Vermont Water Resources and Lake Studies Center
Annual Technical Report
FY 2015

Introduction

The Vermont Water Resources and Lake Studies Center (Water Center) works with faculty at Vermont colleges and universities to support water resources related research. Research priorities are identified each year, determined by the Water Center Advisory Board, as well as through collaboration with the State of Vermont Department of Environmental Conservation, Lake Champlain Sea Grant, Lake Champlain Basin Program, and other programs in the state. The Director works with state, regional, and national stakeholders to identify opportunities to link science knowledge with decision making in water resource management and policy development. The Director of the Water Center is also the director of Lake Champlain Sea Grant (LCSG) and both programs share the same advisory board, which leverages the strengths of each program. The LCSG currently has limited funds available for research, but is dedicated to research extension through outreach and education. By working closely with LCSG, research extension of the Water Center is enhanced. The Director of the Water Center is also a member of the Steering Committee of Lake Champlain Basin Program (LCBP) and regularly brings information from Center-funded projects to the attention of LCBP committees. His activity on these committees also helps to inform the directions of the Water Center and has led to a number of productive partnerships.

Research Program Introduction

During the 2015-2016 project year, the Water Center funded two projects; proposals were reviewed by external peers and the advisory board. Water resources management research, including physical, biological, chemical, social science, and engineering were solicited in the RFP. These topics are of interest to stakeholders of the Water Center, including the Vermont Department of Environmental Conservation, the Lake Champlain Basin Program, the Lake Champlain Research Consortium, and Lake Champlain Sea Grant.

The research projects supported by the 104b funds in the 2015-16 project year were:

1. Organic phosphorus forms and transformations in Lake Champlain stream corridor soils, Year 2. Don Ross (Department of Plant and Soil Science, University of Vermont) and Beverley Wemple (Department of Geography, University of Vermont).

1. System-wide rapid quantification of streambank erosion, Year 1. Mandar Dewoolkar (School of Engineering, University of Vermont), Jarlath O'Neil-Dunne (Spatial Analysis Laboratory, Rubenstein School of Environment and Natural Resources, University of Vermont), Donna Rizzo (School of Engineering, University of Vermont), Jeff Frolik (School of Engineering, University of Vermont).

Organic phosphorus forms and transformations in Lake Champlain stream corridor soils

Basic Information

Title:	Organic phosphorus forms and transformations in Lake Champlain stream corridor soils
Project Number:	2014VT75B
Start Date:	3/1/2015
End Date:	2/28/2016
Funding Source:	104B
Congressional District:	Vermont-at-large
Research Category:	Water Quality
Focus Category:	Nutrients, Non Point Pollution, Water Quality
Descriptors:	None
Principal Investigators:	Donald Ross, Beverley Wemple

Publications

There are no publications.

1. Title. Organic phosphorus forms and transformations in Lake Champlain stream corridor soils

2. Project Type. Research

3. Focus Categories. nutrients, non-point source pollution, water quality

4. Research Category. Water Quality

5. Keywords. soil phosphorus, organic phosphorus, bioavailable phosphorus, phosphorus release, streambank erosion

6. Start Date. March 1, 2015

7. End Date. February 28, 2016

8. Principal investigators.

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9. Congressional District: Vermont-at-large

10. Abstract.

Understanding the mechanisms of bioavailable phosphorus delivery from the landscape to fresh water bodies remains a key need. Recent work has shown that streambank erosion is responsible for a large portion of the sediment load entering Lake Champlain. The speciation and reactivity of the P in that sediment has not been adequately researched. Our recent work has shown that concentrations of soil test phosphorus (correlated with bioavailable phosphorus) are usually relatively low in near-stream soils and streambanks—even when high in adjacent land use. Additionally, we have shown that a large portion of the bioavailable phosphorus is in an organic form. Organic soil phosphorus is much less understood than inorganic phosphate, largely because of the difficulties involved in analysis. For this study, soils in four specific land uses and nearby associated streambanks were sampled in the Missisquoi Watershed in northwestern Vermont. The land uses were silage corn, established hay, wetland and forest, and eight sites were sampled for each, with five composite samples taken 10 m from a streambank and five samples taken along the stream. These were analyzed for total phosphorus, total organic phosphorus, plant-available phosphorus and the degree of phosphorus saturation. The latter two measurements predict potential bioavailability. Two pairs from each land use/streambank combination were randomly selected for detailed organic phosphorus speciation via ^{31}P NMR. Soils in corn, hay and wetland were elevated in total phosphorus relative to associated streambanks and relative to the average phosphorus content previously found in Vermont soils. Forest soils were consistently low in total phosphorus, as were their nearby streambank soils. Total organic phosphorus was lowest in the streambank soils, both as a percentage of the total phosphorus and as an absolute amount. Plant-available phosphorus (soil test) was high in the corn and hay fields but very low in all other locations, streambanks included. The degree of phosphorus saturation was < 21% in all of the streambanks but averaged 36% in the corn fields. The combination of low soil phosphorus and low saturation suggests that the streambank soils will not release phosphorus if eroded into the adjacent streams. Initial results from the ^{31}P NMR scans show a range of organic phosphorus compounds. This project has provided training to a Ph.D. student and two undergraduate students. Overall, the results confirm the low phosphorus status on streambank soils in the Lake Champlain Basin.

13. **Organic phosphorus forms and transformations in Lake Champlain stream corridor soils**

14. Statement of regional or State water problem.

 It is now clear that streambank erosion can contribute a large portion of the sediment load delivered to Lake Champlain (e.g. Langendoen et al. 2012). Phosphorus, in various forms, is associated with this sediment. There are three relatively unknown factors associated with streambank erosion: i) how much P is released (or sorbed) by the sediment when it enters the stream channel, ii) how much of the sediment is delivered to the lake and iii) how much of the sediment-bound P will become bioavailable once it reaches the lake. We have been measuring soil P in a large number of Lake Champlain stream corridor soils (along Lewis Creek, LaPlatte River, Allen Brook, Alder Brook, Indian Brook, Mad River, Rugg Brook, Black Creek, Missisquoi River and Rock River) with prior funding from the Water Center and other sources. We found a relatively narrow range of *average* total soil P in each watershed with somewhat more variability in 'available' (soil test) P and the degree of phosphorus saturation (DPS). Two findings are relevant to this proposal: i) overall, available P tended to be low in streambank soils (Ishee et al. 2015, Young et al. 2012) and ii) a large portion of this available P was found to be in the organic form (Young et al. 2013). In order to understand the bioavailability of riparian soil P, we need a better understanding of the nature of the organic P in these soils. The proposed work will determine the fraction and class of organic P in streambank soils, investigate how this P transforms within the stream and, making some assumptions about the particle size transported, investigate how this sediment P will transform in the lake environment.

15. Statement of results or benefits.

   1. A better understanding of the forms (speciation) of organic phosphorus in four different land uses and associated streambank soils of the Lake Champlain Basin.

   2. A better understanding of the P release potential of these soils once eroded.

These will aid in our mechanistic understanding of the delivery of bioavailable P to the water column in Lake Champlain. This should help both in mechanistic and predictive modeling.

16. Nature, scope, and objectives of the project, including a timeline of activities.

Objectives:

   1. **Determine the total inorganic and organic phosphorus fractions and speciation of stream corridor soils.**

   2. **Determine the potential bioavailability of phosphorus from these soils, if eroded.**

17. Methods, procedures, and facilities.

Soil sampling and analysis: Soil samples were obtained throughout the Missisquoi watershed using the sampling design detailed below (Fig. 1). The strategy was to locate and sample eight sites each of four different land uses: silage corn, established hay, wetland and forest. These sites were selected based on i) distribution throughout the entire Missisquoi watershed and ii) obtaining landowner permission. At each site, five composite 0-15 cm samples were taken 3-5 m apart along a transect 10-15 m from the streambank and five composite samples were taken at corresponding locations vertically down the streambank (Fig. 1). To be comparable with adjacent streambanks, the forest floor was not included in the forest soil samples. Samples were returned to the lab, air dried and analyzed as described below.

Soil characterization included total carbon and nitrogen by elemental analyzer, pH by electrode (2:1 *v:*v in H_2O, and particle size analysis by with hydrometer method (Ashworth et al., 2001). Total P was measured by ICP-OES after microwave-assisted nitric acid digestion (Method 3051a; USEPA 2007). Total organic P was obtained by extraction with NaOH-EDTA (0.25 M NaOH + 0.05 M EDTA) for 16h (Turner et al., 2005). The difference between ICP-P and colorimeteric-P (Murphy-Riley, 1962) in this extract was the organic fraction. Plant-available P was determined with the modified Morgan extraction (pH 4.8 ammonium acetate buffer in a 1:5 ratio, McIntosh 1969) and the Murphy-Riley colorimetric method. The degree of phosphorus saturation (DPS) was calculated as the ratio of acid ammonium oxalate-extractable P to Al + Fe (Paulter and Sims, 2000).

To determine the general categories of organic P, we began using the enzymatic-microplate method of Johnson and Hill (2010) with the NaOH-EDTA extracts. However, after exhaustive trial runs, we abandoned the method because of poor repeatability. In its place, we are performing ^{31}P NMR analysis with the assistance of Monika Ivanic of UVM's Chemistry Dept. and Barbara Cade-Menun of Agriculture and Agri-Food Canada (an expert in this area). This approach provides definitive identification and quantification of specific organic-P compounds in soils (e.g. Hill and Cade-Menun 2009, Young et al. 2013). It is the preferred method for determining organic P in soils but, until recently, the capability for doing this did not exist at UVM. The new NMR facility director (Monika Ivanic) has done this exact type of work in her most recent position and is assisting us in performing the work here. Because this technique is time-consuming and somewhat expensive, we have randomly selected a subset of two each of land-use/streambank combinations for a total of 16 scans. Preliminary interpretation of the results will be presented.

Statistical analysis was performed by SAS with linear mixed-effects modeling, using restricted maximum likelihood method. Comparisons were made among the different land uses and streambanks.
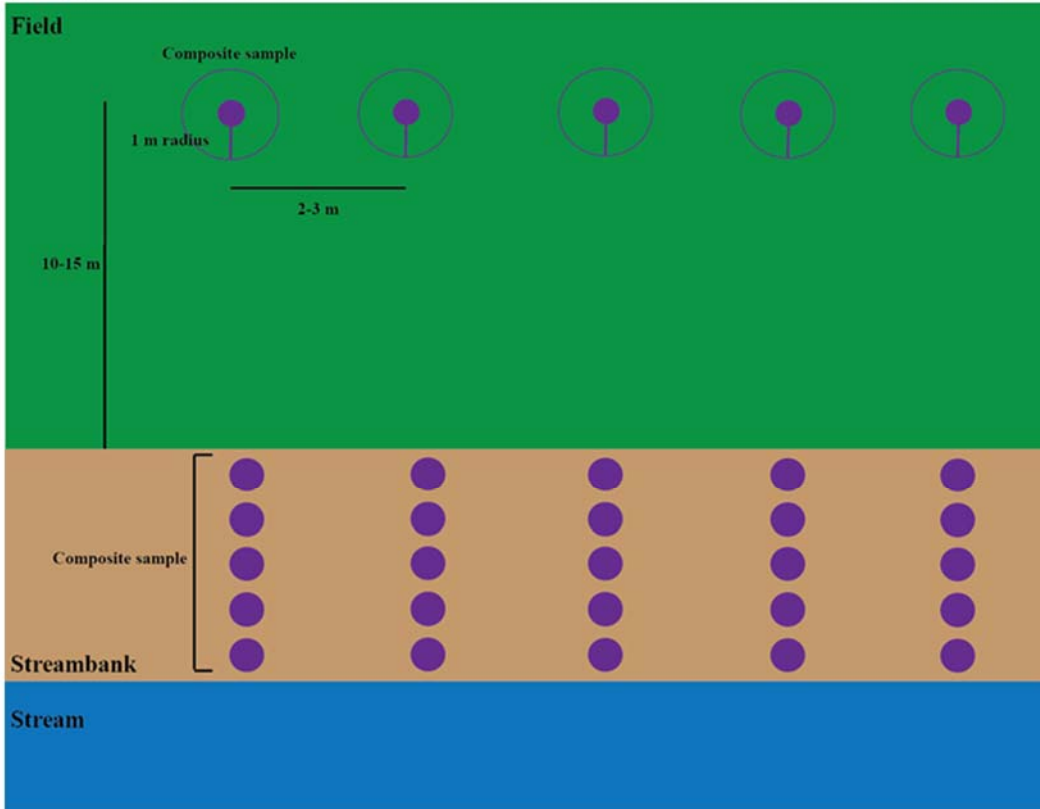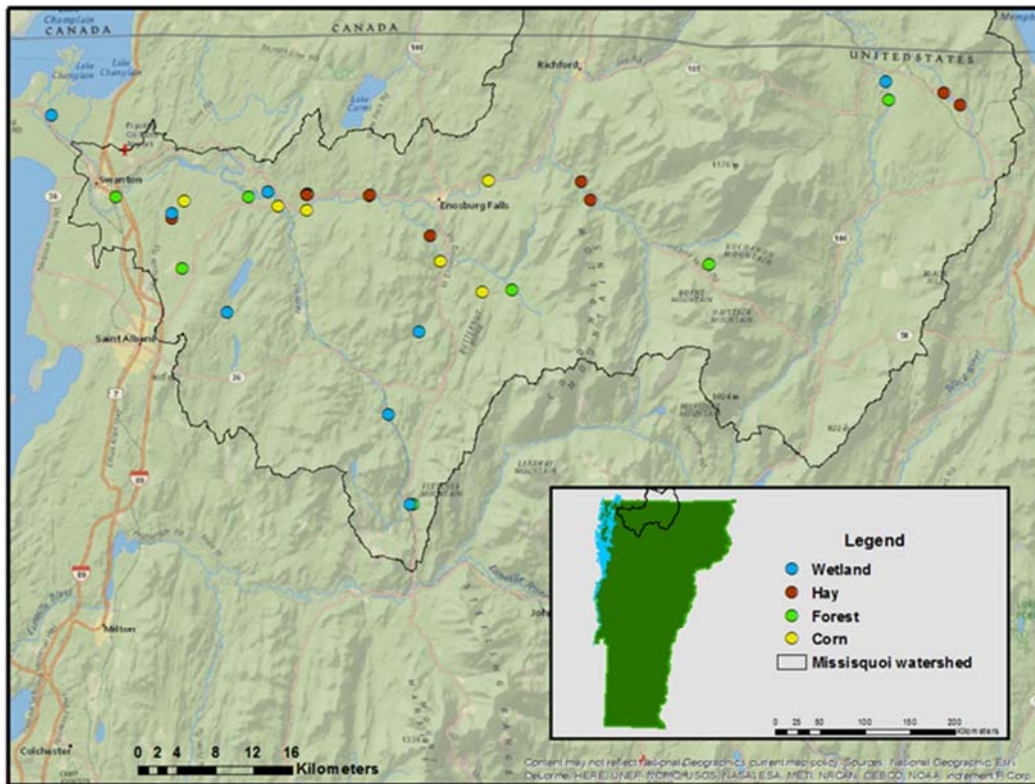
Fig 1. Top: map of sampling locations in the Missisquoi watershed. Bottom: Sampling design used at each location.

17. Findings.

The means of the soil characteristics showed a few trends among the different land uses and between a particular land-use and the adjacent streambank (Table 1). Carbon was highest in the wetland soils and, in all cases, there was lower carbon in the streambanks than the adjacent land use. The mean pH values were all 6.0 or higher, except in the forest soils, which averaged 5.5. The textures were generally loamy (sandy loam, loam and silt loam, with a few loamy sands) but the streambank soils were consistently coarser textured (higher in sand and lower in silt).

Table 1. Soil characterization averaged by land-use and adjacent streambank (± standard deviation). Each number is the mean of transect averages from each of 8 sites, except the forest and wetland streambank where $n =7$.

	Land Use: Corn	Nearby Streambank	Land Use: Hay	Nearby Streambank	Land Use: Wetland	Nearby Streambank	Land Use: Forest	Nearby Streambank
Carbon (%)	2.3 ± 0.8	1.7 ± 1.0	3.6 ± 1.2	1.2 ± 0.8	6.2 ± 4.1	3.2 ± 1.9	3.4 ± 1.9	1.6 ± 0.9
Nitrogen (%)	0.21 ± 0.06	0.21 ± 0.21	0.31 ± 0.09	0.10 ± 0.06	0.46 ± 0.31	0.22 ± 0.12	0.26 ± 0.18	0.11 ± 0.04
pH	6.7 ± 0.5	6.8 ± 0.4	6.3 ± 0.6	6.4 ± 0.4	6.0 ± 0.6	6.0 ± 0.3	5.5 ± 0.8	6.0 ± 1.1
Sand (%)	51.5 ± 14.4	65.6 ± 13.3	32.0 ± 10.8	63.3 ± 24.3	31.4 ± 12.5	47.0 ± 19.5	57.1 ± 13.8	69.7 ± 11.3
Silt (%)	40.3 ± 12.8	27.2 ± 12.4	53.9 ± 7.4	26.5 ± 20.1	56.0 ± 9.7	42.0 ± 16.3	31.8 ± 10.9	20.9 ± 9.6
Clay (%)	8.3 ± 3.6	7.1 ± 2.5	14.2 ± 9.8	10.2 ± 8.4	12.6 ± 7.0	11.0 ± 6.8	11.2 ± 6.1	9.4 ± 4.1

Total phosphorus was high in the corn and hay fields relative to their streambanks (Table 2 and Fig. 2), which is to be expected if the fields have been receiving fertilizer and manure inputs. Wetland total P was also significantly higher than the nearby streambank, which may be the result of the much higher carbon content that resulted in nearly double the amount of organic P (Table 2 and Fig. 2). The forest soils and streambanks were similarly low in total P. Organic phosphorus showed a somewhat similar trend among the land uses to total P. Streambank organic P was only about half that found in the nearby land-use, significantly lower in three of the four pairs (Table 2 and Fig. 2). Plant-available phosphorus (soil test P using pH 4.8 ammonium acetate) was much higher in the corn and hay fields than any of the streambanks, forest or wetland sites (Table 2 and Fig. 3). This, again, is a reflection of P inputs. The soil test interpretation for all the other sites was 'low', i.e. there would be a high probability of crop response to added P if these soils were in agriculture (Jokela et al. 2004). The hay fields were in the optimum range and the corn fields were 'high', suggesting that more P inputs have been added than needed for crop growth.

Table 2. Soil phosphorus classes averaged by land-use and adjacent streambank (± standard deviation).

|	Land Use: Corn	Nearby Streambank	Land Use: Hay	Nearby Streambank	Land Use: Wetland	Nearby Streambank	Land Use: Forest	Nearby Streambank
Total P (mg/Kg)	1211 ± 135	759 ± 195	1230 ± 112	657 ± 252	1048 ± 189	861 ± 106	577 ± 190	563 ± 112
Inorganic P (mg/Kg)	958 ± 149	651 ± 164	886 ± 128	544 ± 184	730 ± 140	701 ± 100	445 ± 134	501 ± 101
Organic P (mg/Kg)	253 ± 130	107 ± 89	432 ± 196	172 ± 94	324 ± 126	160 ± 95	132 ± 93	62 ± 34
Plant Available P (mg/Kg)	18 ± 11	2.7 ± 2.5	8.9 ± 4.9	1.8 ± 1.4	2.5 ± 1.6	2.1 ± 1.9	1.5 ± 0.5	1.6 ± 1.4
Degree of P Saturation (%)	36.0 ± 10.4	20.7 ± 6.3	30.4 ± 7.3	19.3 ± 5.2	22.2 ± 6.0	20.3 ± 5.4	14.0 ± 4.5	15.2 ± 5.5
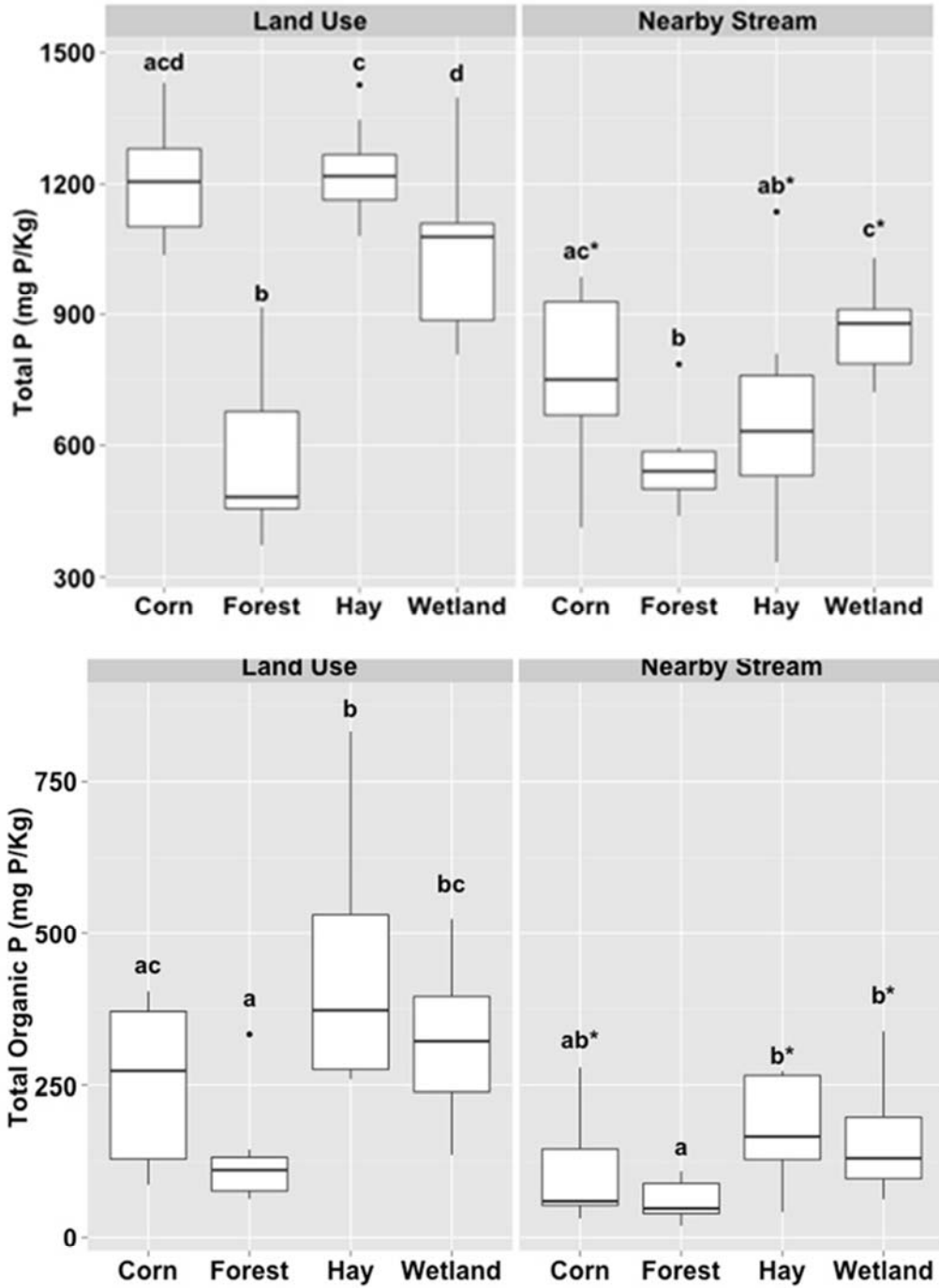
Figure 2. Total phosphorus (top) and organic phosphorus (bottom) by land use. The left-hand panel has the samples from ~10 m away from the streambank and the right-hand panel shows the adjacent streambanks. Different letters within each panel denote statistically significant differences among land-use and an asterisk in the right-hand box denotes a statistically significant difference between the stream-bank and associated land-use ($p<0.05$). The boxes encompass the 25th and 75th quartile, the whiskers cover the 5th and 95th quartile and the bold horizontal line is the median.
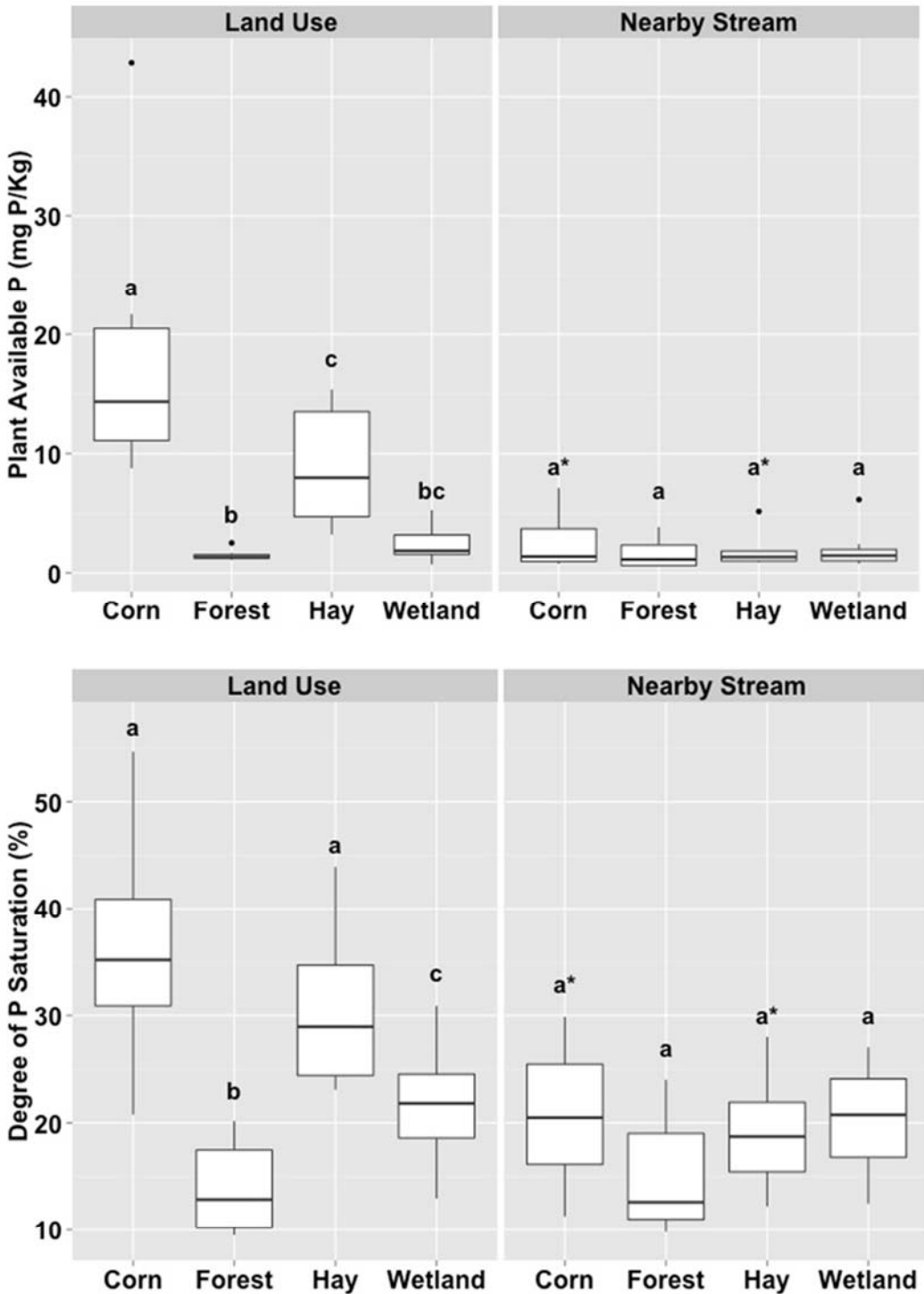
Figure 3. Plant-available phosphorus (top) and the degree of phosphorus saturation (bottom) by land use. The left-hand panel has the samples from ~10 m away from the streambank and the right-hand panel shows the adjacent streambanks. Different letters within each panel denote statistically significant differences among land-use and an asterisk in the right-hand box denotes a statistically significant difference between the stream-bank and associated land-use ($p < 0.05$). The boxes encompass the 25th and 75th quartile, the whiskers cover the 5th and 95th quartile and the bold horizontal line is the median.

The bioavailability of the phosphorus in the streambank soils can be assessed in two ways: i) using the plant-available P as an indicator (Magdoff et al. 1999) and by using the degree of phosphorus saturation (DPS). The exact 'change point', above which significant release of sorbed P takes place, has not been determined for Vermont soils and it appear to vary region to region (Ishee et al. 2015). However, no study has reported P release below a DPS of 20% and the mean DPS of streambank soils adjacent to each land-use ranged from 15-21% (Table 2 and Fig. 3). This, coupled with the low plant-available P, suggests little potential for immediate P release if the streambanks were eroded into the Missisquoi or its tributaries. On the other hand, the corn and hay fields had relatively high mean DPS (36% and 30% respectively) and relatively high plant-available P (Table 2 and Fig. 3). These soils would be much more likely to release P if eroded into the waterways.

The eight corn fields sampled in this study had three different fertility treatments—two received only inorganic P fertilizer, three had liquid manure surface applied before tillage and three had liquid manure injected into the soil. This latter method is a current 'best management practice' to minimize nutrient runoff, recommended by the USDA Natural Resource Conservation Service. Differences in total P were not great but there were dramatic differences in organic P (Fig. 4). As might be expected, the inorganic P treatment had the lowest amount of organic P, statistically significantly lower than the injected manure treatment (the low n for each treatment limits the statistical interpretation). The DPS was also much higher for the fields with injected manure. The associated streambanks soils showed no differences and were either significantly lower or trended lower in all P categories relative to the corn fields.

The specific organic P compounds present in the different soils from different land uses are being identified and quantified using ^{31}P NMR. Initial scans of streambank soils (Fig. 5) are showing the range of organic P species usually found in soils, i.e. nucleic acids, components of phytic acid (a plant and microbial P storage compound) and possibly components of lipid membranes. Ongoing work will produce high quality scans of composite samples from two each of the four land-use/streambank pairs (i.e. 16 total). This approach will have numerous advantages over the originally proposed enzymatic method. The primary advantage is the NMR can identify and quantify individual organic P compounds whereas the enyzmes provide only broad classes. This will enable us to more clearly identify the differences among the land uses and between each land use and adjacent streambank.
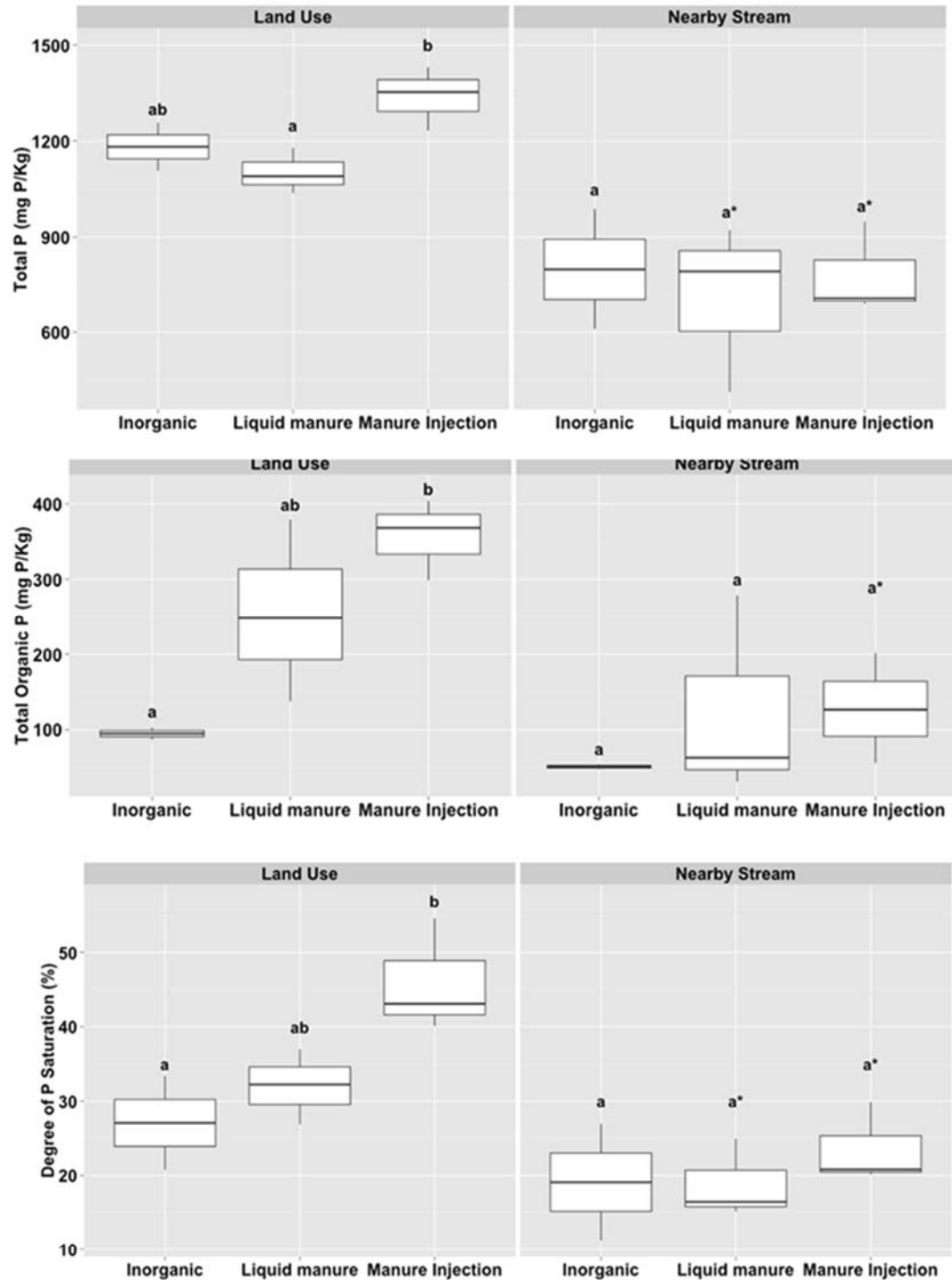
Figure 4. Total phosphorus (top), organic phosphorus (middle) and the degree of phosphorus saturation (bottom) for three different phosphorus fertility treatments in corn fields. The left-hand panel has the samples from ~10 m away from the streambank and the right-hand panel shows the adjacent streambanks. Different letters within each panel denote statistically significant differences among land-use and an asterisk in the right-hand box denotes a statistically significant difference between the stream-bank and associated land-use ($p<0.05$). The boxes encompass the 25th and 75th quartile, the whiskers cover the 5th and 95th quartile and the bold horizontal line is the median.
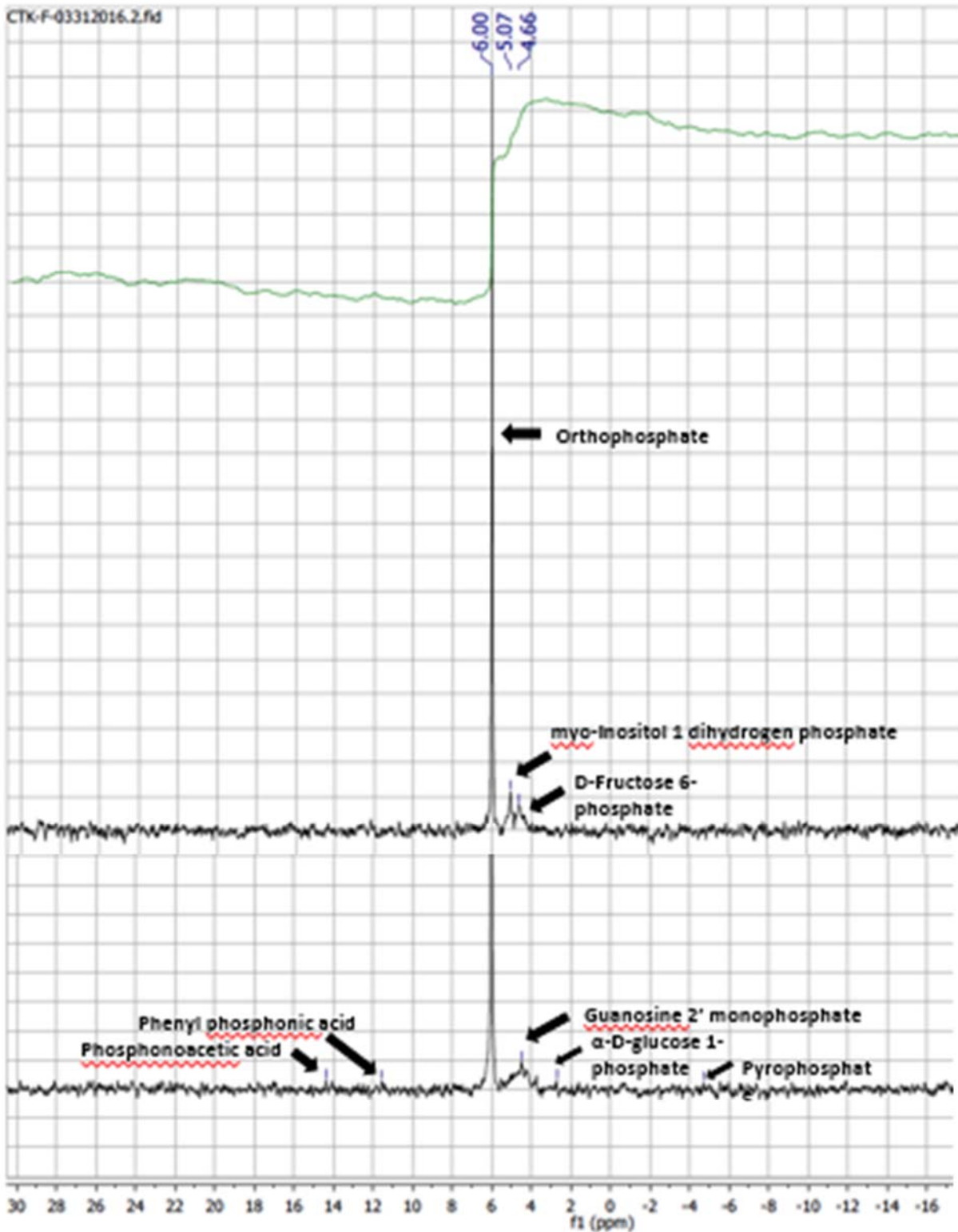
Figure 5. Preliminary ^{31}P NMR spectra of two streambank soils adjacent to corn fields in the Missisquoi watershed. The tallest peak is orthophosphate (PO_4) and all other peaks are organic P except for a small pyrophosphate (O_3POPO_3) peak in the lower scan. Peak identification is preliminary.

18. Discussion.

Recent studies have found the average total P in stream corridor soils of Vermont's Lake Champlain Basin to be about 620 mg/kg (Ishee et al. 2015, Young and Ross 2016—both funded by the USGS Water Center). This likely reflects the background or 'native' P concentration in these soils, inherited from the soil parent material. There is some variation around this mean, so it is not possible to unequivocally conclude that higher total P is due to recent anthropogenic P additions. In this study, the forest soils and associated streambanks were about 50 mg/kg lower than the 620 mg/kg mean but all other soils were higher. The three other land-uses (corn, hay and wetland) were much higher, all >1000 mg/kg total P. This suggests enrichment and, in the case of the corn and hay fields, a possible near doubling of the total P through repeated P additions. The associated streambank mean total P of the non-forest land-use ranged from 657 mg/kg adjacent to hay fields (not really elevated relative to the mean) to 861 mg/kg adjacent to wetlands (probably elevated).

A recent study of near-stream soils of four Lake Champlain Basin tributaries by Ishee et al. (2105) found that the mean degree of phosphorus saturation was <18%. In the present study, the streambank soils ranged from 15-21% DPS. While slightly higher, the results still suggest a low history of P inputs and probably a capacity to sorb more P. This is supported by the low plant-available P, < 3 mg/kg in both this study and in Ishee et al. (2015). The DPS in the associated land uses ranged from 14% in the forest (quite low) to 36% in the corn fields, a value that is within the range in which P release might be expected. More work is needed to determine the exact change point at which soils in the Lake Champlain Basin release P.

The soil texture differed between each land-use and nearby streambank, with the streambank soils having greater sand and lower silt content. This suggests that the streambanks are of different depositional origin than the land-use that is only 10 m away. It is also evident that the agricultural land uses have elevated the amount of total phosphorus in the soil. There does not appear to be any convincing evidence that the elevated P in the fields is moving to the streambanks. However, both overland runoff and continued streambank erosion could move the higher-P soils into the streams. Climate change induced increased intensity of precipitation will likely lead to increased erosion and the current low-P streambanks may no longer be there to provide a buffer.

19. Training potential.

This project has supported Vanesa Perillo for part of her Ph.D. dissertation research. The following presentations have been given:

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.

Perillo, Vanesa L., Courtney Balling, Donald S. Ross, and Beverley Wemple. Movement and release of phosphorus from stream bank soils into Lake Champlain, Global Lake Ecological Observatory Network (GLEON) 16. Orford, Québec, Canada, 27 - 31 October 2014.

Ross, D.S., E.R. Ishee, K.M. Garvey and R.R. Bourgault. 2015. Phosphorus contribution from eroding streambank soils of Vermont's Lake Champlain Basin. Soil Science Society of America annual meetings, Minneapolis, MN, November.

Ross, D.S., B.C. Wemple and V.L. Perillo. 2016. Phosphorus in streambank soils in the Lake Champlain Basin. Lake Champlain Basin Program, Technical Advisory Committee, Grand Isle, VT, January.

In addition to supporting a Ph.D. candidate, undergraduate students participated and were trained in a variety of both field and laboratory research techniques.

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System-wide quantification of streambank erosion

Basic Information

Title:	System-wide quantification of streambank erosion
Project Number:	2015VT77B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	VT
Research Category:	Engineering
Focus Category:	Sediments, Models, Geomorphological Processes
Descriptors:	None
Principal Investigators:	Mandar M. Dewoolkar, Jarlath ONeilDunne, Donna M. Rizzo, Jeff frolik

Publication

1. Bryce, T. 2016. Quantifying streambank erosion through Terrestrial LiDAR (TLS) and an Unmanned Aircraft System (UAS). M.S. School of Engineering, University of Vermont, Burlington, VT.

1	**Project Title:**	System-wide rapid quantification of streambank erosion
2.	**Project Type:**	Research
3.	**Focus Categories:**	Sediments, Models, Geomorphological Processes
4.	**Research Category:**	Engineering
5.	**Keywords:**	Riverbank stability, erosion, fluvial geomorphology, unmanned aircraft system, Vermont
6.	**Start Date:**	March 1, 2015
7.	**End Date:**	February 28, 2017
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9.	**Congregational District:**	Vermont-at-large

10.   Abstract - <u>System-wide rapid quantification of streambank erosion</u>

Streambank erosion is estimated to account for 30-80% of sediment loading into waterways.   In many cases, this sediment is carrying important pollutants, such as phosphorus. Langendoen et al. (2012) recently completed a study involving extensive fieldwork and BSTEM (Bank Stability and Toe Erosion Model) modeling for the State of Vermont to estimate sediment loadings from streambank erosion in main stem reaches of Missisquoi River. Using the flow records between 1979 and 2010, they predicted that 36% of the total suspended-sediment load entering Missisquoi Bay (31,600 t/yr) was derived from streambank erosion. These estimates were based on "one-time", yet labor and resource intensive, field work conducted at 27 sites that were extrapolated to 110 km of stream length and across 30 years in time. Although this study demonstrated that the estimates of streambank erosion can be obtained at the watershed level, this approach requires tremendous resources. Recent approaches such as aerial LiDAR have proved effective for watershed level assessment, but airborne LiDAR data collection is costly. Terrestrial LiDAR is more affordable if the equipment is available, but the equipment is bulky (especially for reaching remote locations) and data collection is time consuming and limited to relatively small areas. Therefore, cost-effective approaches to reliably quantify streambank erosion at the watershed level have remained an elusive goal. Recent developments in Unmanned Aircraft Systems (UAS) provide opportunities for rapidly and economically determining streambank erosion and deposition at variable scales (from site specific to watershed scale).

The objectives of the proposed study are to: (1) develop decision support tools to effectively acquire and process continuous streambank profiles using an affordable UAS; (2) compare the results at select sites from terrestrial and airborne LiDAR-based surveys; (3) develop and validate a methodology to reliably quantify annual system-level streambank erosion and deposition rates; and (4) develop and incorporate related educational modules for the University of Vermont (UVM) coursework and conduct professional development workshops for Vermont state and government personnel, and disseminate the results through publications.

Considerable progress has been made in the first year of this project (March 1, 2015 to February 29, 2016). A total of 18 km of stream reaches within the Mad River watershed, 2 km along the Winooski River, and 1.5 km along the New Haven River were flown using the SenseFly eBee UAS during 2015. Seven streambank sites were simultaneously surveyed using terrestrial LiDAR and RTK-GPS. Data processing for all seven sites has been completed and shows good agreement between the UAS and terrestrial LiDAR data in areas not obscured by vegetation.

Year 2 effort will include repeat flights and scans again in spring and fall, with additional flights in response to storm events. Analysis in Year 2 will also include similar comparison to the aerial LiDAR data expected to be released in spring 2016, and will allow assessment of the ability of UAS to reliably quantify annual streambank erosion and deposition rates at a watershed level.

This work should have substantial impact on the understanding of bank stability and sediment input to Vermont streams. In particular, we will be able to provide a field-validated methodology that will allow reliable quantification of the contribution of streambanks to sediment loadings in waterways, using Vermont as the case study. The developed methodology will be cost-effective for measuring rate and quantity of streambank erosion and transferrable to other regions in and outside of Vermont.

11. Budget Breakdown

Project Title: System-wide rapid quantification of streambank erosion

Cost category	Amount ($) Federal	Amount ($) Non-Federal	Total ($)
1. Salaries and Wages			
-Mandar Dewoolkar		9,688	9,688
-Jarlath O'Neil-Dunne	790		790
-Donna Rizzo		7,322	7,322
-Jeff Frolik		7,007	7,007
-Staff	2,529		2,529
-Graduate student	24,720		24,720
-Undergraduate student	3,000	6,500	9,500
Total Salaries and Wages	31,039	30,517	61,556
2. Fringe Benefits	3,302	10,854	14,156
3. Supplies	1,000	1,500	2,500
4. Equipment			
5. Services of Consultants			
6. Travel	1,500		1,500
7. Other Direct Costs (tuition)	6,110		6,110
8. Total Direct Costs	42,951	42,871	85,822
9a. Indirect Costs on Federal Share		19,894	19,894
9b. Indirect Costs on Non-Federal Share		23,150	23,150
10. Total Estimated Costs	**42,951**	85,915	128,866

12. Budget Justification

<u>Salaries and Wages</u>: PI Dewoolkar will commit 8.56% of his academic time for this project. Co-PIs Rizzo and Frolik will commit 5.85% of their academic time for this project. O'Neil-Dunne will also serve as a Co-PI on the project. He will devote 0.1 month of his time annually to the project, charged to the project. Dewoolkar will be responsible for overall management of the project, overall data collection, and data management. O'Neil-Dunne will oversee UAS operations and data processing. A staff member (Sean MacFaden, 0.5 month/yr charged to the project) will assist him in the UAS operations. Rizzo will be responsible for comparisons to airborne LiDAR data and overall data processing methods development. Frolik will be responsible for terrestrial LiDAR data collection and analysis. The PIs will be assisted by at least one graduate student and one undergraduate student each year of the project. Support for $24,720 in stipend is requested for the graduate student for Year 1 ($24,720 for Year 2). The undergraduate summer stipend of $6,500 and associated supplies of $1,500 are provided as a match. The source of this funding will be the Richard Barrett Scholarship program. Support for $3,000 for a student researcher during academic year is requested.

<u>Fringe Benefits</u>: Fringe benefits are calculated at 43% for the PIs and staff. The fringe for the graduate student wage is calculated at 6.6%. The fringe for the undergraduate student wage is calculated at 8.1%.These rates are in accordance with the current university rates.

<u>Supplies</u>: An amount of $1,000 is requested to cover costs associated with UAS accessories. A match of $1,500 in supplies is provided, which will cover other incidental supplies such as reflectors, pins, carts, etc.

<u>Equipment</u>: None requested.

<u>Services of consultants</u>: None requested.

<u>Travel</u>: An amount of $1,500 per year is requested for traveling to many field sites multiple times a year.

<u>Other Direct Costs</u>: Amount of $6,110 is requested for graduate student tuition. F&A is not charged on this amount.

<u>Indirect Costs</u>: Indirect costs are calculated as 54% of MTDC.

13.   Evaluating Quantitative Models of Riverbank Stability

14.   Regional or State Water Problem

A growing concern over the past few decades in the Lake Champlain region is the eutrophication of Lake Champlain. The Vermont Agency of Natural Resources identified sediment and phosphorus as the largest contributors to the impairment of surface water quality and aquatic habitat in the State (e.g. VTANR, 2011). Phosphorus has also been identified as the rate-limiting nutrient for the algal blooms in Lake Champlain and has been blamed for accelerating eutrophication for the past several decades (Meals and Budd, 1998). With over 7,000 miles of streams and rivers feeding the Lake, massive amounts of sediment and associated nutrients are discharged each year. High phosphorus levels allow algae to flourish because phosphorus is often the limiting nutrient for growth. Understanding where sediment and its particle-associated nutrients come from is therefore critical for informed and effective land and water management.

Streambank erosion is estimated to account for 30-80% of sediment loading into lakes and waterways (Simon and Rinaldi 2006; Evans, et al. 2006; Fox, et al. 2007). In the Lake Champlain Phosphorus Total Maximum Daily Load (TMDL) report, the Vermont and New York Departments of Environmental Conservation (VTDEC and NYSDEC, respectively), suggested that streambank erosion, such as the example shown in Figure 1, could be one of the most important nonpoint sources of sediment and phosphorus entering streams, rivers, and lakes in the state (VTDEC and NYSDEC, 2002). The Lake Champlain Basin Program (LCBP) also considers

Figure 1: Example riverbank failure

streambank erosion to be a potentially important source of phosphorus loading and has advocated the funding of streambank stabilization measures to reduce these loads (Lake Champlain Management Conference, 1996). Langendoen et al. (2012) conducted a study involving extensive field work and BSTEM (Bank Stability and Toe Erosion Model) modeling for the State of Vermont to quantify sediment loadings from streambank erosion in main stem reaches of Missisquoi River. Using the flow records between 1979 and 2010, they predicted that 36% (31,600 t/yr) of the total suspended-sediment load entering Missisquoi Bay was from streambank erosion. These estimates were based on "one-time", yet labor and resource intensive, field work performed at 27 sites that were extrapolated to 110 km of stream length. Although this study demonstrated the feasibility of obtaining estimates of streambank erosion at the watershed level, this approach requires tremendous resources. Also, this method could not provide estimates of deposition; all eroded material was considered to be transported. Here, an alternate approach of using an affordable Unmanned Aircraft System (UAS) is proposed.

15. Statement of Results or Benefits

We propose to assess the capability of the low-cost UAS technology to make reliable quantification of streambank erosion and deposition at variable scales (ranging from site specific to the watershed scale). An UAS can be quickly deployed and acquire continuous images of several kilometers of streambanks, yielding orthorectified imagery and 3D topographic models. Because UAS are not subjected to the high costs and atmospheric constraints of aerial and

satellite systems, data can be acquired for a given location at numerous times throughout the year, particularly in early spring and late fall when the vegetation is sparse. Multi-temporal UAS data have the potential to track streambank erosion and stream migration over a desired period of time. This will lead to a reliable and affordable way of quantifying streambank erosion and deposition. The project will capitalize on significant experience developed at UVM in applying UAS and terrestrial LiDAR technologies for characterizing built and natural environments. The proposed study site is Mad River Watershed, which has been one of the major subjects of study under the current NSF EPSCoR RACC research project (http://epscor.w3.uvm.edu/2/node/30). The study area was recently flown for airborne LiDAR by the State; these data will also be useful to the proposed project to some extent. The educational components include graduate and undergraduate researchers and incorporation of research methods and results of this project into UVM courses. Professional development workshops will be developed and conducted for Vermont state and government personnel.

16. Objectives and Timeline

The specific objectives of the proposed study are to:

(1) develop decision support tools to effectively acquire and process continuous streambank profiles using an affordable UAS;

(2) compare the results at select sites from terrestrial LiDAR-based surveys;

(3) develop and validate a methodology to reliably quantify annual system-level streambank erosion and deposition rates; and

(4) develop and incorporate related educational modules for UVM coursework and conduct professional development workshops for Vermont state and government personnel; and prepare and submit manuscripts to journals and relevant conferences.

Our testable hypotheses are summarized in Table 1 below along with the criteria for success.

Table 1 – Research hypotheses

#	Hypothesis	Performance Criterion
1	The UAS-based analysis will yield accurate measurements of streambank changes.	When compared to measurements of streambank changes measured from terrestrial LiDAR the target level of match will be within 10%.
2	UAS streambank mapping will be more cost effective and timely than field survey or terrestrial LiDAR mapping.	A single UAS flight (~40 minutes in duration) will capture 2-8 km of stream and multiple flights will capture at least 10 km of a stream in a single outing. Data processing will be largely automated.
3	UAS streambank mapping will be timely and responsive.	UAS data acquisition will be conducted at key times during the year to coincide with optimal mapping conditions. Following a major event (e.g. flooding) UAS data will be collected within 72 hours. UAS data processing will be largely automated and yield 2D and 3D products within 24 hours of data acquisition.

Selection of sites, UAS flights, terrestrial LiDAR scans, and RTK-GPS survey have been completed for 2015. In year two, we will continue with repeat flights and scans of sites to

determine longer-term erosional activity along the river corridor. Additionally, it is anticipated that the aerial LiDAR dataset will be published and that the focus can shift to in-depth comparisons of the UAS and terrestrial LiDAR. These additional re-surveys will allow for the critical analysis of identifying changes along the river corridor due to bank erosion.

The project builds on the bank stability work we have done under previous Water Center projects, which also laid the foundation for the streambanks related work currently underway for the ongoing National Science Foundation-funded EPSCoR RACC project in the Mad River Valley. The project also benefited from the recent developments of UAS technologies at UVM that are funded by an ongoing U.S. Department of Transportation-funded project on applying UAS imagery for disaster response and recovery.

17.   Methods, Procedures, and Facilities

Several methods have been used to quantify streambank erosion and deposition as depicted in Figure 2. One of the most basic methods is direct measurement. For example, Lawler, et al. (1999) made use of longitudinal surveys and pins to quantify sediment loading through bank erosion. Longitudinal surveys allow the measurement of bank top retreat, while the pins allow measurement of toe erosion of laterally migrating streambanks. Direct techniques such as these have been found valuable in determining sediment loads in small watersheds; however, they are very labor intensive. Other approaches have included estimates of lateral channel movements based on the analysis of aerial photography (e.g. Reinfelds, 1997; Hughes, et al., 2006), and more recently, using remote sensing (e.g. aerial or terrestrial LiDAR) observations (e.g. De Rose and Basher, 2011), which are quite expensive.

Analytical approaches have used slope stability analysis based on the limit equilibrium method (e.g. Osman and Thorne, 1988; Darby and Thorne, 1996)

Figure 2: Methods for quantifying streambank retreats

and often employ computer programs such as SLOPE/W (e.g. Dapporto, et al., 2003; Borg et al., 2014) and BSTEM (e.g. Simon, et al., 2000; Langendoen et al. 2012). The latter model includes fluvial erosion in addition to geotechnical failure. These approaches rely heavily on determination of relevant soil properties and site characterization (e.g. soil classification, unit weights, shear strength parameters, soil suction, root strengths, etc.) requiring extensive field work (e.g. Simon, et al., 2000; Borg, et al. 2014). With the exception of remote sensing applications such as airborne LiDAR, which is expensive; the above mentioned other methods (erosion pins, traditional and terrestrial LiDAR-based surveys, analytical slope stability methods) provide only site specific information requiring crude extrapolations to make watershed-level estimates of streambank erosion. Recent developments in UAS technology provide opportunities to develop methodologies for rapidly and economically determining streambank erosion at
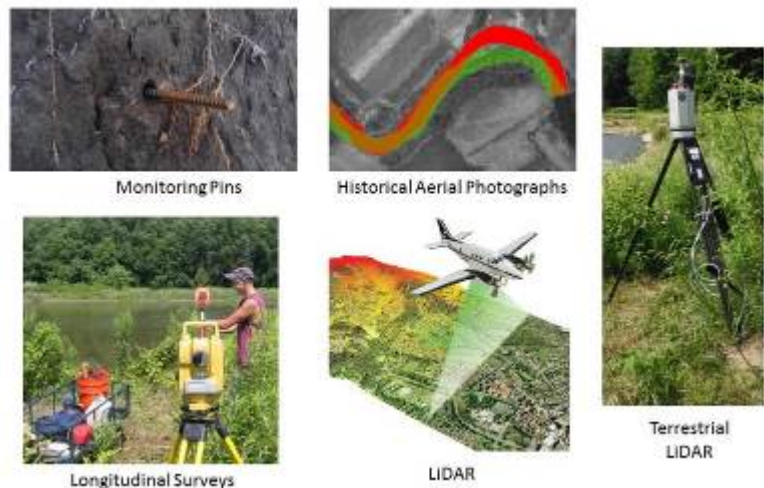
system-wide scale. The proposed research employs the following UAS system and terrestrial LiDAR. Both are owned and operated by UVM.

Figure 3. The UAS team preparing for launch of the UAS at Lareau site in Waitsfield

Figure 4. The UAS being launched at Moretown site by graduate student Scott Hamshaw

The UAS to be used for this research is SenseFly eBee, shown in Figures 3 and 4. The eBee is owned and operated by UVM Spatial Analysis Lab (SAL) in collaboration with the Transportation Research Center (TRC). The eBee was purchased under a US Department of Transportation grant. Over 300 flight operations have been conducted yielding over 20TB of 2D and 3D data products. The eBee is lightweight autonomous foam aircraft that contains an integrated 16 MP camera capable of recording aerial imagery at resolutions as fine as 2 cm/pixel. The entirety of this system's hardware can be easily transported in a flight case and rapidly assembled in the field. With a well-practiced team following a set of established standard guidelines, the eBee can be deployed in a few minutes. A field-swappable rechargeable battery provides up to 45 minutes of flight time and allows the eBee to cover areas up to 10 km^2 (3.9 mi^2) in a single flight; and the system can be used in light rain or snow and can tolerate winds as high as 10 m/s (22 mph) (Zylka, 2014). An integrated GPS unit and radio module facilitates communication between the UAS and the associated software (eMotion2) to provide real-time flight monitoring. The stream environment can sometimes be unsafe during storm events and conventional surveying often requires targets to be held in the stream; making UAS a much better alternative.

The terrestrial LiDAR used in this research is a RIEGL VZ1000 model (Figures 4 and 5), which was acquired through a National Science Foundation grant. It is capable of remote three-dimensional mapping of surfaces with very fine resolution (better than 1 cm) that are from 2.5 m to 1,000 m in distance. Each return from the laser pulse system has range and intensity values, as well as spatial position measured in three dimensions. When plotted in 3D space, these returns are referred to as a point cloud. By distributing reflective control targets around an area of interest, it is possible to combine the data collected by several scans at unique locations into a single composite point cloud. UVM also owns copies of the software RiScan and QT-Modeler, which are used to post-process the LiDAR data. The former also allows for multi-station alignment which alleviates the need for specific targets and aligns scans using environmental features. It is to be noted that control targets will not be necessary for the UAS because it is fitted with a GPS unit making it even easier to deploy and use.

A total of about 20 km of stream reaches within the Mad River, New Haven River, and Winooski River watersheds have been selected for this investigation. These include the main stems as well as some tributaries. Seven specific sites within these 20 km stream reaches have been selected for terrestrial LiDAR scans, which cover about 100 m length of the stream at each

location. It is anticipated that a total of about eight sets of UAS and companion terrestrial LiDAR datasets would be collected over the 2-year project duration. Data will be gathered in early spring and late fall when the vegetation is sparse; these will total to four sets of data. Two additional data sets will be gathered following significant storm events and also when water levels in the stream are lowest. UAS and terrestrial LiDAR data will be collected concurrently to allow direct comparison and assess the accuracy of UAS-based measurements against the terrestrial LiDAR-based measurements.

The analyzed data will be compared to airborne LiDAR data. The Airborne LiDAR was recently (~May 2014) flown in the Mad River Watershed and the associated data are expected to be released sometime in early 2016 (there is usually about a year-long lag between data collection and dissemination owing to time-consuming data processing and QA/QC). Unfortunately, multi-date airborne LiDAR data will not be available for the study area. Nonetheless, the airborne LiDAR-based data from May 2014 when compared to the UAS and terrestrial LiDAR-based data to be collected as part of this project will allow estimation of streambank retreats between this duration of about a year. This retreat rate could then be qualitatively compared to the ones determined between 2015 and 2016 obtained using UAS and terrestrial LiDAR.

Findings from Year 1 of Project

Data Collection

During the first year of this project the UAS was deployed to survey 21 km of river corridors in Central Vermont. Terrestrial laser scanning and GPS surveying were also utilized at 7 detailed streambank monitoring sites. River corridor and stream bank sites are displayed in Figure 6; areas that were surveyed a single time and multiple times with the UAS are identified. Approximately 50% of river corridors were repeat-surveyed. During April to December 2015, 45 individual UAS flights were executed capturing 21 km of river reaches along the Winooski River, Mad River, Shepard Brook, and New Haven River and resulting in over 280 GB of imagery and topographic data.

Figure 5. Mapping area along a section of the Mad River covering the MR-B site for a single flight. Yellow lines are user-selected, pre-programmed flight lines that the UAS follows automatically.

The river corridors were surveyed using an eBee (SenseFly) UAS resulting in the successful acquisition of orthoimagery, true color point clouds, and digital surface models (DSMs). Two models of the eBee were used in this study, the eBee and eBee RTK. The standard eBee UAS was utilized for the first round of flights in late spring (April and May) 2015. Later flights were completed using the eBee RTK which is a survey-grade system that features a more accurate GPS receiver capable of connecting to a virtual or local GPS base station. The UAS imagery was collected at a ground resolution of 3.6 cm with an overlap of 60% to allow for creation of high resolution DSM. An example of the flight path flown by the UAS in a single flight is shown in Figure 5.
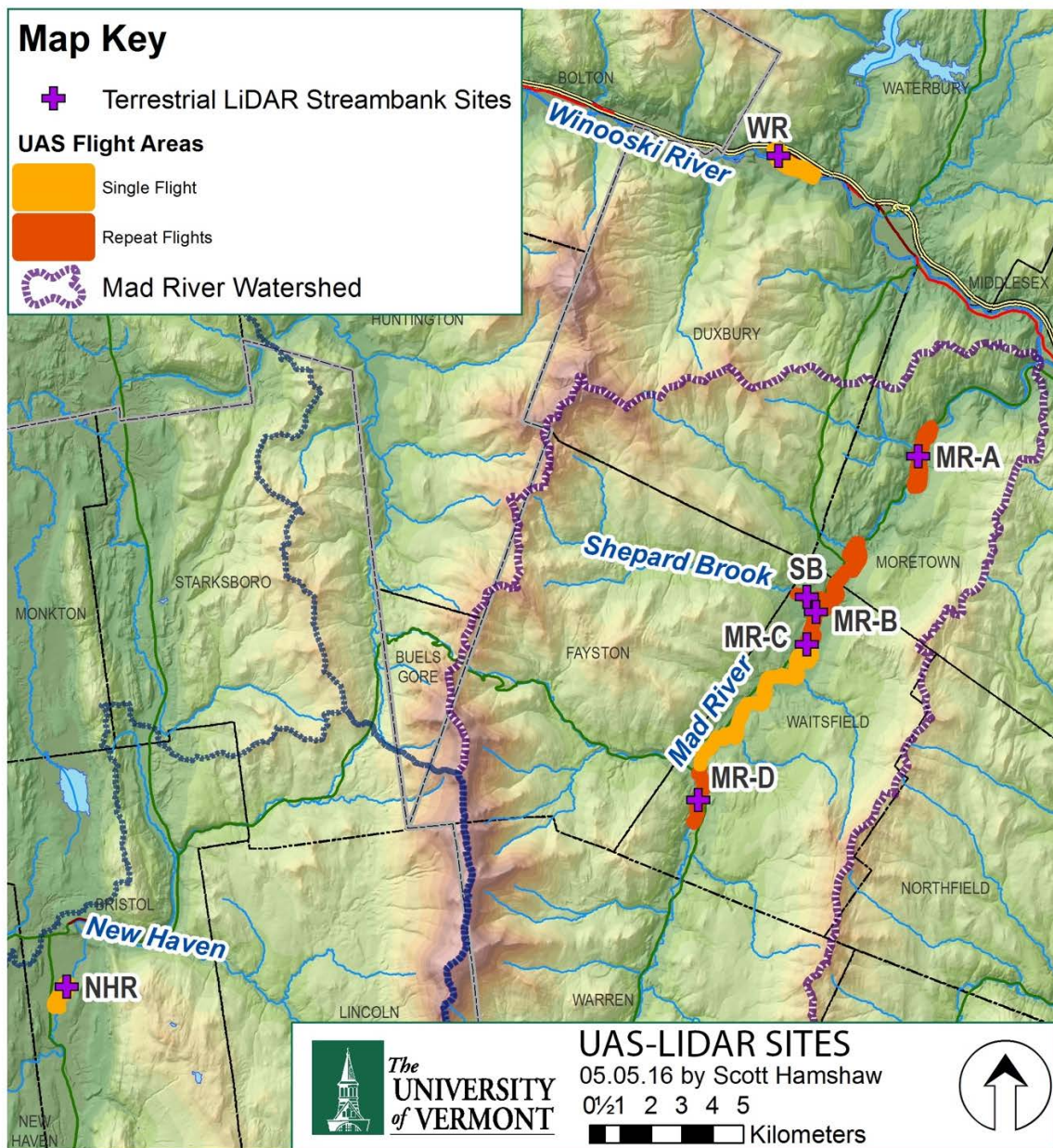
Figure 6. Map of streambank sites for terrestrial LiDAR surveying and areas where data were acquired using UAS.

All areas were flown in late April and early May prior to leaf out to minimize vegetative cover while collecting topographic data. Following a moderate storm event on June 1, 2015, three 1 km reaches were re-surveyed for comparison of pre- and post-storm events. Finally, a 2 km section of the Winooski River in Waterbury was flown and scanned (Figures 7 and 8) in August to assess similar methods on taller streambanks. Repeat surveys of approximately 50% of the river corridors in the Mad River watershed were conducted in November after leaf off. An active river reach in Bristol on the New Haven River was also added to the study area and flown in late December.

To assess the accuracy of the UAS derived topographic data, seven streambank sites were identified for simultaneous data collection using all three methods - UAS, terrestrial LiDAR, and GPS survey. These seven monitoring sites (Figure 6) were selected to represent a variety of bank heights, vegetative conditions, and lateral instability. As summarized in Table 2, bank heights ranged from 1.4 m to 3.7 m and featured different soil types ranging from fine sand to silt loam. Vegetative conditions ranged from no tree cover with only grass to brush and heavy brush and tree cover.

Table 2. Streambank location and characteristics of detailed comparison sites

Site	River	Bank Height	Bank Soil Type	Channel Substrate	Vegetation	Erosion Sensitivity
WR	Winooski	3.7 m	Fine sand	Silt	Grass	High
MR-A	Mad	2.8 m	Fine sandy loam	Silt	Grass / brush	Low
MR-B	Mad	2.2 m	Very fine sandy loam	Gravel	Heavy brush & trees	Medium
MR-C	Mad	2.1 m	Fine sandy loam	Gravel	Heavy brush & trees	Medium
MR-D	Mad	2.0 m	Fine sandy loam	Gravel	Grass / brush	High
SB	Shepard	1.4 m	Silt loam	Gravel	Grass	High
NHR	New Haven	1.9 m	Very fine sandy loam	Gravel	Grass	High

Figure 7. Terrestrial LiDAR data collection along the Winooski River with graduate student Thomas Bryce and undergraduate researchers

Figure 8. Streambank site along Winooski River with active erosion being scanned by the terrestrial LiDAR

Short sections (50 - 100 m) of streambanks were scanned using the Riegl VZ-1000 terrestrial laser scanner to acquire true color point clouds of the bank surface (e.g. Figure 9). A Topcon HiperLite+ RTK GPS System was used to capture a bank profile and ground control points. Table 3 summarizes the timing of data collection at each site and also the equipment utilized. During data collection river flows were not above normal, but high enough to not be

safe for wading and setup of the TLS at all sites. Where the TLS could be setup, scans were completed on the same day as UAS flights.

Table 3. Type of survey instrument and date of survey

	Spring		Summer		Fall	
SITE	Survey Date	Survey Systems	Survey Date	Survey Systems	Survey Date	Survey Systems
WR	--	--	8/3/15	eBee RTK	--	--
MR-A	5/6/15	eBee, TLS	--	--	11/9/15	eBee RTK, TLS, GPS
MR-B	4/29/15	eBee, TLS	--	--	11/10/15	eBee RTK, TLS, GPS
MR-C	4/29/15	eBee, TLS	--	--	11/10/15	eBee RTK, TLS, GPS
MR-D	4/22/15	eBee	6/22/15	eBee RTK, TLS	11/10/15	eBee RTK, TLS, GPS
SB	4/27/15	eBee	8/26/15	eBee RTK, TLS	11/9/15	eBee RTK, TLS, GPS
NHR	--	--	--	--	12/22/15	eBee TLS, GPS

Figure 9. MR-B field site on the Mad River showing UAS imagery, area of terrestrial laser scanning, ground control points and also location of cross section survey with GPS

UAS-derived DEM Accuracy

Analysis in this first year has focused on assessing the accuracy of the UAS data through comparison of the UAS, LiDAR, and GPS datasets at the seven streambank sites. Point cloud data from both the UAS and LiDAR methods have been registered using surveyed ground control points (GCPs) to allow for direct comparison and assessment of accuracy of the UAS data. The UAS data were compared to the terrestrial LiDAR data to assess the performance and accuracy of the UAS streambank surveys. Figure 10b shows an example of this raw cross-sectional data that is then filtered and processed to a bare-earth surface for comparison.
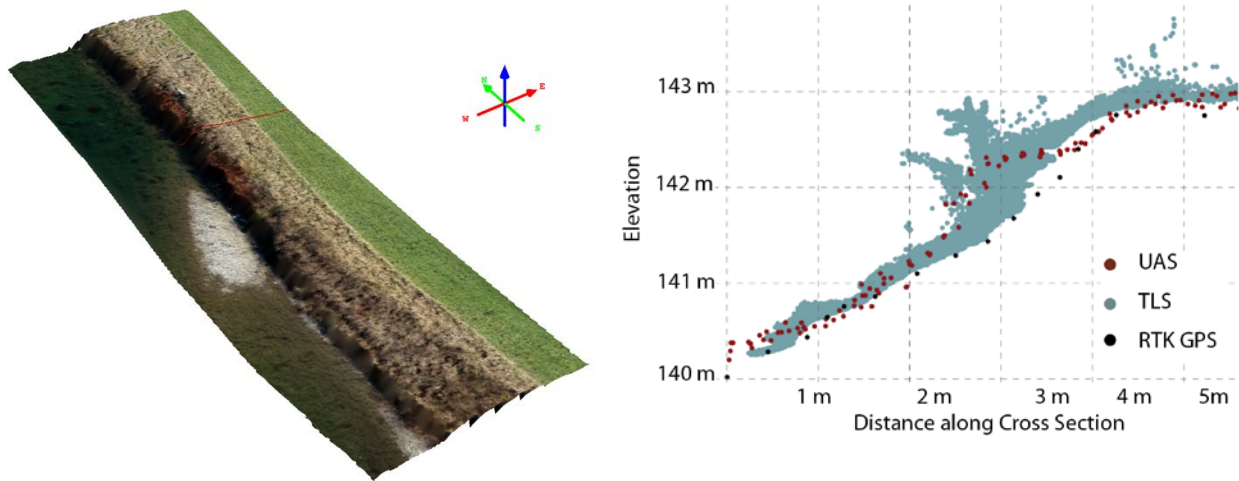
(a) Cross-section and true color DEM of the MR-A streambank site on Mad River in Moretown generated by senseFly eBee RTK UAS

(b) Comparison between bank profile obtained by the UAS system (brown), the Riegl VZ-1000 terrestrial LiDAR (blue) and RTK-GPS (black)

Figure 10. UAS and LiDAR comparison at MR-A streambank site on Mad River

Because all study sites featured some amount of vegetation, filtering of the TLS data was necessary to extract a bare-earth surface. This filtering was performed in Quick Terrain Modeler (QTM). A minimum Z (or 2.5D Raster) filter was utilized to minimize the effect of vegetation in the DEMs. Results from filtering were sufficient to allow creation of both UAS and TLS-derived DEMs at each of the streambank sites. The DEMs created by both survey methods and collected at different dates were then differenced against one another to calculate mean errors. At the MR-A streambank site the RMSE between surfaces created by UAS and TLS data was 0.250 m.

Figure 11. 3D view of UAS-derived DEM colored by difference from bare-earth TLS-derived DEM

The quality of both UAS and TLS survey data are affected by vegetation. To determine the error that vegetation growth can introduce into the DEMs generated from the UAS, analysis was done to compare the DEMs collected at the same site on different dates when differing amount of vegetation growth was present. At the MR-A site, it was observed that
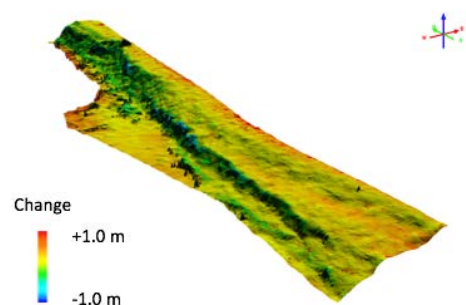
13

insignificant bank erosion occurred between the three flights during 2015 allowing for change to be attributed primarily to the amount of vegetation present (Figure 12). Table 4 summarizes the mean errors and RMSE between the UAS-derived DEMs from the three flights at this site. The vegetation condition at the MR-A site along and near the bank was similar on May 6 and Nov 9 when the grass was mowed to a similar height and bank brush was not lush. In contrast, on May 27 the vegetation was in active growth including approximately 12" tall grass along the top of the bank. This was reflected in the differenced DEMs where the lowest mean error (0.105 m) between surfaces was seen between May 6 and Nov 9 dates. Higher mean errors (up to 0.591 m) were seen in comparing either the spring (May 6) or fall (Nov 9) DEM to the early summer (May 27) DEM. Similar trends of mean errors corresponding to the amount of vegetation growth present were seen at other streambank sites, however, due to some minor erosion that was observed at other sites, the error cannot be attributed as easily to vegetation growth.

Table 4. Mean Error and RMSE of differenced DEMs from MR-A site

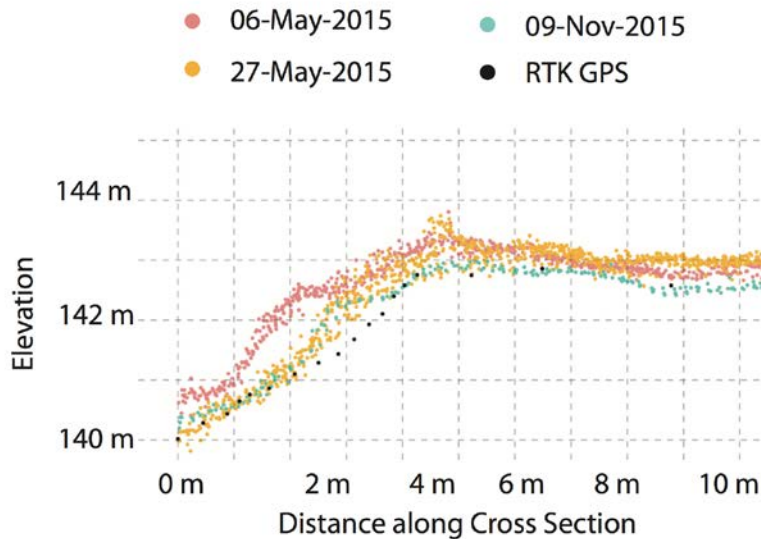| Site	UAS-derived DEM Comparison Dates	Mean Error (m)	RMSE (m)
MR-A	May 6 - Nov 9	0.105	0.391
MR-A	May 6 - May 27	0.591	0.353
MR-A	May 27 - Nov 9	0.333	0.304

Figure 12. Comparison of UAS-derived point cloud data and RTK GPS points along cross section at MR-A streambank

Change Detection

Between the 2015 survey dates there was generally minimal erosion of streambanks in the study area. On June 1, 2015, a bankfull flow event took place in the Mad River and caused some minor erosion along certain sections of the river including at the SB and MR-D sites. While no large bank failures occurred, minor bank erosion took place which can be seen in Figure 13 as the

areas in red. The green patches signifying an increase in ground elevation between dates is most likely due to vegetation growth.
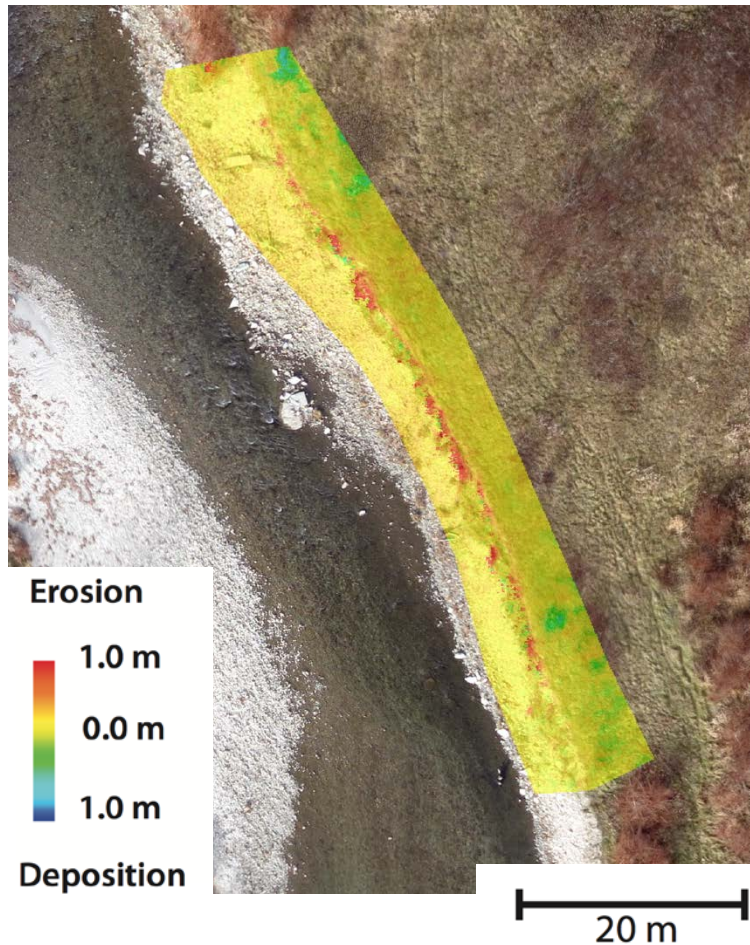
Figure 13. Erosion along MR-D streambank site that occurred between April 22, 2015 and November 10, 2015 seen in overlay of erosion depth calculated from difference between April and November UAS-derived DEMs

Integration of Research and Education:

So far, four undergraduate students, one MS student, and one PhD student have had direct involvement in the data collection and analysis in this project. Of these, only the PhD student, Scott Hamshaw, was supported by the VT Water Resources and Lake Studies Center grant. The MS student, Thomas Bryce, performed the work for academic credits. The four undergraduate students participated in the fieldwork and research efforts through a variety of summer internships. Two of the undergraduate students (Nathalie Simoes and Wimara Sa Gomes) used VT EPSCoR Research on Adaptation to Climate Change (RACC) summer internships for participating in this research. The other two undergraduate students, Anna Waldron and Kira Kelley, were supported on Richard Barrett Foundation Scholarships. Additional students (PhD student Kristen Underwood, MS student Jordan Duffy, undergraduate intern Alex Morton) were

able to participate in some elements of the fieldwork and analysis. The UAS work involved six staff and ten undergraduate students from UVM's Spatial Analysis Laboratory.

18.   Discussion

Data collection and processing workflows and methods were successfully implemented during the first year of the project. This has allowed for analysis of the UAS technology to reliably capture topographic data along streambanks to be able to detect bank retreat over time. During the 2015 project period, very little erosion of streambanks in the study area occurred. This prevented a robust analysis of change detection in support of testing Hypothesis #1 (Table 1) that suggested UAS-derived surfaces would be able to detect change within 10% of that detected by terrestrial laser scanning. It is expected that more extensive erosion has occurred during the 2016 spring melt that will provide more opportunity for evaluating the performance of the UAS for detecting change.

With the repeat flights taken during 2015 under different vegetation conditions and at different times of year, analysis of the effects of vegetation on data was possible. Based on the results at streambank site MR-A mean error in elevation of 0.1 m was determined between UAS flights conducted at different dates but with similar vegetation growth. This would suggest the lower limit for detection of a change due to erosion is 0.1 m with higher detection thresholds if data are collected when vegetation is more extensive.

The efficiency of UAS data collection is an important criterion in assessing Hypothesis #2 described in section 16. Single UAS flights performed in the Mad River have covered on average 600 meters of river length and include the entire river corridor with flight times ranging from 25 – 35 minutes. With this length of river covered in a single flight, it was feasible to cover a 5 km reach during a single field outing of about 8 hours. In general, due to suitable landing and take-off locations and visibility of the UAS from the landing/take-off area, two to three flights could be made from a single setup location. This translated to requiring a setup location for approximately each 1.5 km of river length. While this is less than the proposed performance criteria that Hypothesis #2 hoped, the high ground resolution and overlap did allow for complete data coverage in the area and higher accuracy. Expanding the coverage during a single flight to 2 km would be feasible with a crew that had additional spotters to be deployed upstream or downstream and also if the UAS target ground resolution is reduced allowing flights at higher altitudes. However, currently FAA regulations limit the use of UAS at higher altitudes.

In support of testing Hypothesis #3, post processing of the UAS data from a single outing in under 24 hours has been successfully accomplished for the spring and summer flights. While some additional filtering or post-processing may be desired, complete coverage of orthoimagery, DSM, and point cloud are easily completed in under 24 hours. The current requirements for UAS operation have a 72-hour approval process for air space which makes it practical to be on site and collecting data within 72 hours following a major event. There is also a rapid approval process if the situation is time sensitive.

Summary of Planned Year 2

Year 2 effort will include repeat flights and scans again in spring and fall, with additional flights in response to storm events. During the 2016 spring melt, two significant storm events have caused some significant erosion in places. More robust analysis of the UAS in comparison to the terrestrial laser scanner in quantifying this change is planned. Analysis in Year 2 will also include similar comparison to the aerial LiDAR data expected to be released in spring 2016, and

will allow assessment of the ability of UAS to reliably quantify annual streambank erosion and deposition rates at a watershed level. Additional work is also planned for increasing the efficiency of filtering vegetation from the raw point cloud data to more easily create bare-earth surfaces.

<u>Project Leverage of Additional Funding Sources</u>

This project leveraged several additional sources of funding during the first year and is expected to do the same during the second year. Funding from the U.S. Department of Transportation Office of the Assistant Secretary for Research & Technology provides additional support for UAS operations and processing resources. Funding from the National Science Foundation (NSF) (VT EPSCoR Grant No. EPS-1101317) provides additional support for undergraduate internships and graduate student and faculty support. Additional NSF support through the graduate research fellowship program (Grant No. DGE-0925179) provided additional resources for the full time graduate student on the project. The Robert and Patricia Switzer Foundation provides additional funding support to the full time graduate student on the project. Finally, the Richard Barrett Foundation provides support for undergraduate internships assisting with the project.

19. Training Potential

This research has a strong educational and mentoring component at a variety of levels. A number of graduate and undergraduate researchers have already been engaged in the project and the PIs will continue this effort of integrating research into education. These students are and will gain experience operating UAS and processing UAS data as well as with the terrestrial LiDAR. That the PIs are from different backgrounds (Civil, Environmental, and Electrical Engineering and Natural Resources), further enriches both the students' experience as well as the potential for the research to make significant gains. The methodology and results have been integrated into educational modules in the CE010 geomatics course at the University of Vermont. The data and methodologies will also be integrated into the VermontView Remote Sensing Workshop. This workshop, offered annually at UVM, trains geospatial professionals from federal, state, and local government agencies throughout the state on cutting-edge technologies. The results of this research are being presented at relevant on-campus and off-campus conferences (e.g. AGU 2015, AGU 2016, Geocongress 2017) and will be submitted to proceedings and refereed journals, thus educating a wider group of individuals, researchers and agencies interested in riverbank behavior.

Additional outreach to engage stakeholders and the general public have and will include presentations of the project to different non-profit/community organizations and governmental agencies. To-date these have included presentations to the Vermont Society of Professional Land Surveyors and members of the Bristol Conservation Commission. Presentations are currently being lined up to the Friends of the Mad River organization and Vermont Agency of Natural Resources. Additional offers for presentations will be made to Lake Champlain Basin Program, the Vermont chapter of American Society of Civil Engineers (ASCE), and the Agency of Transportation.

20. Investigators' Qualifications

Mandar Dewoolkar is an Associate Professor in Civil and Environmental Engineering. Through his graduate and post-doctoral research work and industry experience, he has developed significant expertise in the fields of *in situ* and laboratory soil testing, equipment and instrument development and computer-aided slope stability and flow analyses among other types of analytical methods. He has been the PI on two previous Water Center projects.

Jarlath O'Neil-Dunne is the Director of the Spatial Analysis Laboratory (SAL) at the University of Vermont. His research focuses on the application of geospatial technology to a broad range of natural resource issues ranging from water quality to urban ecosystems to land cover change. For the past two years he has served as the principal investigator on a US Department of Transportation grant that pioneered techniques for using unmanned aerial systems to rapidly map and measure transportation and hydrologic networks.

Donna Rizzo is a Professor in Civil and Environmental Engineering. She is a surface and groundwater hydrologist whose research focuses on the development of new computational tools to improve the understanding of human-induced changes on natural systems and the way we make decisions about natural resources. Her involvement using advanced GIS and remote sensing technologies in the above-mentioned research project funded by NSRC in coordination with the USDA Forest Service most closely relates to the proposed work.

Jeff Frolik is an Associate Professor in Electrical Engineering at UVM. His expertise is in sensor networks and he was PI on the NSF Major Research Instrumentation award (CMMI-1229045) that acquired the RIEGL VZ-1000 Terrestrial LiDAR. He has led the use of the terrestrial LiDAR for characterizing a wide range of built and natural environments including streambanks, snow packs, historical structures, and civil infrastructure. In this project, he will train students on the use of the LiDAR system and supervise its use.

Publications and Outreach

Presentations:

Hamshaw, S. D., Dewoolkar, M., Rizzo, D. M., O'Neil-Dunne, J., Rizzo, D.M., Frolik, J., Underwood, K.L., Bryce, T., Engel, T., & Waldron, A. (2015). *Quantifying streambank erosion: a comparative study using an unmanned aerial system (UAS) and a terrestrial laser scanner.* (Poster), American Geophysical Union 2015 Fall Meeting, San Francisco, California.

O'Neil-Dunne, J., & Hamshaw, S.D. (December 16, 2015). *LiDAR roundtable.* Vermont Society of Professional Land Surveyors December Roundtable, Montpelier, Vermont.

Dewoolkar, M. *Assessment of streambank stability within the context of stream pollution*, presentation at the Indian Institute of Technology, Mumbai, India, March 18, 2016.

Hamshaw, S.D. *Streambank erosion and prediction of suspended sediment flux.* Vermont EPSCoR Annual Meeting, St. Michael's College.

Graduate Student Thesis and Projects:

Bryce, T. (March 2016) *Quantifying streambank erosion through Terrestrial LiDAR (TLS) and an Unmanned Aircraft System (UAS)*. M.S. Civil & Environmental Engineering Project

Press and Outreach:

"Drones put to work to avoid natural disasters" Segment on WCAX aired August 3, 2016. Interviews of O'Neil-Dunne, J. and Hamshaw, S.D.

Presented research brief on project to staff from offices of Sen. Sheldon Whitehouse (RI) and Sen. Patrick Leahy (VT), March 14, 2016.

Education:

Presented UAS technology and performed demonstration to Waitsfield Elementary School 5th grade science class, May, 2015

Class module on UAS and terrestrial-LiDAR technologies incorporated in to UVM CE010 Geomatics course, Fall 2015 semester

Conference papers and presentations in progress:

Hamshaw, S. D., Bryce, T., Dewoolkar, M., Rizzo, D. M., O'Neil-Dunne, J., Rizzo, D.M., Frolik, J., & Engel, T. *Site specific to system-level analysis of streambank erosion using unmanned aerial systems.* Geocongress 2017 Conference, Orlando, Florida. Abstract Accepted

Peer-reviewed manuscripts in progress:

Hamshaw, S. D., Dewoolkar, M., Rizzo, D. M., O'Neil-Dunne, J., Rizzo, D.M., Frolik, J., Bryce, T., & Engel, T. *Evaluation of unmanned aircraft system (UAS) photogrammetry for quantifying streambank erosion and comparison to terrestrial laser scanner (TLS).* In progress, to be submitted to Earth Surface Processes and Landforms, 2016

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Information Transfer Program Introduction

The Vermont Water Resources and Lake Studies Center facilitates information transfer in a variety of ways. The Center maintains a web site that highlights emerging research funded by the Center or relevant to water resources management in Vermont.

A regional network website was developed for the New England Regional Water Resources and Research Centers. The website is updated with relevant news, RFP announcements, and links to each of the New England (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont) Water Resources Research Institutes, and the Water Science Centers.

Support by the Water Center of the e-digest publication, ecoNEWS VT, continued in 2015, highlighting ecological research from across Vermont. The publication is a collaboration with several other organizations, including Lake Champlain Sea Grant, Northeastern States Research Cooperative, and Vermont Monitoring Cooperative. Three issues with eleven new stories were produced in 2015, including several articles about Water Center funded projects. Each issue reaches approximately 250 subscribers. The readership includes university, state government, environmental non-profit, and general public subscribers. Articles are written for a non-expert audience.

In addition to the e-digest issues, all articles are archived online and tagged for cross-reference of similar topics. A new section was added to the website this year to capture ecological research being conducted outside Vermont, but relevant to issues found in Vermont. Events are also maintained on the website to inform visitors about seminars, public meetings, and workshops.

Elissa Schuett manages the communications and information transfer for the Water Center. Ms. Schuett also coordinates communications for Lake Champlain Sea Grant, bringing knowledge from the Sea Grant network and being able to broaden the reach of the information transfer from the Water Center. A graduate student was supported part-time by the Water Center to assist Ms. Schuett with writing feature stories and management of the outreach efforts of ecoNEWS VT.

USGS Summer Intern Program

None.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	0	0	0	0	0
Masters	2	0	0	0	2
Ph.D.	1	0	0	0	1
Post-Doc.	0	0	0	0	0
Total	3	0	0	0	3

Notable Awards and Achievements

Publications from Prior Years

1. 2011VT57B ("Determining phosphorus release potential from eroding streambank sediments in the Lake Champlain Basin of Vermont") - Articles in Refereed Scientific Journals - Ishee, E. R., D. S. Ross, K. M. Garvey, R. R. Bourgault, and C. R. Ford. 2015. Phosphorus Characterization and Contribution from Eroding Streambank Soils of Vermont's Lake Champlain Basin. J. Environ. Qual. 44:1745-1753.
2. 2015VT77B ("System-wide quantification of streambank erosion") - Articles in Refereed Scientific Journals - Hamshaw, S. D., Dewoolkar, M., Rizzo, D. M., O'Neil-Dunne, J., Rizzo, D.M., Frolik, J., Bryce, T., & Engel, T. Evaluation of unmanned aircraft system (UAS) photogrammetry for quantifying streambank erosion and comparison to terrestrial laser scanner (TLS). In progress, to be submitted to Earth Surface Processes and Landforms, 2016