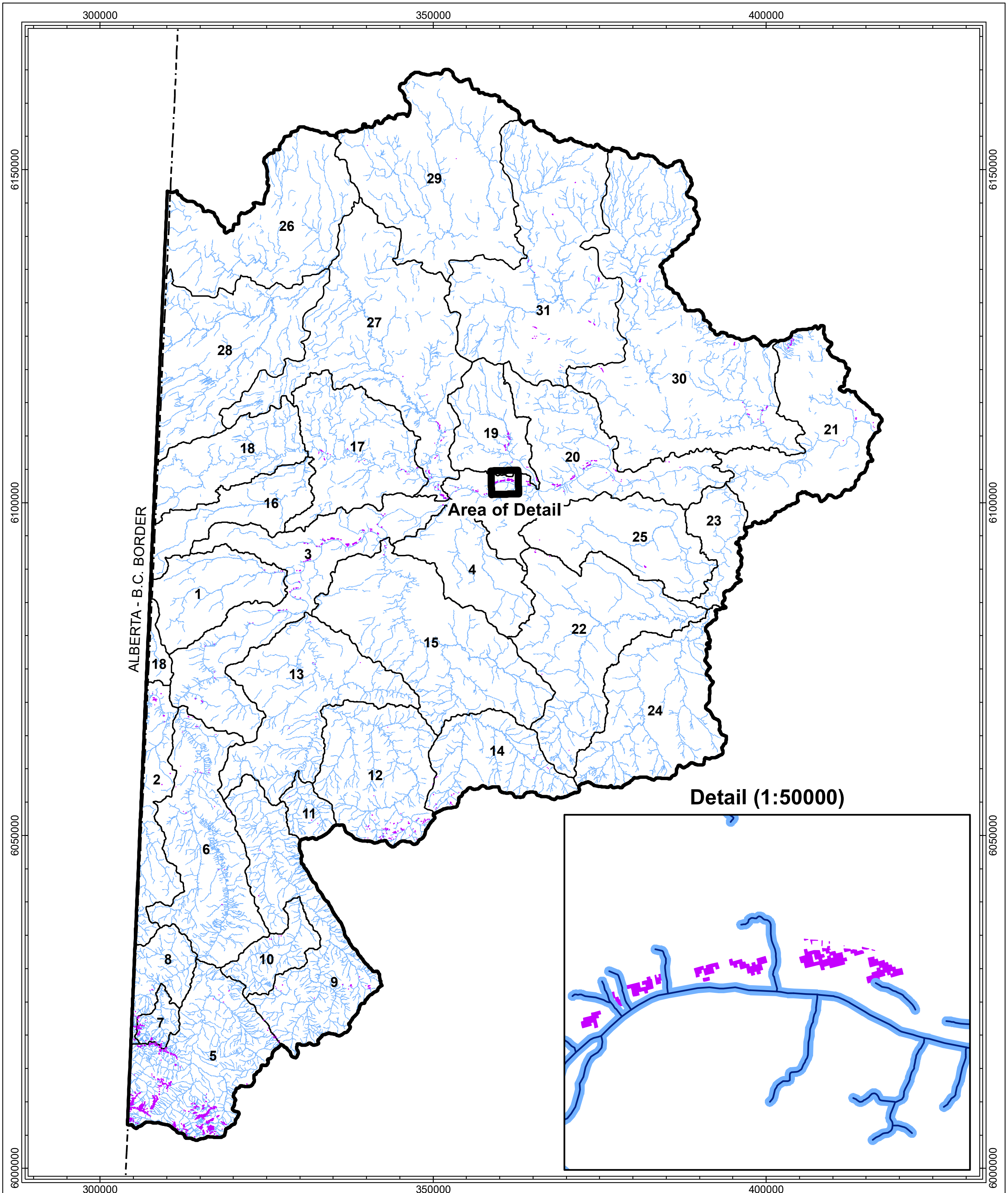
Table 18. Riparian zone export multiplication factors from Donahue (2013).

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

;

Figure 28 shows the portions of the study area that are within 50m of a stream or >50m with a slope exceeding 10%. Figures 29 and 30 show the resultant export coefficients for all land uses for nitrogen (Figure 29) and phosphorus (Figure 30).



Legend

Study Area

Subwatershed

Riparian Zone[1]

Steeper catchment slope angles[2]

Notes: (1) 50 m buffer from watercourses, (2) only affected classes shown.

Sources: AltaLIS Hydrography and Natural Resources Canada - CDEM.

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0 10 20 30 km

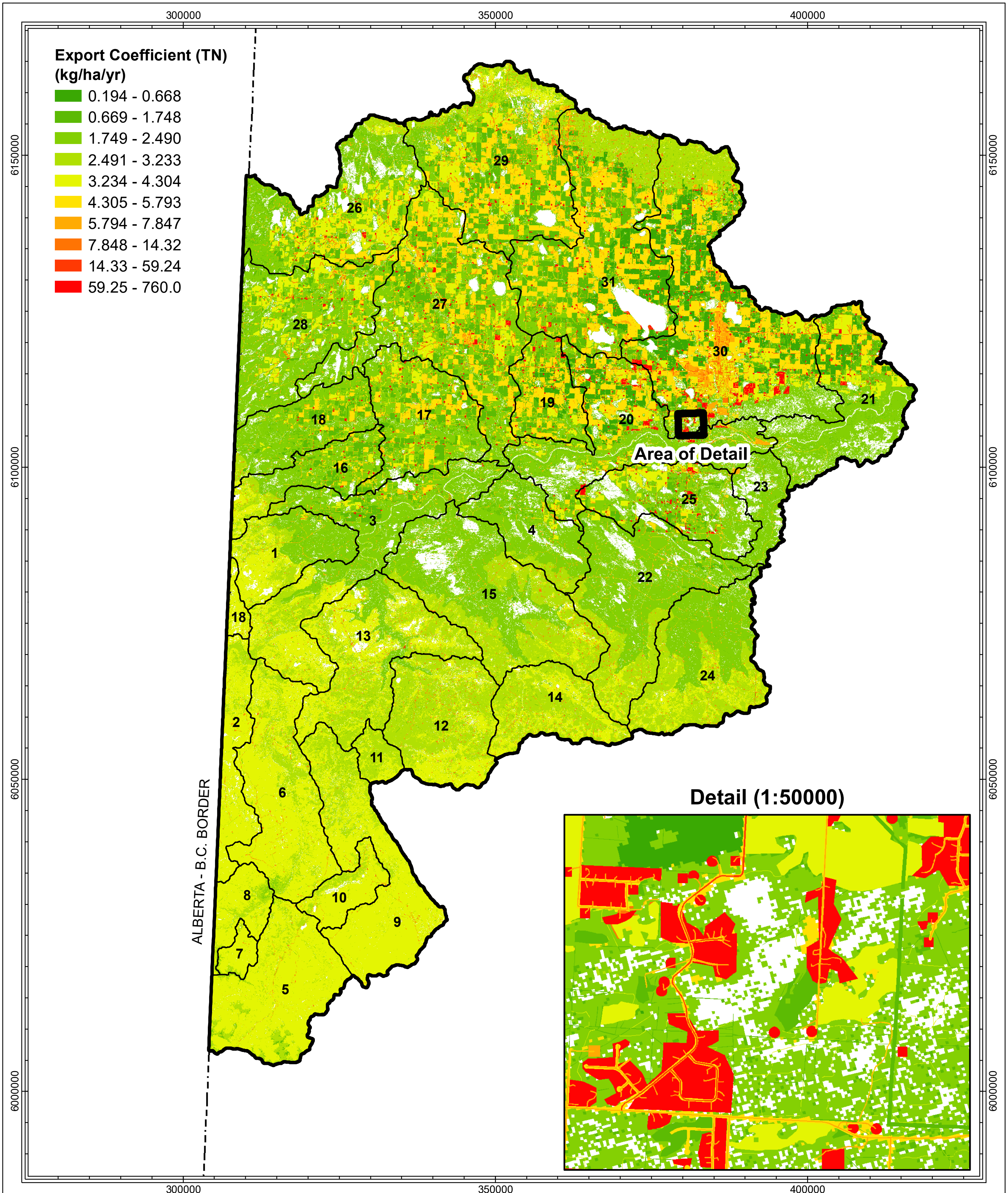
N

Scale = 1:750000

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Mar 30, 2018

Riparian Multiplier Factor Areas

FIGURE 28



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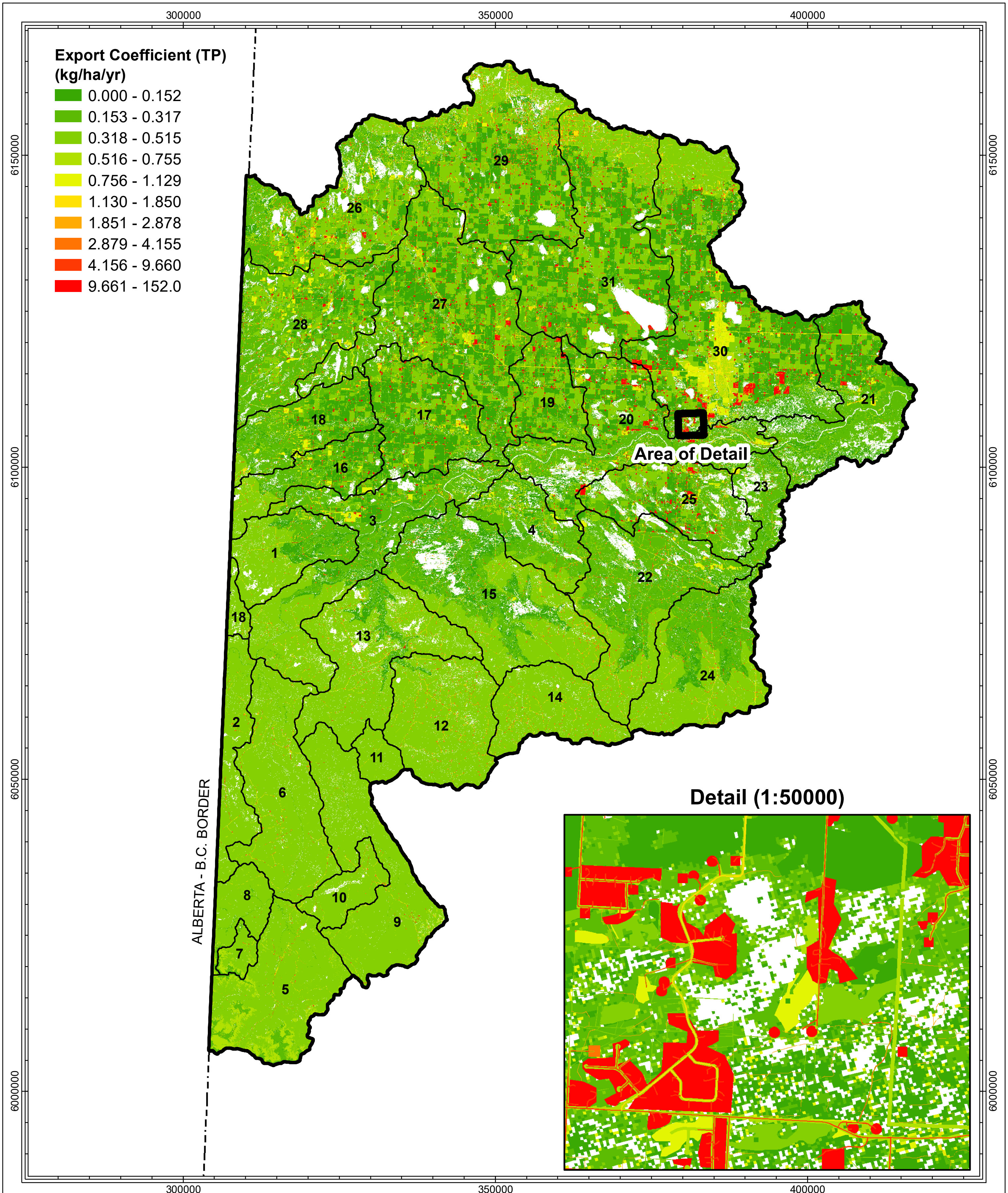
PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Mar 22, 2018

Export Coefficients Nitrogen - Riparian Zone Modifications

FIGURE 29



Legend

Study Area

Subwatershed

Hutchinson Environmental Sciences Ltd.

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

0 10 20 30 km

Scale = 1:800000

N

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Mar 22, 2018

Export Coefficients Phosphorus Riparian Zone Modifications

FIGURE 30

Incorporation of the modifiers for location within 50m of a stream bed and steep slopes >50 from a stream bed altered average export coefficient values and total watershed loads, by less than 1% (Table 19,20) in 19 of 31 subwatersheds (Table 21) but did not alter the previous classifications of Low, Medium and High NPS export. Changes in total annual export for individual subwatersheds are presented in Table 22. The minimal change in annual NPS export related to the riparian corrections did not change the classifications of subwatersheds as "Low", "Medium" or "High" export that were presented and so Figures 12, 14, 16, 23, 25 and 27 represent the classifications of NPS loadings from each subwatershed.

Table 19. Influence of Riparian Zone Export Multiplication Factors on Average Export Coefficient Values for 31 Subwatersheds.

	Export Coefficients (kg/ha/yr)					
	No Riparian Multiplier			With Riparian Multiplier		
	Nitroge	Phosphorus	Solids	Nitrogen	Phosphorus	Solids
Average	4.49	0.71	403	4.51	0.71	403
Minimum	1.88	0.24	318	1.88	0.24	318
Maximum	12.1	1.87	486	12.2	1.87	486
Median	3.23	0.54	403	3.23	0.54	403
25th Percentile	2.91	0.48	377	2.91	0.48	377
75th Percentile	5.16	0.82	429	5.21	0.82	429

Table 20. Influence of Riparian Zone Export Multiplication Factors on Total Annual Export for 31 Subwatersheds.

	Total Annual Loads (tonnes)					
	No Riparian Multiplier			With Riparian Multiplier		
	Nitrogen	Phosphorus	Solids	Nitrogen	Phosphorus	Solids
Average	5,234	822	408,110	5,253	824	408,110
Minimum	169	26.5	13,165	169	26.6	13,165
Maximum	12.0	1.80	1,369	12.0	1.85	1,369
Median	978	151	37,636	980	151	37,636
25th Percentile	118	19.1	14,435	118	19.1	14,435
75th Percentile	57.0	9.40	7,338	57.4	9.43	7,338
Total	5,234	822	408,110	5,253	824	408,110

Table 21. Influence of Riparian Zone Export Multiplication Factors on Export Coefficient Values for 31 Individual Subwatersheds. Bolded values represent changes.

Number	Watershed Name	Area (ha)	Nitrogen kg/ha/yr		Phosphorus kg/ha/yr		Solids kg/ha/yr	
			Original	Revised	Original	Revised	Original	Revised
1	CALAHOO CREEK	19468	2.657	**2.662**	0.404	**0.405**	426	426
2	UPPER WAPITI RIVER ABOVE NARRAWAY RIVER	15865	3.178	3.178	0.523	0.523	391	391
3	UPPER WAPITI RIVER BELOW NARRAWAY RIVER	44525	3.048	**3.050**	0.472	0.472	397	397
4	IROQUOIS CREEK	19423	2.328	**2.330**	0.352	**0.353**	422	422
5	TORRENS RIVER	35788	3.304	**3.306**	0.532	**0.534**	403	403
6	LOWER NARRAWAY RIVER	38031	3.184	3.184	0.535	0.535	418	418
7	DINOSAUR CREEK	3605	3.316	**3.318**	0.512	**0.513**	380	380
8	UPPER NARRAWAY RIVER	9483	3.185	3.185	0.498	0.498	375	375
9	UPPER NOSE CREEK	38029	3.199	3.199	0.527	0.527	415	415
10	GUNDERSON CREEK	9292	3.231	3.231	0.571	0.571	438	438
11	GRAYLING CREEK	5065	2.897	2.897	0.472	0.472	425	425
12	MUDDY CREEK	31780	2.926	2.926	0.536	0.536	465	465
13	LOWER NOSE CREEK	39120	2.843	2.843	0.490	0.490	431	431
14	UPPER PINTO CREEK	21035	2.990	2.990	0.552	0.552	475	475
15	LOWER PINTO CREEK	50762	2.308	2.308	0.351	0.351	427	427
16	CALAHOO CREEK	16721	3.985	**4.007**	0.630	**0.632**	388	388
17	LOWER REDWILLOW RIVER	29287	6.379	**6.435**	0.985	**0.991**	318	318
18	UPPER REDWILLOW RIVER	24028	3.615	**3.643**	0.566	**0.569**	395	395
19	PIPESTONE CREEK	16064	9.891	**9.918**	1.510	**1.512**	358	358
			Original	Revised	Original	Revised	Original	Revised
20	LOWER WAPITI RIVER ABOVE BIG MOUNTAIN CREEK	43516	9.232	**9.250**	1.440	**1.441**	441	441
21	LOWER WAPITI RIVER ABOVE SMOKY RIVER	35282	4.595	**4.618**	0.627	**0.628**	338	338
22	BALD MOUNTAIN CREEK	44806	2.642	**2.643**	0.416	**0.417**	453	453
23	LOWER BIG MOUNTAIN CREEK	10441	1.883	1.883	0.240	0.240	381	381

Number	Watershed Name	Area (ha)	Nitrogen kg/ha/yr		Phosphorus kg/ha/yr		Solids kg/ha/yr	
24	UPPER BIG MOUNTAIN CREEK	36769	2.698	2.698	0.422	0.422	486	486
25	UNNAMED - BIG MOUNTAIN CREEK	26768	8.684	**8.691**	1.395	1.395	410	410
26	UPPER BEAVERLODGE RIVER	42609	4.423	**4.477**	0.697	**0.705**	374	374
27	LOWER BEAVERLODGE RIVER	62067	7.842	**7.894**	1.211	**1.216**	349	349
28	BEAVERTAIL CREEK	41085	4.644	**4.699**	0.727	**0.733**	386	386
29	UPPER BEAR RIVER	56114	5.683	**5.723**	0.913	**0.916**	350	350
30	LOWER BEAR RIVER	80539	12.144	**12.173**	1.869	**1.870**	467	467
31	LOWER BEAR RIVER ABOVE GRANDE PRAIRIE CREEK	66199	6.389	**6.414**	1.001	**1.003**	321	321
Total		1,013,569						

Table 22. Influence of Riparian Zone Export Multiplication Factors on Total Annual Export for 31 Individual Subwatersheds. Bolded values represent changed totals

Number	Watershed Name	Area (ha)	Nitrogen tonnes/yr		Phosphorus tonnes/yr		Solids tonnes/yr	
			Original	Revised	Original	Revised	Original	Revised
1	CALAHOO CREEK	19468	51.7	**51.8**	7.87	**7.89**	8,293	8,293
2	UPPER WAPITI RIVER ABOVE NARRAWAY RIVER	15865	50.4	50.4	8.30	8.30	6,201	6,201
3	UPPER WAPITI RIVER BELOW NARRAWAY RIVER	44525	135.7	**135.8**	21.02	**21.03**	17,673	17,673
4	IROQUOIS CREEK	19423	45.2	**45.3**	6.84	**6.85**	8,188	8,188
5	TORRENS RIVER	35788	118.23	**118.3**	19.05	**19.13**	14,435	14,435
6	LOWER NARRAWAY RIVER	38031	121.10	121.1	20.34	20.34	15,881	15,881
7	DINOSAUR CREEK	3605	11.95	12.0	1.84	1.85	1,369	1,369
8	UPPER NARRAWAY RIVER	9483	30.21	30.2	4.72	4.72	3,552	3,552
9	UPPER NOSE CREEK	38029	121.66	121.7	20.06	20.06	15,789	15,789
10	GUNDERSON CREEK	9292	30.02	30.0	5.31	5.31	4,071	4,071
11	GRAYLING CREEK	5065	14.67	14.7	2.39	2.39	2,155	2,155
12	MUDDY CREEK	31780	92.98	93.0	17.03	17.04	14,789	14,789
13	LOWER NOSE CREEK	39120	111.22	111.2	19.17	19.17	16,861	16,861
14	UPPER PINTO CREEK	21035	62.89	62.9	11.61	11.62	9,996	9,996
15	LOWER PINTO CREEK	50762	117.17	117.2	17.83	17.83	21,654	21,654
16	CALAHOO CREEK	16721	66.64	**67.0**	10.54	**10.56**	6,488	6,488
17	LOWER REDWILLOW RIVER	29287	186.82	**188.5**	28.84	**29.02**	9,300	9,300
18	UPPER REDWILLOW RIVER	24028	86.86	**87.5**	13.59	**13.68**	9,487	9,487

Number	Watershed Name	Area (ha)	Nitrogen tonnes/yr		Phosphorus tonnes/yr		Solids tonnes/yr	
19	PIPESTONE CREEK	16064	158.88	**159.3**	24.26	**24.28**	5,752	5,752
20	LOWER WAPITI RIVER ABOVE BIG MOUNTAIN CREEK	43516	401.75	**402.5**	62.66	**62.72**	19,173	19,173
21	LOWER WAPITI RIVER ABOVE SMOKY RIVER	35282	162.14	**162.9**	22.11	**22.15**	11,941	11,941
22	BALD MOUNTAIN CREEK	44806	118.39	118.4	18.66	18.67	20,301	20,301
23	LOWER BIG MOUNTAIN CREEK	10441	19.66	19.7	2.50	2.50	3,981	3,981
24	UPPER BIG MOUNTAIN CREEK	36769	99.22	99.2	15.51	15.51	17,877	17,877
25	UNNAMED - BIG MOUNTAIN CREEK	26768	232.45	**232.6**	37.34	**37.35**	10,962	10,962
26	UPPER BEAVERLODGE RIVER	42609	188.45	**190.8**	29.69	**30.03**	15,936	15,936
26	UPPER BEAVERLODGE RIVER	42609	188.45	**190.8**	29.69	**30.03**	15,936	15,936
27	LOWER BEAVERLODGE RIVER	62067	486.74	**490.0**	75.16	**75.44**	21,660	21,659
28	BEAVERTAIL CREEK	41085	190.80	**193.0**	29.88	**30.13**	15,869	15,869
29	UPPER BEAR RIVER	56114	318.90	**321.2**	51.24	**51.42**	19,615	19,615
30	LOWER BEAR RIVER	80539	978.03	**980.4**	150.50	**150.63**	37,636	37,636
31	LOWER BEAR RIVER ABOVE GRANDE PRAIRIE CREEK	66199	422.93	**424.6**	66.30	**66.42**	21,224	21,224
Total		1,013,569	5,253	5,234	824	822	408,110	408,110

Overall, incorporation of the riparian zone multipliers for individual crops had little influence on NPS loading, reflecting the low percentage of affected agricultural lands and crops (Table 18) and the lack of steep topography (Figure 28) in the agricultural areas of the Wapiti watershed.

6. Point source (PS) estimates

Point source loadings of nitrogen, phosphorus and TSS were derived from a variety of sources. AECOM (2009) summarized all licensed point source discharges of sewage effluent in Alberta, including discharges to the Wapiti River. Measured loads for the Grande Prairie Airport and Silver Point Village were not available and so these were estimated from AECOM (2009) as follows:

- Estimated 2017 serviced populations of 481 and 123 for Grande Prairie Airport and Silver Point Village respectively,
- Average daily flows of 400 L/C/day,
- Lagoon discharge with assumed treatment effectiveness for Total N, Total P and TSS as provided in Table 2.5 from AECOM 2009 (Table 23).

Annual point source loads are presented in Table 24. Annual loadings of N and P from International Paper in Grande Prairie were retrieved from annual reports provided by AEP and are presented in Table 24.

Table 23. Assumed Wastewater Treatment Effectiveness from AECOM (2009).

Table 2.5 Typical Effluent Discharge Values Used for Each Technology Type

Parameter	Lagoon Stabilization Pond – Conforms to AENV Standard	Lagoon Stabilization Pond – Does Not Conform to AENV Standard	Mechanical Aerated Lagoon	Mechanical WWTP	Units
Average Day Flow (ADF)	Service Population x 0.4 m^3/person/day	Service Population x 0.4 m^3/person/day	Service Population x 0.4 m^3/person/day	Service Population x 0.4 m^3/person/day	m^3/d
cBOD*	ADF x Discharge Limit (mg/L)/1000 OR if no Discharge Limit ADF x 25 (mg/L)/1000	ADF x Discharge Limit (mg/L)/1000 OR if no Discharge Limit ADF x 25 (mg/L)/1000	ADF x Discharge Limit (mg/L)/1000 OR if no Discharge Limit ADF x 25 (mg/L)/1000	ADF x Discharge Limit (mg/L)/1000 OR if no Discharge Limit ADF x 20 (mg/L)/1000	kg/d
Total Suspended Solids-TSS	ADF x Discharge Limit (mg/L)/1000 OR if no Discharge Limit ADF x 25 (mg/L)/1000	ADF x Discharge Limit (mg/L)/1000 OR if no Discharge Limit ADF x 25 (mg/L)/1000	ADF x Discharge Limit (mg/L)/1000 OR if no Discharge Limit ADF x 25 (mg/L)/1000	ADF x Discharge Limit (mg/L)/1000 OR if no Discharge Limit ADF x 20 (mg/L)/1000	kg/d
Total Nitrogen-N	ADF x Discharge Limit (mg/L)/1000 OR if no Discharge Limit ADF x 3 (mg/L)/1000	ADF x Discharge Limit (mg/L)/1000 OR if no Discharge Limit ADF x 15 (mg/L)/1000	ADF x Discharge Limit (mg/L)/1000 OR if no Discharge Limit ADF x 30 (mg/L)/1000	ADF x Discharge Limit (mg/L)/1000 OR if no Discharge Limit ADF x 20 (mg/L)/1000	kg/d
Organic Nitrogen-N	ADF x 1.0 mg/L/1000	ADF x 1.0 mg/L/1000	ADF x 1.0 mg/L/1000	ADF x 1.0 mg/L/1000	kg/d
Ammonia-N Winter		ADF x Discharge Limit (mg/L)/1000 OR if no Discharge Limit ADF x 13 (mg/L)/1000	ADF x Discharge Limit (mg/L)/1000 OR if no Discharge Limit ADF x 20 (mg/L)/1000	ADF x Discharge Limit (mg/L)/1000 OR if no Discharge Limit ADF x 10 (mg/L)/1000	kg/d
Ammonia-N Summer	ADF x Discharge Limit (mg/L)/1000 OR if no Discharge Limit ADF x 1 (mg/L)/1000	ADF x Discharge Limit (mg/L)/1000 OR if no Discharge Limit ADF x 13 (mg/L)/1000	ADF x Discharge Limit (mg/L)/1000 OR if no Discharge Limit ADF x 10 (mg/L)/1000	ADF x Discharge Limit (mg/L)/1000 OR if no Discharge Limit ADF x 5 (mg/L)/1000	kg/d
Nitrate-N Winter	Total Nitrogen (kg/d) - Organic Nitrogen (kg/d) - Ammonia Winter (kg/d)	Total Nitrogen (kg/d) - Organic Nitrogen (kg/d) - Ammonia Winter (kg/d)	Total Nitrogen (kg/d) - Organic Nitrogen (kg/d) - Ammonia Winter (kg/d)	Total Nitrogen (kg/d) - Organic Nitrogen (kg/d) - Ammonia Winter (kg/d)	kg/d
Nitrate-N Summer	Total Nitrogen (kg/d) - Organic Nitrogen (kg/d) - Ammonia Summer (kg/d)	Total Nitrogen (kg/d) - Organic Nitrogen (kg/d) - Ammonia Summer (kg/d)	Total Nitrogen (kg/d) - Organic Nitrogen (kg/d) - Ammonia Summer (kg/d)	Total Nitrogen (kg/d) - Organic Nitrogen (kg/d) - Ammonia Summer (kg/d)	kg/d
Total Phosphorus-P	ADF x Discharge Limit (mg/L)/1000 OR if no Discharge Limit ADF x 2.5 (mg/L)/1000	ADF x Discharge Limit (mg/L)/1000 OR if no Discharge Limit ADF x 2.5 (mg/L)/1000	ADF x Discharge Limit (mg/L)/1000 OR if no Discharge Limit ADF x 3.7 (mg/L)/1000	ADF x Discharge Limit (mg/L)/1000 OR if no Discharge Limit ADF x 3.5 (mg/L)/1000	kg/d

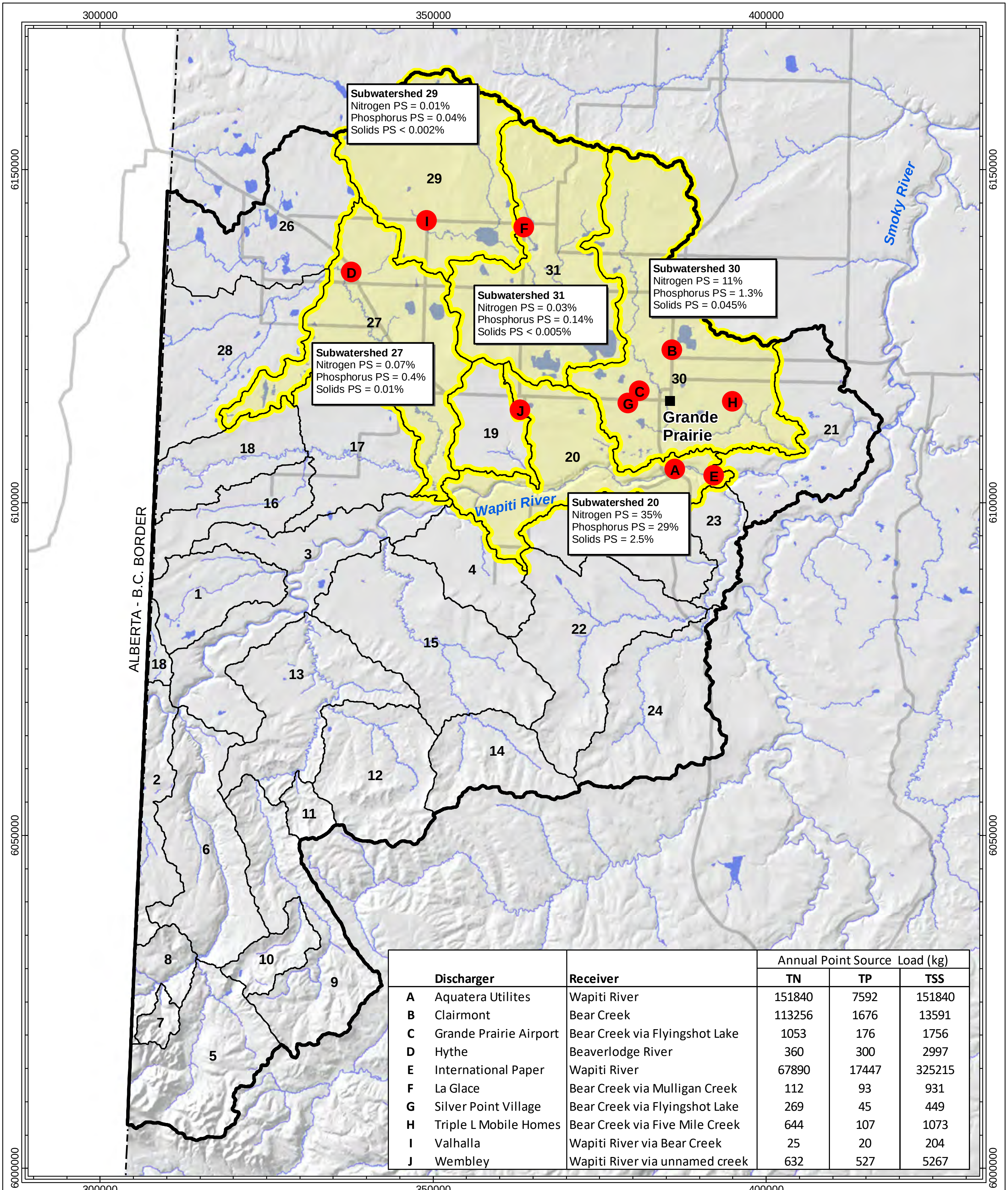
*Note: * carbonaceous biochemical oxygen demand*

Table 24. Point Source Dischargers in Wapiti Basin.

Discharger	Approval Number	Receiver	Total Annual Loads (kg)		
			Nitrogen	Phosphorus	Solids
Aquatera Utilities	197502	Wapiti River	151840	7592	151840
Clairmont	518	Bear Creek	113256	1676	13591
Grand Prairie Airport	18188	Bear Creek via Flyingshot Lake	1053	176	1756
Hythe	148503	Beaverlodge River	360	300	2997
[A,B]**International Paper**		Wapiti River	67890	17447	325215
La Glace	909	Bear Creek via Mulligan Creek	112	93	931
Silver Point Village	68153	Bear Creek via Flyingshot Lake	269	45	449
Triple L Mobile Home	1235	Bear Creek via Five Mile Creek	644	107	1073
Valhalla	1246	Wapiti via Bear Creek	25	20	204
Wembley	1292	Wapiti River via unnamed creek	632	527	5267

[A]International paper loads were based on daily calculations, extrapolated to yearly loads.
[B]International paper total nitrogen load only takes into consideration total Kjeldahl nitrogen, as no nitrate and nitrite estimates were available.

Figure 31 shows the location of each point source discharge in the basin and the annual loading of nitrogen, phosphorus and solids from each.



	Discharger	Receiver	Annual Point Source Load (kg) TN	TP	TSS
A	Aquatera Utilites	Wapiti River	151840	7592	151840
B	Clairmont	Bear Creek	113256	1676	13591
C	Grande Prairie Airport	Bear Creek via Flyingshot Lake	1053	176	1756
D	Hythe	Beaverlodge River	360	300	2997
E	International Paper	Wapiti River	67890	17447	325215
F	La Glace	Bear Creek via Mulligan Creek	112	93	931
G	Silver Point Village	Bear Creek via Flyingshot Lake	269	45	449
H	Triple L Mobile Homes	Bear Creek via Five Mile Creek	644	107	1073
I	Valhalla	Wapiti River via Bear Creek	25	20	204
J	Wembley	Wapiti River via unnamed creek	632	527	5267

Legend
- Study Area
- Subwatershed
- Affected Subwatershed
- Highway

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0 10 20 30 km

N

Scale = 1:750000

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Apr 02, 2018

Point Source **Loadings to Wapiti Basin**

FIGURE **31**

6.1 Total Loading Estimates

Point source loads were discharged to five of the 31 subwatersheds, three of which form the Bear Creek subwatershed (Table 25). Subwatershed 20 contains the Aquatera WWTP and International Paper facilities which discharge directly to the Wapiti River. Point source loads from these facilities made up 35%, 29% and 2.5% of the total loading of nitrogen, phosphorus and solids, respectively, in these subwatersheds (Tables 26, 27, 28). The low proportional contribution of solids indicates that much of the nitrogen and phosphorus in these discharges was more readily bioavailable and not associated with solids to the same extent as NPS loadings.

Table 25. Point Source Loadings for Five Subwatersheds in Wapiti Basin.

	Subwatershed	No. Dischargers	Nitrogen Load in kg/yr	Phosphorus Load in kg/yr	Solids Load in kg/yr
20	LOWER WAPITI RIVER ABOVE BIG MOUNTAIN CREEK	2	220362	25566	482322
27	LOWER BEAVERLODGE RIVER	1	360	300	2997
29	UPPER BEAR RIVER	1	25	20	204
30	LOWER BEAR RIVER	4	115222	2004	16869
31	LOWER BEAR RIVER ABOVE GRANDE PRAIRIE CREEK	1	112	93	931

Table 26. Total Nitrogen NPS and PS Loads for Five Subwatersheds in the Wapiti Basin.

	Subwatershed	NPS kg/yr	PS Kg/yr	Total Kg/yr	PS as % of Total	Export in kg/ha/yr	Classification NPS/Total
20	LOWER WAPITI RIVER ABOVE BIG MOUNTAIN CREEK	402,518	220,362	622,880	35	14.3	High/High
27	LOWER BEAVERLODGE RIVER	489,980	360	490,340	0.07	7.900	High/High
29	UPPER BEAR RIVER	321,164	25	321,189	0.01	5.724	High/High
30	LOWER BEAR RIVER	980,418	115,222	1,095,640	11	13.60	High/High
31	LOWER BEAR RIVER ABOVE GRANDE PRAIRIE CREEK	424,630	112	424,742	0.026	6.42	High/High

Table 27. Total Phosphorus NPS and PS Loads for Five Subwatersheds in the Wapiti Basin.

	Subwatershed	NPS kg/yr	PS Kg/yr	Total Kg/yr	PS as % of Total	Export in kg/ha/yr	Classification NPS/Total
20	LOWER WAPITI RIVER ABOVE BIG MOUNTAIN CREEK	62,718	25,566	88,284	29	2.03	High/High
27	LOWER BEAVERLODGE RIVER	75,444	300	75,744	0.40	1.22	High/High
29	UPPER BEAR RIVER	51,425	20	51,445	0.04	0.92	High/High
30	LOWER BEAR RIVER	150,631	2,004	152,635	1.3	1.90	High/High
31	LOWER BEAR RIVER ABOVE GRANDE PRAIRIE CREEK	66,423	93	66,516	0.140	1.00	High/High

Table 28. Total Solids NPS and PS Loads for Five Subwatersheds in the Wapiti Basin.

	Subwatershed	NPS kg/yr	PS Kg/yr	Total Kg/yr	PS as % of Total	Export in kg/ha/yr	Classification NPS/Total
20	LOWER WAPITI RIVER ABOVE BIG MOUNTAIN CREEK	19,172,802	482,322	19,655,124	2.5	452	High/High
27	LOWER BEAVERLODGE RIVER	21,659,498	2,997	21,662,495	0.014	349	Low/Low
29	UPPER BEAR RIVER	19,615,486	204	19,615,690	0.001	350	Low/Low
30	LOWER BEAR RIVER	37,635,617	16,869	37,652,486	0.045	468	High/High
31	LOWER BEAR RIVER ABOVE GRANDE PRAIRIE CREEK	21,223,555	931	21,224,486	0.0044	321	High/High

Although the point sources added additional loads to the river from these subwatersheds they did not change the classifications of relative loadings. Those subwatersheds which exceeded the 75th percentile for NPS loading (”High”) remained in that classification when total loadings were considered.

7. NPS Delivery - Sensitivity Classifications

The study objectives required identification of the areas and pathways most likely to deliver nutrient loads from the landscape to a stream, and ultimately to the Wapiti River. Although Donahue (2013) recommend use of a series of "Riparian Zone Export Multiplication Factors" to modify the specific export coefficients for land uses classes based on distance to a stream and slope for areas, our analysis (Section 5.2) concluded that this approach did not refine the NPS model sufficiently to generate useful assessments of stream sensitivity to NPS delivery.

Beven et al. (2005) documented the complexity of processes influencing phosphorus delivery to surface water (Figure 32) and concluded that model accuracy was dependent on a) the ability of the predictive model and b) the resolution and accuracy of the measurement of delivery to surface water. There are no available measurements of nutrient delivery to surface water for the study area and so our approach focused on the identification of factors determining the sensitivity of surface waters to the delivery of NPS loading from source areas to the water body.

Figure 32. Pathways of phosphorus delivery to surface water, from Beven et al. (2005).

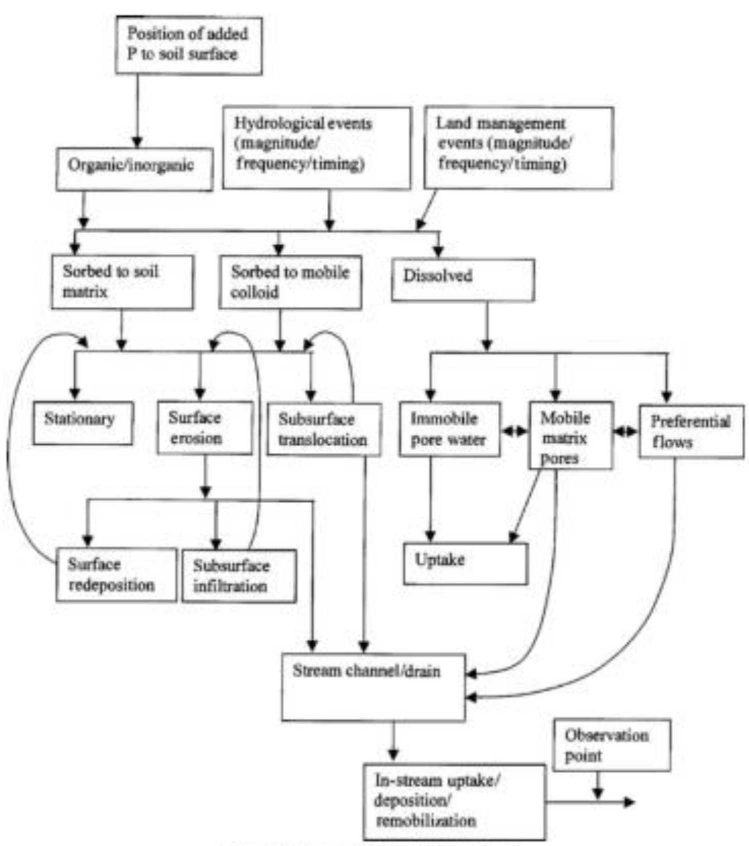
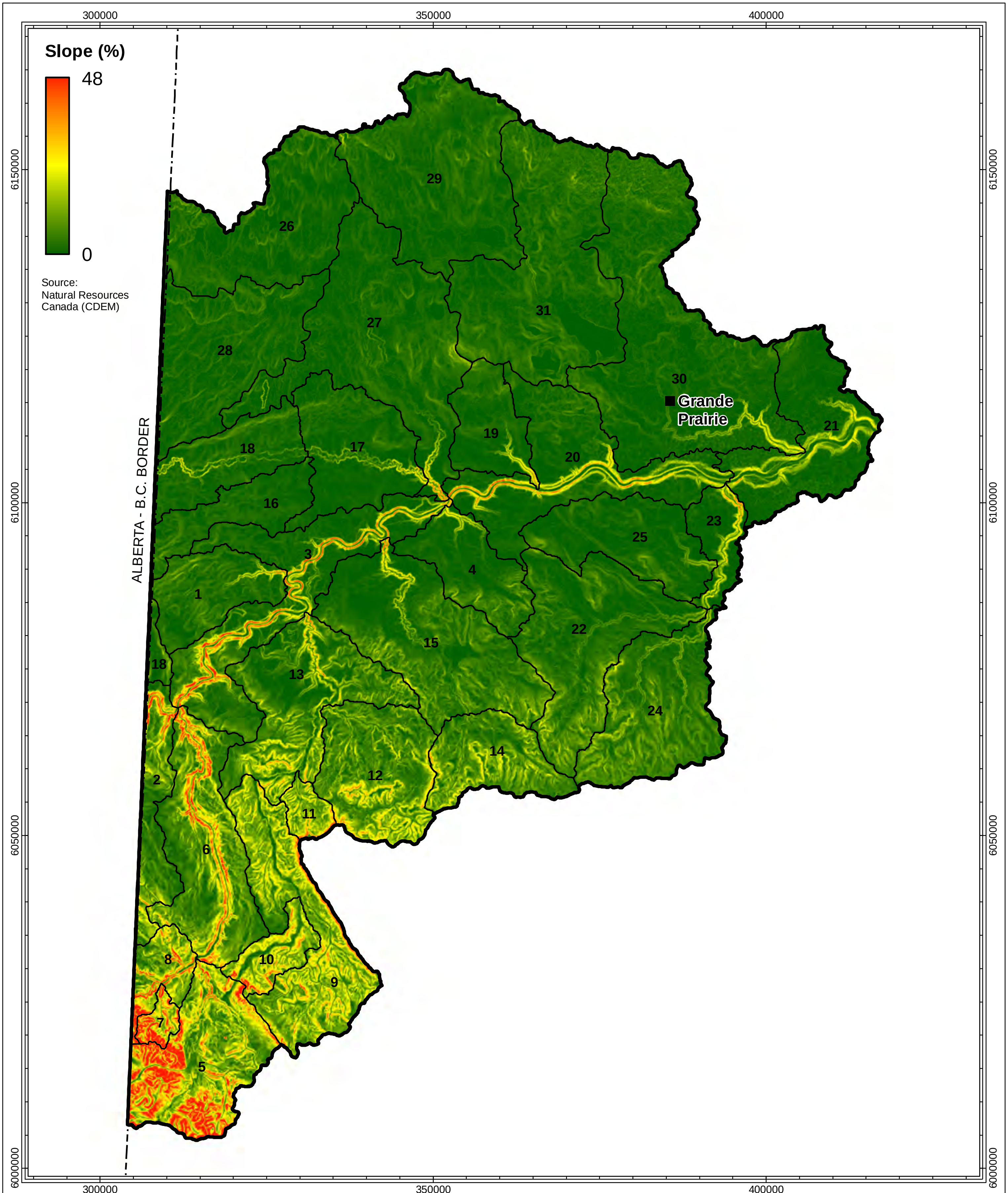


Figure 1. Pathways of P delivery to stream channels

Behrendt and Opitz (2000) reviewed studies on 100 central European watersheds ranging from 121 – 194,000 km^2 and reported that estimates of nitrogen load derived from export coefficients were 40% greater than measured loads. The difference was reduced to 20% through use of a statistical model incorporating the specific runoff of the basin, the proportion of the basin area occupied by surface water, the basin size itself and the mean annual nitrogen concentration at a specific monitoring station. Although this approach was useful, it addressed only in-stream nutrient reduction processes with no accounting for, or estimation of, on-land processes that may prevent or mitigate the delivery of nutrients to surface water

Development and application of a nutrient delivery model is clearly complex and beyond the scope of this study. The original NPS model and results described in Sections 4 and 5 described and estimated the potential for a given land use and area to produce runoff of solids and associated nutrients to surface water as a function of natural region and land use using the methods of Donahue (2013). Management of NPS loading must combine this information with additional factors that describe the potential for the loading to be delivered to surface water. The GIS model was therefore refined by adding criteria and data to classify and compare the relative potential of different areas and land uses to contribute NPS loadings of N and P using criteria such as erosion rate, slope, sediment yield or drainage density to identify priority areas for future management. We therefore developed three criteria to model the sensitivity of each land use and subwatershed to deliver NPS pollutants to surface water.

A digital elevation model was used to develop a slope overlay for the study area using the three classifications of topography provided by Donahue (2013): Type I (rolling-high potential, >10%), II (hummocky-moderate potential, 5%-10%) and III (flat-low potential, <5%). Figure 33 provides the range of slopes throughout the study area and Figure 33 shows the resultant classifications of "Low", "Moderate" and "High" sensitivity to NPS runoff based on slope.



Legend

Study Area

Subwatershed

Hutchinson Environmental Sciences Ltd.

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0 10 20 30 km

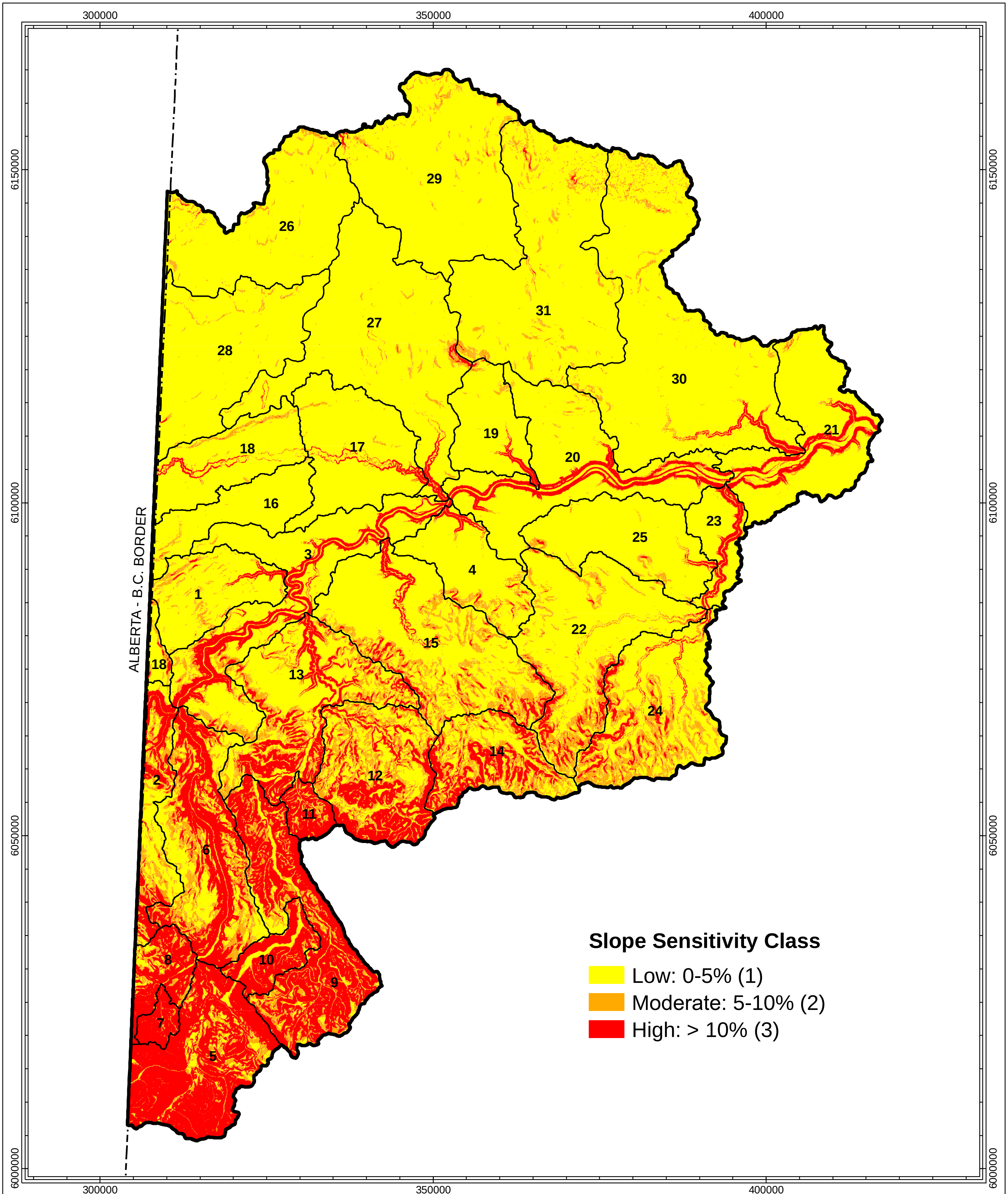
N

Scale = 1:750000

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Mar 30, 2018

Slope Values in the Wapiti River Watershed

FIGURE **33**



Legend

Study

Subwatershed

Hutchinson Environmental Sciences Ltd.

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0 10 20 30 km

N

Scale = 1:750000

PROJECT:	13186	PROJECTION:	UTM Zone 11N
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CHECKED:	D. Sacco	DATE:	Mar 29, 2018

Slope Sensitivity
Classification

FIGURE **34**

Erosion is also dependent on soil type and texture which determine the partitioning of precipitation into infiltration or runoff. Donahue (2013) provides three relevant soil classifications

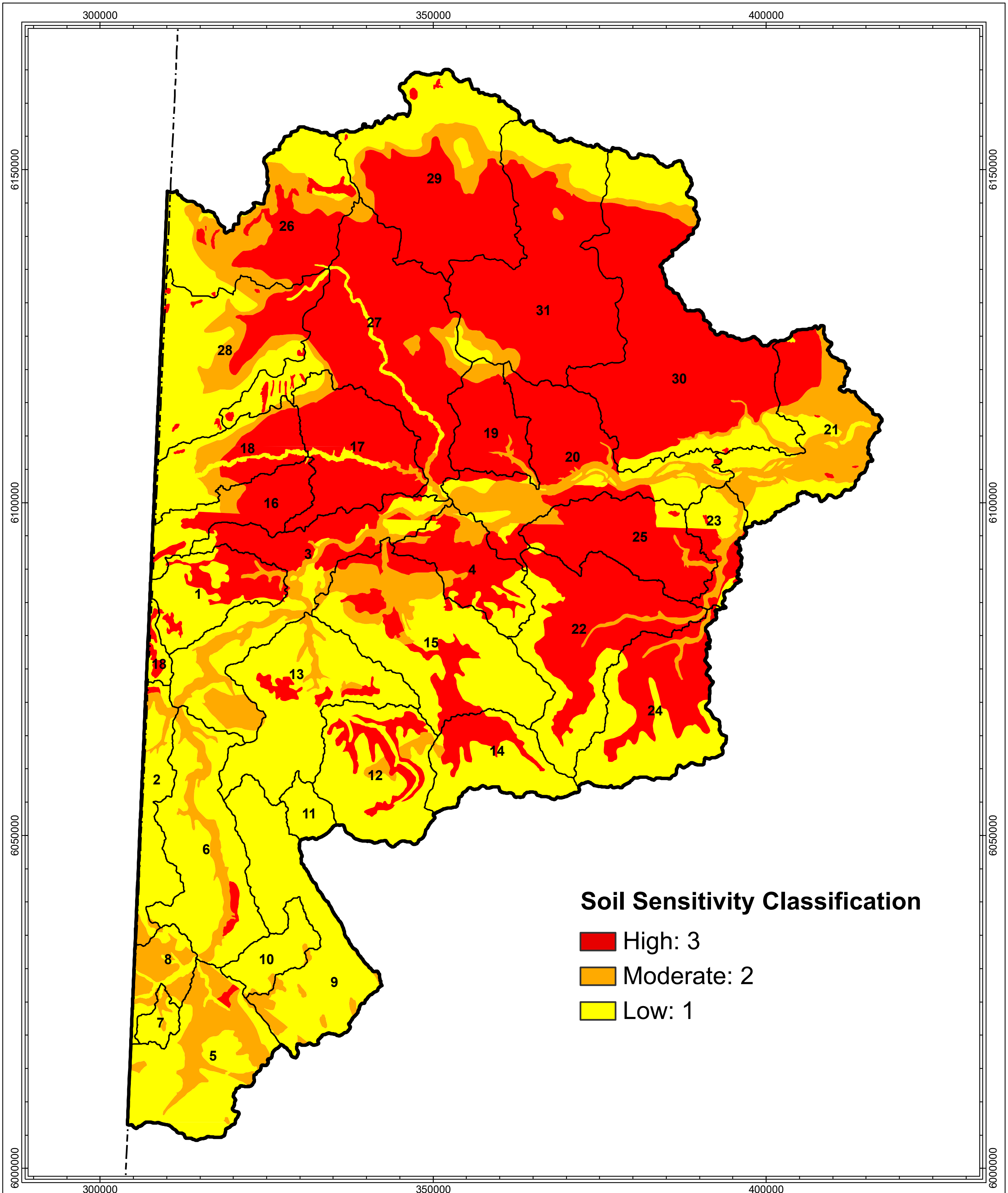
- High potential– fine textured silts, clays and loams with shallow humic horizons which promote runoff, are easily erodible and tend to adsorb nutrients because of their surface charge,
- Moderate Potential – loams, silty loams and fine sandy loams with moderately deep humic horizons and moderate textures
- Low potential – loams, sandy loams and sands with moderate to coarse textures and deeper humic horizons

These general classifications were applied to the specific soil types available in GIS mapping layers according to Table 29 and resultant soil classifications mapped in Figure 35. Figure 356shows the soil sensitivity classifications as average values for each subwatershed.

Table 29. Classifications of Soil Types by Erosional Sensitivity.

Data Reference	Shapefile attribute	Shapefile Attribute entry	Description	Erosion potential
AGS Map 150 and 239	SRC_UNIT			
		Aeolian deposits	fine-grained well-sorted sand	M
		Alluvial fans and Aprons	generally coarse-grained gravels	L
		Bedrock	In Rockies predominantly Palaeozoic age carbonates and quartzites; in foothills Mesozoic age shale, siltstone and sandstone with minor coal and limestone	L
		Cirque tills	Angular cobble to boulder with minor sand and gravel	L
		Coarse stream alluvium	gravelly sand to pebble gravel	L
		Colluvial deposits	mixed glacial sediments and bedrock; dissagregated till	M
		Colluvium	soil and rock creep; coarse angular material reflecting underlying bedrock	L
		Deeply leached till, Cordilleran Provenance	highly compacted diamict containing clay to boulder	M
		Fluvial deposits	dominantly sandy to gravel deposits with minor layers of silt	L
		Glaciolacustrine deposits	silt and clay with minor sand	H
		Gravel	coarse-grained glaciofluvial deposits	L
		Ground moraine	highly compacted diamict containing clay to boulder	L
		Hummocky moraine	clayey to sandy till; less compact than ground moraine	M
		Ice contact	well to poorly sorted sand and gravel	L
		Meltwater channel deposits	gravel and minor sand	L
		Moraine-colluvium undifferentiated	Compacted stony weathered till with clay to sand matrix	M
		Organic deposits	bogs, fens, peat, minor silt, clay and marl	H
		Sand	outwash sand with minor gravel, silt, clay	L
		Sandstone		L

		Shale, siltstone and coal		L
		Silt and clay	silt and clay	H
		Silt and minor sand		H
		Slightly leached till, Cordilleran provenance	highly compacted diamict containing clay to boulder	M
		Undifferentiated glaciofluvial and aeolian	veneer of sorted fine sand; commonly overlies glaciofluvial and glaciolacustrine deposits; pebbly sand	L
Liverman, 1989	SRC_GENET	Bedrock, till and glacial lake clay and silt resedimented by slope failures	diamicton and bedrock	M
		Till, probably meltout at surface	compacted clay to boulder diamicton	L
		Melt-out till	mod to low compact silt to boulder diamicton	L
		Aeolian dome dunes and sand sheet	fine sand and silt some clay	M
		Post glacial terraces	gravel and sand	L
		Modern alluvium	gravel sand and minor silt	L
		Bedrock	sandstone, shale and coal	L
		Parabolic dunes	medium sand over gravel silt and clay	L
		Modern lacustrine and swamp deposits	peat and clay	H
		Glaciofluvial outwash	poorly sorted sand and gravel	L
		Esker or kame	poorly sorted sand and gravel	L
		Till (ablation?)	sandy diamict	L
		Glaciolacustrine drape over thin till and bedrock	sand and clay diamict	H
		Glaciolacustrine silt pitted by wind	silt and clay with minor organict	H
		Glaciolacustrine	silt and clay, few coarse clasts	H
		Glaciolacustrine drape over diamicton, bedrock lineation	silt and clay, few coarse clasts	H
		Ice proximal glaciolacustrine and strandlines	silt/clay with many stones	M



Legend

Study

Subwatershed

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PALMER ENVIRONMENTAL CONSULTING GROUP INC.

0 10 20 30 km

Scale = 1:750000

N

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
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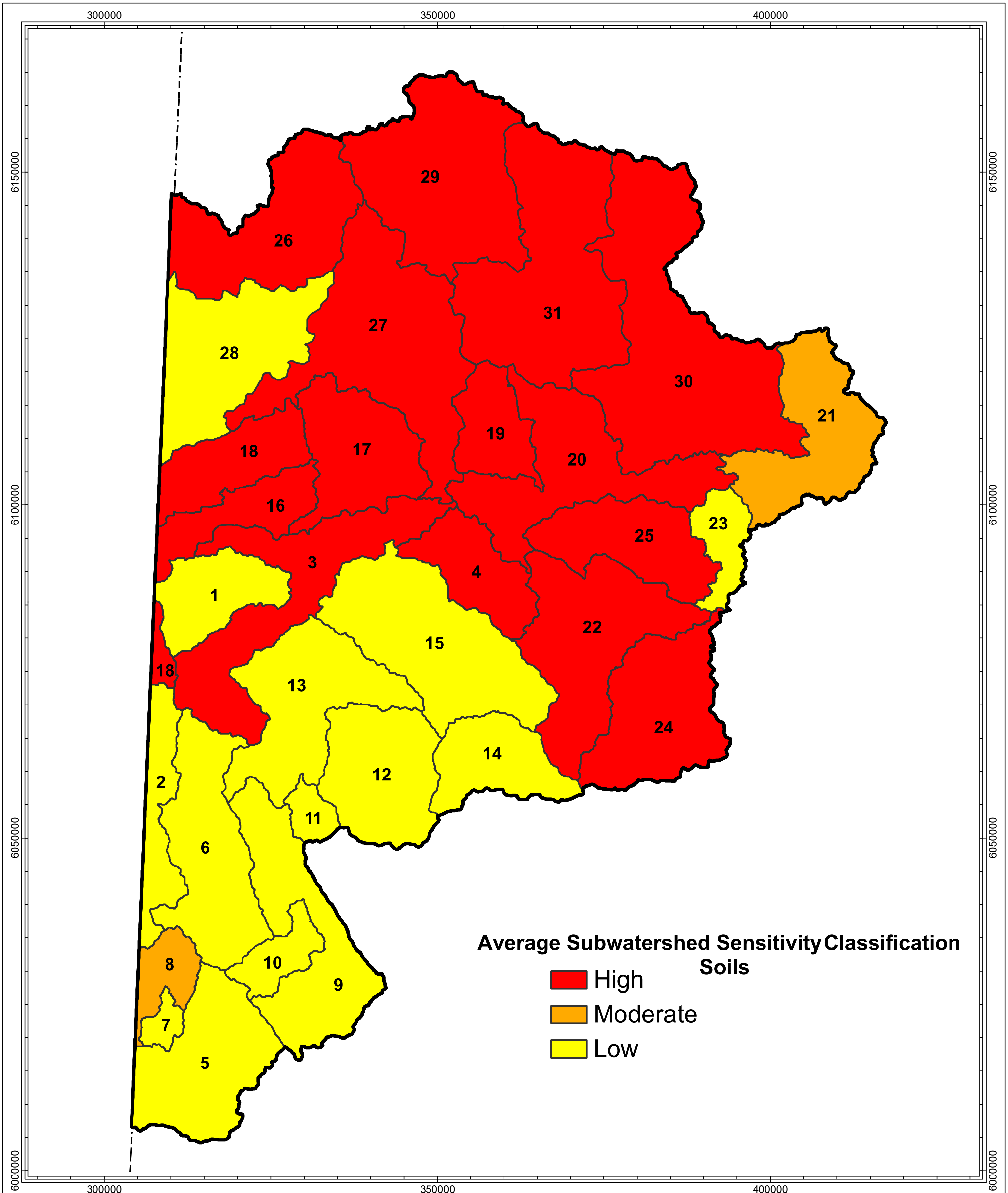
Soil Sensitivity

FIGURE 35



Legend

Study Area

Subwatershed

Hutchinson Environmental Sciences Ltd.

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0 10 20 30 km

N

Scale = 1:750000

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Apr 05, 2018

Average Subwatershed Soils Sensitivity

FIGURE 36

Drainage density reflects the proximity of surface water to non-point sources and hence the likelihood that runoff will deliver a NPS load to surface water and hence to a major tributary and the Wapiti River itself. Drainage density (= total length of stream channel / stream catchment area) was calculated from mapping of permanently flowing streams (Figure 38) and catchment delineation and classified as “Low”, “Medium” and “High” (Figure 39) as a sensitivity factor influencing the likelihood of NPS loading.

Taken together, these three classifications of sensitivity provided 27 potential sub-classifications of the relative potential of different areas and land uses to contribute NPS loadings. These 27 sub-classifications were then assigned scores of “Low” = 1, “Moderate” = 2 and “High” = 3 and reduced back to four overall sensitivity classifications by summing the individual sensitivity scores as follows :

- any combination of Low/Low/Low classification = “No sensitivity” to NPS load (1 classification)
- any combination including only Low and Moderate classifications = “Low” sensitivity to NPS load (9 classifications)
- any combination of two Low and one High classification, three moderate classifications or moderate and high classification = “Moderate” sensitivity to NPS load (13 classifications)
- any combination of two high and a moderate classification score or three high classifications = “High” sensitivity to NPS load. (4 classifications)

The sensitivity classification schematic is provided in Figure 37.

Figure 37. Schematic of NPS sensitivity classification.

	Classification																										
Slope	L	L	L	L	L	L	L	L	L	M	M	M	M	M	M	M	M	M	H	H	H	H	H	H	H	H	H
Soils	L	L	L	M	M	M	H	H	H	L	L	L	M	M	M	H	H	H	L	L	L	M	M	M	H	H	H
Drainage	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Sum	3	4	5	4	5	6	5	6	7	4	5	6	5	6	7	6	7	8	5	6	7	6	7	8	7	8	9

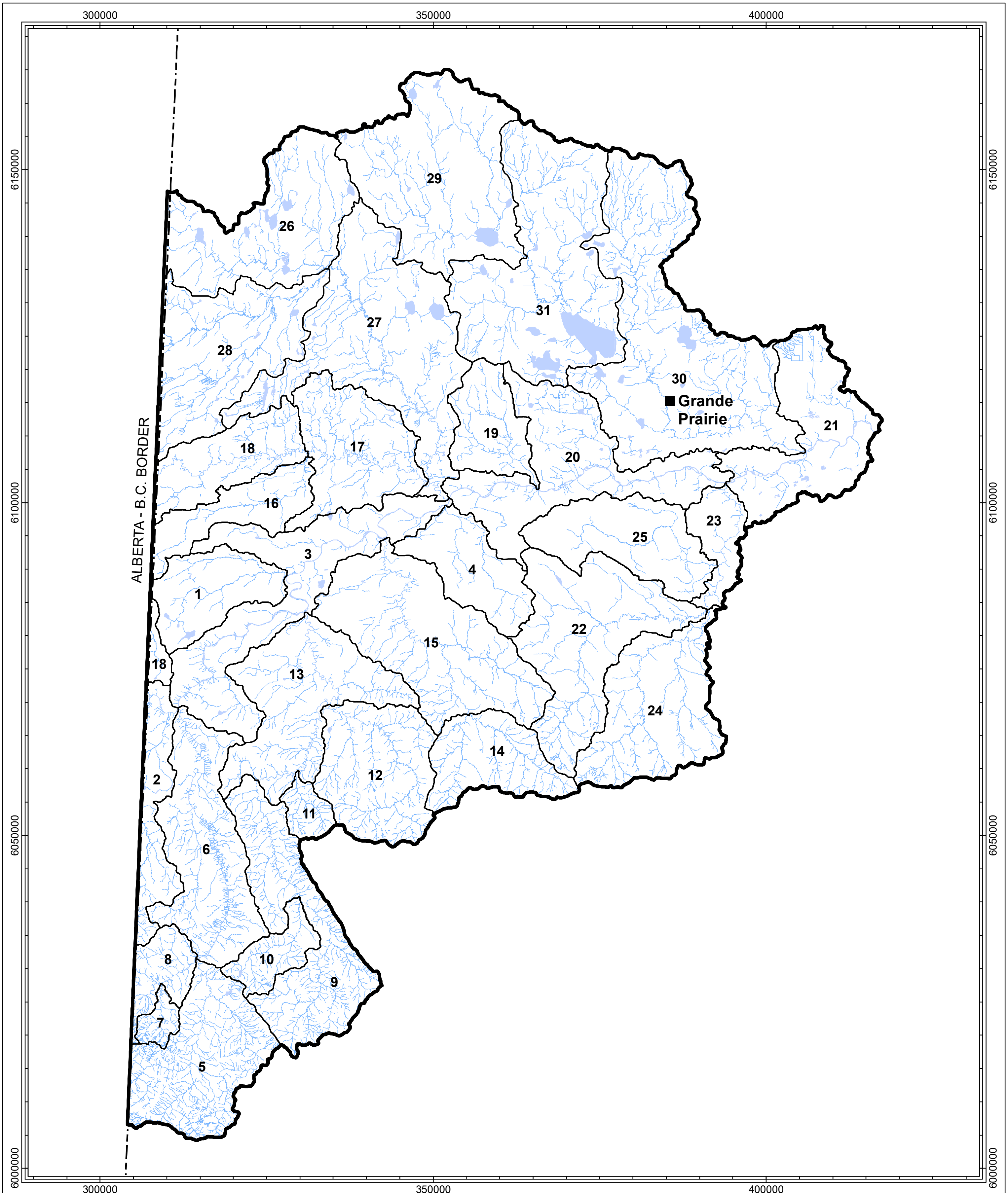
Sum	Number	Sensitivity Category
3	1	No Sensitivity
4	3	Low Sensitivity
5	6	Low Sensitivity
6	7	Moderate Sensitivity
7	6	Moderate Sensitivity
8	3	High Sensitivity
9	1	High Sensitivity
Total	27	

Low Classification = 1
Moderate Classification = 2
High Classification = 3
Sum = Sensitivity Category

The resultant overall sensitivity of the Wapiti Basin to NPS loading is summarized in Figures 40 and 41.

- Figure 40 shows results which were not averaged for each of the 31 individual subcatchments in order to preserve the classification status at a finer scale to pinpoint areas of concern.
- Figure 41 shows one average value for each subwatershed which was used to identify the catchments of highest priority for management.

The management implications of the final classifications are developed in Section 9.



Legend

- Study Area
- Subwatershed
- Watercourse
- Waterbody (not included)

Source: AltaLIS Hydrography

Hutchinson Environmental Sciences Ltd.

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0 10 20 30 km

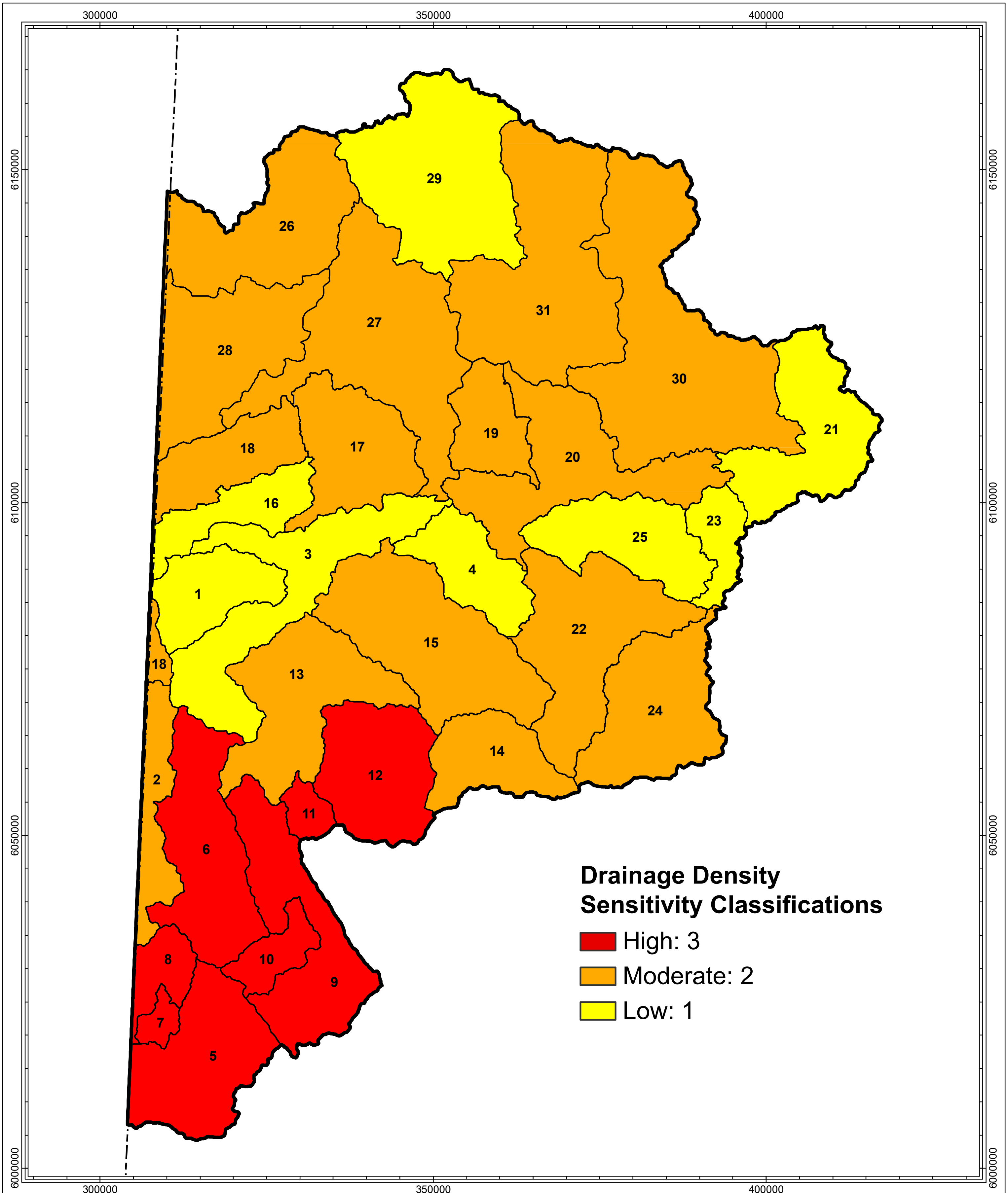
Scale = 1:750000

N

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Mar 30, 2018

Drainage Density in the Wapiti River Watershed

FIGURE 38



Legend

Study Area

Subwatershed

Hutchinson Environmental Sciences Ltd.

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0 10 20 30 km

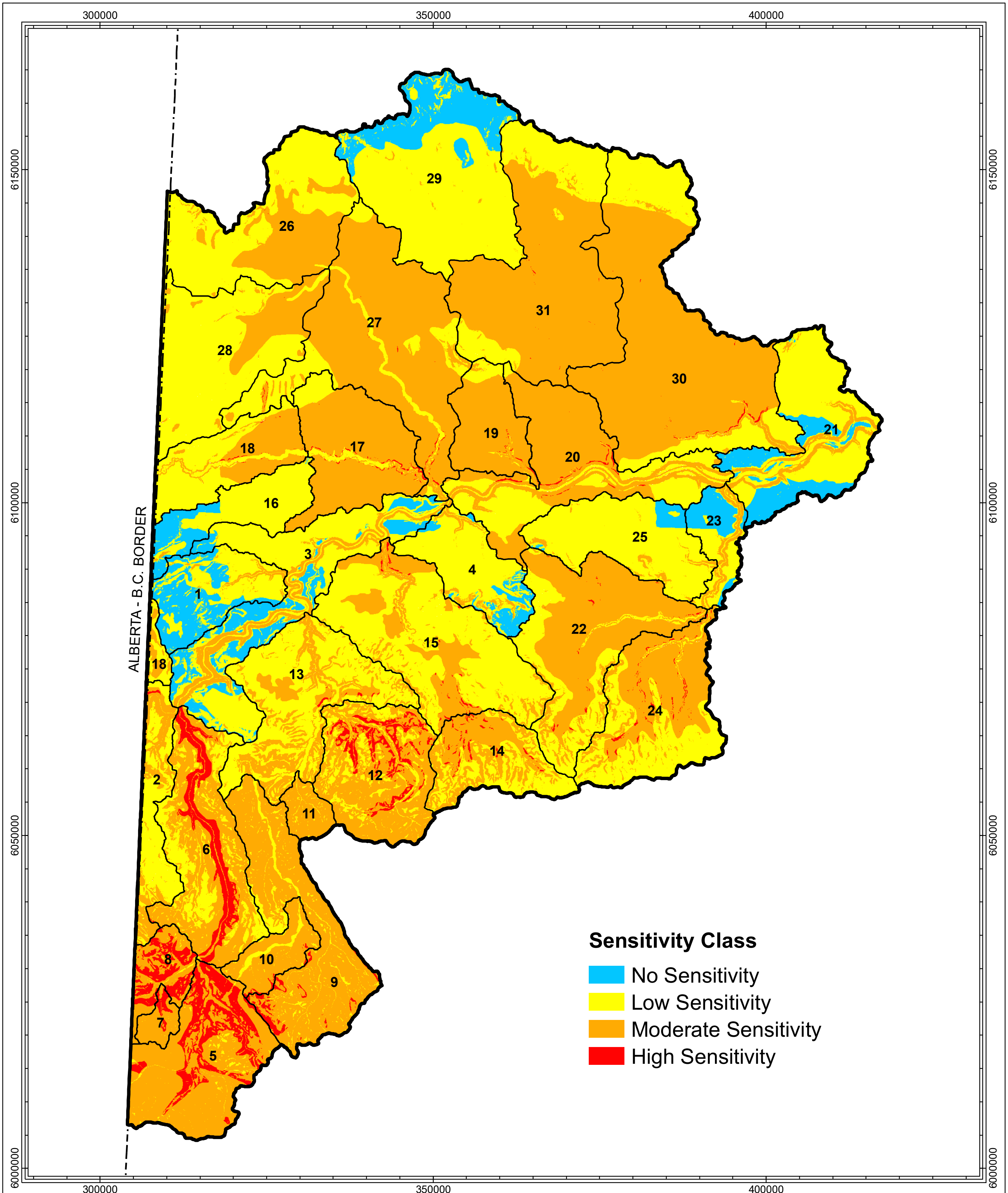
N

Scale = 1:750000

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Mar 29, 2018

Drainage Density Sensitivity

FIGURE 39



Legend

Study Area

Subwatershed

Hutchinson Environmental Sciences Ltd.

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

0 10 20 30 km

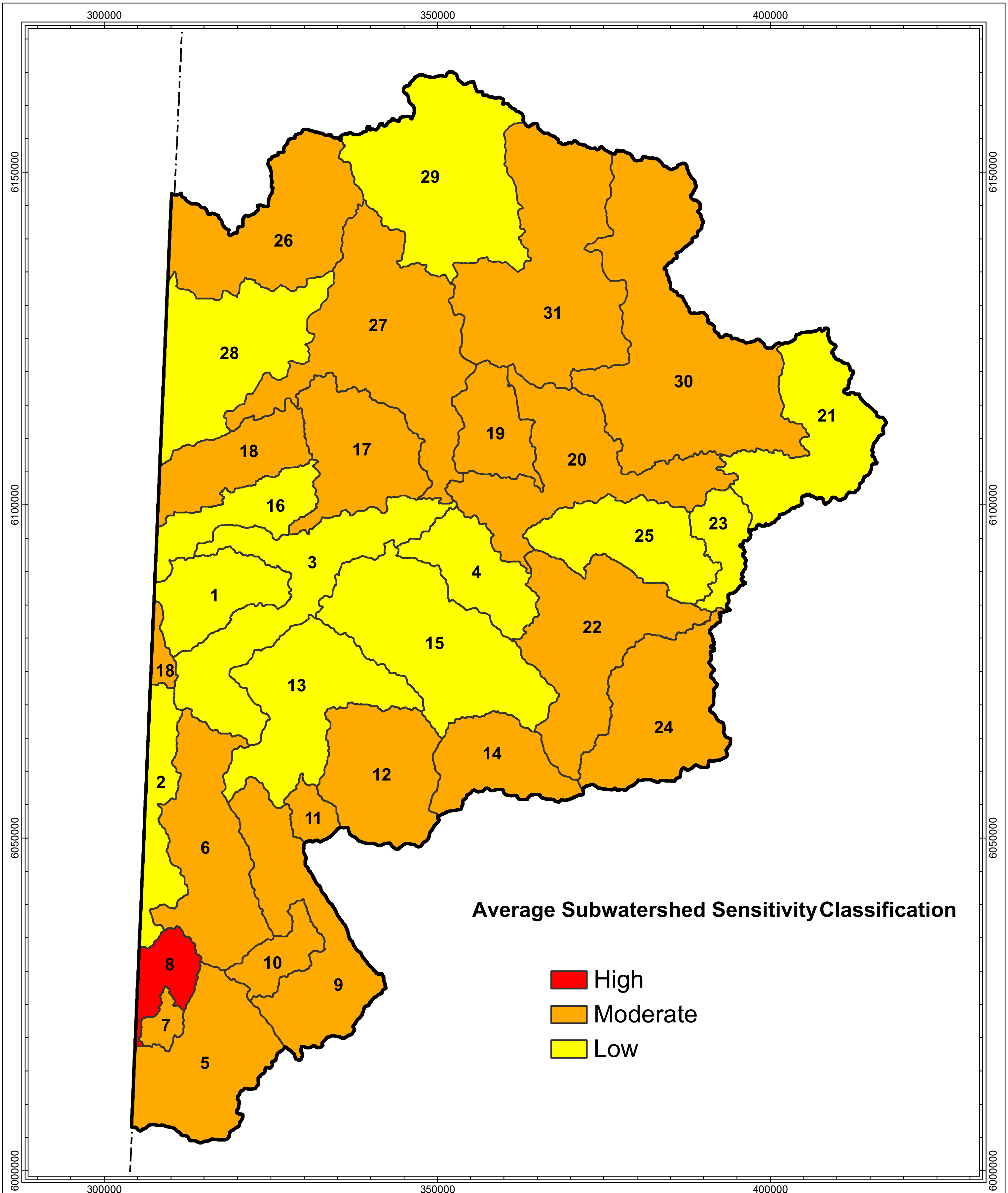
Scale = 1:750000

N

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Mar 29, 2018

Overall Sensitivity Classification

FIGURE 40



Legend
Study Area
Subwatershed

Hutchinson Environmental Sciences Ltd.

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

0 10 20 30 km

Scale = 1:750000

N

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Apr 05, 2018

Average Subwatershed NPS Sensitivity

FIGURE 41

8. Wapiti River Response

Donahue (2013) cautions that: *"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 land uses, where insufficient data or resources precludes more detailed mechanistic modeling of loading and water quality*."

This section of the report provides an assessment of the accuracy and the ecological implications of the NPS loadings developed in previous sections of the report.

8.1 Accuracy of NPS Model

The response of the Wapiti River to the NPS and PS loadings was described by comparison of the modelled loads to loads estimated from measured data on flow and water quality in the Wapiti River. Long term records of flow and water quality were available from the Water Survey of Canada upstream of Grande Prairie (07GE001, Wapiti River at Hwy 40) and Long-term River Monitoring Network sites (AB07GE0020, Hwy 40) and AB07GJ0030 (Wapiti River at confluence with Smoky River).

8.1.1 Methods

Nutrient loads in tonnes/yr (t/yr) were calculated at the WSC station using the last 10 years of available flows (2004-2013) coupled with Long Term River Monitoring Network TP and TN data for the same period of record. Monthly water quality concentration results were multiplied by daily flows, averaged over the period two weeks prior to and two weeks following the water quality sample collection, to estimate monthly nutrient loads. We then summed those monthly loading estimates for each year to provide ten annual estimates of annual load. The average of these ten estimates was used for comparison to the non-point source model predictions.

Values below method detection limit were rare, occurring in 11 of 158 LTRN TP samples (7%). Where TP was below the detection limit a value of ½ of the detection limit (DL = 0.003 mg/L) was used to calculate load. TN values did not fall below detection in any samples collected.

NPS loading estimates were based on values calculated using the 31 Subwatershed GIS model described in Section 5. Non-point source loads from subwatersheds upstream of the WSC and LTRN station (i.e., subwatersheds 1-20 and 26-28, Figure 5) were summed to provide an estimate of the NPS loading.

In addition to estimates of nutrient loading at the WSC station at Highway 40, we calculated loads downstream at the LTRN station upstream of the Smoky River confluence (AB07GJ0030), however no flow data were available at this station. To estimate flow, we prorated daily flows from the upstream WSC station based on watershed area and then followed identical procedures to those described above, i.e., averaged flow over the period two weeks prior to and following the water quality sample collection.

8.1.2 Results and Discussion

Annual measured total phosphorus loads showed a high degree of interannual variability, ranging between 73 and 751 t/yr (~10X) with an average of 324 t/yr). Total nitrogen loads ranged between 793 and 3406 t/yr (~4X) with an average of 1746 t/yr; Table 30). This degree of variability was not unexpected as a) annual discharge of the Wapiti River ranged from 4178 – 10814 ML/d (~2.5X) over the same period and b) the estimates of nutrient loading were coarse; based on monthly water quality measurements made in a dynamic environment.

Average annual non-point source nutrient loading from the 23 upstream watersheds was estimated at 458 t/yr of phosphorus and 2882 t/yr of nitrogen (Table 31). Both these estimates fall within the range of variability based on measured data and thus the NPS model should provide a useful tool to identify priority watersheds. NPS TP estimates were 41% greater than the mean of the 10-year measured data, while NPS TN measurements were 65% greater than the average measured loads.

Average annual nutrient loading was measured at 620 t/yr of phosphorus and 3519 t/yr of nitrogen at the Smoky River confluence (Table 32). NPS modelled loadings of TP and TN of 850 and 5577 tonnes/yr overestimated these measured values by 37 and 58% respectively (Table 33) and the agreement between measured and modelled values was closer than at the upstream site. Downstream loads included a significant input of nutrients from two major point sources, i.e., the Aquatera wastewater treatment facility and International Paper Mill. Loads from these point sources are well constrained by ongoing monitoring data and thus the downstream estimates of TN and TP from point and non-point sources would be expected to be more accurate than those made upstream based solely on non-point source modelling.

Table 30. Annual Measured Total Loads of Nitrogen and Phosphorus Upstream of Grande Prairie (LTRN Site 07GE0001).

Year	Annual TP Load (t/yr)	Annual TN Load (t/yr)
2004	362	1,176
2005	287	1,305
2006	163	793
2007	751	3,067
2008	206	886
2009	276	1,486
2010	177	1,328
2011	548	3,000
2012	73	1,008
2013	400	3,406
Average	**324**	**1,746**
Minimum	73	793
Maximum	751	3,406

Table 31. Non-point Source Estimates of Total Phosphorus and Total Nitrogen Loadings Upstream of Grande Prairie.

Watershed ID Number	Watershed Name	Total Nitrogen (t/yr)	Total Phosphorus (t/yr)
1	CALAHOO CREEK	52	8
2	UPPER WAPITI RIVER ABOVE NARRAWAY RIVER	50	8
3	UPPER WAPITI RIVER BELOW NARRAWAY RIVER	136	21
4	IROQUOIS CREEK	45	7
5	TORRENS RIVER	118	19
6	LOWER NARRAWAY RIVER	121	20
7	DINOSAUR CREEK	12	2
8	UPPER NARRAWAY RIVER	30	5
9	UPPER NOSE CREEK	122	20
10	GUNDERSON CREEK	30	5
11	GRAYLING CREEK	15	2
12	MUDDY CREEK	93	17
13	LOWER NOSE CREEK	111	19
14	UPPER PINTO CREEK	63	12
15	LOWER PINTO CREEK	117	18
16	CALAHOO CREEK	67	11
17	LOWER REDWILLOW RIVER	187	29
18	UPPER REDWILLOW RIVER	87	14
19	PIPESTONE CREEK	159	24
20	LOWER WAPITI RIVER ABOVE BIG MOUNTAIN CREEK	402	63
26	UPPER BEAVERLODGE RIVER	188	30
27	LOWER BEAVERLODGE RIVER	487	75
28	BEAVERTAIL CREEK	191	30
	Total	**2882**	**458**

Table 32. Annual Measured Total Loads of Nitrogen and Phosphorus Prorated to Smoky River Confluence LTRN Station (AB07GJ0030)

Year	Annual Total Phosphorus Load (t/yr)	Annual Total Nitrogen Load (t/yr)	Year	Annual Total Phosphorus Load (t/yr)	Annual Total Nitrogen Load (t/yr)
2004	696	2,037	2011	621	5,713
2005	536	2,971	2012	248	2,185
2006	384	1,479	2013	658	6,067
2007	1,906	5,684			
2008	234	2,651	**Average**	**620**	**3,519**
2009	694	3,832	Minimum	227	1,479
2010	227	2,576	Maximum	1,906	6,067

Table 33. Annual Modelled Total Loads of Nitrogen and Phosphorus at Smoky River Confluence.

	N in tonnes	P in tonnes
LOWER WAPITI RIVER ABOVE SMOKY RIVER	163	22.1
BALD MOUNTAIN CREEK	118	18.7
LOWER BIG MOUNTAIN CREEK	20	2.5
UPPER BIG MOUNTAIN CREEK	99	15.5
UNNAMED - BIG MOUNTAIN CREEK	233	37.4
UPPER BEAR RIVER	321	51.4
LOWER BEAR RIVER	980	150.6
LOWER BEAR RIVER ABOVE GRANDE PRAIRIE CREEK	425	66.4
Upper Wapiti Watershed	2882	458.0
Point Sources	336	27.7
Total Modelled	5577	850
Measured Annual Average at Smoky River Confluence	3519	620
% Overestimate of modelled	58	37

8.2 Bear Creek

The non-point source subwatershed model results show that Bear Creek represents an area of significant interest in better understanding water quality in the Wapiti River and the importance of point source discharges to the health of the system. Despite containing significant agricultural development, discharge form several smaller wastewater lagoons and stormwater discharge from the City of Grand Prairie, little information is currently available on Bear Creek. Recent data were collected in 2014/2015 by the City of Grande Prairie and analyzed by Hutchinson Environmental Sciences Ltd. Five water quality samples were collected in 2017 at the mouth of Bear Creek along with samples upstream and downstream of the City in August/Oct 2014 and April/June 2015. These data supplement earlier data collections in May 2007 and April 2008 but are not adequate to characterize the seasonal and inter-annual variability of the creek.

Water quality data in Bear Creek suggest that stormwater runoff from the City could have a significant impact on water quality in the creek. Increases were reported in chloride, total suspended solids and associated parameters such as total phosphorus, total Kjeldahl nitrogen, and several total metals (e.g., total aluminum, arsenic, cadmium, copper, and lead) from upstream of the City to downstream during high flow events including spring freshet and a storm event on October 2014. The City was also considered a source of pesticides 2,4-D, fluroxypyr and MCPP (HESL 2015).

Non-point source loading estimates in Bear Creek show that the Bear Creek subwatersheds (29, 30 and 31) account for 1720 and 268 t/yr of TN and TP respectively. These loads represent a significant input of nutrients to the system, equivalent to approximately 60% of the load from all watersheds upstream of Grand Prairie combined (Subwatersheds 1-20 and 26-28). Furthermore, Subwatershed 30 which contains the City accounts for over half (56%) of the Bear Creek nutrient load. Therefore, we believe that an improved understanding of Bear Creek is essential to the watershed monitoring of the Wapiti River and to establishing the impact of point source discharges to water quality in the area.

8.3 Ecological Response

The nutrient responses of the Wapiti River to the known Aquatera and International Paper discharges downstream of the City of Grande Prairie have been well characterised (PECG/HESL 2011, 2018), and these sources, plus AEP records, provide a) valid measurements of point source loads to the river, b) a summary of changes in concentrations of N and P in the river from these known discharges and c) a summary of ecological responses (periphyton) to the inputs. We therefore compared the changes in periphytic chlorophyll "a" to the measured changes in concentration of nitrogen and phosphorus in the river to provide an assessment of the responses of periphyton to known loads as an estimation of how the river might respond to NPS loads.

Epilithic chlorophyll-a, a measure of algae biomass, was used to asses the primary ecological response to increases in TP and TN downstream of the Aquatera Utilities and International Paper effluent discharges. Data collected by PECG and HESL in 2011 and 2017 were used to compare concentrations of chlorophyll-a upstream of the WWTP discharge (CMP 1), downstream of the WWTP effluent but upstream of the pulp mill (CMP 3) and downstream of the pulp mill effluent discharge (CMP 4). Concentrations upstream of the dischargers were between an order of magnitude and two orders of magnitude lower than downstream concentrations. Increases in chlorophyll-a concentrations downstream of the two dischargers were also described by Hatfield Consultants (2007) based on data collected between August and October in 2002, 2003 and 2006.

A seasonal pattern in chlorophyll-a concentrations (based on data collected between 2011 and 2017) were observed over the sampling period of late summer/ early fall. Concentrations of chlorophyll-a peaked in late summer and decreased over the fall at all three stations (Figure 42). Data are provided for the 2017 surveys except for August 30, 2011 to illustrate the seasonality of algal growth in the Wapiti River. Differences in flow were likely driving this pattern as Hatfield Consultants (2007) identified a negative relationship between average monthly flow and periphyton biomass in this reach of the Wapiti River. Flows preceding the September and October (2017) sampling events ranged between 50.5 and 90.5 m^3/s (September) and 166 and 235 m^3/s (October), compared to August flows which ranged between 18.8 and 35.7 m^3/s. High flows in September and October were the result of rain events.

Figure 42. Seasonal Changes in Chlorophyll-a Concentrations in the Wapiti River.

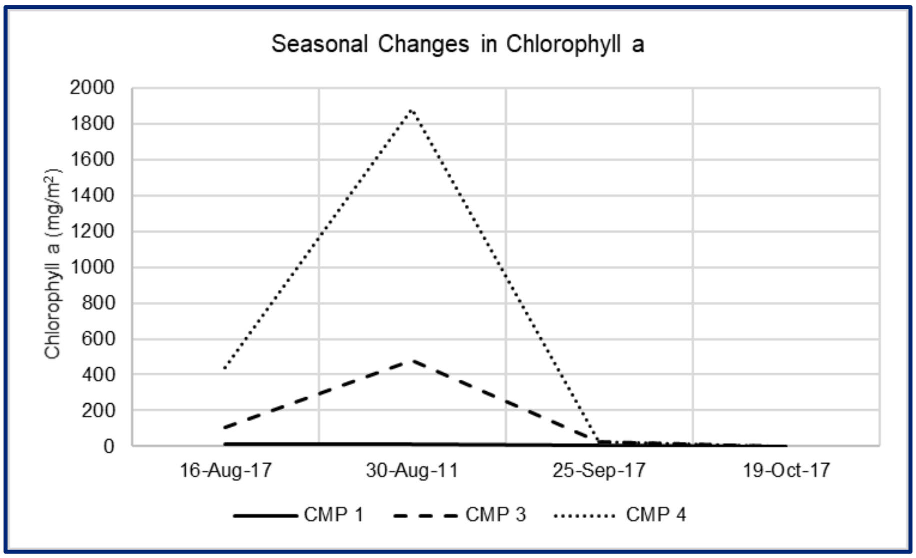


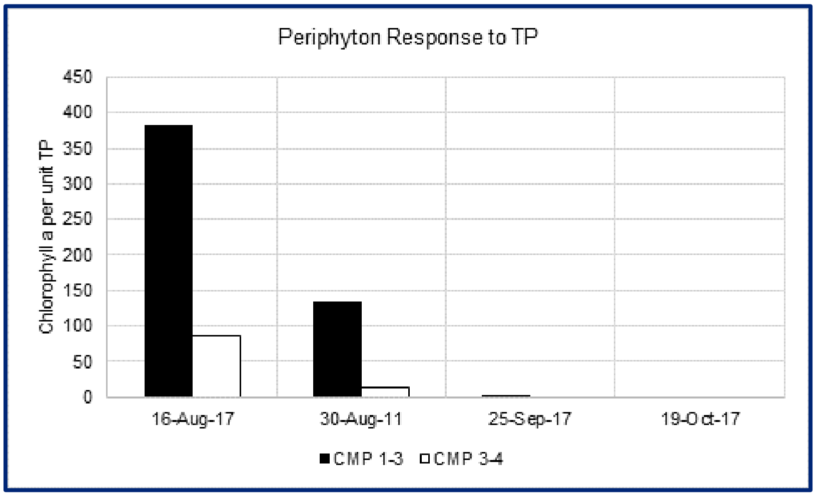
Table 34. Epiphytic chlorophyll "a" Response to Point Source Phosphorus Additions.

Site	Date	Chlorophyll "a" in mg/m^2			Total Phosphorus in µg/L			
		CMP 1	CMP 3	Change	CMP 1	CMP 3	Change	Change of Chl-a per unit of TP
CMP 1 vs. 3	30-Aug-11	16.0	477	461	7.2	8.4	1.2	384
CMP 1 vs. 3	16-Aug-17	10.3	104.4	94.1	4.6	5.3	0.7	134
CMP 1 vs. 3	25-Sep-17	3.6	25.0	21.4	14.4	40.5	26.1	0.82
CMP 1 vs. 3	19-Oct-17	0.02	0.02	0.00	207	767	560	0.00
		CMP 3	**CMP 4**		**CMP 3**	**CMP 4**		
CMP 3 vs. 4	30-Aug-11	477	1878	1401	8.4	24.9	16.5	85
CMP 3 vs. 4	15-Aug-17	104	441	337	5.3	32.3	27	12
CMP 3 vs. 4	26-Sep-17	25.0	24.1	-0.9	40.5	63.1	22.6	0
CMP 3 vs. 4	18-Oct-17	0.02	0.02	0.0	767	1140	373	0

There were clear increases of epiphytic chlorophyll "a" concentrations in response to point source additions of phosphorus and nitrogen but the responses varied with the growth phase of the periphyton and differed between the two point sources. At the beginning of August an increase of 1.2 µg/L of total phosphorus downstream of the WWTP discharge was related to an increase of 384 mg/m^2 of chlorophyll-a compared to an increase of 85 mg/m^2 of chlorophyll-a downstream of the pulp mill effluent discharge (Table 34, Figure 43). At the end of August the same pattern prevailed but the magnitude of the increase was reduced to 134 and 12 mg/m^2 of epiphytic chlorophyll downstream of the WWTP and pulp discharges. Unit changes were minor in September and October driven by the decline in overall biomass measured during both events.

The large response observed downstream of the WWTP discharge compared to downstream of the pulp mill discharge suggests periphyton were phosphorous limited in this reach of the Wapiti River. Hatfield Consultants (2007) found that total phosphorus was primarily made up of particulate phosphorus upstream of the pulp mill discharge and the proportion of dissolved phosphorus (made up primarily of soluble reactive phosphorus) increased downstream of the pulp mill discharge. Data collected by PECG and HESL (2011 and 2018) support this observation. Concentrations of orthophosphate were generally below detection upstream of the pulp mill, but above the periphyton limiting growth concentration (5 µg/L) identified by Hatfield Consulting (2007) downstream of the pulp mill (station CMP 4 ranging from 4.5 to 64.4 µg/L) during low flow sampling events in 2011 and 2017.

Figure 43. Phosphorus Induced Changes in Chlorophyll-a Concentrations in the Wapiti River.

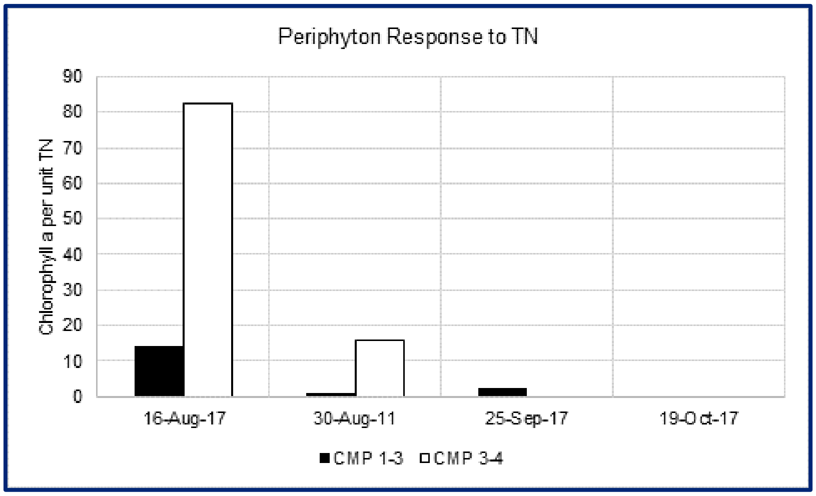


A similar analysis was completed for total nitrogen. Epiphytic chlorophyll “a” concentrations increased in response to effluent discharges in August but decreased as flows increased in September and October and the relative magnitude of responses to the Aquatera and IP discharges differed (Table 35, Figure 44). Increases in chlorophyll-a (mg/m^2) per µg/L of total nitrogen were greater downstream of the pulp mill effluent discharge (CMP 3-4) (ranging from 0 to 82 mg/m^2) than downstream of the WWTP (CMP 1-2) where increases in chlorophyll-a ranged from 0 to 14 mg/m^2. This suggests that growth downstream of the pulp mill was nitrogen limited. Hatfield Consulting (2007) found that dissolved inorganic nitrogen was the main predictor of periphyton biomass in the lower Wapiti River.

Table 35. Epiphytic chlorophyll “a” response to Point Source Nitrogen Additions.

Site	Date	Chlorophyll “a” in mg/m^2			Total Nitrogen in µg/L			
		CMP 1	CMP 3	Change	CMP 1	CMP 3	Change	Change of Chl-a per unit of TN
CMP 1 vs. 3	30-Aug-11	16.0	477	461	98.0	131	33	14
CMP 1 vs. 3	16-Aug-17	10.3	104.4	94.1	103	186	83	1.1
CMP 1 vs. 3	25-Sep-17	3.6	25.0	21.4	181	190	9	2.5
CMP 1 vs. 3	19-Oct-17	0.02	0.02	0.00	295	805	510	0
		CMP 3	**CMP 4**		**CMP 3**	**CMP 4**		
CMP 3 vs. 4	30-Aug-11	477	1878	1401	131	148	17	82
CMP 3 vs. 4	15-Aug-17	104	441	337	186	207	21	16
CMP 3 vs. 4	26-Sep-17	25.0	24.1	-0.9	190	198	8	0
CMP 3 vs. 4	18-Oct-17	0.02	0.02	0.0	805	770	-35	0

Figure 44. Nitrogen Induced Changes in Chlorophyll-a Concentrations in the Wapiti River.



The role of phosphorus as a limiting nutrient was clearly evident upstream of the Aquatera WWTP discharge where unit changes in chlorophyll per unit of phosphorus were 1-2 orders of magnitude greater than for nitrogen in the early season. Downstream of Aquatera epiphytic growth was limited by both phosphorus and nitrogen and responded equally to the increase in both nutrients (Table 36).

Table 36. Comparison of Epiphytic chlorophyll "a" response to Point Source Additions of Nitrogen and Phosphorus.

Site	Date	Unit Change of Chl-a per unit change of TP	Unit Change of Chl-a per unit change of TN
CMP 1 vs. 3	30-Aug-11	384	14
CMP 1 vs. 3	16-Aug-17	134	1.1
CMP 1 vs. 3	25-Sep-17	0.82	2.5
CMP 1 vs. 3	19-Oct-17	0.00	0
CMP 3 vs. 4	30-Aug-11	85	82
CMP 3 vs. 4	15-Aug-17	12	16
CMP 3 vs. 4	26-Sep-17	0	0
CMP 3 vs. 4	18-Oct-17	0	0

8.4 Point vs Non Point Source Responses

The Aquatera WWTP and IP Outfall discharge 152 and 67.9 tonnes of total nitrogen and 7.59 and 17.5 tonnes of total phosphorus, respectively, to the Wapiti River each year (Table 20). By comparison, measured estimates of NPS loadings to the Wapiti River averaged 324 tonnes of phosphorus and 1746 tonnes of nitrogen annually (Table 30) while the NPS model provides estimates of 458 and 2882 (Table 31) tonnes/yr, respectively, upstream, of the Aquatera discharge. The total point source loadings of nitrogen are 5.3-8.7% of the NPS loading while total point source loadings of phosphorus are 14.9-21% of the NPS loadings. These small incremental point source loadings, however, stimulate very large proportional increases in algal growth in the river. Upstream of Grande Prairie there are no significant point source discharges and August 30 peak epilithic chlorophyll "a" concentration was 16 mg/m^2, or 0.035 mg/tonne of phosphorus and 0.006 mg/tonne of nitrogen NPS load.

The Aquatera WWTP discharge adds, on average, 7.6 and 152 tonnes of phosphorus and nitrogen each year, which stimulate 61 and 3 mg/m2 of epilithic chlorophyll "a" (Table 37). Further downstream the International Paper discharge adds, on average, 17.4 and 67.9 tonnes of phosphorus and nitrogen, which stimulate 55 and 6.3 mg/m2 of epilithic chlorophyll "a". Hatfield Consultants (2007) found that total phosphorus was primarily made up of particulate phosphorus upstream of the pulp mill discharge and the proportion of dissolved phosphorus (made up primarily of soluble reactive phosphorus) increased downstream of the pulp mill discharge. The low algal responses upstream of the point source discharges therefore reflect the high proportions of particulate phosphorus and nitrogen that make up the NPS loads upstream compared to the large increases seen downstream of the point source inputs of bio-available nutrients.

Table 37. Comparison of Epiphytic Chlorophyll "a" Response to Point and NPS Additions of Nitrogen and Phosphorus.

	CMP1		CMP3		CMP4	
Chlorophyll "a"	mg/m2	mg/tonne NPS	mg/m2	mg/tonne PS	mg/m2	mg/tonne PS
Phosphorus	16.0	0.035	477	61	1878	55
Nitrogen	16.0	0.006	477	3.0	1878	6.3

The Wapiti River has amongst the lowest pesticide concentrations of the major rivers in Alberta suggesting a lower overall impact from non-point sources (agricultural land comprises 26 % of the Wapiti basin study area, Table 9). Furthermore, in agricultural watersheds studied in Ohio, the majority of total phosphorus was exported in particulate form (53-66% depending on the watershed; Vanni et al. 2001), however local agricultural practices play an important role in determining dissolved vs particulate nutrient loading from agricultural lands (Withers and Jarvie 2008). Particulate nutrients are less bioavailable to algae and would therefore not stimulate periphyton growth as directly as soluble, bioavailable forms. Nutrients which arrive in particulate form (>0.45 μm), tend to occur during storm events via surface runoff and are therefore associated with periods of high river flow which do not support nutrient retention for periphyton growth

(Withers and Jarvie 2008). Point source contributions of soluble reactive phosphorus are proportionally higher during low flow events, which can be considered ecologically sensitive periods (Jarvies et al. 2006). Therefore, although there are significant NPS loadings to the Wapiti River, those upstream of Grande Prairie have a low ecological consequence and do not stimulate nuisance periphyton growths. Downstream of Grande Prairie, discharge of highly concentrated, soluble nutrients from the WTTP and IP discharges, which comprise >20% of the annual nutrient loads in the Wapiti River (Chambers et al. 2000), stimulate significant periphyton growth.

Further downstream, the Bear Creek subwatershed enters the Wapiti River. It receives discharges from numerous small WWTPs and urban runoff from the City of Grande Prairie and so a portion of its load may be bioavailable. Biological monitoring of Bear Creek, and of the Wapiti River upstream and downstream of its inflow is recommended to assess the significance of these loads.

9. Management Implications

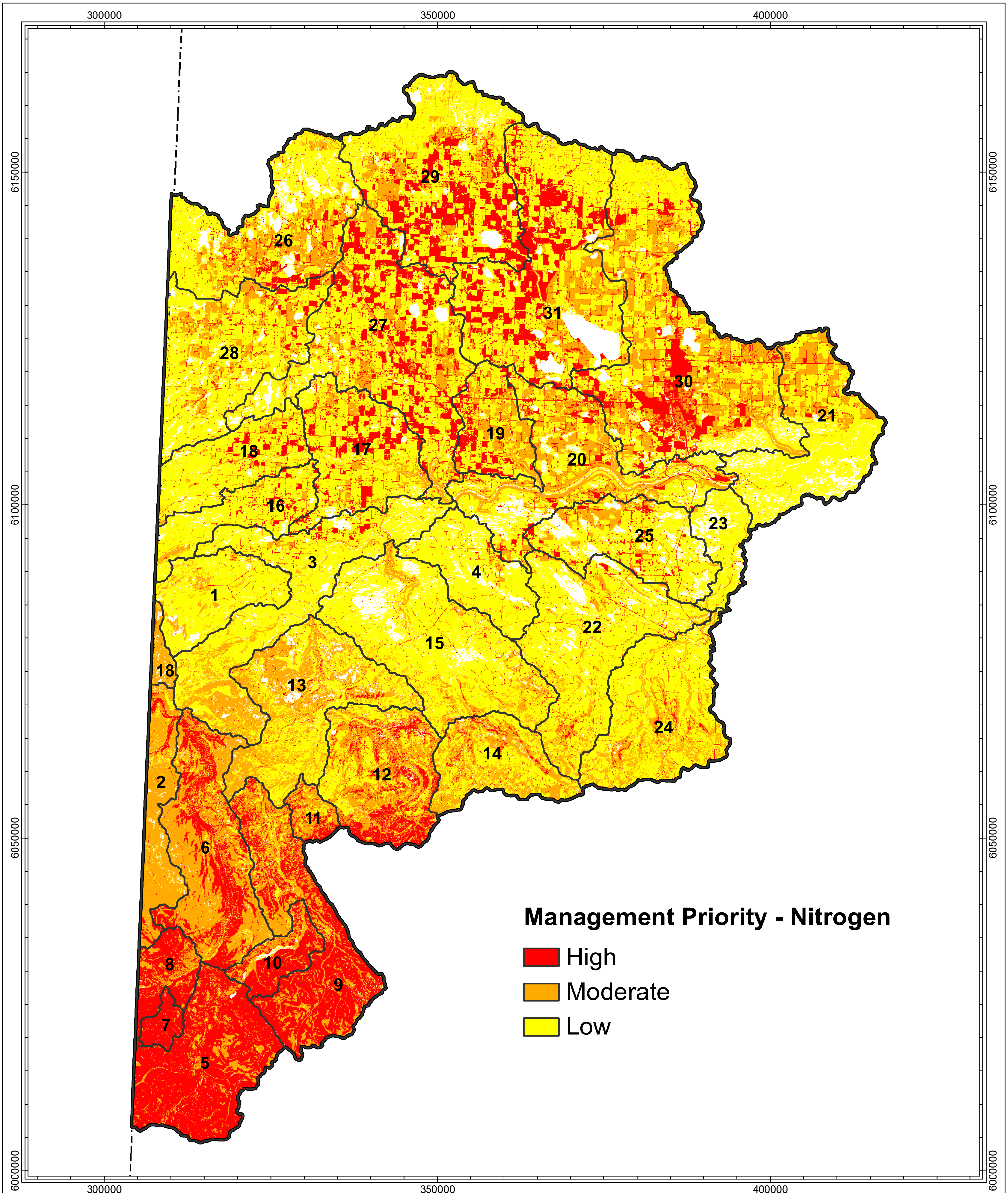
The final mapping and classification exercise combined the classifications of NPS loading (Section 5) with the classifications of sensitivity (Section 7) to identify those areas and subwatersheds where the combination of a) land use and associated potential for NPS loading interacted with b) sensitivity based on slope, soils and drainage density. This interaction produced mapping of overall management sensitivity – to determine those areas in which management activities should be focussed to control NPS runoff.

The fine scale mapping of overall sensitivities based on classification of drainage density, slope and soil within each subwatershed (Figure 40) was further classified to one value (“Low”, “Moderate” or “High”) for the entire subwatershed (Figure 41). The classifications of “Low”, “Moderate” or “High potential for export of nitrogen, phosphorus and solids for each subwatershed were then compared to the sensitivity classification for the same subwatershed to produce a classification of “Low”, “Moderate” or “High” for “Management Priority” according to the matrix provided in Table 38.

Table 38. Schematic of Classification for Management Priority.

		Export Coefficient Classification		
		Low	Moderate	High
Sensitivity Classification	Low	Low	Low	Moderate
	Moderate	Low	Moderate	High
	High	Moderate	High	High

Mapping of final management priority scores for the study area is provided in Figures 45, 47 and 49 for nitrogen, phosphorus and solids, respectively. Average management priority scores for each subwatershed are mapped in Figures 46, 48 and 50 for nitrogen, phosphorus and solids, respectively.



Legend
Study Area
Subwatershed

Hutchinson Environmental Sciences Ltd.

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

0 10 20 30 km

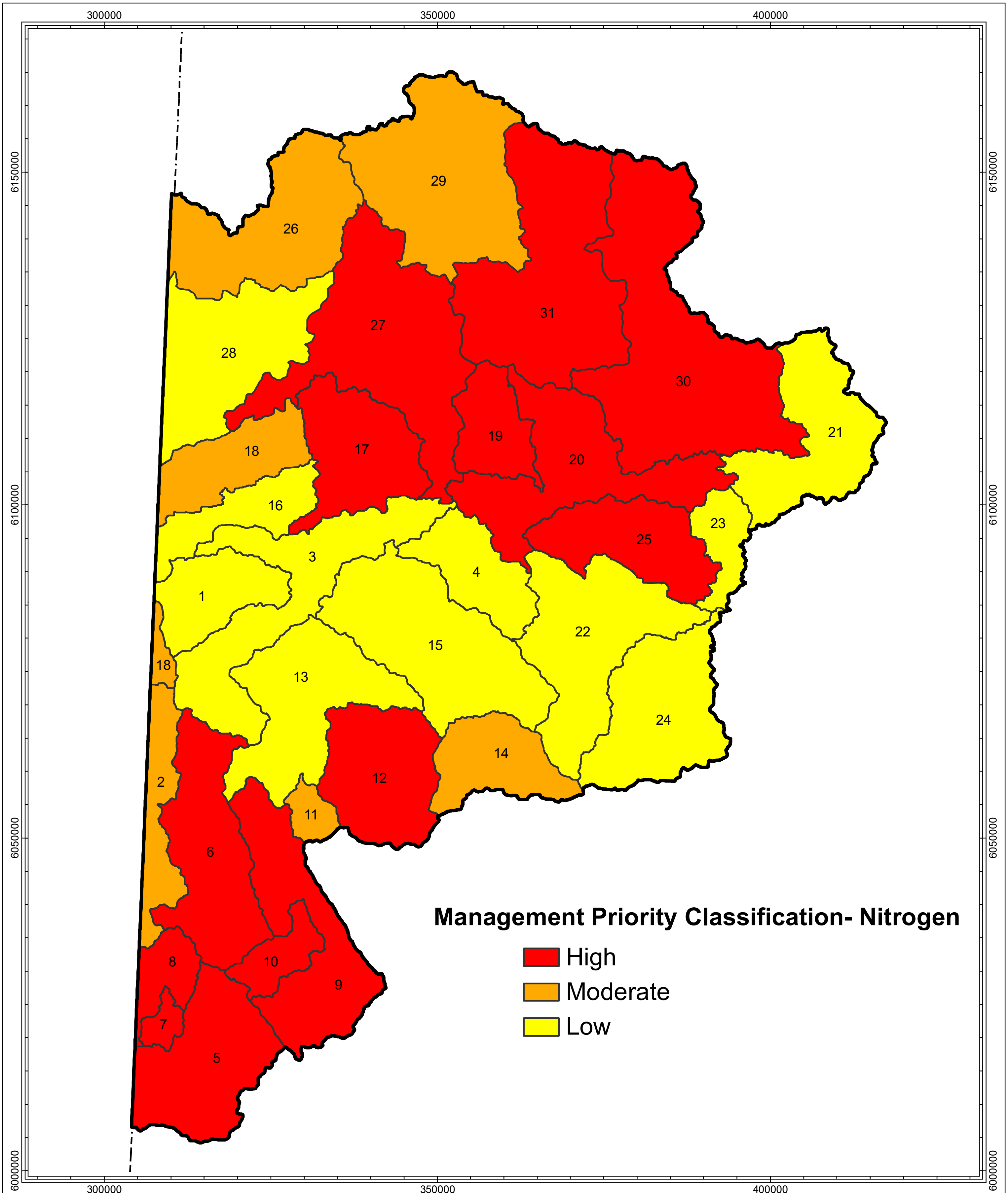
Scale = 1:750000

N

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Apr 03, 2018

Management Priority - Nitrogen

FIGURE 45



Legend

Study Area

Subwatershed

Hutchinson Environmental Sciences Ltd.

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

0 10 20 30 km

Scale = 1:750000

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PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Apr 03, 2018

Management Priority - Nitrogen

FIGURE 46

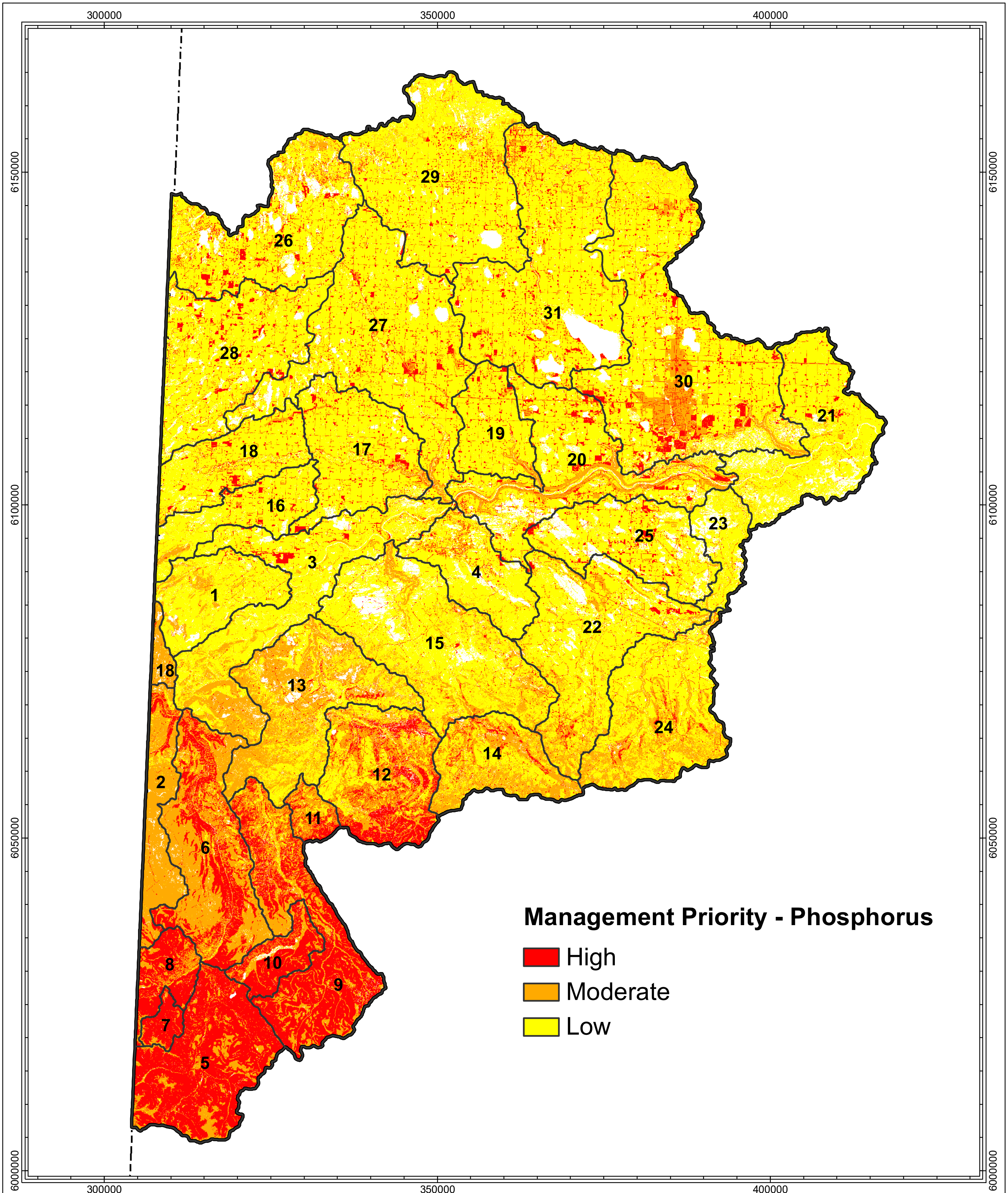
9.1 Management Priority – Nitrogen

Seven subwatersheds (#17,19,20,25,27,30,31) were identified as highest potential management priorities for NPS nitrogen loading based on the classification analysis of a) High (>75[th] percentile) classification of export coefficients and/or annual loading of nitrogen from the NPS model and b) High Management Priority by combination of the NPS model, High soil sensitivity to erosion and Moderate drainage density. Of these, the Lower Bear River had the highest potential for nitrogen export with an export coefficient of 12.17 kg/ha/yr (Table 39).

Another seven subwatersheds were identified as high priority based on Moderate (25th-75[th] percentile) classifications for NPS phosphorus export and High classifications for drainage density and steep slope and Moderate classification for soils (Upper Narraway River).

Table 39. High Management Priority Subwatersheds – Nitrogen

ID	Name	Export Coefficient kg/ha/yr	Annual Export tonnes	Management Priority	Overall Sensitivity	Drainage	Soil	Slope
5	TORRENS RIVER	3.31	118	H	M	H	L	H
6	LOWER NARRAWAY RIVER	3.18	121	H	M	H	L	H
7	DINOSAUR CREEK	3.32	12	H	M	H	L	H
8	UPPER NARRAWAY RIVER	3.19	30	H	H	H	M	H
9	UPPER NOSE CREEK	3.20	122	H	M	H	L	H
10	GUNDERSON CREEK	3.23	30	H	M	H	L	H
12	MUDDY CREEK	2.93	93	H	M	H	L	H
17	LOWER REDWILLOW RIVER	6.43		H	M	M	H	L
19	PIPESTONE CREEK	9.92		H	M	M	H	L
20	LOWER WAPITI RIVER ABOVE BIG MOUNTAIN CREEK	9.25	403	H	M	M	H	L
25	UNNAMED - BIG MOUNTAIN CREEK	8.69	233	H	L	L	H	L
27	LOWER BEAVERLODGE RIVER	7.89	490	H	M	M	H	L
30	LOWER BEAR RIVER	12.17	980	H	M	M	H	L
31	LOWER BEAR RIVER ABOVE GRANDE PRAIRIE CREEK	6.41	425	H	M	M	H	L



Legend

Study Area

Subwatershed

Hutchinson Environmental Sciences Ltd.

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

0 10 20 30 km

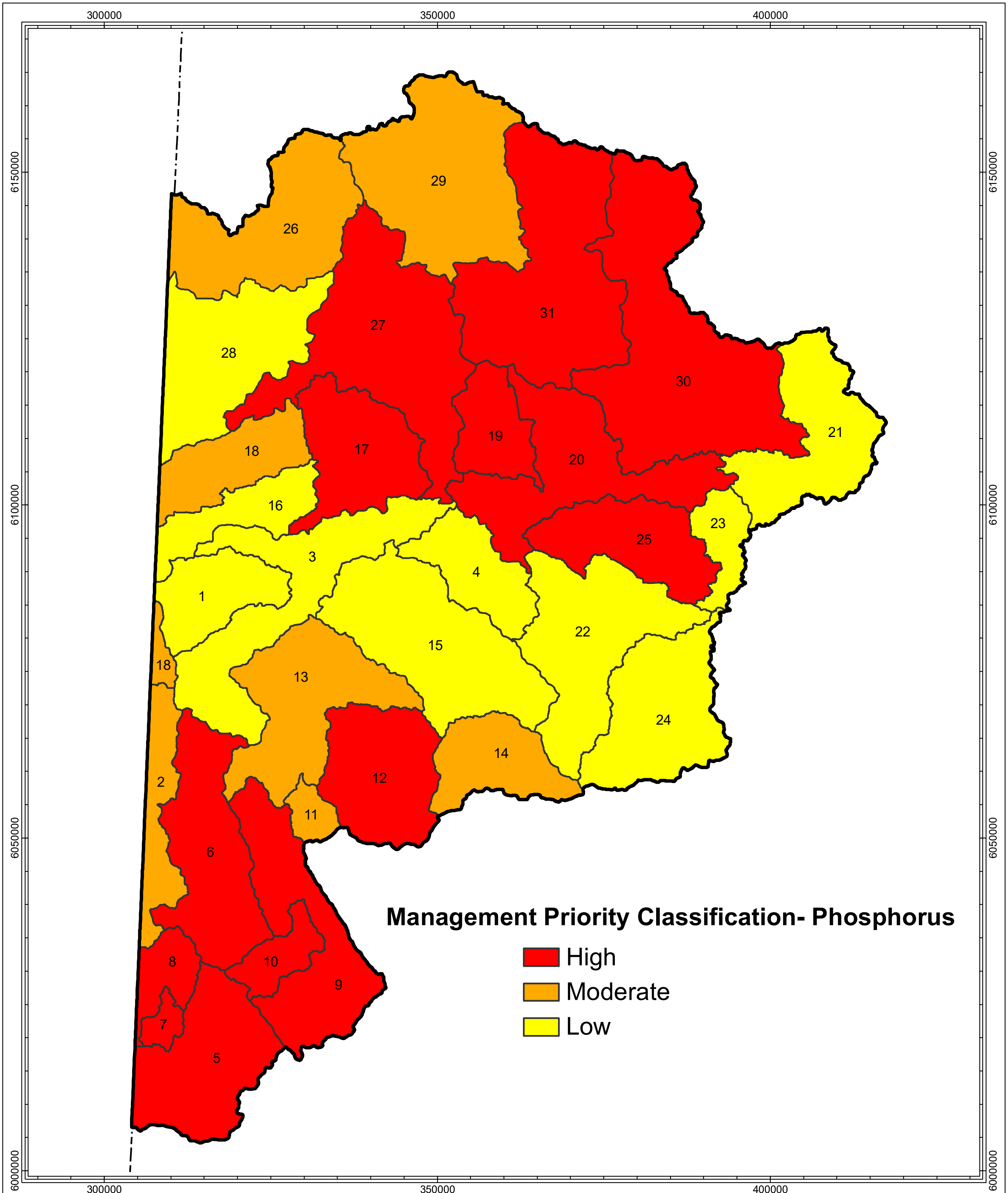
Scale = 1:750000

N

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Apr 03, 2018

Management Priority - Phosphorus

FIGURE 47



Legend

Study Area

Subwatershed

Hutchinson Environmental Sciences Ltd.

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

0 10 20 30 km

Scale = 1:750000

N

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Apr 03, 2018

Management Priority - Phosphorus

FIGURE 48

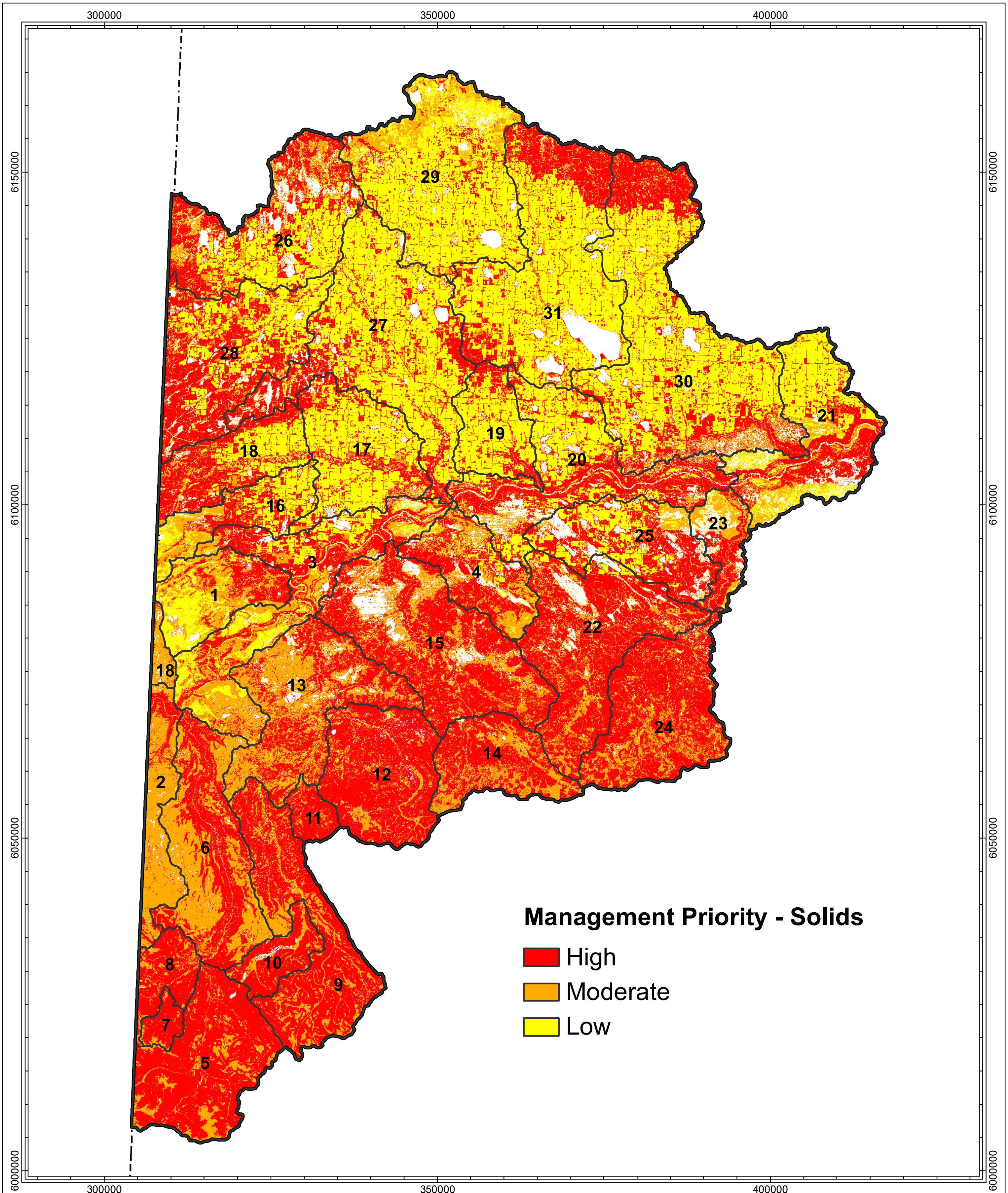
9.2 Management Priority – Phosphorus

Six subwatersheds (#17,19,20,27,30,31) were identified as highest potential management priorities for NPS phosphorus loading based on the classification analysis of a) High (>75th percentile) classification of export coefficients and/or annual loading of nitrogen from the NPS model and b) High Management Priority by combination of the NPS model, High soli sensitivity to erosion and Moderate drainage density. Of these, the Lower Bear River had the highest potential for phosphorus export with an export coefficient of 1.87 kg/ha/yr (Table 40.

Another seven subwatersheds were identified as high priority based on Moderate (25th-75th percentile) classifications for NPS phosphorus export and High classifications for drainage density and steep slope and Moderate classification for soils (Upper Narraway River).

Table 40. High Management Priority Subwatersheds – Phosphorus

ID	Name	Export Coefficient kg/ha/yr	Annual Export tonnes	Management Priority	Overall Sensitivity	Drainage	Soil	Slope
5	TORRENS RIVER	0.534	19.1	H	M	H	L	H
6	LOWER NARRAWAY RIVER	0.535	20.3	H	M	H	L	H
7	DINOSAUR CREEK	0.513		H	M	H	L	H
8	UPPER NARRAWAY RIVER	0.498		H	H	H	M	H
9	UPPER NOSE CREEK	0.527	20.1	H	M	H	L	H
10	GUNDERSON CREEK	0.571		H	M	H	L	H
12	MUDDY CREEK	0.536	17.0	H	M	H	L	H
17	LOWER REDWILLOW RIVER	0.991		H	M	M	H	L
19	PIPESTONE CREEK	1.512		H	M	M	H	L
20	LOWER WAPITI RIVER ABOVE BIG MOUNTAIN CREEK	1.441	62.7	H	M	M	H	L
27	LOWER BEAVERLODGE RIVER	1.216	75.4	H	M	M	H	L
30	LOWER BEAR RIVER	1.870	151	H	M	M	H	L
31	LOWER BEAR RIVER ABOVE GRANDE PRAIRIE CREEK	1.003	66.4	H	M	M	H	L



Legend
Study Area
Subwatershed

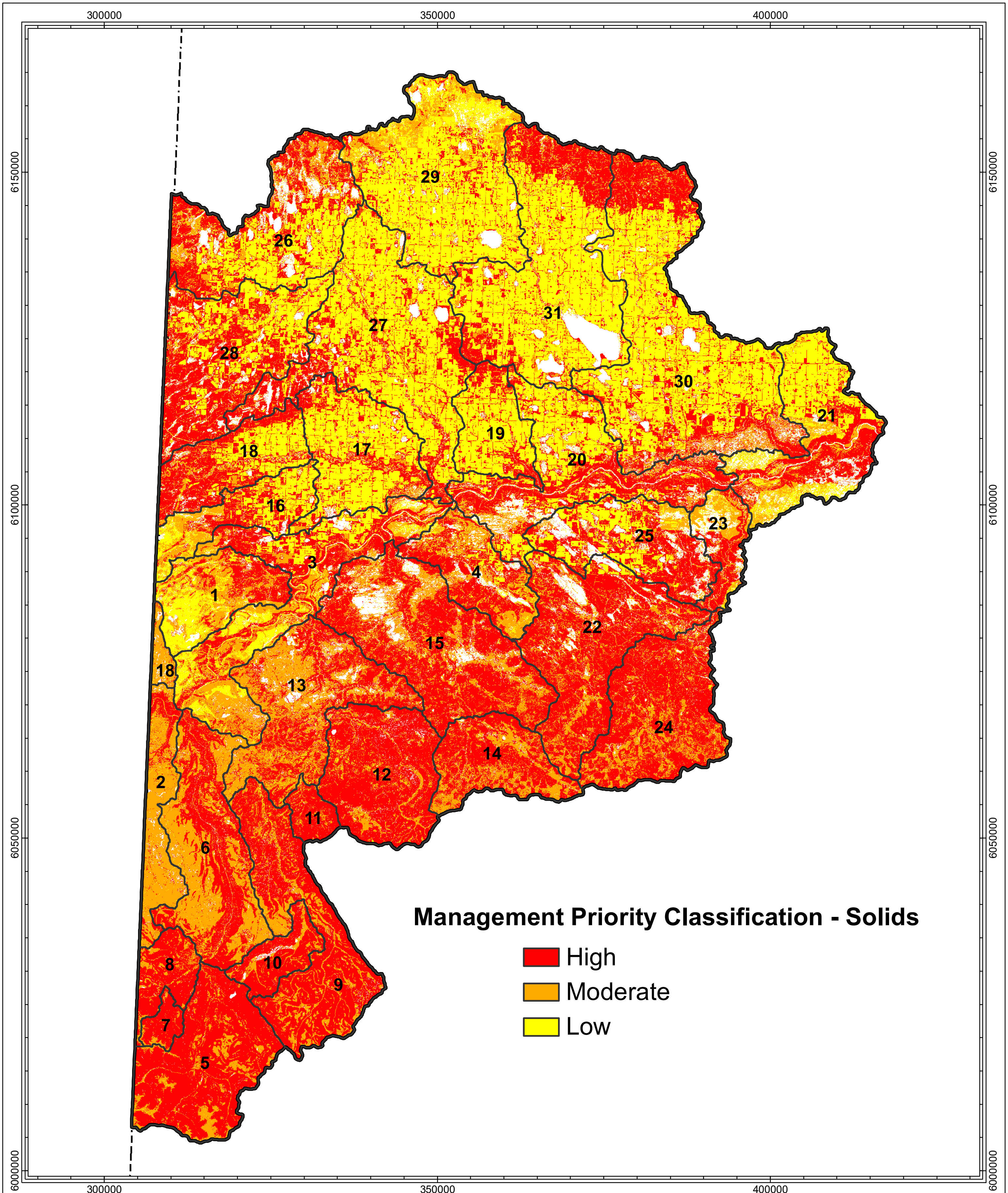
Hutchinson Environmental Sciences Ltd.
PALMER ENVIRONMENTAL CONSULTING GROUP INC.

0 10 20 30 km
Scale = 1:750000
N

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Apr 03, 2018

Management Priority - Solids

FIGURE 49



Legend
Study Area
Subwatershed

Hutchinson Environmental Sciences Ltd.

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

0 10 20 30 km
N

Scale = 1:750000

PROJECT:	13186	PROJECTION:	UTM Zone 11N
DRAWN:	B. Elder	DATUM:	NAD 1983
CHECKED:	D. Sacco	DATE:	Apr 03, 2018

Management Priority - Solids

FIGURE 50

9.3 Management Priority – Solids

Five subwatersheds (#10,20,22,24 and 30) were identified as highest potential management priorities for NPS solids loading based on the classification analysis of a) High (>75th percentile) classification of export coefficients and/or annual loading of nitrogen from the NPS model and b) High Management Priority by combination of the NPS model and high soil sensitivity to erosion, moderate drainage density and moderate slope (Upper Big Mountain Creek). Of these, the Lower Bear River ad the highest potential for phosphorus export with an export coefficient of 1.87 kg/ha/yr (Table 41).

Another three subwatersheds were identified as high priority based on Moderate (25th-75th percentile) classifications for NPS phosphorus export and High classifications for drainage density and steep slope.

Table 41. High Management Priority Subwatersheds – Solids

ID	Name	Export Coefficient kg/ha/yr	Annual Export tonnes	Management Priority	Overall Sensitivity	Drainage	Soil	Slope
5	TORRENS RIVER	403	14435	H	M	H	L	H
6	LOWER NARRAWAY RIVER	418	15881	H	M	H	L	H
7	DINOSAUR CREEK	380		H	M	H	L	H
10	GUNDERSON CREEK	438		H	M	H	L	H
20	LOWER WAPITI RIVER ABOVE BIG MOUNTAIN CREEK	441	19173	H	M	M	H	L
22	BALD MOUNTAIN CREEK	453	20301	H	M	M	H	L
24	UPPER BIG MOUNTAIN CREEK	486	17877	H	M	M	H	M
30	LOWER BEAR RIVER	467	37636	H	M	M	H	L

10. Conclusions

An inventory and evaluation of non-point pollution sources in the Wapiti River Basin was undertaken to understand the relative importance of point and non-point sources of nutrients to the Wapiti River. This evaluation helped identify missing data and gaps in understanding helped provide recommendations to guide and improve the development and implementation of Wapiti River Water Management Plan.

The study approach used export coefficients derived by Donahue (2013) for specific Natural Regions of Alberta and land use data housed in an ArcView GIS platform to estimate phosphorus, nitrogen and suspended solid loads for non-point sources from 31 subwatersheds within the Wapiti River Basin in Alberta. Average export coefficients for nitrogen and phosphorus were found to be significantly related to watershed area, but there was no significant relationship between the export coefficients for solids and those for nitrogen and phosphorus.

Point source loads (from 11 dischargers) were discharged to five of the 31 subwatersheds delineated. Point source loads from these facilities made up 35%, 29% and 2.5% of the total loading of nitrogen, phosphorus and solids, respectively, in their respective subwatersheds. The low proportional contribution of solids indicates that much of the nitrogen and phosphorus in these discharges was more readily bioavailable and not associated with solids to the same extent as non-point source loadings.

The non-point source model overestimated measured nutrient loads by 30 to 60%, but estimates fell within the range of natural variability. Overestimates were consistent with literature values for non-point source models. Therefore, the model was considered a useful tool for identifying priority watersheds. The application of Riparian Zone Export Multiplication Factors resulted in less than a 1% change in NPS load estimates and did not improve understanding of stream sensitivity to non-point sources. The GIS model was therefore refined to include classifications of slope, soil erosion sensitivity and drainage density to identify priority areas for future management. High management priority subwatersheds for phosphorus and nitrogen included the Lower Redwillow River (subwatershed 17), Pipestone Creek (subwatershed 19), Lower Wapiti River above Bigmountain Creek (subwatershed 20), the Lower Beaverlodge River (subwatershed 27), Lower Bear River (subwatershed 30) and Lower Bear River above Grande Prairie Creek (subwatershed 31) Of these, the Lower Bear River had the highest potential for NPS loading of phosphorus and nitrogen. Subwatershed 25 (Big Mountain Creek) was also identified as a high management priority subwatershed for nitrogen. High management priority subwatersheds for solids were identified as Gunderson Creek (subwatershed 10), Lower Wapiti River above Bigmountain Creek (subwatershed 20), Bald Mountain Creek (subwatershed 22), Upper Big Mountain Creek (subwatershed 24) and the Lower Bear River (subwatershed 30). The priority subwatersheds which did not overlap between nutrient sensitivity and solids sensitivity were considered areas where non-point source loads had greater proportions of dissolved nutrients.

Non-point source loadings to the Wapiti River were high (5577 tonnes/yr of nitrogen and 850 tonnes/yr of phosphorus), however low algal response upstream of point source dischargers suggested particulate forms of nutrients made up the majority of non-point source nutrient loads upstream of the City of Grande Prairie. Biologically available nutrients from point source dischargers appeared to be driving biological responses communities in the Lower Wapiti River but the generality of this conclusion for all NPS loadings is qualified by the lack of biological monitoring in other subwatersheds were NPS loadings may be high .

11. Recommendations

Results of the development of the NPS model for the Wapiti River Watershed were encouraging, however we have identified several important data gaps. In general, geospatial data availability was excellent and we were able to acquire the necessary GIS layers to classify the Wapiti subwatersheds according to the approach of Donahue (2013). Estimation of increased export from high intensity cereal crops in which manure is applied was not possible as there were no GIS records of manure application in the study area and so these areas were modelled as cereal crops with no manure application.

Non-point source estimates of both TN and TP were within the range of variability of measured nutrient loads in the Lower Wapiti River and similar in error to model estimates in the literature (~40%). The discrepancy between measured and modelled nutrient loads is in part a consequence of the limited data available for both estimations. Potential improvement to the measured estimations of nutrient loading to the Wapiti River could be made with higher resolution (more frequent) water quality data, which would improve the validation of the NPS export model. Current estimates were based on a single water quality measurement per month, which given the substantial temporal variability in water quality in Wapiti River could be improved with higher resolution data. The long-term record available from the LTRN program, however, provides a good record for assessing interannual variability in the river.

Analysis of the impact of non-point source loading in the Wapiti River in this report and several other studies has suggested that NPS nutrient loading has not had a significant impact on the river, however ecological data to make these assessments was limited. Periphyton data available in the river do not necessarily coincide with high risk reaches in the river where a combination of high NPS loads and high sensitivity are likely to yield a significant biological response. We have identified several key watersheds for consideration as management and monitoring priorities in the future. These watersheds represent areas where our model estimations suggest that the impacts of NPS loading are likely to have the highest impact. High risk watersheds identified were focussed around the northern tributaries of the Wapiti River, including Bear Creek (subwatersheds 29-31), the Beaverlodge River (subwatersheds 26-28), and Redwillow River (subwatersheds 16-18).

Bear Creek represents a significant input of nutrients, coliforms, total metals and pesticides 2,4-D, fluroxypyr and MCPP (HESL 2015). Despite naturally elevated nutrient concentrations and a watershed area containing significant agricultural development, discharge from several smaller wastewater lagoons and stormwater discharge from the City of Grand Prairie, information on the Bear Creek watershed is limited (Charette Pell Poscente Environmental Corp. and Hutchinson Environmental Sciences Ltd. 2012). The scope and resolution of data available from Bear Creek represents a significant data gap in the region. Inputs from Bear Creek may be a significant contributor to the downstream Wapiti/Smoky River system and should be monitored more intensively in the future. Furthermore, the Bear Creek watershed presents the best opportunity to assess NPS loading from urban land use and to validate modelled estimates. Subwatersheds 30 and 31 were therefore identified as the highest management priorities for monitoring and potential management of NPS nitrogen and phosphorus by our analysis (Section 9).

Limited data have been collected in the Beaverlodge and Redwillow Rivers. Significant agricultural development in these watersheds suggests they would be ideal candidates for refining NPS nutrient loading estimates from agricultural lands using existing data supplemented by additional monitoring, measuring the effectiveness of agricultural BMPs and assessing the impact of NPS loads on biological communities. Both rivers have been identified as highest potential management priorities for NPS nitrogen loading (Section 9). Specifically, Lower Redwillow River (subwatershed 17) and Lower Beaverlodge River (subwatershed 27) subwatersheds were identified as highest priority watersheds for both nitrogen and phosphorus.

Our data suggest that NPS loading in the region, while significant, has not impacted the Wapiti River as significantly as point source discharges. NPS loading may be dominated by particulate rather than dissolved and bioavailable nutrient species. Future monitoring should include efforts to distinguish between particulate, dissolved and soluble reactive fractions of phosphorus to confirm the importance of PS and NPS P in driving water quality and biological communities in the Wapiti River.

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APPENDICES

Appendix A. Donahue (2013) Export Coefficient Tables

Appendix B. Reconciliation between Donahue (2013) Land Use Types and GIS Layers used in NPS Model.

Table A. Reconciliation with Donahue (2013) Natural and Agricultural Land Use Types.

Donahue (2013) Categories	Equivalent GIS Layer(s)	GIS Layer Description	Source
Conifer Dominated Forest	210-Coniferous	Predominantly coniferous forests or treed areas	Crop Inventory 2016
Hardwood Dominated Forest	220-Broadleaf Forest	Predominantly broadleaf/deciduous forests or treed areas	
Wooded	230-Mixed Forest	Forest that is a combination of both coniferous and broadleaf	
Shrubland	50-Shrubland	Predominantly low woody vegetation, may include grass or wetlands with woody vegetation,	
Native Grassland	110-Grassland	Predominantly native grasses and other herbaceous vegetation, may include some shrubland cover	
Natural Unvegetated (rock/ice/sand)	30-Exposed Land/Barren	Predominantly non-vegetated and non-developed land including glacier, rock, sediments, burned areas, rubble, mines, other naturally occurring non-vegetated surfaces, excludes fallow agriculture	
Cereal Crop (intensive)	132-Cereals, 133-Barley,136-Oats, 137-Rye, 139-Triticale, 146-Spring Wheat	No description provided	
Cereal Crop (extensive)			
Forage Crop (intensive) – alfalfa	122-Pasture/Forages	Periodically cultivated, includes tame grasses and other perennial crops such as alfalfa and clover grown alone or as mixtures for hay, pasture or seed	
Forage Crop (extensive) – alfalfa			
Native Grazing – Flat (0-5% slope)	ROUGH_PASTURE	Lands where the forest and/or shrubs have been removed so that native or introduced grasses can flourish for grazing livestock, pasture has not been irrigated or fertilized and the soil has not been disturbed to improve productivity	Human Footprint Inventory 2014
Native Grazing – Rolling (5-10% slope)			
Native Grazing – Hilly (10-30% slope)			

Donahue (2013) Categories	Equivalent GIS Layer(s)	GIS Layer Description	Source
Intensive Grazing – Flat (0-5% slope)	TAME_PASTURE	Lands where the soil has been disturbed and planted with perennial grass species used primarily for grazing livestock, areas of grasses, legumes or grass-legume mixtures planted for livestock grazing or hay collection	
Intensive Grazing – Rolling (5-10% slope)			
Intensive Grazing – Hilly (10-30% slope)			
General Agriculture – Flat (0-5% slope)	All other crops (147-199)	Corn, oilseeds (canola/rapeseed), pulses (peas, beans, lentils)	Crop Inventory 2016
General Agriculture – Rolling (5-10% slope)			
General Agriculture – Hilly (10-30% slope)			
Water + Wetlands	LAGOON, RESERVOIR	Lagoon: artificial holding or treatment pond for industrial, agricultural or municipal wastewater, human-made water and sewage lagoons for municipal purposes Reservoir: artificial lake or storage pond resulting from human-made dam, a body of water created by excavation or human-made damming of a river or stream	Human Footprint Inventory 2014
	20-Water, 80-Wetland	Water: waterbodies (lakes, reservoirs, rivers, streams, salt water etc.) Wetland: land with a water table near, at or above soil surface for enough time to promote wetland or aquatic processes (semi-permanent or permanent wetland vegetation, including fens, bogs, swamps, sloughs, marshes etc.)	Crop Inventory 2016

Table B. Reconciliation with Donahue (2013) Transportation, Industrial, Recreational and Residential Land Use Types.

Donahue (2013) Categories	Equivalent GIS Layer(s)	Description	So
Soft Roads (gravel/dirt)	ROAD-GRAVEL-1L, ROAD-GRAVEL-2L, ROAD-UNPAVED, ROAD-UNIMPROVED, ROAD-	One and two lane roads covered with gravel or dirt	
Hard Roads (paved)	ROAD-PAVED-1L, ROAD-PAVED-2L, ROAD-PAVED-3L, ROAD-PAVED-4L, ROAD-PAVED-DIV, ROAD-PAVED-UNDIV-1L, ROAD PAVED-UNDIV-2L, ROAD-PAVED-UNDIV-4L, INTERCHANGE-RAMP, AIRP-RUNWAY	Up to four lane roads covered with asphalt or concrete, with or without a median, includes ramps, overpasses and underpasses, and airport runways	
Trails (motorized)	TRUCK-TRAIL, TRAIL-ATV	Truck-trail: roadway covered with dirt or low vegetation with few ditches and usually no bridges over streams Trail-ATV: trail primarily used for ATV activities	
Trails (non-motorized)	TRAIL	No description provided	
Industrial Plants	OIL-GAS-PLANT, MISC-OIL-GAS-FACILITY, CAMP-INDUSTRIAL, FACILITY-OTHER, FACILITY-	Industrial facilities used for oil production, oil and gas, and associated activities (e.g., employee residences)	Hu
Transmission Lines	TRANSMISSION-LINE	Utility corridor for transmitting electricity	
Seismic Lines	PRE-LOW-IMPACT-SEISMIC	Area including and surrounding a pre-low-impact seismic centreline	
Wellpads	WELL-ABAND, WELL-CASED, WELL-CLEARED-DRILLED, WELL-CLEARED-NOT-DRILLED, WELL-	Clearings for oil/gas and gas well pads and associated areas	
Pipelines	PIPELINE	Line of underground and over ground pipes for transporting petrochemicals	
Processing Plants	MILL	Intense industrial and commercial development for pulp or pater production	
Feedlots	CFO	Confined feeding operations with large buildings and fenced pens for livestock	
Surface Mines	GRVL-SAND-PIT, OPEN-PIT-MINE, BORROWPITS, BORROWPIT-DRY, BORROWPIT-WET	Area of surface disturbance for extracting sand and/or gravel, or for mining, as well as pits dug to build forestry	

Donahue (2013) Categories	Equivalent GIS Layer(s)	Description	Sc
Construction 1	CLEARING-UNKNOWN, RESIDENCE_CLEARING, VEGETATED-EDGE-ROADS, VEGETATED-EDGE-RAILWAYS	Human-made clearings, including areas cleared for building developments (that do not yet have construction), as well as disturbed vegetation along road and railway edges	
	34- Urban/Developed	Predominantly built-up or developed, and associated vegetation, including road and railway surfaces, buildings and paved surfaces, urban areas, industrial sites, mine structures, golf courses etc.	Cr
Recreational – Golf Courses	GOLF COURSE	Large recreational area comprised of a series of grass patches surrounded by trees	
Recreational - Campgrounds	CAMPGROUND	Disturbed vegetation with facilities for RVs and tents, including gravel or concrete roads	
Urban – City Core	URBAN-INDUSTRIAL	An industrial facility within the boundary of an urban residence	Hu
Urban - Suburban	URBAN-RESIDENCE, GREENSPACE	Residential areas in cities, town, villages, hamlets and ribbon developments dominated by dwellings (>100 buildings per quarter section), including greenspace used for recreation (including schools, school yards and sport fields)	
Rural Residential (farm yard)	RURAL-RESIDENCE, COUNTRY-RESIDENCE	Developments with density of < 10 buildings per quarter section and 10-100 buildings per quarter section	