MOOSE LAKE WATERSHED

NUTRIENT EXPORT STUDY

Prepared for: Alberta Environment and Sustainable Resource Development

Prepared by: Théo Charette, M.Sc.
Reid Cai, B.Sc.

Completed on: March 23, 2015

CPP ENVIRONMENTAL
Charette Pell Poscente

#154 – 150 Chippewa Road
Sherwood Park, AB, T8A 6A2
P 780.570.5818

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Executive Summary

Water quality and flow sampling data collected during 2005 to 2007 were used to estimate mean annual export from Moose Lake watershed tributaries, with the purpose to inform lake watershed management. At this time, only about half of the Moose Lake watershed contributed to Moose Lake itself due to the recharge of groundwater and lakes following a two-decade regional water deficit. Thus, Bangs and Kehiwin lakes did not discharge to Moose Lake (via the Thinlake River). The main source of discharge and nutrient load to Moose Lake was Yelling Creek, via the Thinlake River. Yelling Creek had the highest flow-weighted concentrations and export coefficients for all constituents (Total Nitrogen, Total Inorganic Nitrogen, Total Phosphorus, Total Dissolved Phosphorus), producing very high nutrient loads to Moose Lake from the Thinlake River. Valere Creek, another tributary to Moose Lake, had the second-highest concentrations and nutrient loads. A strong linkage between nutrient production per hectare and human disturbance was evident by the linear relationship between the percentage of watershed as human disturbance and nutrient export coefficients. Watersheds with the greatest percentage of human disturbance (i.e., Yelling Creek, Valere Creek, Kehiwin Boat Launch) also had the highest inorganic to toal nitrogen ratio, which is an indicator of agricultural disturbance. We recommend that nutrient management in the Moose Lake watershed focus on watersheds that have a percentage of human disturbance greater than 50%, with watershed slope having a magnifying effect.

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Introduction

Moose Lake is a popular recreational lake in the M.D. of Bonnyville of northeastern Alberta. Its water quality has long been a source of concern with permanent residents, seasonal residents and daily users. As the Town of Bonnyville's source of drinking water, Moose Lake has been under Alberta Health Services advisories for blue-green algae and fecal coliforms in the past, most recently in 2012. Because of high levels of organic material, substantial amounts of chlorine disinfectant is added to the source water at the drinking water treatment plant. The 2014 State of the Watershed report identifies Moose Lake as having the second highest nutrient concentrations, which lead to algal blooms, in the Beaver River watershed (Beaver River Watershed Alliance, 2014). The highest concentrations are found in Kehiwin Lake, which is located in the upstream portion of the Moose Lake watershed. These concerns have led to the development of an intensive stream monitoring program for the Moose Lake watershed, including about a dozen sampling sites. The purpose of this project is to synthesize this information into a report that determines and quantifies sources of nutrient loading to Moose Lake, and suggests management strategies for stressors.

Methodology

Characteristics of the Moose Lake Watershed

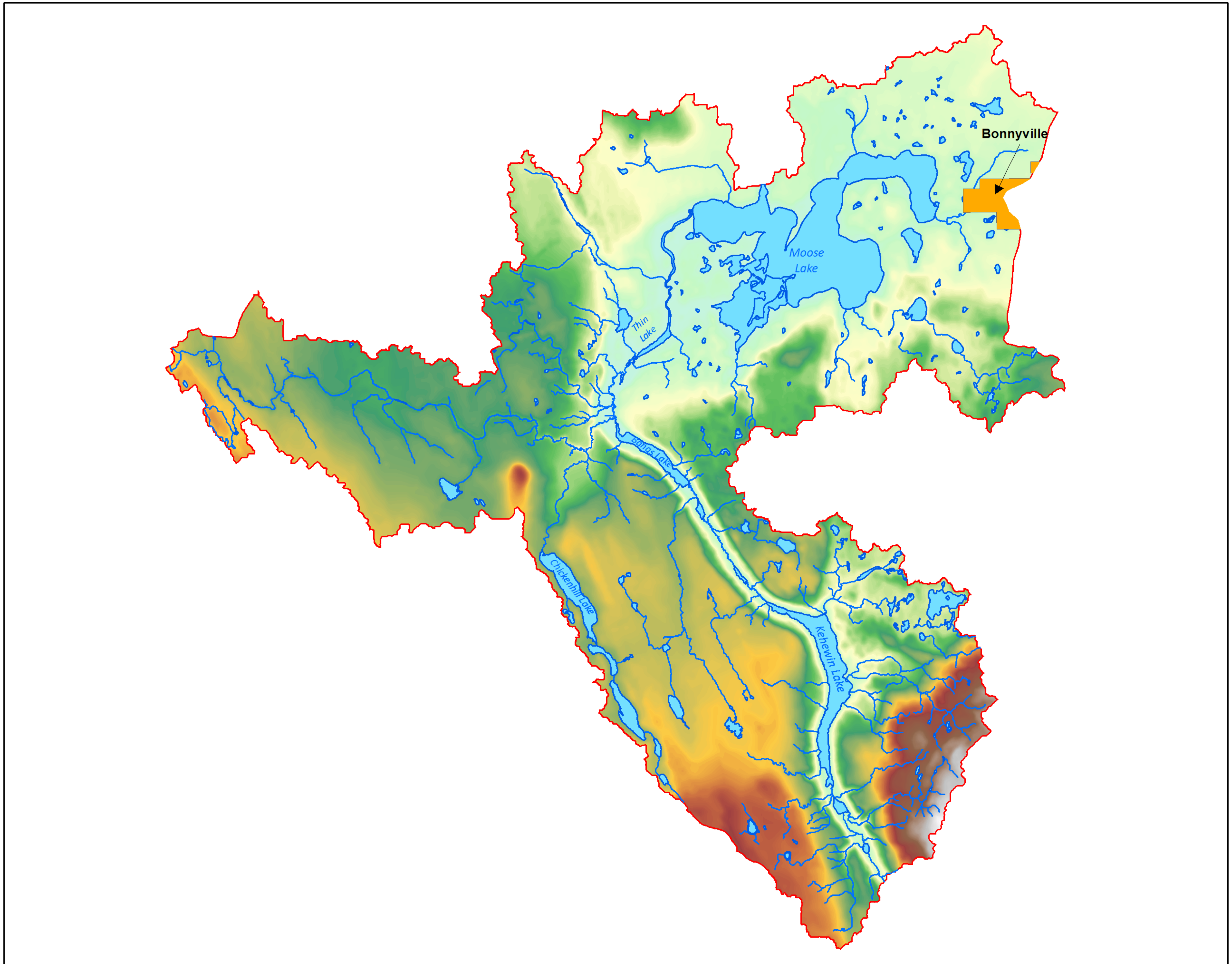
<u>Ecoregion and Geology</u>

The Moose Lake watershed is located within the Boreal Transition ecoregion of the Beaver River watershed in northeastern Alberta. The topography of the watershed generally consists of flat to gentle rolling terrain, although it is moderately rolling and hilly in the southern portion surrounding Kehiwin Lake (Figure 1). Natural regions in the watershed can be described by dry mixedwood dominated by species of trembling aspen, balsam poplar, white birch, white spruce and balsam fir (Mitchell and Prepas, 1990). As of 2013, more than 60% of the watershed has been cleared for agriculture, with the area surrounding Yelling Creek having the highest agricultural intensity. Most of the developments are mixed farming and large areas for cattle grazing (BRWA, 2014).

Surficial deposits, sometimes referred to as drifts, consist of all unconsolidated deposits above the top of bedrock to ground surface. Surficial geology of the Moose Lake watershed is mainly comprised of successive till and intertill formations, unconsolidated sediments deposited during glacial and interglacial episodes respectively. Andriashek (1989) mapped the glacial formations in the drift based on their dominant lithological characteristics, and members within several formations were identified based on their transition from glacial to interglacial depositional environment. Subsequent work by the Alberta

Moose Lake Watershed: Nutrient Export Study

Figure 1: Moose Lake watershed overview.



Streams
Town of Bonnyville
Waterbodies
Gross Drainage Basin

Elevation MASL
819 m
525 m

Source: Altalis

0 2.5 5 10 km

Coordinates system: NAD 1983 UTM Zone 12N

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Geologic Survey (AGS) classified these formations, based on generic stratigraphy hydrogeologic properties, as aquifers and aquitards (aquicludes). In general, aquifers consist of coarse unconsolidated materials such as sand and gravel, which have greater permeability than fine materials such as silt and clay.

Coarse materials such as sand and gravel are important from the perspective of nutrient movement in the watershed. Water has a shorter residency time in sand and gravel which provides an ideal situation for nutrient transport. Sand and gravel deposit near the ground surface also allows faster infiltration of nutrients and other constituents into the groundwater table. Not only is the residency time for water in fines (silt and clay) exponentially greater than sand and gravel, nitrogen and phosphorus can attach to fine grains and higher pore space (porosity) of fines, so that nutrients are “absorbed” by the silt and clay. Natural geochemical processes also take advantage of the long residency time to reduce/alter subsurface nutrients.

In terms of soils, a combination of organic, loamy and sandy soils is present at the low lying areas surrounding Moose Lake. Roughly 40% of the shoreline consists of well drained loamy soils along the north and east side of the lake. Another 50% of the shoreline consists of well drained loamy sands that occupy the area northwest and southwest of the lake (Prather et al., 2005). A large portion of the natural shoreline around Moose Lake has been modified due to cottage developments, which makes up the majority use of land around the lake.

Climate

Continental boreal climate prevails in the Moose Lake watershed. In general, short summers and long winters are common throughout the Beaver River watershed. The Environment Canada weather station at Cold Lake has recorded year round climate data since 1951. Mean annual temperature at Cold Lake from 1956 to 2003 is 1.65°C. An increase in average temperature was observed from 1986 to 2003 when the mean annual temperature was 2.2°C. This temperature increase has been correlated with the regional warming effects of Pacific Decadal Oscillation (Komex, 2005). Mean annual precipitation in the Moose Lake watershed ranges from 430 mm to 470 mm per year. Figure 2 shows the average monthly precipitation at the Cold Lake weather station during the period of the Moose Lake water quality sampling, compared with the long-term average.

The Lake Basin

Moose Lake can be divided into four distinctive bays: Franchere Bay, Island Bay, Bonnyville Beach Bay (Main Bay) and Vezeau Bay, each of which have their own distinctive physical and chemical characteristics (Mitchell and Prepas, 1990). The lake outflows to the Mooselake River at the northern edge of Franchere Bay, only 3.5 km from the main tributary’s (Thinlake River) inflow point. The outlet of Moose Lake has been regulated by a weir since 1951, and has not produced consistent flow to the Mooselake River. When it flows, the Mooselake River discharges north into the Beaver River.

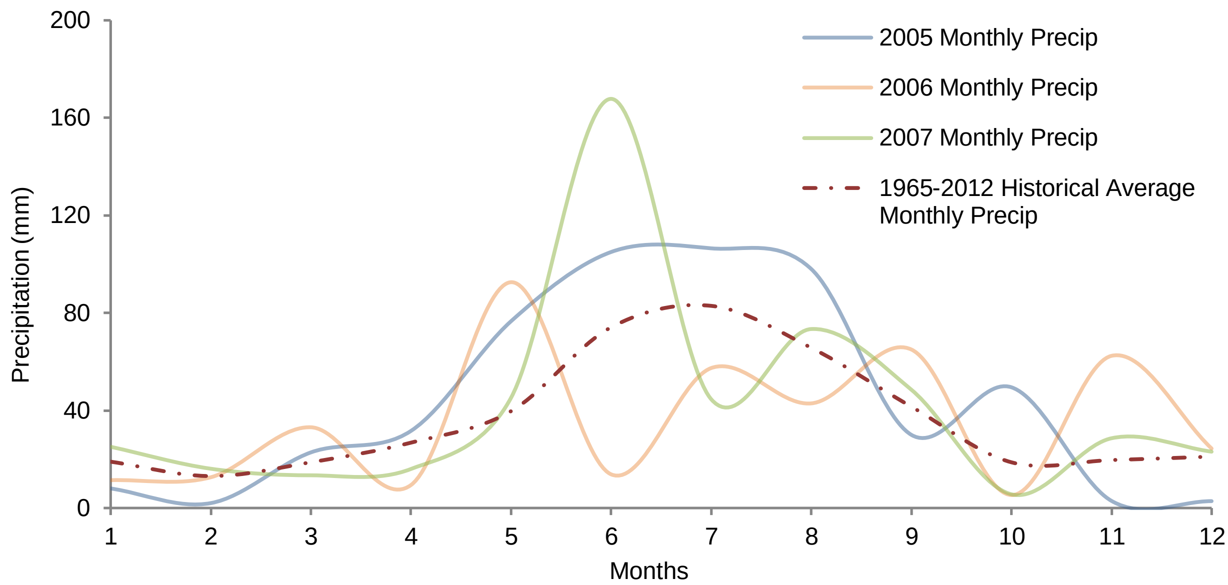


Figure 2: Precipitation at Cold Lake climate station during the study period.

<u>The Watershed</u>

The Moose Lake watershed has a gross drainage area of roughly 932 km². Some of this area (334.6 km^2), referred to as non-contributing drainage, is expected not to contribute runoff under average conditions. The surface area of Moose Lake is roughly 40 km², which corresponds to a watershed to lake surface area ratio of 20 to 1. Notable lakes within the Moose Lake watershed include Kehiwin Lake and Chickenhill Lake, both of which drain the southern portion of the watershed. The Kehiwin Lake sub-watershed, which drains into Bangs Lake and then the Thinlake River to Moose Lake, is about 168 km^2. Adjacent to the Kehiwin Lake sub-watershed, Bentley Lake and Chickenhill Lake, which then flow into Yelling Creek and then to the Thinlake River to Moose Lake. The Thinlake River flows though Thin Lake and eventually into Moose Lake, after draining 75% of the entire watershed. The remaining 25% of the watershed consists of five intermittent streams draining directly into Moose Lake. Several large non-contributing areas are located near the extremities of the watershed, east of Bentley Lake and Chickenhill Lake, as well as a portion north of Moose Lake (BRWA, 2014).

Data & Analyses

The Moose Lake nutrient loading study is a quantitative estimation of nutrient loading and export in several sub-watersheds of the Moose Lake watershed. We also describe the relationship between loading and land use, for the purposes of informing management. This was done through the following tasks:

- Data collection (both ESRD and AAFRD data) and QA/QC of the datasets;
- Sub-watershed delineation;
- Streamflow modelling; and
- Load modelling over the sampling period.

Sub-watershed Delineation

Sub-watersheds were delineated to support flow modelling and estimating annual loads for each sampling site. Both gross (entire watershed area), and effective (gross minus non-contributing areas) sub-watersheds were generated. Gross drainage areas were delineated by combining the Base Features Defined Watersheds (ESRD) that flow toward the sampling site, as determined by the Base Features Hydrography Single Line Network (ESRD). The Agriculture and Agri-Food Canada's (AAFC) Watersheds Projects (2012) non-contributing areas were clipped out of the gross drainage areas to produce effective watersheds (Figure 2).

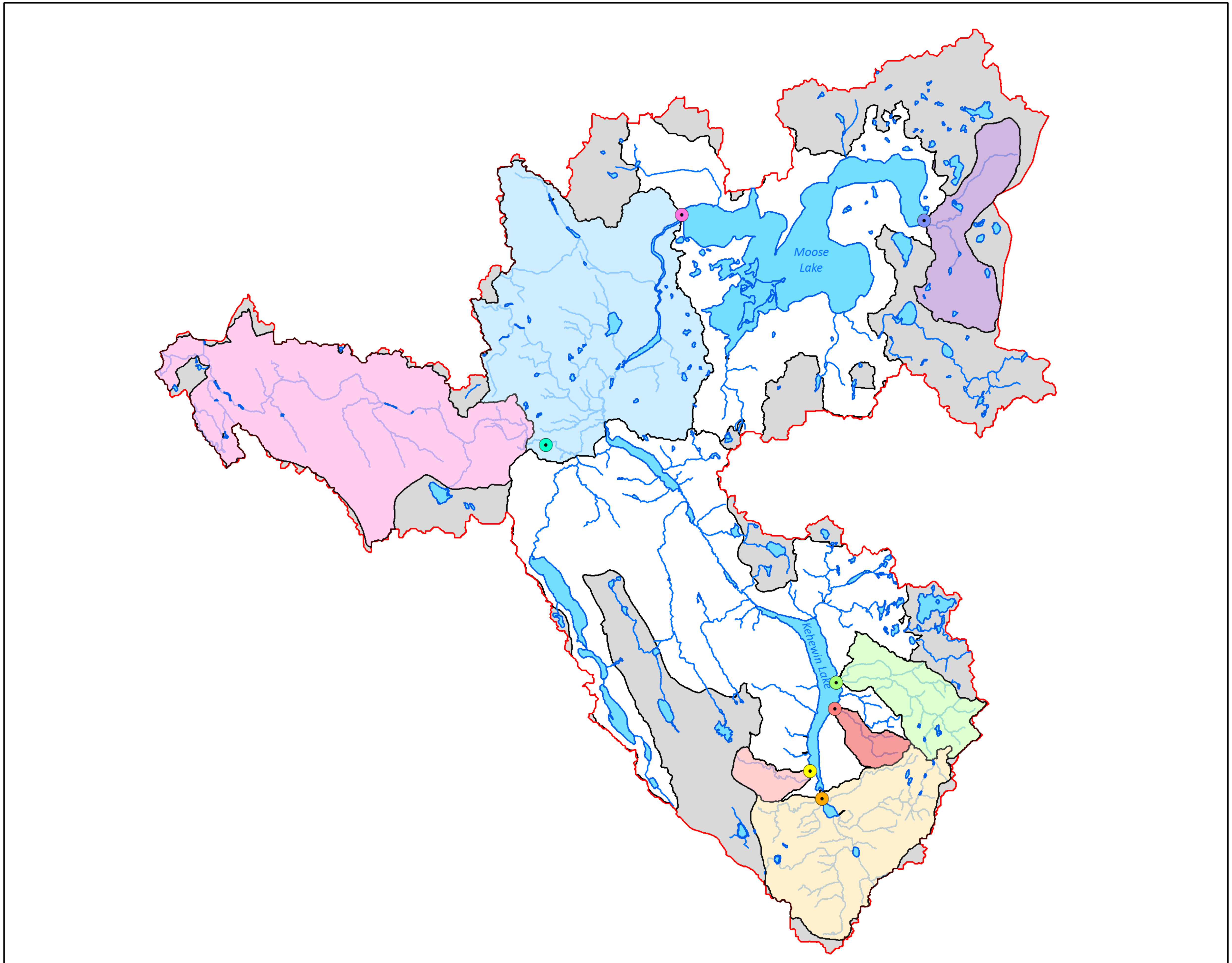
Flow Modelling

In order to estimate the nutrient load from the Moose Lake sub-watersheds, the amount of runoff from each of the sub-watersheds was estimated. Seasonal and annual discharges from nearby Water Survey of Canada (WSC) stream flow monitoring stations were compiled over the common period of record from 2005-2007 to correspond with the duration of the sampling campaign in Moose Lake (Table 1). The watersheds of the selected stations share many similarities in topography, land cover and climate with the Moose Lake watershed. For these stations, a strong linear relationship (R^2>0.92) is observed between the cumulative annual discharge vs. size of the effective drainage basin (Figure 4).

Table 1: WSC stream flow stations nearest to the Moose Lake watershed.

Station ID	Station Name	Effective Drainage Area (Km²)	Years of Data on Record
05ED002	Atimoswe Creek Near Elk Point	250	1975-2011
06AA002	Amisk River at Hwy 36	1890	1971-2012
05EC002	Waskatenau Creek Near Waskatenau	205	1971-2012
05ED003	Moosehills Creek Near Elk Point	36.5	1978-2009
06AC001	Jackfish Creek Near La Corey	333	1972-2011
06AA001	Beaver River Near Goodridge	3780	1967-2011
06AD006	Beaver River at Cold Lake Reserve	11600	1955-2013

Alberta Environment and Sustainable Resource Development had previously selected Atimoswe Creek to model water level in Moose Lake (AENV, 2006a). Atimoswe Creek is immediately adjacent to the Moose Lake watershed, thus both watersheds are similar in size, topography, and land cover which leads to similar responses to storm events. Using the linear relationship, relative effective watershed areas, and daily flow averages from Atimoswe Creek, we estimated mean daily flow rates at each of the sampling stations in the Moose Lake watershed. Sample flows and daily flows for the period of record are required for load estimation using FLUX32.



Moose Lake Watershed:
Nutrient Export Study

Figure 2: Sampling stations and their effective sub-watersheds.

Streams

Sampling Station Location

- Kehiwin East
- Kehiwin Lake @ Highway 28
- Kehiwin Lake Boat Launch
- Lloyd's Creek
- Thinlake River
- Valere Creek
- Yelling Creek

Waterbodies

Gross Moose Lake Watershed

Non Contributing Areas

Sampled Sub-Watersheds

- Boat Launch
- Highway 28
- Kehewin East
- Lloyd's Creek
- Thinlake River
- Valere Creek
- Yelling Creek

Source: Altalis

0 2.5 5 10 km

Coordinates system:
NAD 1983 UTM Zone 12N

Date:
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Nutrient Load Estimation

Annual flow-weighted concentrations and loading estimates were derived for each sampling site using the FLUX32 software (US Army Corps of Engineers). FLUX32 requires 2 files; one file with measured concentrations and flows, the other file with daily flows for the site. Measured constituent concentrations and flows are used in loading estimation. For days with missing data, FLUX32 uses daily load estimates from measured data to fill in the blanks, based on the daily flow dataset. Since they were unavailable, daily flows were modelled from Atimoswe Creek (Walker, 1999; see flow modelling).

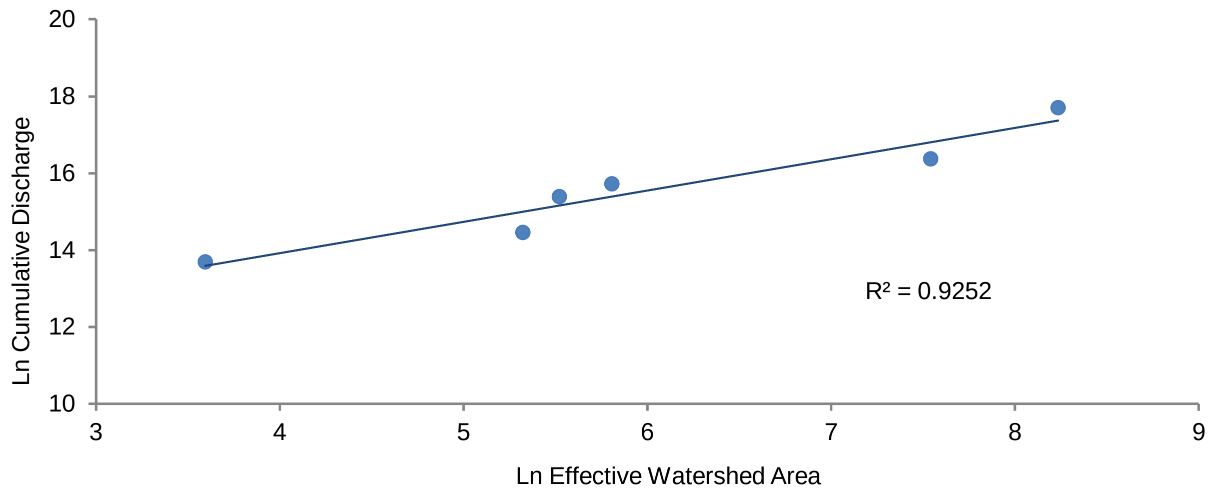


Figure 4: Mean (March to May of 2005 to 2007) cumulative discharge versus effective watershed area of selected WSC stations.

Linear regressions were drawn between measured nutrient concentrations and flows. Due to the weak linear relationship between constituent concentrations and flows, regression-based load estimation was not used (Walker, 1999). Loads were estimated based on the following "ratio estimate" equation:

$$Load\ (kg/yr) = CQ * Q/q$$

CQ = mean flux over N days (kg/yr)

Q = mean annual flow (m^3/yr)

q = mean of instantaneous measured flows

This method bases the loading estimate on the flow-weighted average concentration times the mean flow over the averaging period. This method performs best when flow and concentration are unrelated or weakly related (Cochran, 1977). The jackknife procedure (Mosteller and Tukey, 1978) is used to estimate error variances in FLUX32. Using these methods, Annual Mean Flow Weighted Concentration (AMFWC) for Total Nitrogen (TN), Total Inorganic Nitrogen (TIN), Total Phosphorous (TP), Total Dissolved Phosphorous (TDP), and Chloride (Cl) were estimated as an average of the 3 year sampling period.

Results and Discussion

General Hydrological Conditions

During the years of this study, the entire Beaver River watershed region had experienced a 20-year hydrological water deficit, which significantly lowered groundwater and surface water levels in the region (AENV, 2006a). From the 1980s to the early 2000s, Moose Lake water levels had dropped by over 2 meters, indicating a negative water balance. During 2005 to 2007, Kehiwin Lake and Bangs Lake did not outflow, and thus the southern portion of the Moose Lake watershed did not contribute to the Moose Lake water balance. Despite average to above-average precipitation (Figure 2), streams in the Moose Lake watershed, as well as the adjacent Atimoswe Creek continuous monitoring station, had short ephemeral flow that generally stopped by late spring or early summer. Thus, from 2005 to 2007, water produced in the Moose Lake watershed was predominantly recharging local ground and surface water.

Due to the hydrological conditions at the time, only “primary streams” flowed and were sampled, and data was collected mainly during the March to May timeframe of each year. During the first year of study (2005), 12 sites were visited. However, only 7 streams flowed at that time. Sites that didn’t flow were not visited again in 2006 and 2007. Only two tributaries contributed loading to Moose Lake: the Thinlake River and Valere’s Creek. Yelling Creek was the main source of discharge to the Thinlake River and the southern portion of the Moose Lake watershed was non-contributing.

Flow Modelling

Streamflow was sampled approximately 14 times during the spring from 2005 to 2007. FLUX32 requires a daily flow dataset for the period of sampling, which can be created through flow modelling. Although daily streamflow modelling can be relatively inaccurate on a day to day basis, in general, modelled flows corresponded reasonably well to measured flows (see Figure 5 for Thinlake River). Also, since the FLUX32 output is annual loading, daily variance on flow isn’t likely to significantly influence the results. Annual discharge is highly predictable regionally, based on watershed area, which is what was used for flow modelling.

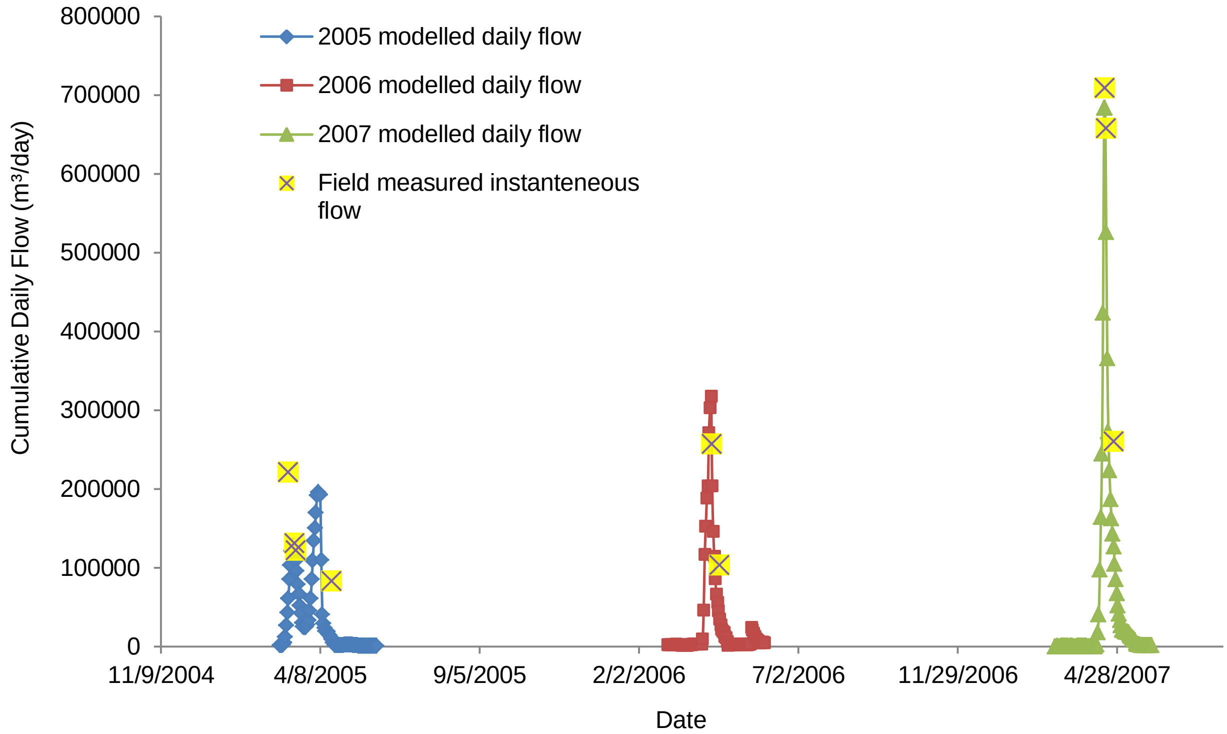


Figure 5: Modelled and measured flow at the Thinlake River station near the inflow to Moose Lake.

Constituent Concentrations

Phosphorus and nitrogen Flow-weighted concentrations (AMFWCs) were higher for tributaries flowing into Moose Lake (Thinlake River and Valere Creek) and lower for those flowing into Kehiwin Lake (Table 2). Yelling Creek, which feeds the Thinlake River, had the highest concentrations in the entire Moose Lake Watershed. TN and TP concentrations were double or more in Yelling Creek than those of the tributaries feeding Kehiwin Lake, which were relatively uniform. TIN concentrations were relatively low in the tributaries on the east side of Kehiwin Lake. In general, nutrient concentrations were lowest in the Kehiwin Lake sub-watersheds, reflecting the lower intensity of land use.

Chloride concentrations were generally higher in streams with low topographic position and along glacial meltwater channels (Kehiwin Hwy 28, Yelling Creek, Thinlake River, Valere Creek), reflecting groundwater influence. Out of these sites, chloride concentrations were relatively higher in Valere, Yelling, and Kehiwin Hwy 28 streams, despite the lower topographic position of the Thinlake River, which is also at the terminus of the main glacial meltwater channel that runs toward Moose Lake. This may be the result of anthropogenic influence since the three other sites are located in areas with high agriculture and urban development. Agro-chemicals and road salt, in particular, are known to influence chloride concentrations (See Figures 6 and 7 for Agricultural & Human Footprint). Valere Creek drains urban areas and is next to a parking lot. Kehiwin Hwy 28 is at the bottom of two steep hills that produces ditch runoff to the site. That said, chloride concentrations are about 10 times lower than levels expected to affect aquatic life, thus there is no imminent threat.

Table 2: Mean (2005-2007) flow weighted concentration, annual load, and annual runoff in sampled sub-watersheds of the Moose Lake watershed.

Constituents		Station						
		Kehewin L. Inflows				Moose L. Inflows		
		Kehewin Boat Launch	Kehewin Hwy 28	Kehewin East	Lloyd's Creek	Yelling Creek	Thinlake River	Valere Creek
Total Nitrogen (TN)	Constituent Flux (kg/yr)	634	3,444	509	1,130	11,023	16,865	2,175
	Flow Weighted Concentration (mg/L)	2.92	2.95	2.28	1.88	5.77	4.40	3.24
	Coefficient of Variance	0.13	0.08	0.06	0.03	0.09	0.08	0.11
	Mean Annual Discharge (dam³/yr)	217	1,166	223	600	1,909	3,833	673
	Mean Annual Runoff per Watershed Area(dam³/km²/year)	42	25	41	30	22	18	29
Total Inorganic Nitrogen (TIN)	Constituent Flux (kg/yr)	173	795	36	146	4,986	7,035	539
	Flow Weighted Concentration (mg/L)	0.80	0.68	0.16	0.24	2.61	1.84	0.80
	Coefficient of Variance	0.22	0.16	0.20	0.11	0.12	0.13	0.21
	Mean Annual Discharge (dam³/yr)	217	1,166	223	600	1,909	3,833	673
	Mean Annual Runoff per Watershed Area(dam³/km²/year)	42	25	41	30	22	18	29
Total Phosphorus (TP)	Constituent Flux (kg/yr)	134	686	145	300	2,895	3,146	614
	Flow Weighted Concentration (mg/L)	0.62	0.59	0.65	0.50	1.52	0.82	0.92
	Coefficient of Variance	0.14	0.13	0.14	0.12	0.10	0.11	0.11
	Mean Annual Discharge (dam³/yr)	217	1,166	223	600	1,909	3,833	673
	Mean Annual Runoff per Watershed Area(dam³/km²/year)	42	25	41	30	22	18	29
Total Dissolved Phosphorus (TDP)	Constituent Flux (kg/yr)	87	489	112	182	2,161	2,510	518
	Flow Weighted Concentration (mg/L)	0.40	0.42	0.50	0.30	1.14	0.66	0.77
	Coefficient of Variance	0.21	0.17	0.19	0.20	0.10	0.12	0.09
	Mean Annual Discharge (dam³/yr)	217	1,166	223	600	1,909	3,833	673
	Mean Annual Runoff per Watershed Area(dam³/km²/year)	42	25	41	30	22	18	29
Chloride (Cl)	Constituent Flux (kg/yr)	1,193	26,380	804	2,680	41,802	62,242	16,314
	Flow Weighted Concentration (mg/L)	5.5	22.6	3.6	4.5	22.0	16.2	24.3
	Coefficient of Variance	0.20	0.11	0.12	0.24	0.32	0.15	0.09
	Mean Annual Discharge (dam³/yr)	217	1,166	223	600	1,909	3,833	673
	Mean Annual Runoff per Watershed Area(dam³/km²/year)	42	25	41	30	22	18	29

Nutrient Flux

Spatial patterns in phosphorus and nitrogen load differed than those of AMFWCs since load is the product of concentration and flow. In general, streams that had high flows and/or high nutrient concentrations generally had high loading values. For Kehiwin Lake tributaries, since TP and TN concentrations were fairly consistent among sites, loads reflected flows. Thus, Kehiwin Hwy 28, which has a relatively large watershed area (and thus flow), provided the majority of the nutrient load to Kehiwin Lake. The Thinlake River produced the greatest nutrient load to Moose Lake. Yelling Creek supplied 65% of the TN and 86% of the TP load from the Thinlake River to Moose Lake.

Per hectare, nutrient export is much more consistent among sub-watersheds than other metrics (Table 3). With the exception of Lloyd's Creek, TN and TP export coefficients are similar among all sub-watersheds. This is somewhat surprising, given the spatial differences in concentration and loading among the watersheds. The TN export coefficient was highest in the Yelling Creek and Kehiwin Boat Launch sub-watersheds. TN export for these watersheds was in the top 30% of 80 streams in Alberta with available data, meaning that these coefficients are relatively high (Regier and Trew, 2015). TN export coefficients in the rest of the sampled sub-watersheds (Valere Creek, Thinlake River, etc.) are near the median or slightly higher, as compared to other streams with data in the province. Lloyd's Creek recorded the lowest TN export coefficient in the Moose Lake Watershed.

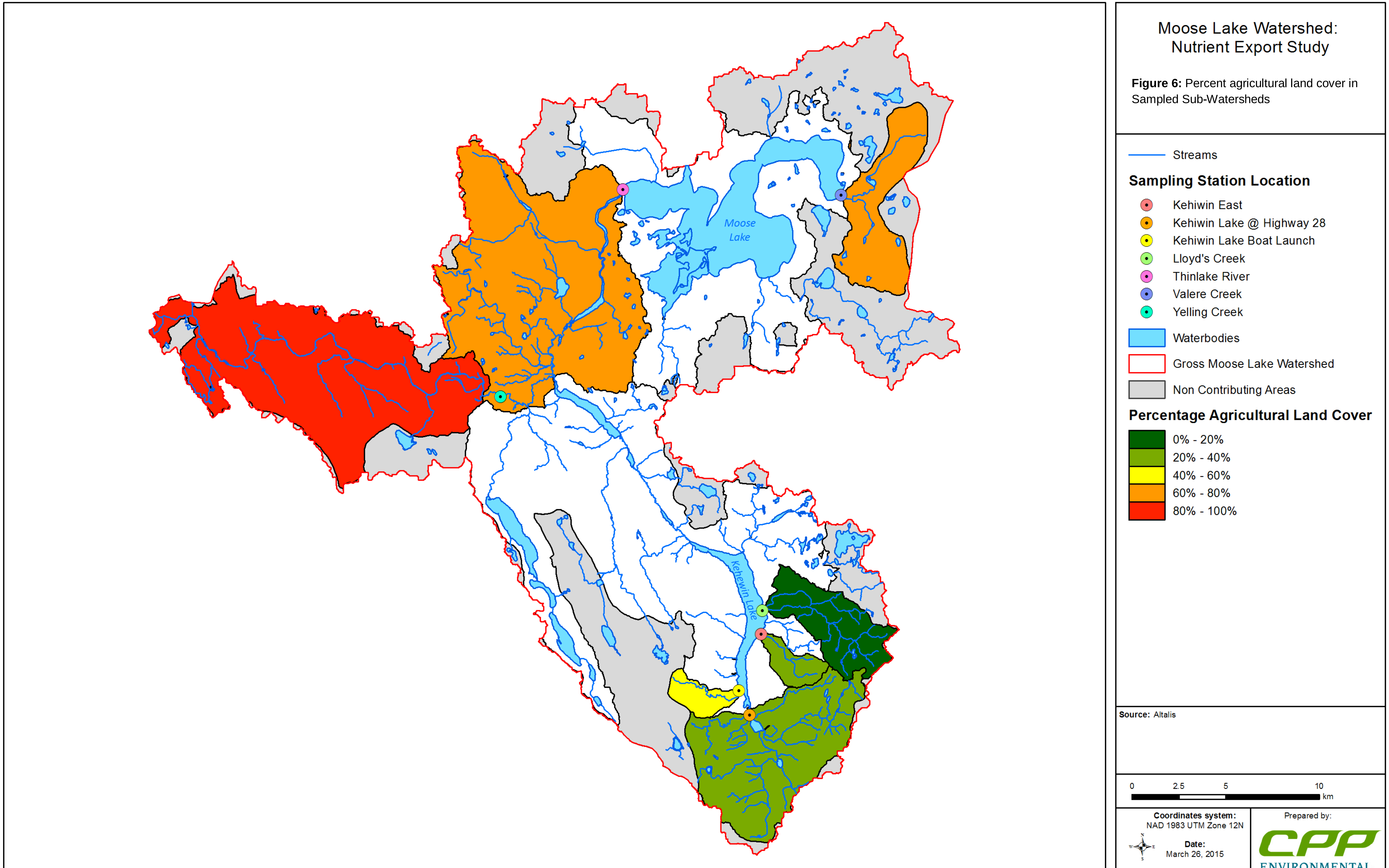
TP export coefficients in all sub-watersheds are high from a provincial standpoint. As per nitrogen, Yelling Creek had the highest TP export (0.33 kg/ha/yr) in the Moose Lake watershed, which places it in the top 15% of 97 streams in the province (Regier and Trew, 2015). Yelling Creek also had the highest TDP export (0.24 kg/ha/yr) in the Moose Lake watershed. TP export from the Kehiwin Boat Launch, Kehiwin East, and Valere Creek (0.26, 0.27, and 0.27 kg/ha/yr, respectively) sub-watersheds correspond to the top 20% of streams in the province. These three sub-watersheds also recorded the second-highest TDP export coefficients. TP and TDP export coefficients in Lloyd's Creek are the lowest in the Moose Lake watershed, and were near the median of other streams in the province.

Export coefficients from Kehiwin Boat Launch, Kehiwin East, Yelling Creek and Valere Creek sub-watersheds are similar to those of moderate agricultural intensity, as defined by the Alberta Environmentally Sustainable Agriculture program. Watersheds with similar productivity include Blindman River, Grande Prairie Creek, Kleskun Drain, Rose Creek, Strawberry Creek and Tomahawk Creek Watersheds (Lorenz et al., 2008)

Similarly to Lorenz et al. (2008), a higher proportion of TP export is comprised of the dissolved fraction than for TN (Figures 8 and 9), meaning that phosphorus produced in the sampled sub-watersheds is highly bio-available. Since agriculture can use high amounts of inorganic nitrogen and phosphate, the ratio of inorganic to total nutrients is often used as an indicator of agricultural pollution. The higher the agricultural intensity, the higher the ratio of dissolved nutrients (Lorenz et al., 2008). Our study shows similar patterns where the ratio of dissolved inorganic to total N export was highest in watersheds with the greatest % agricultural land cover (Figure 8). For phosphorus, however, no pattern was discernable. Dissolved inorganic N export can be used as an indicator for agricultural influence of stream nutrient concentrations (Lorenz et al., 2008).

Table 3: Total nitrogen (TN), total inorganic nitrogen (TIN), total phosphorus (TP), total dissolved phosphorus (TDP), and chloride (Cl) mean (2005-2007) export coefficients in Moose Lake sub-watersheds.

Constituent	Station						
	Kehiwin L. Inflows				Moose L. Inflows		
	Kehiwin Boat Launch	Kehiwin Hwy 28	Kehiwin East	Lloyd's Creek	Yelling Creek	Thinlake River	Valere Creek
	Export Coefficients (kg/ha/yr)						
TN	1.22	0.73	0.94	0.57	1.24	0.79	0.94
TIN	0.33	0.17	0.07	0.07	0.56	0.33	0.23
TP	0.26	0.15	0.27	0.15	0.33	0.15	0.27
TDP	0.17	0.10	0.21	0.09	0.24	0.12	0.22
Cl	2.29	5.58	1.49	1.34	4.71	2.91	7.06



Moose Lake
Kehewin Lake
Moose Lake Watershed: Nutrient Export Study
Figure 6: Percent agricultural land cover in Sampled Sub-Watersheds
Streams
Sampling Station Location
Kehiwin East
Kehiwin Lake @ Highway 28
Kehiwin Lake Boat Launch
Lloyd's Creek
Thinlake River
Valere Creek
Yelling Creek
Waterbodies
Gross Moose Lake Watershed
Non Contributing Areas
Percentage Agricultural Land Cover
0% - 20%
20% - 40%
40% - 60%
60% - 80%
80% - 100%
Source: Altalis
0 2.5 5 10 km
Coordinates system: NAD 1983 UTM Zone 12N
Date: March 26, 2015
Prepared by:
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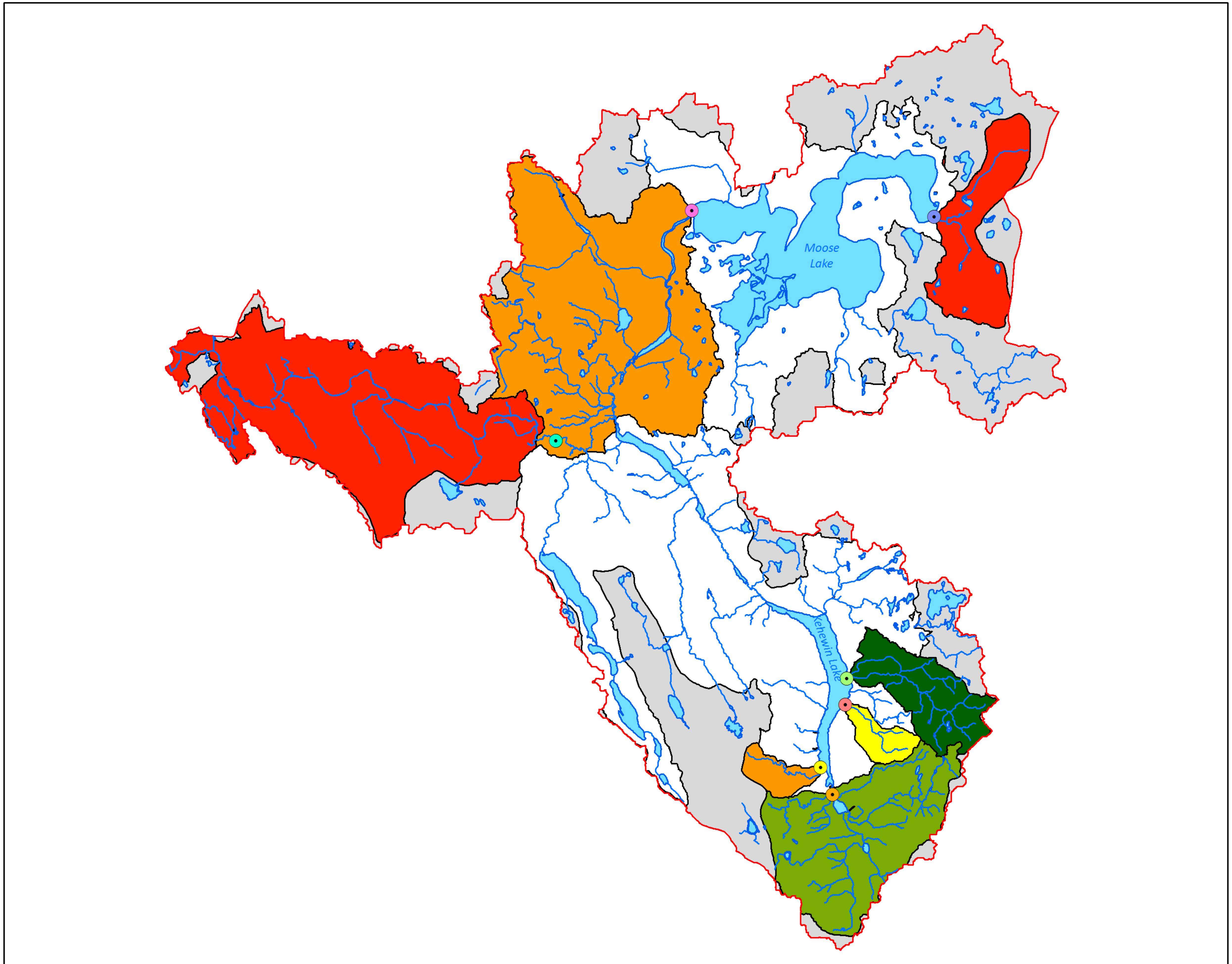
Moose Lake Watershed: Nutrient Export Study

Figure 7: Human Footprint in the Sampled Sub-Watersheds



Source: Altalis

Coordinates system: NAD 1983 UTM Zone 12N

Date: March 26, 2015

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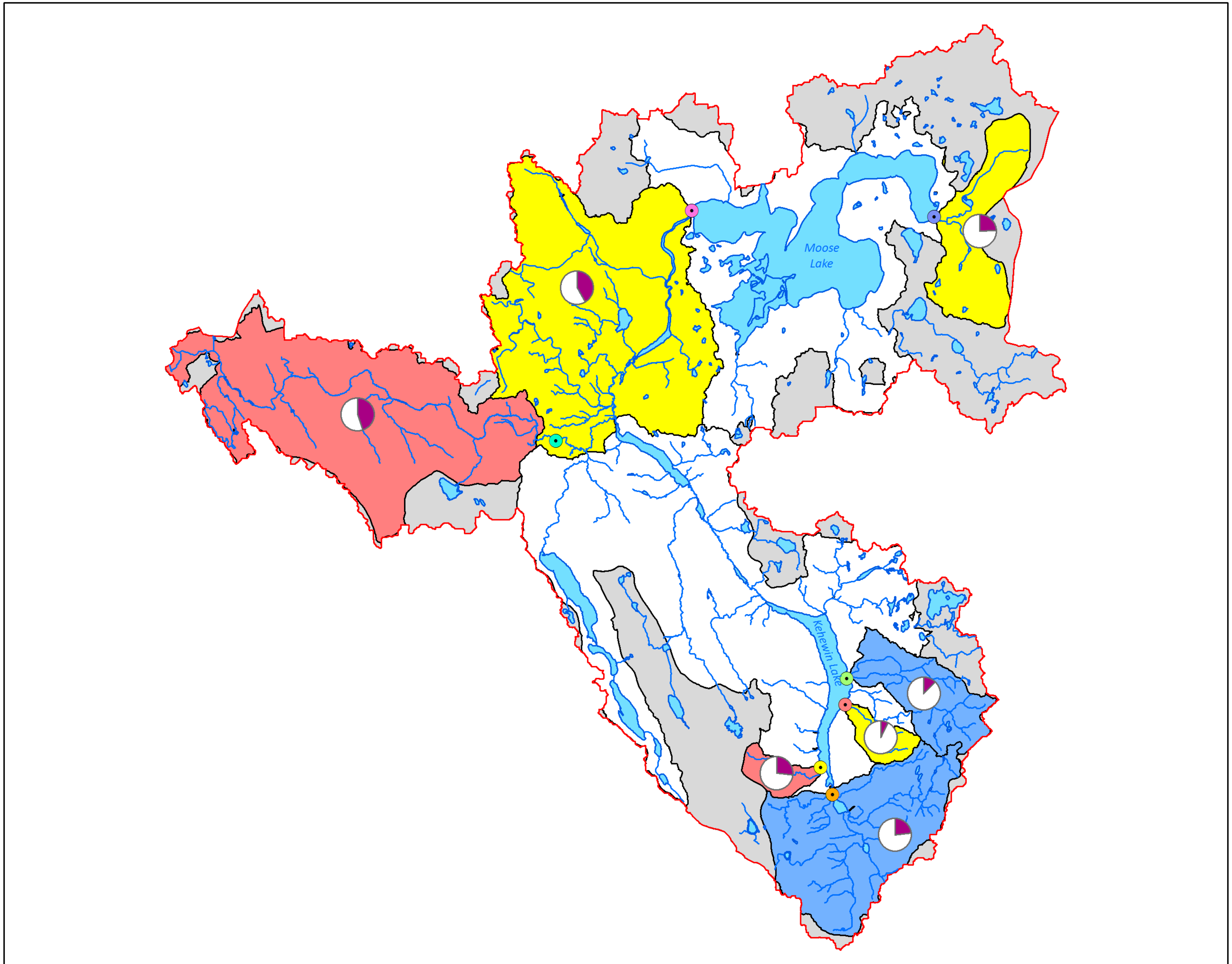

Moose Lake Watershed: Nutrient Export Study

Figure 8: Total Nitrogen export coefficients and proportion of Total Nitrogen export as Total Inorganic Nitrogen in Sampled Sub-Watersheds

Streams

Sampling Station Location

- Kehiwin East
- Kehiwin Lake @ Highway 28
- Kehiwin Lake Boat Launch
- Lloyd's Creek
- Thinlake River
- Valere Creek
- Yelling Creek

Waterbodies

Gross Moose Lake Watershed

Non Contributing Areas

Total Nitrogen Export Coefficient (kg/ha/yr)

- 0.57 - 0.75
- 0.75 - 1
- 1 - 1.25

Percentage of Total Nitrogen As Inorganic Nitrogen

Kehewin Lake Boat Launch: 27%
Kehewin Lake @ Highway 28: 23%
Kehewin East: 7%
Lloyd's Creek: 12%
Yelling Creek: 45%
Thinlake River: 42%
Valere Creek: 24%

Source: Altalis

0 2.5 5 10 km

Coordinates system: NAD 1983 UTM Zone 12N

Date: March 26, 2015

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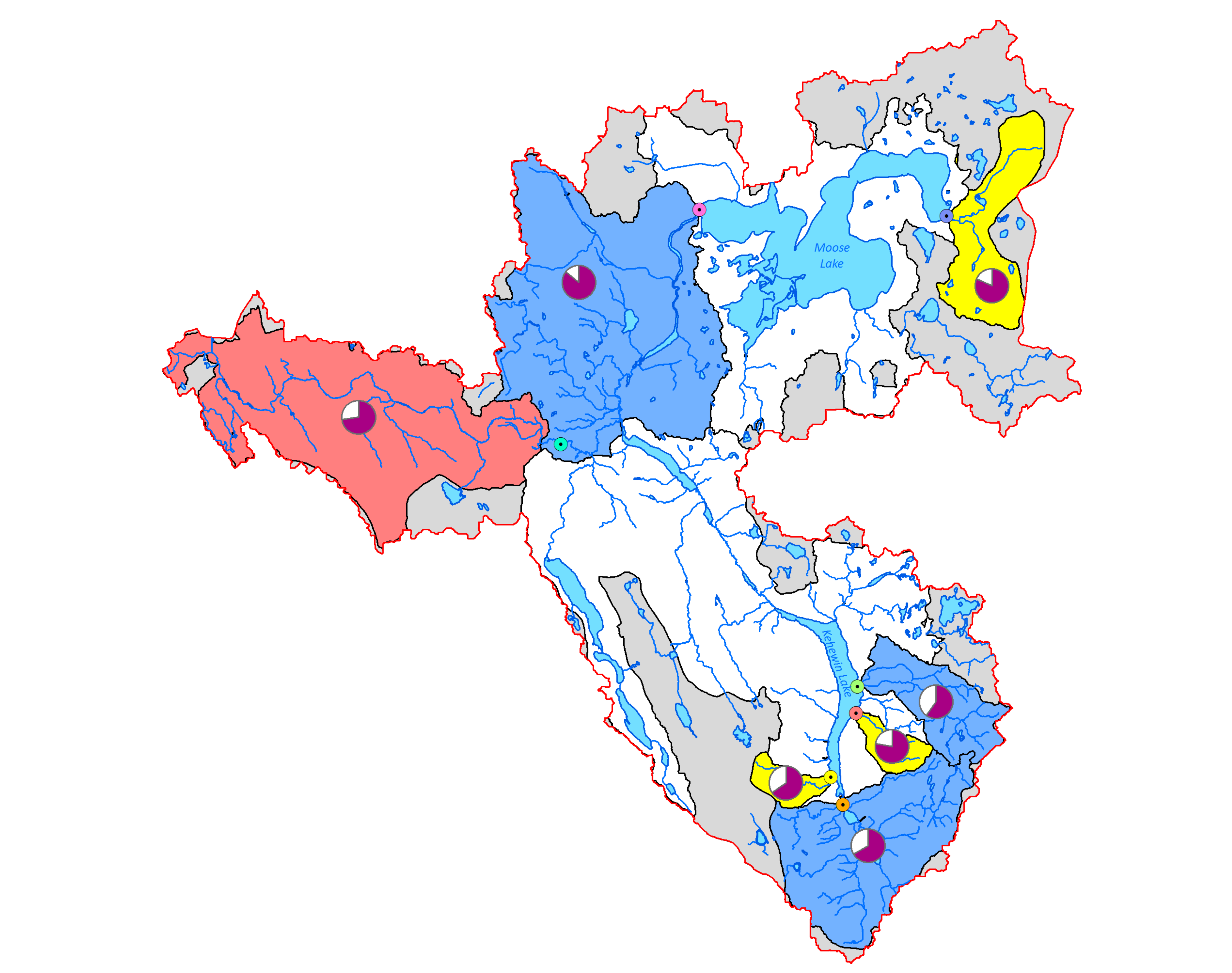


Moose Lake Watershed: Nutrient Export Study

Figure 9: Total Phosphorus export coefficients and proportion of Total Phosphorus export as Total Dissolved Phosphorus in Sampled Sub-watersheds.

Streams

Sampling Station Location

- Kehiwin East
- Kehiwin Lake @ Highway 28
- Kehiwin Lake Boat Launch
- Lloyd's Creek
- Thinlake River
- Valere Creek
- Yelling Creek

Waterbodies

Gross Moose Lake Watershed

Non Contributing Areas

Total Phosphorus Export Coefficient (kg/ha/yr)

0.15 - 0.2

0.2 - 0.3

0.3 - 0.33

Percent of Total Phosphorus As Dissolved Phosphorus

Kehewin Lake Boat Launch: 65%

Kehewin Lake @ Highway 28: 67%

Kehewin East: 78%

Lloyd's Creek: 60%

Yelling Creek: 73%

Thinlake River: 83%

Valere Creek: 81%

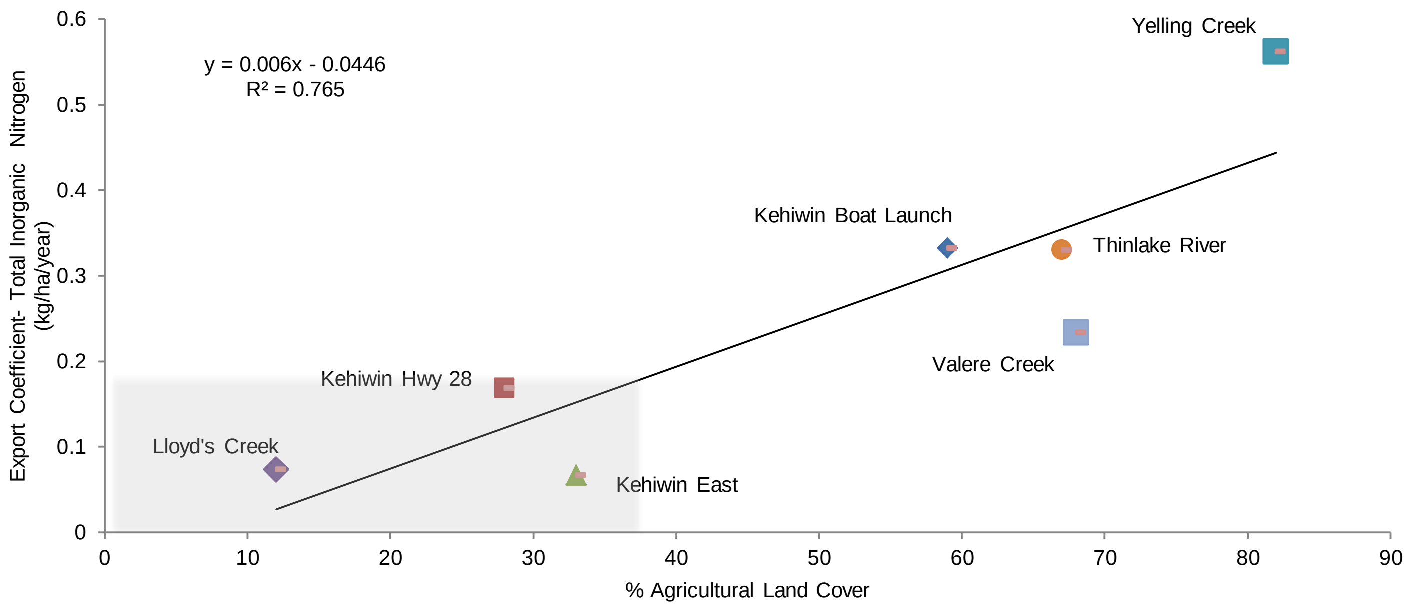
Source: Altalis

0 2.5 5 10 km

Coordinates system: NAD 1983 UTM Zone 12N

Date: March 26, 2015

Prepared by: CPP ENVIRONMENTAL



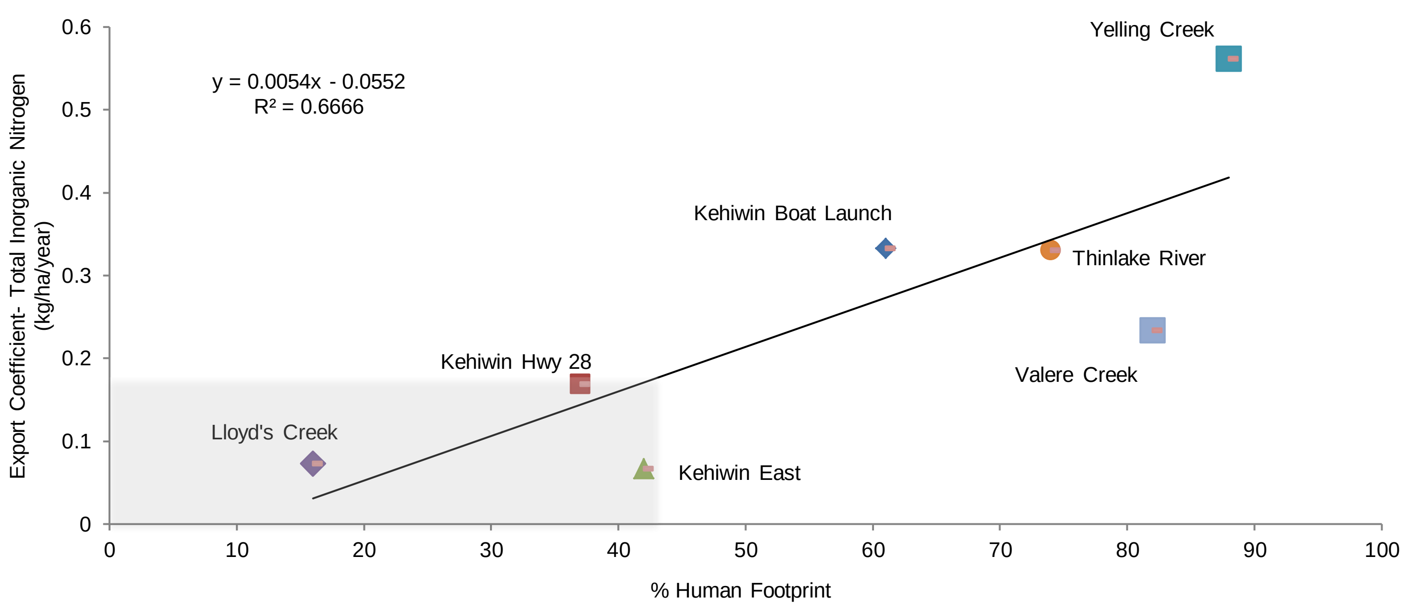


Figure 10: Export coefficients vs total disturbance (agricultural intensity and human footprint) in sampled sub-watersheds. Shaded areas represent the area in the graph where TIN is always low.

Total Inorganic Nitrogen correlated well with land cover in the sampled watersheds, while the relationship was weaker (R^2<0.5) with other metrics (Appendix B). A positive linear relationship was observed between TIN export coefficients and % of the watershed as agriculture (R^2 = 0.67) and human footprint (R^2 = 0.76) (Figure 10). In a study examining the effects of logging on streams in the boreal mixedwood ecoregion, Prepas et al. (2008) suggests a lack of response under 50% watershed disturbance. In the Beaver River watershed, AENV (2006b) suggests a lack of response in lake nutrients and water clarity under 40% disturbances. Our results are consistent when drawing a preliminary threshold analysis (Figure 10). TIN concentrations are always low when the % human disturbance is less than about 40%.

Although there is a relatively strong relationship between human footprint and nutrient export coefficients given the low sample size, a good amount of variability in the dataset is not explained by land use alone. For instance, Kehiwin Boat Launch and Yelling Creek sub-watersheds produce an equal amount of TN per hectare, despite the 27% difference in human footprint. Another example is Valere Creek and Kehiwin East, which have the same export coefficient, in spite of the 35% difference in human footprint. Since nutrient concentrations in Kehiwin Lake tributary sites are substantially lower than that of Moose Lake tributaries, Kehiwin Boat Launch and Kehiwin East must produce much more runoff per hectare than other watersheds in the Moose Lake Watershed (export ≈ (constituent concentration * flow) / watershed area). Climate and geology being equal (all sites are on the Glaciated Plain), topography must be responsible for this difference in runoff (Winter, 2001). Indeed, the two Kehiwin sites are at the toe of the substantial Moose Hills whereas the Moose Lake tributary watersheds are relatively flat. Since nutrient export coefficients are highly influenced by runoff, topography has an important role to play in nutrient export.

Conclusions

Streamflow and water quality data collected at several streams and tributaries in the Moose Lake watershed were used to develop streamflow and nutrient loading models for the 3 year sampling period of this study (2005-2007). Annual Mean Flow Weighted Concentrations and Export Coefficients for Total Nitrogen, Total Inorganic Nitrogen, Total Phosphorous, Total Dissolved Phosphorous and Total Chloride were quantified for 7 stream sampling stations in the Moose Lake watershed. Interestingly, the southern portion of the Moose Lake watershed, which drains Bangs and Kehiwin Lake, did not flow between 2005 and 2007. Thus, this sub-watershed did not provide any loading to Moose Lake. This reflects a hydrological recovery from a long-term water deficit in the region.

In general, all metrics were highest in streams with highly developed watersheds. Phosphorus and nitrogen flow-weighted concentrations were highest in the tributaries flowing into Moose Lake. They were highest in Yelling Creek, which supplies the majority of flow to the main Moose Lake tributary (Thinlake River). Loads also followed this pattern, with Yelling Creek via the Thinlake River, contributing the highest load to Moose Lake. The Kehiwin Hwy 28 stream supplied the most nutrient load to Kehiwin Lake, largely due to its greater flows generated by a relatively large watershed.

In general, nitrogen and phosphorus export coefficients in the Moose Lake sub-watersheds were higher than most streams in Alberta (Regier and Trew, 2015). The Yelling Creek sub-watershed, the main source of nutrient loading to the Thinlake River and Moose Lake itself, produced the most nutrients per hectare and ranked in the top 15% of streams in the province for nitrogen and phosphorous export. This is explained by the high density of agricultural development in the watershed. In general, export coefficients and watershed land use are highly related in the Moose Lake watershed.

Recommendations

Results from this study can support watershed management planning in the Moose Lake Watershed. In general, we recommend that watershed management strategies be applied to sub-watersheds with greater than 50% human footprint density. If resources are limited, we recommend that management responses focus on Yelling Creek, since it supplies by far most of the load to Moose Lake. Management of Kehiwin Lake water quality should focus on the Hwy 28 sub-watershed, which provides most of the nutrient load. For this site, in addition to watershed management strategies, there is an interesting opportunity for in-lake nutrient management on the pond that discharges to Kehiwin Lake. These strategies (e.g., liming, etc.) are very effective and could significantly reduce loads to Kehiwin Lake. A first step in examining this possibility is to calculate a nutrient budget for Kehiwin Lake. For Yelling Creek, work with agricultural producers will be very important. In addition to this, in-lake nutrient reduction technologies could be applied to the Thin Lake, which receives the entire load from Yelling Creek.

More broadly, we found a strong relationship between nutrient export and watershed development. There also seemed to be a linkage with watershed slope. Due to low sample size, however, we couldn't run models with multiple metrics that best predict nutrient export. Because of this low sample size, our results are not applicable to other streams in the Boreal Transition Ecoregion. Given the strong relationships found in this study, it would be worthwhile to build multi-metric models that predict nutrient export in the Boreal Transition Ecoregion that could be used for other watershed management plans. Such a study could also include a threshold analysis to support our preliminary results that nutrient export coefficients in watersheds with < 40% disturbance are unaffected.

We also recommend future studies of the Moose Lake watershed to examine the role of groundwater pathways for nutrient export. On the Glaciated Plains, surface runoff is relatively rare and most water moves through groundwater pathways (DeVito et al., 2013). Watershed geology, geochemistry and hydrogeology play an important role in nutrient transport. Understanding hydrogeology in the Moose Lake watershed, particularly areas of groundwater recharge, can help pinpoint watershed areas that should be targeted for management within sub-watersheds.

Acknowledgements

We'd like to thank Alberta Environment and Sustainable Resource development for funding this study, providing water quality, hydrology, and geospatial data, and reviewing report drafts. Mike Bilyk, Mike Smilsky, and Doug Rennie collected water quality and hydrology data in the field. Joe Prusak and Nathan Ballard reviewed the report. We'd also like to thank the North Saskatchewan Watershed Alliance for providing a draft copy of their summary report of stream nutrient data in Alberta.

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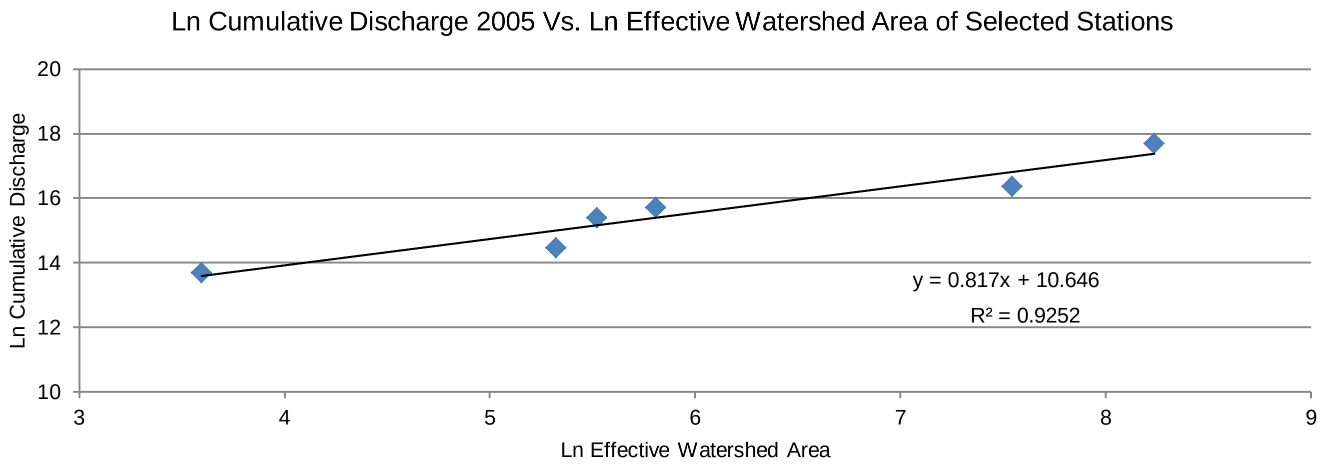
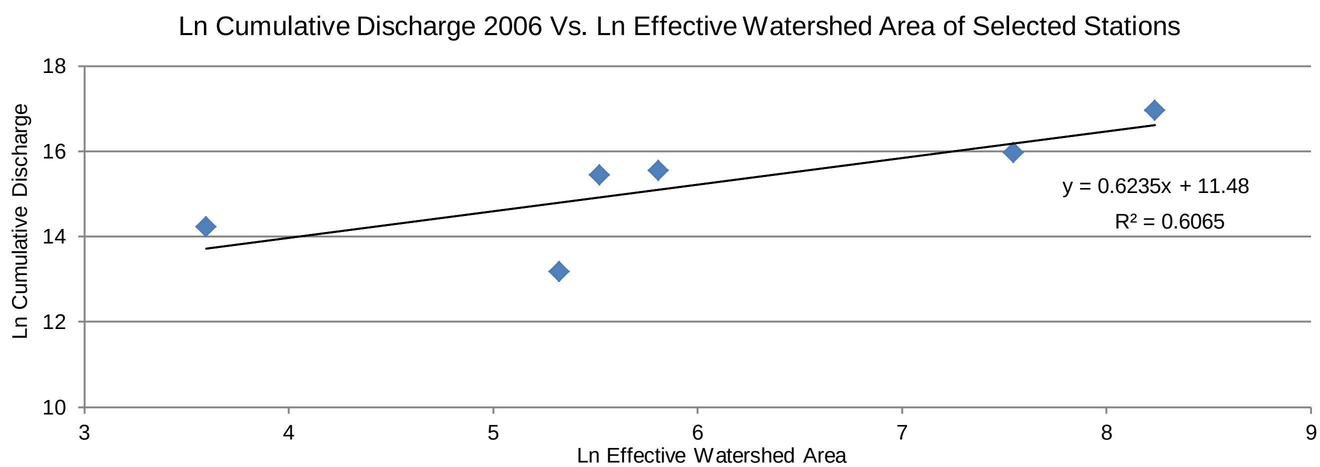
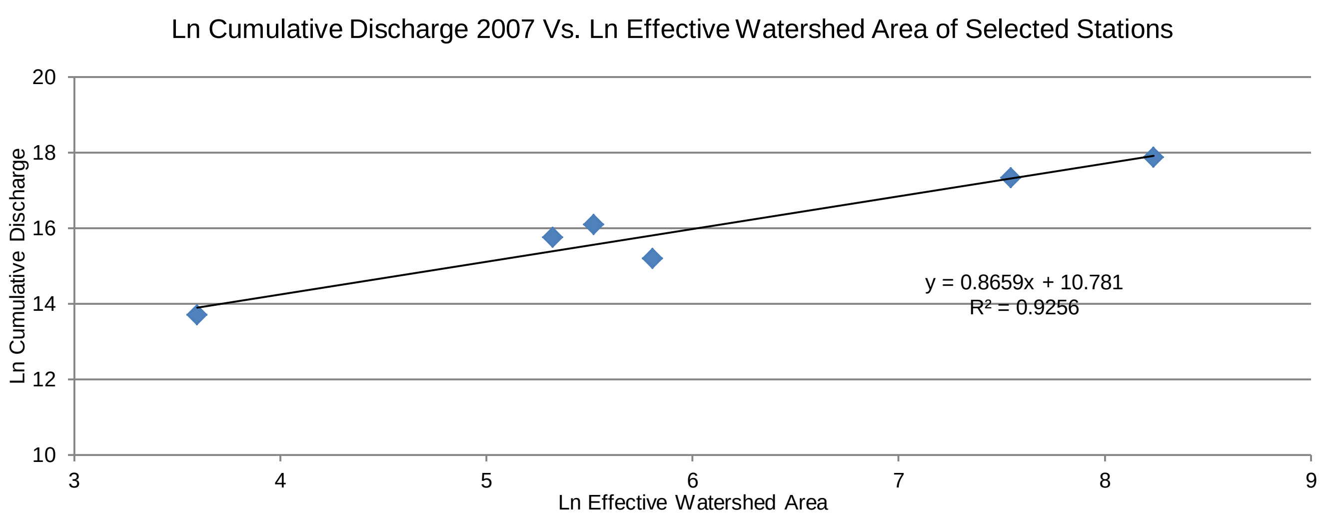
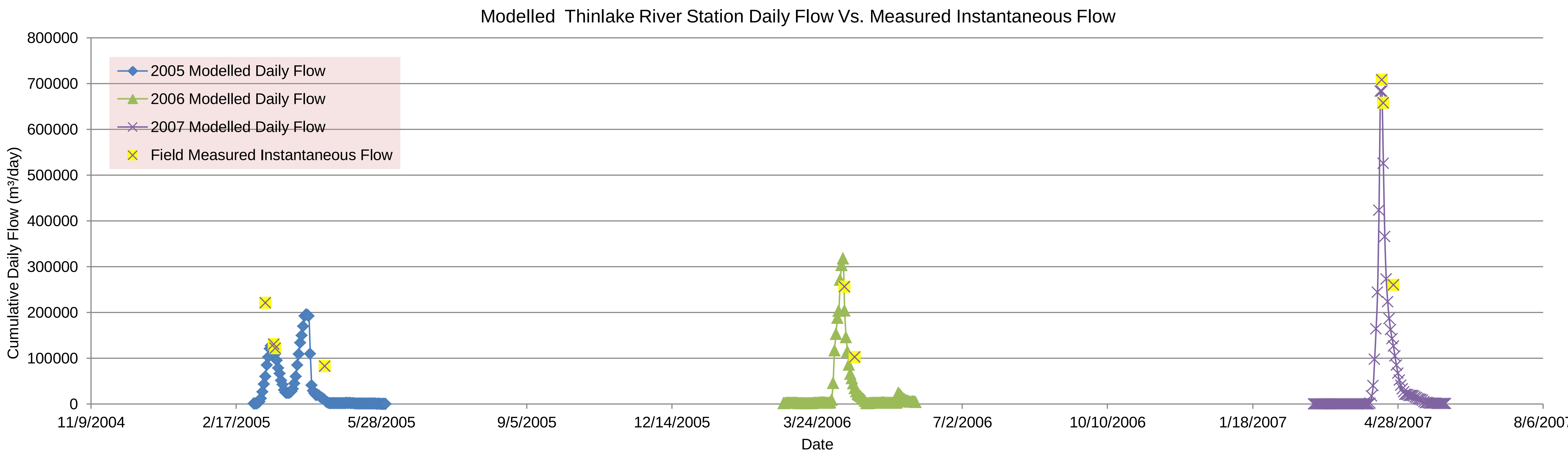
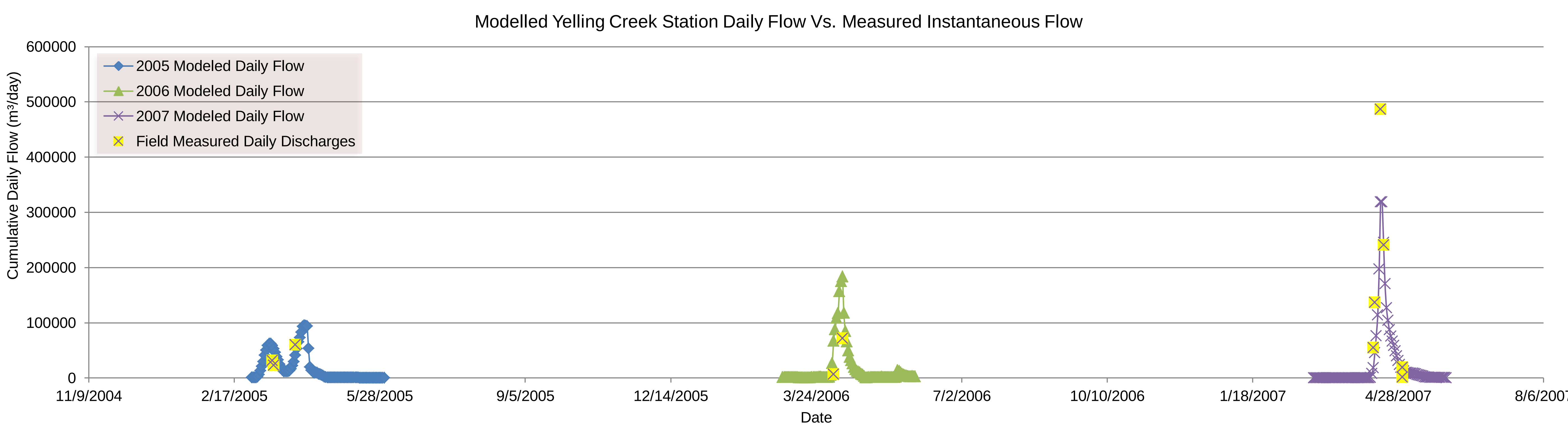
APPENDIX A – Streamflow Models

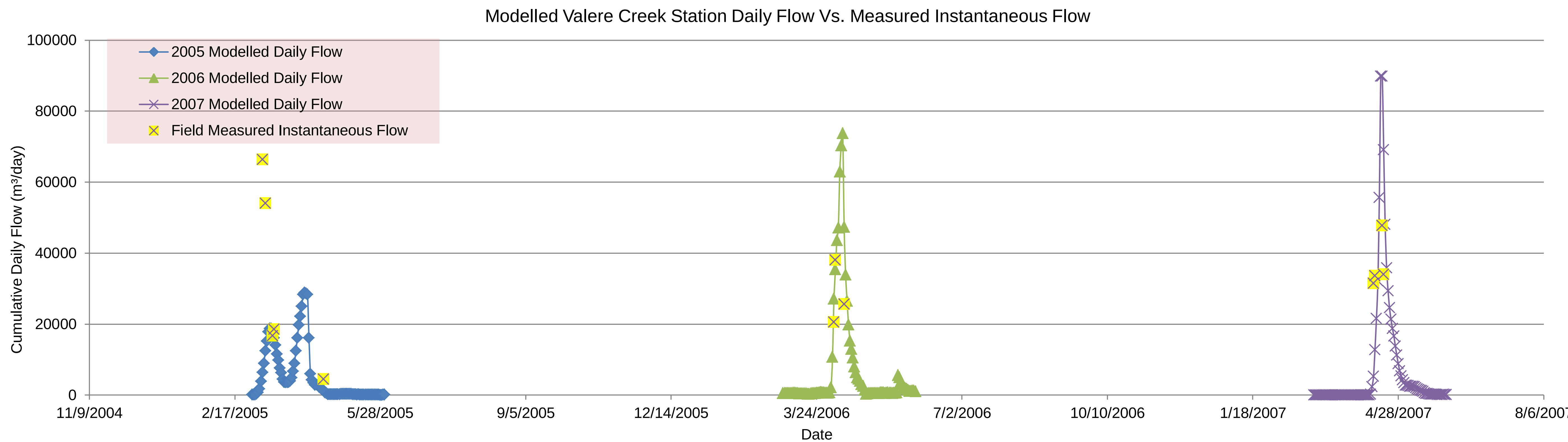


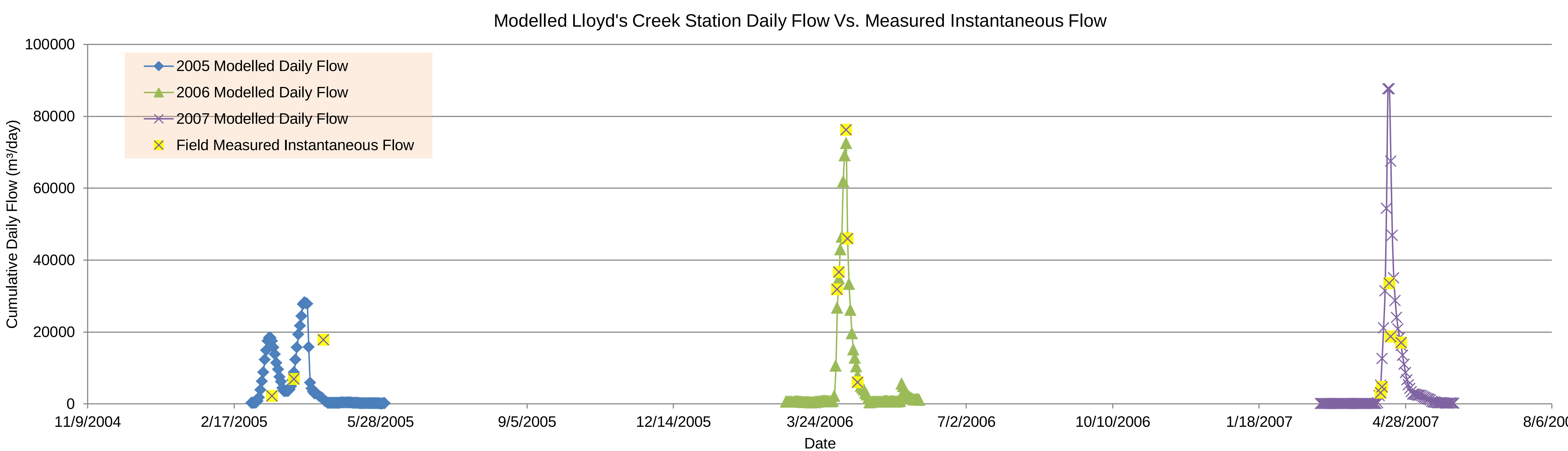


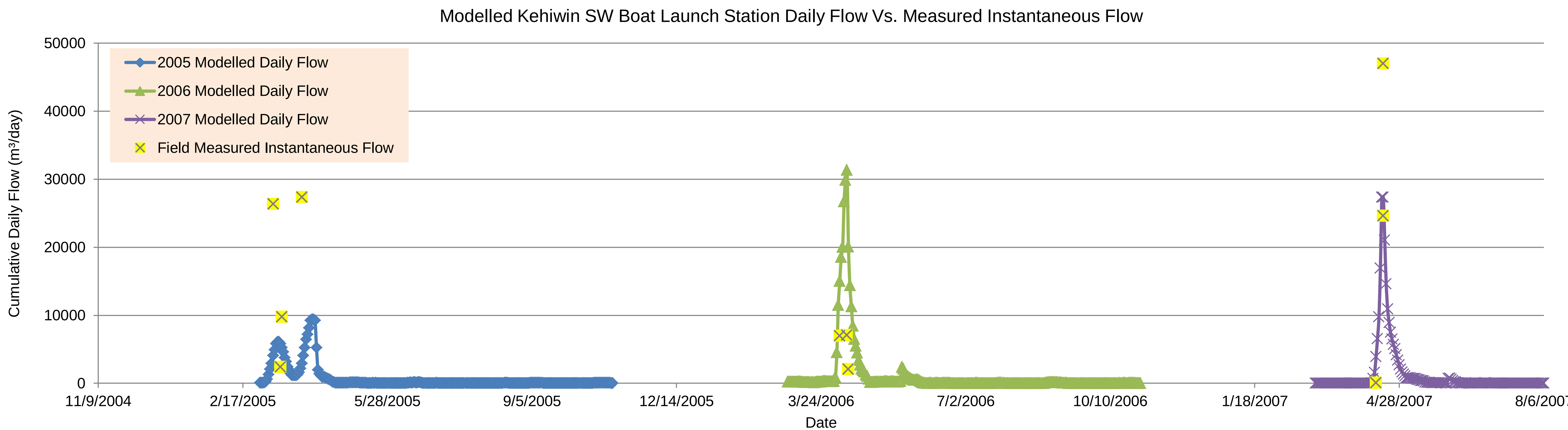


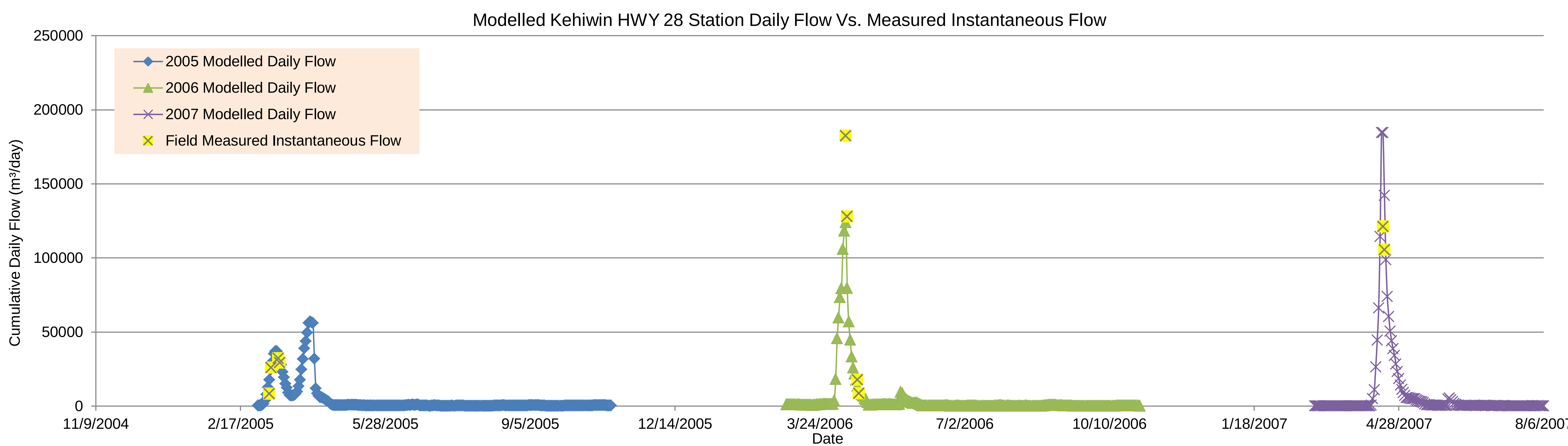

Modelled Thinlake River Station Daily Flow Vs. Measured Instantaneous Flow
2005 Modelled Daily Flow
2006 Modelled Daily Flow
2007 Modelled Daily Flow
Field Measured Instantaneous Flow
Cumulative Daily Flow (m³/day)
800000
700000
600000
500000
400000
300000
200000
100000
0
11/9/2004
2/17/2005
5/28/2005
9/5/2005
12/14/2005
3/24/2006
7/2/2006
10/10/2006
1/18/2007
4/28/2007
8/6/2007
Date

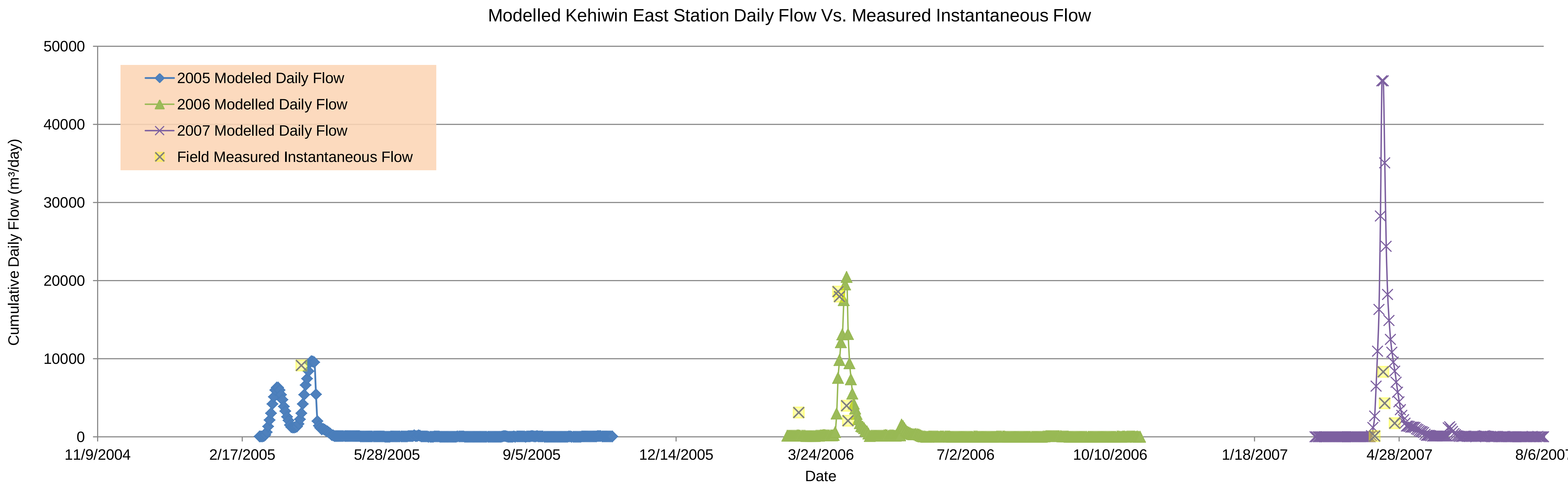

Modelled Yelling Creek Station Daily Flow Vs. Measured Instantaneous Flow
2005 Modeled Daily Flow
2006 Modeled Daily Flow
2007 Modeled Daily Flow
Field Measured Daily Discharges
Cumulative Daily Flow (m³/day)
600000
500000
400000
300000
200000
100000
0
11/9/2004
2/17/2005
5/28/2005
9/5/2005
12/14/2005
3/24/2006
7/2/2006
10/10/2006
1/18/2007
4/28/2007
8/6/2007
Date


Modelled Valere Creek Station Daily Flow Vs. Measured Instantaneous Flow
2005 Modelled Daily Flow
2006 Modelled Daily Flow
2007 Modelled Daily Flow
Field Measured Instantaneous Flow
Cumulative Daily Flow (m³/day)
100000
80000
60000
40000
20000
0
11/9/2004
2/17/2005
5/28/2005
9/5/2005
12/14/2005
3/24/2006
7/2/2006
10/10/2006
1/18/2007
4/28/2007
8/6/2007
Date


Modelled Lloyd's Creek Station Daily Flow Vs. Measured Instantaneous Flow
2005 Modelled Daily Flow
2006 Modelled Daily Flow
2007 Modelled Daily Flow
Field Measured Instantaneous Flow
Cumulative Daily Flow (m³/day)
100000
80000
60000
40000
20000
0
11/9/2004
2/17/2005
5/28/2005
9/5/2005
12/14/2005
3/24/2006
7/2/2006
10/10/2006
1/18/2007
4/28/2007
8/6/2007
Date


Modelled Kehiwin SW Boat Launch Station Daily Flow Vs. Measured Instantaneous Flow
2005 Modelled Daily Flow
2006 Modelled Daily Flow
2007 Modelled Daily Flow
Field Measured Instantaneous Flow
Cumulative Daily Flow (m³/day)
50000
40000
30000
20000
10000
0
11/9/2004
2/17/2005
5/28/2005
9/5/2005
12/14/2005
3/24/2006
7/2/2006
10/10/2006
1/18/2007
4/28/2007
8/6/2007
Date


Modelled Kehiwin HWY 28 Station Daily Flow Vs. Measured Instantaneous Flow
2005 Modelled Daily Flow
2006 Modelled Daily Flow
2007 Modelled Daily Flow
Field Measured Instantaneous Flow
Cumulative Daily Flow (m³/day)
250000
200000
150000
100000
50000
0
11/9/2004
2/17/2005
5/28/2005
9/5/2005
12/14/2005
3/24/2006
7/2/2006
10/10/2006
1/18/2007
4/28/2007
8/6/2007
Date



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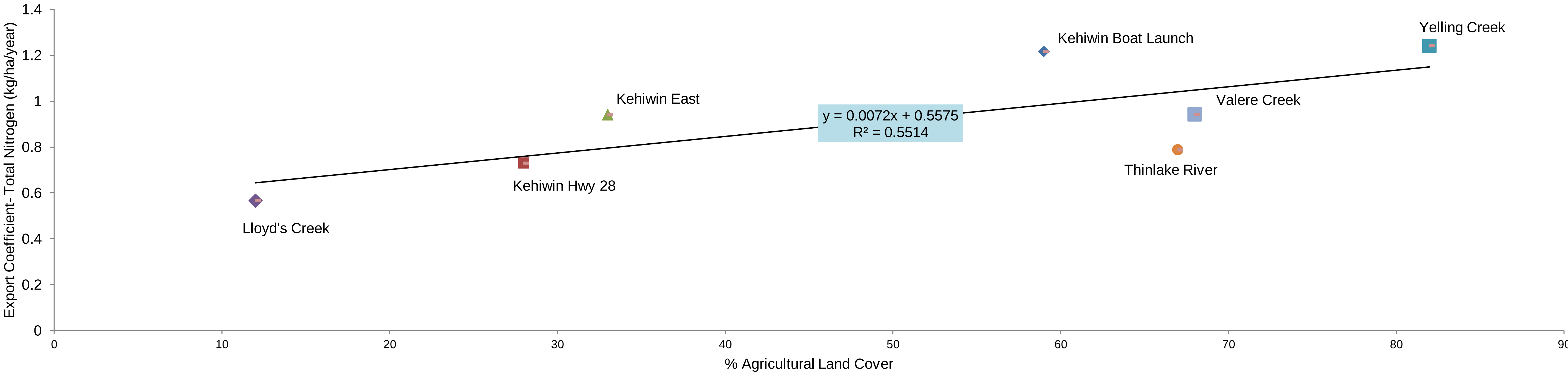
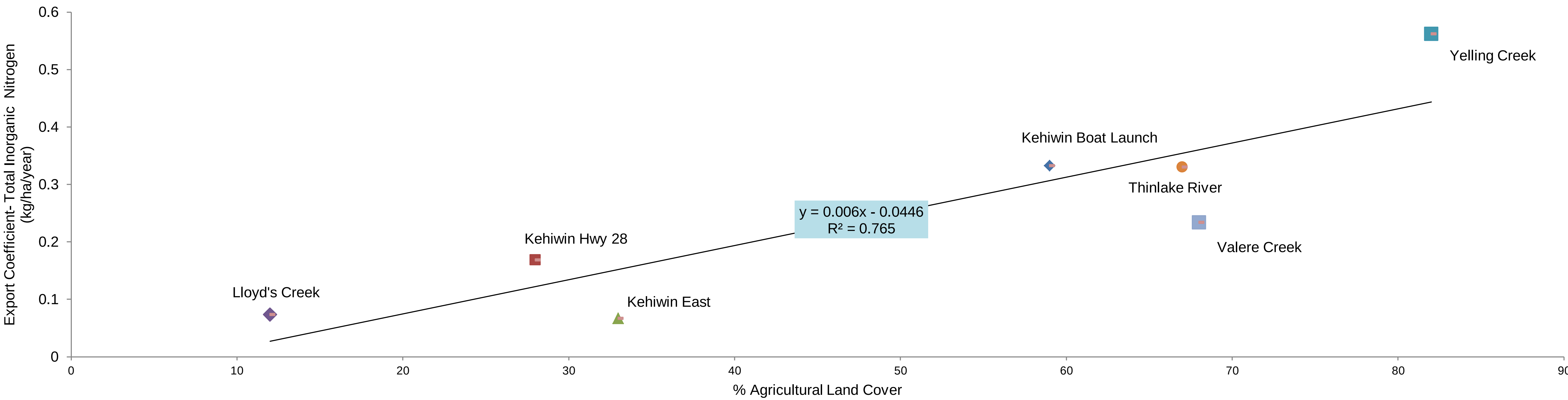
APPENDIX B – Export Coefficients Vs Land Cover Relationships





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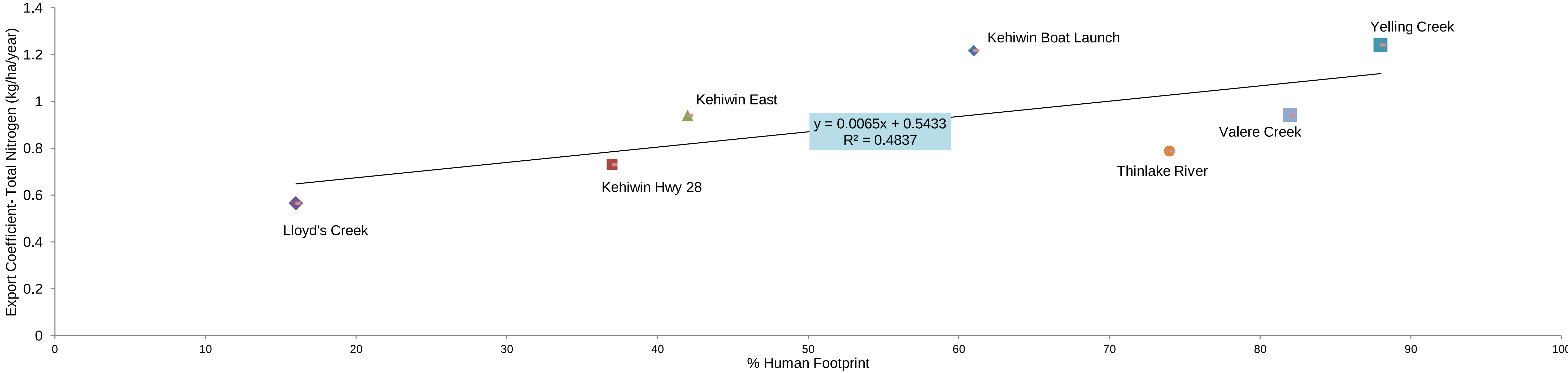
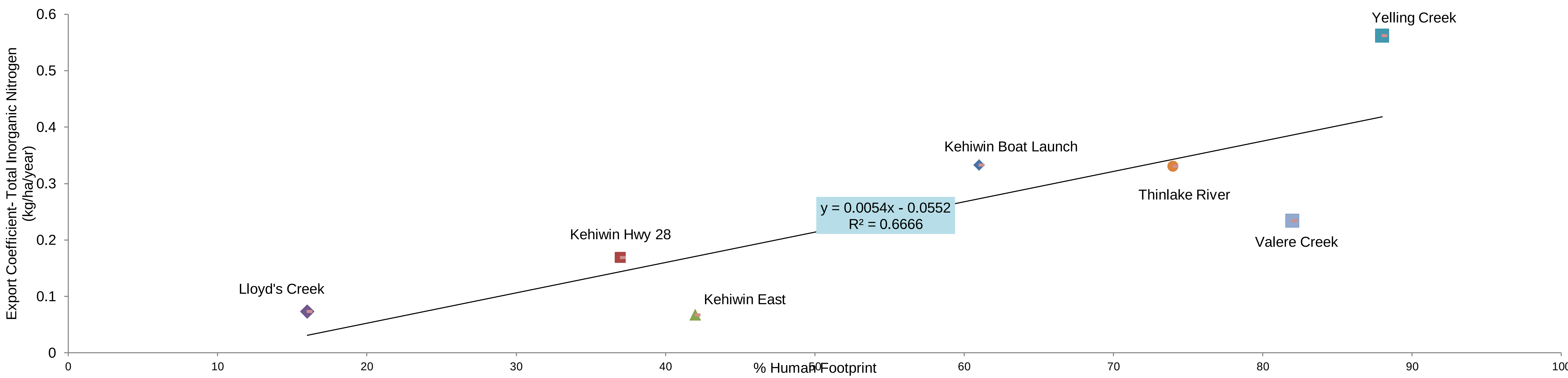
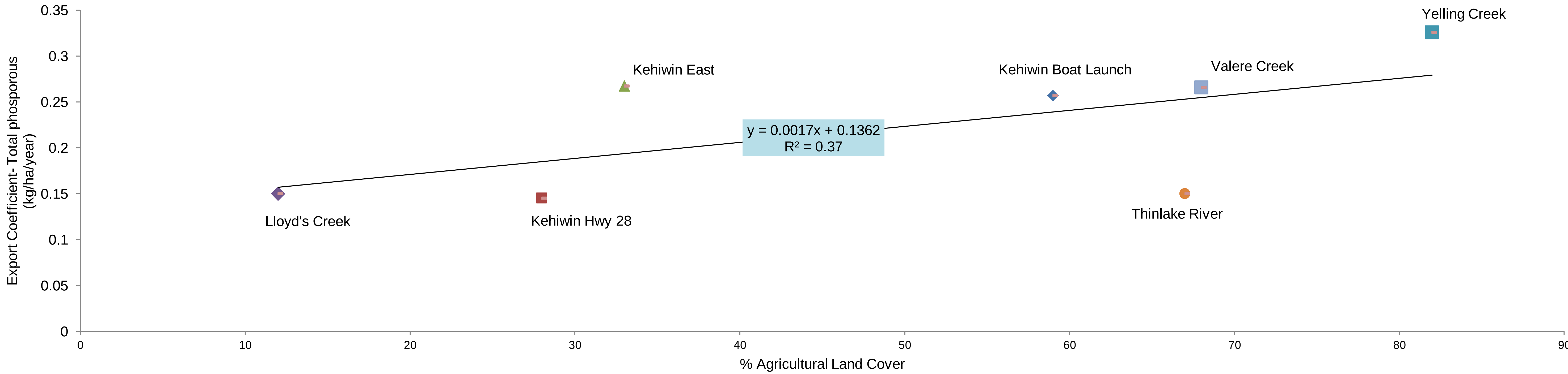
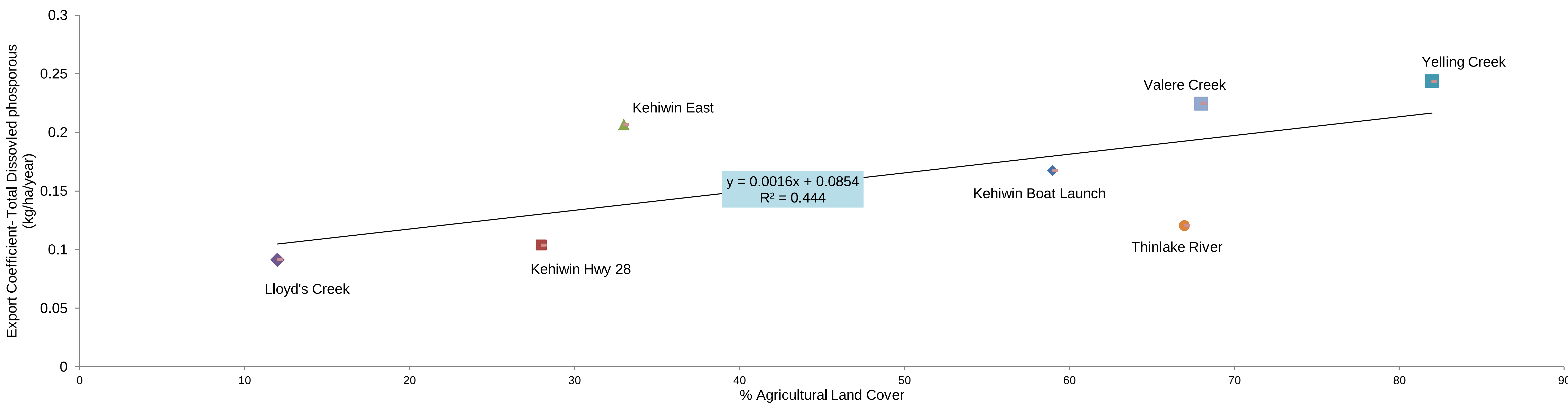

Export Coefficient- Total Nitrogen (kg/ha/year)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
10
20
30
40
50
60
70
80
90
100
% Human Footprint
Kehiwin Boat Launch
Yelling Creek
Kehiwin East
y = 0.0065x + 0.5433
R² = 0.4837
Valere Creek
Thinlake River
Kehiwin Hwy 28
Lloyd's Creek


Export Coefficient- Total Inorganic Nitrogen
(kg/ha/year)
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
90
100
% Human Footprint
Yelling Creek
Kehiwin Boat Launch
Thinlake River
y = 0.0054x - 0.0552
R² = 0.6666
Valere Creek
Kehiwin Hwy 28
Lloyd's Creek
Kehiwin East





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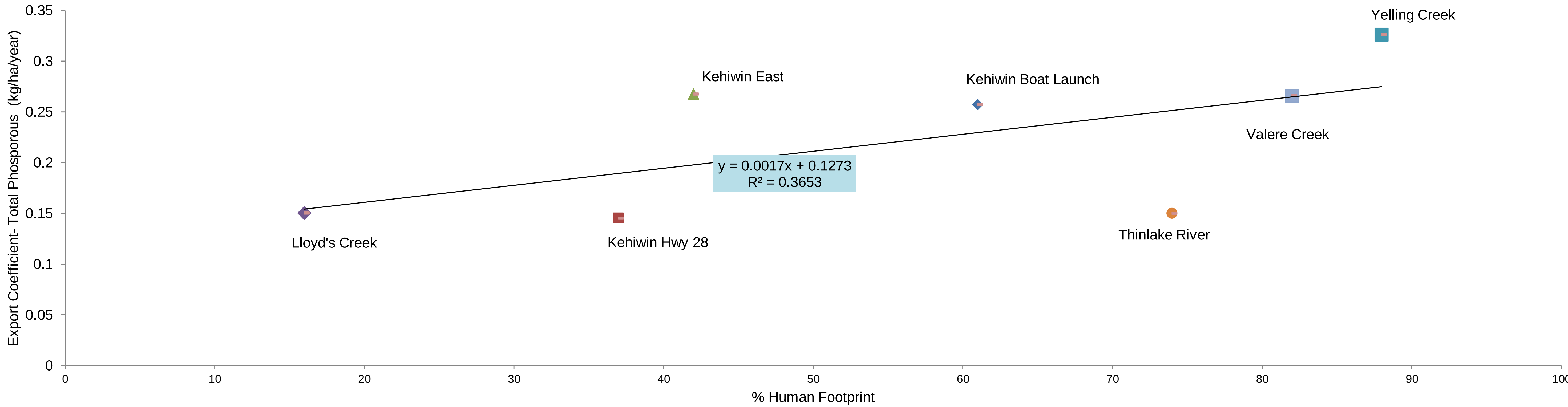

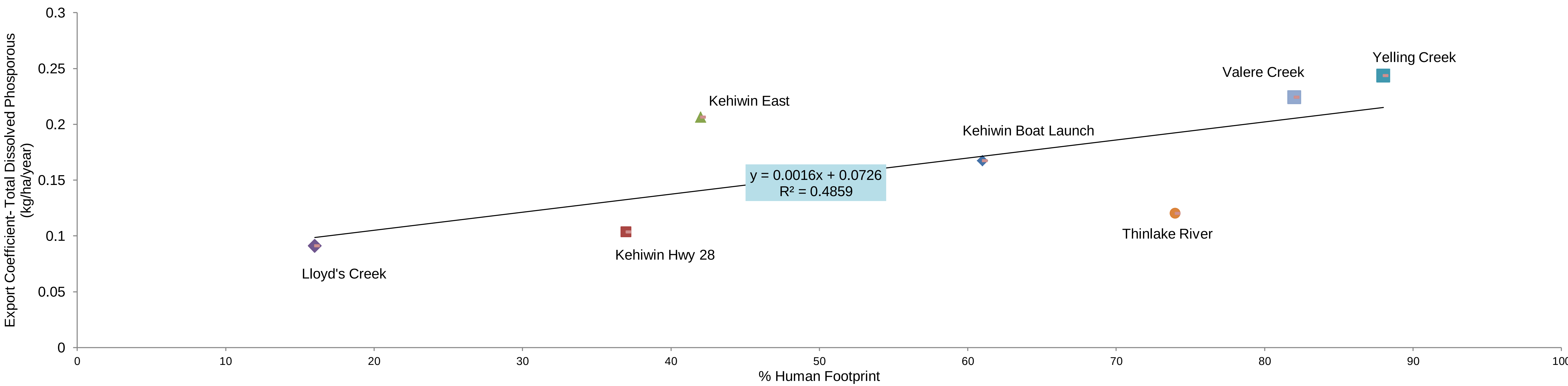

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