1) **Project Title**: Quantifying soil phosphorus concentrations and stream loads in forested watersheds of Vermont: implications for water quality protection

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3) **Brief overview** of project timeline, goals, and objectives and comments on progress related to each category:

Our project goal was to provide a more comprehensive understanding of the potential for phosphorus (P) loading along forested reaches of Lake Champlain tributaries. Our objectives were i) to provide missing baseline data that better characterize P concentration in near-stream forest soils and ii) to quantify road density effects on P loading in streams and therefore the potential effectiveness of management practices in reducing forest contributions to P loads. To accomplish the first goal, we selected ten forested sites to sample in the Missisquoi watershed. These, combined with data from eight other sites from a related study, provide the range of soil phosphorus found under forested land use in this watershed. To accomplish the second goal, three small watersheds in the Missisquoi basin have been instrumented to capture spring and summer storm events. These watersheds are forested and span a gradient of human activity, from the relatively pristine Wade Brook, which has been studied as part of the Vermont EPSCoR Research on Adaptation to Climate Change project, to Ross Brook, which is managed for maple sugar production, to Kings Hill Brook, which includes industrially managed land in much of the watershed. Each site has an automated sampler, pressure transducer for stream depth, and a turbidity sensor. Samples collected by the automated sampler have been analyzed for total suspended solids (TSS), total phosphorus (TP) and soluble reactive phosphorus (SRP). To date, three storm events have been sampled and this work will continue through the summer. Rating curves for Ross Brook and Kings Hill Brook will be developed by measuring discharge at different flow levels to provide data on the export of P from each watershed.

4) **Brief description of project methods**:

Soil sampling: At each site, we composited samples from five locations along the streambank, at approximately 10-m spacing, and took a second composite five locations perpendicular to the streambank samples 10 m into the forest. The following analyses were performed (or are in progress: i) total P by microwave-assisted nitric acid digestion; ii) inorganic and organic P by the soil ignition method; iii) bioavailable P estimated by Modified Morgan's soil test extraction; iv) degree of phosphorus saturation (DPS) by the acid ammonium oxalate procedure; and v) total carbon.

Stream sampling: At each site, we have installed an ISCO automated sampler programmed to collect stream water during storm events by triggering when a set water level is exceeded. Data from the continuous turbidity sensor will be correlated with TSS data from discrete samples to enable calculation of a seasonal TSS export load (and associated total P). All laboratory analyses are following standard procedures: TSS by vacuum filtration, SRP by molybdate colorimetry with ascorbic acid reduction and TP by persulfate digestion.

5) **Highlight of overall project accomplishments to date**:

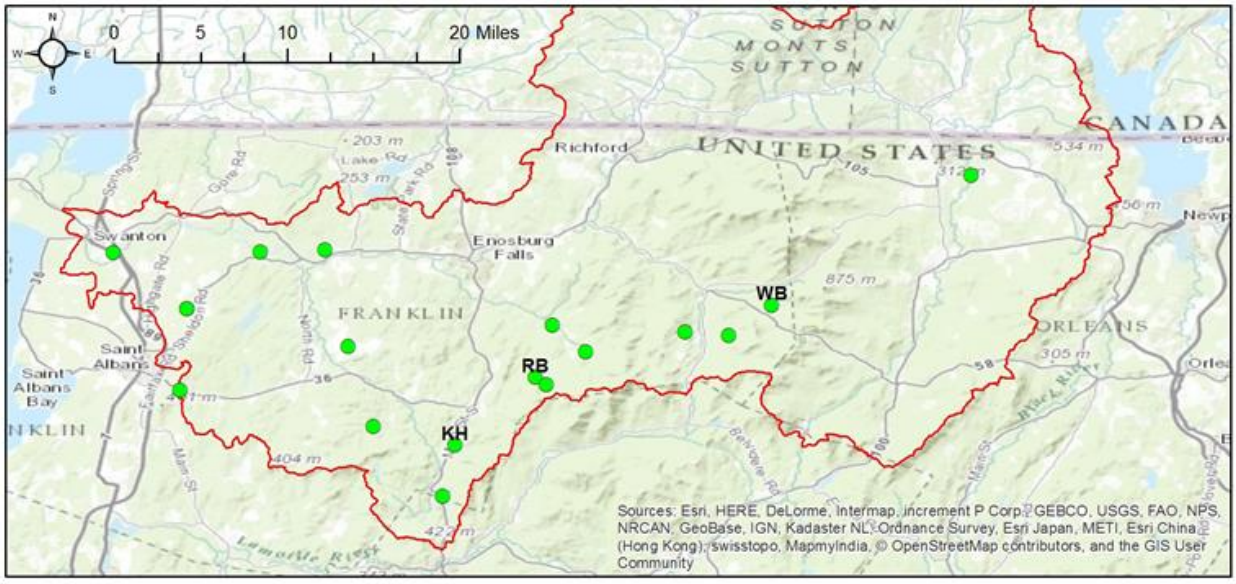

Figure 1. Location of soil and stream sampling sites. The Missisquoi watershed is outlined in red, the soil sampling sites are the green circles and the stream sampling sites are indicated by their initials. KH = Kings Hill Brook, RB = Ross Brook, WB = Wade Brook.

	Total P	Soil test P	DPS	N	C	pH
	(mg/kg)	(mg/kg)	(%)	(%)	(%)	
Forest (average)	**605**	**1.2**	**11.5**	**0.32**	**4.91**	**5.24**
(std. err.)	46	0.1	1.0	0.04	0.67	0.15
Streambank (average)	**600**	**1.1**	**13.4**	**0.12**	**2.12**	**5.99**
(std. err.)	35	0.3	1.2	0.02	0.31	0.19

Table 1. Soil results averaged from the 17 sampling sites.

Soil results. There were no differences between the forest soils and their associated streambank soils in any of the P measurements. Total P was slightly lower than the average found for other Vermont Lake Champlain Basin near-stream soils (620 mg/kg). Bioavailable (soil test) P was in the very low range and reflects no recent anthropogenic inputs of P. The DPS was also quite low and suggests a low P-release potential if the soils were eroded.

Stream results. We have measured streamflow conditions in Ross Brook and Kings Hill Brook since early May 2016 and have collected water samples during discrete storm events (Figure 1). Concentrations of TSS were slightly higher in Ross Brook, ranging from 2 to 183 mg/L, compared to a range of 1 to 119 mg/L in Kings Hill Brook (Figure 2). Concentrations of TP were slightly higher in Kings Hill Brook, ranging from 10 to 552.5 ug/L, compared to a range of 0.14 to 362 ug/L in Ross Brook over the sampling period. At both sites, particulate or sediment-bound phosphorus makes up the major fraction of exported P, with SRP/TP ratios averaging 0.37 at Ross Brook and 0.16 at Kings Hill Brook. At both sites, with limited data to date, there is a relationship between concentration of suspended solids and total phosphorus exported in streamflow (Figure 3).

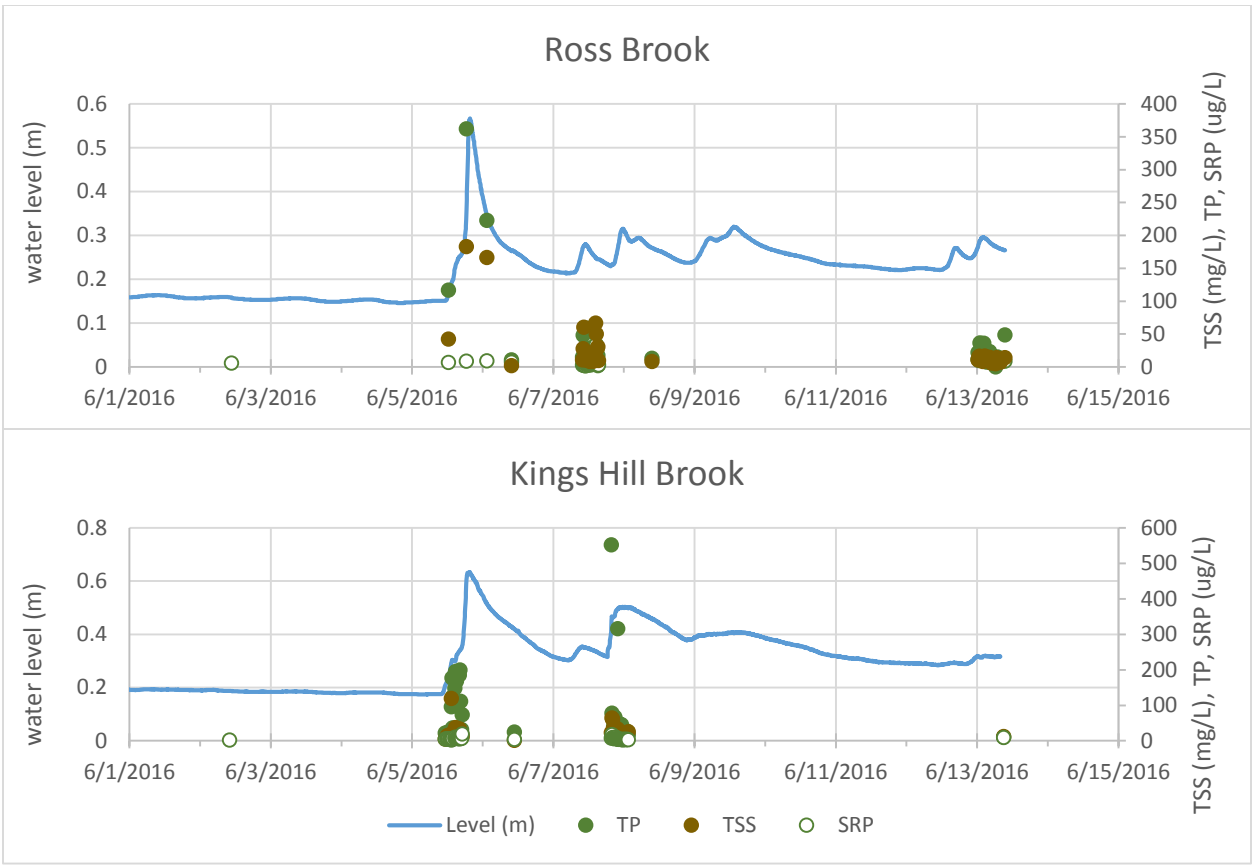

Figure 2: Time series of stream data for study sites. Water level will be used to determine discharge after development of a rating curve for each site.

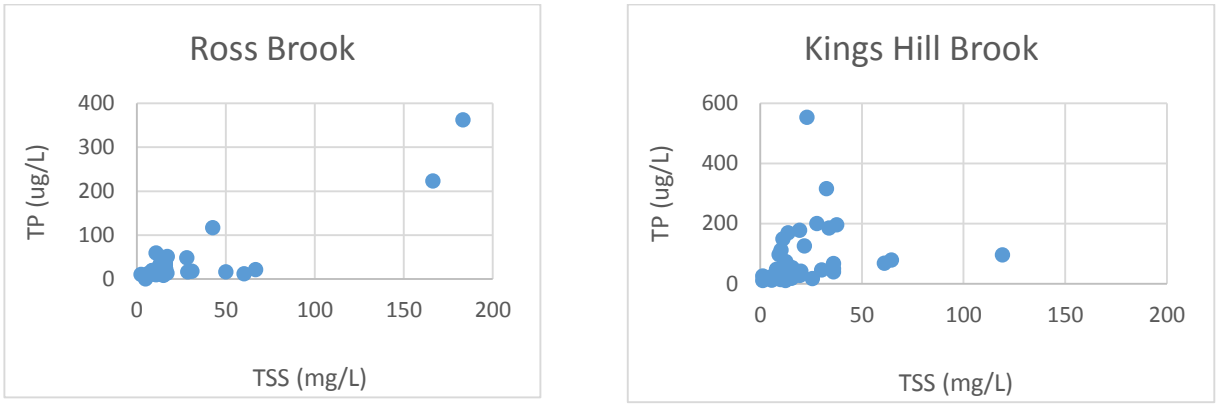

Figure 3: Plots of TP vs TSS concentration for stream water samples collected and analyzed to date.

6) **Project relevance for the Northern Forest region**:

The US EPA is preparing a total maximum daily load (TMDL) that will require the State of Vermont to reduce P within the Vermont portion of Lake Champlain. These include reductions in P loads from forested reaches of tributaries feeding Lake Champlain, yet empirical data on forest P dynamics for this area are lacking. Because forested lands receive little to no additions

of P fertilizers, the major form of P export to streams is sediment bound, usually associated with roads and stream crossings. There is limited knowledge about the concentration of P in forests soils, little local evidence of the role of roads and skid trails on forest sediment and P yields, and little direct evidence for the effectiveness of management practices in reducing sediment and P loads. The data on sediment and total P loads from the forested watersheds with different road densities will be unique for this region of the Northern Forest and help inform implementation of management practices for forest roads. The output from both portions of this project will be immediately available to our collaborators in the VT Dept. of Forest, Parks and Recreation and their counterparts in the VT Dept. of Environmental Conservation to aid in the formulation and adoption of better AMPs and BMPs that will lead to a reduction in the P load from forested land.

7) **List of any and all project products and outcomes** (current and/or projected):

Initial results from forest soil sampling were presented at last year's annual meeting of the Soil Science Society of America (SSSA):

> Perillo, V.L., C. Balling, D.S. Ross and B.C. Wemple. 2015. Preliminary Characterization of Organic Phosphorus Species in Soils along the Missisquoi River (Vermont, USA). Soil Science Society of America annual meetings, Minneapolis, MN, November.

Results will also be presented at this year's SSSA meeting:

> Perillo VL, Balling C, Ross DS, Wemple B. Potential for P Release in Streambank Soils of Different Land Uses in the Missisquoi River (Vermont, USA). Soil Science Society of America annual meetings, Phoenix, AZ, November.

The results from this work will be included in Vanesa Perillo's Ph.D. dissertation and we anticipate that data will be included in two peer-reviewed journal articles—one that puts the forest soil data in context with other land uses and one that compares P export from the four watersheds studied. In addition, results will be immediately available (as stated above) to policy makers in the Vermont Agency of Natural Resources to inform decisions on how to respond to the new TMDLs.

8) **Proposed future steps**:

This work is part of the continuing research efforts of the PIs on sediment and P transport in the Lake Champlain Basin. There is still much to learn about P movement out of forested watersheds and the best approaches to minimize it. The seasonal watershed sampling performed in this study should be expanded into a longer time span and include more watersheds. Additional funding will be sought from the NSRC is the future rfps are relevant to this topic.