Developing a Framework to Advance Statewide Phosphorus Reduction Credits for Leaf Collection

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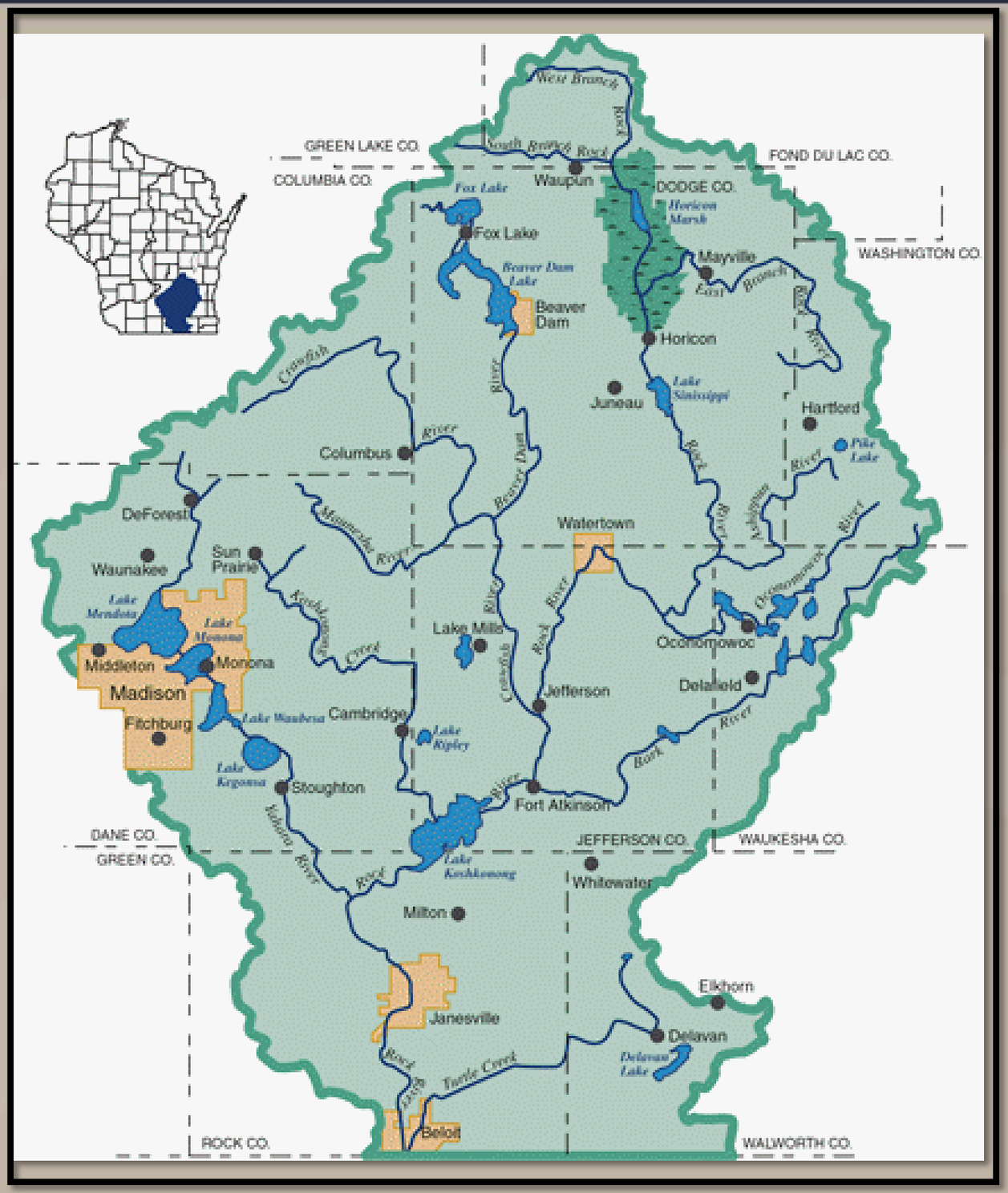
Pilot Study – Leaf Collection Management



Source: Rock River Coalition

- Agricultural and urban sources of phosphorus are targeted in the Adaptive Management plan for Rock River TMDL
- Leaf collection identified as reasonable measure to reduce Total P delivered to lakes
- What percent reduction in nutrients can MS4s expect by collecting leaves?
- Are some leaf collection practices better than others?

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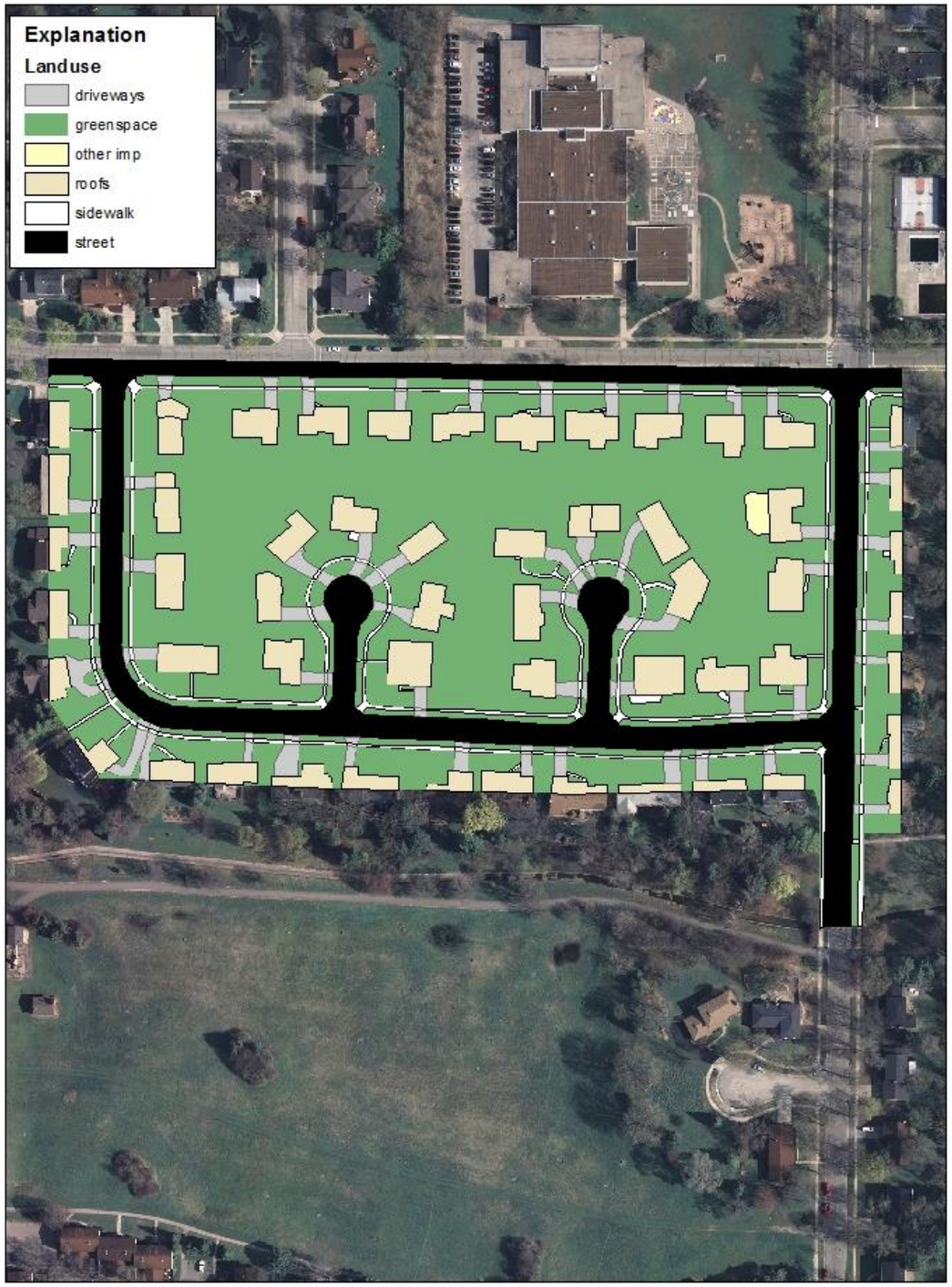
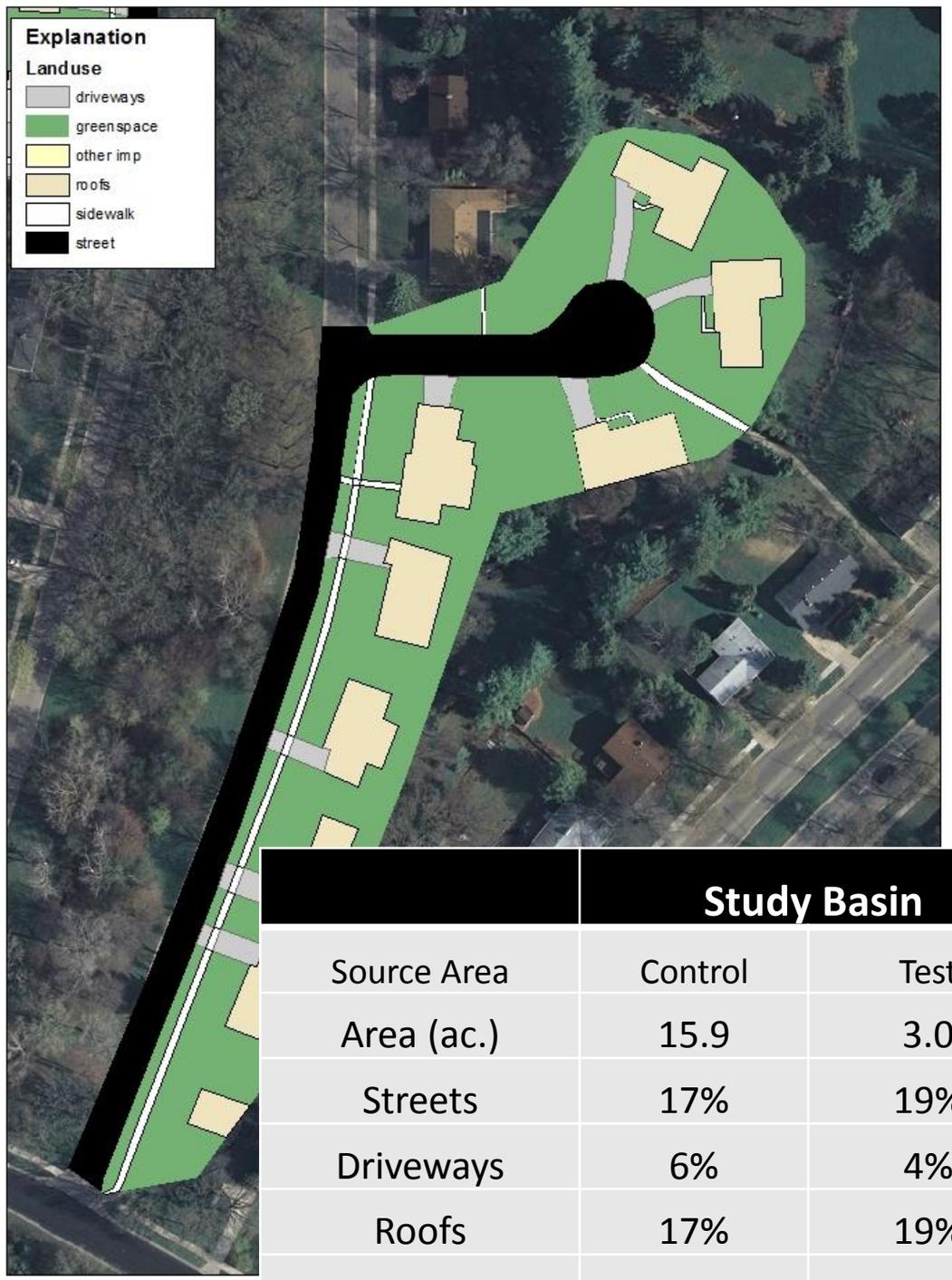
Control



Test



	Study Basin	
Source Area	Control	Test
Area (ac.)	15.9	3.0
Streets	17%	19%
Driveways	6%	4%
Roofs	17%	19%
Sidewalks	5%	3%
Lawns/Open	55%	54%
Other Impervious	<1%	0%
Tree Cover	45%	68%

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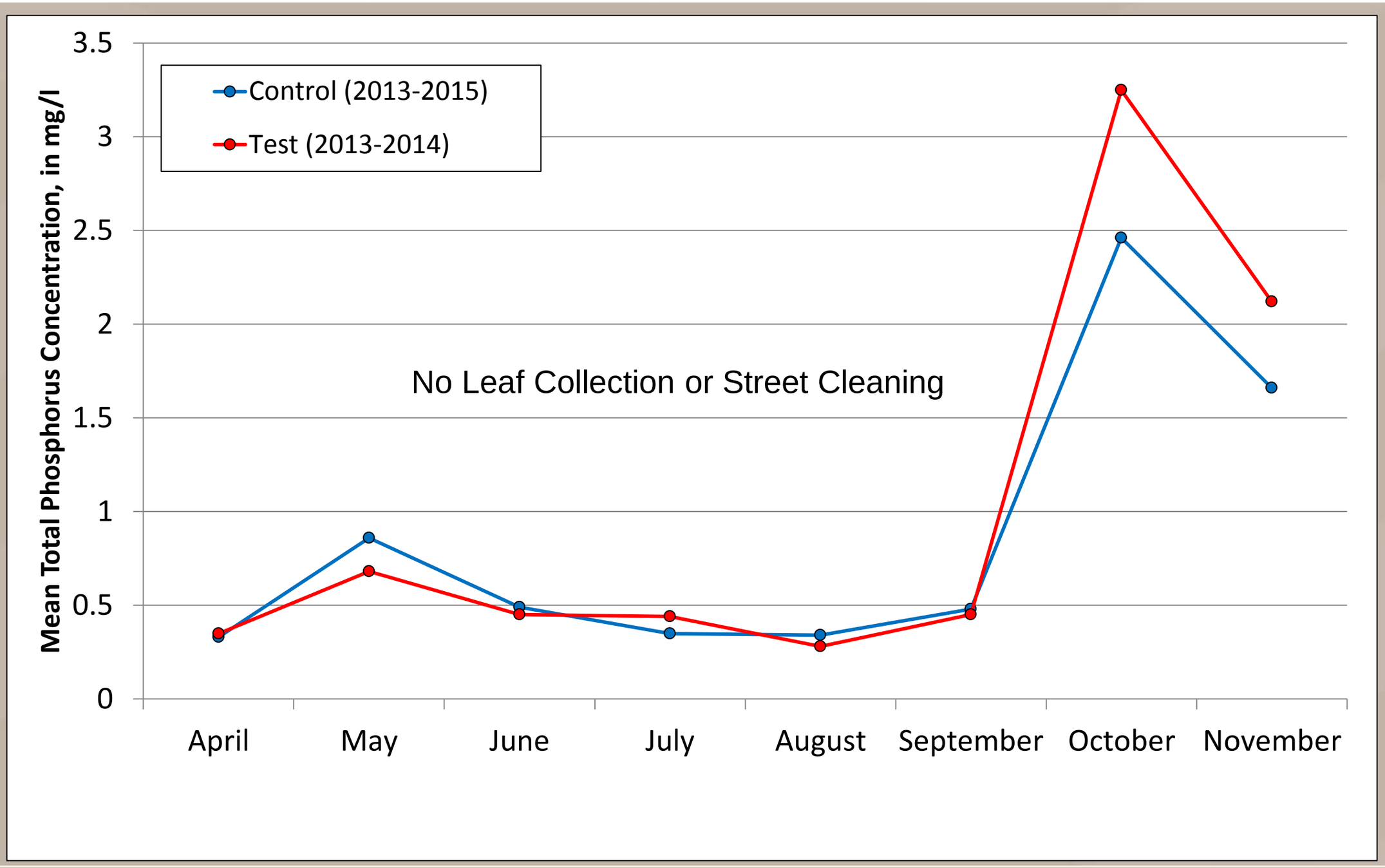

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“Escalated” Leaf Management in Test Basin

Weekly collection of leaf piles followed by high-efficiency street cleaning
October – November 2015

Plus…

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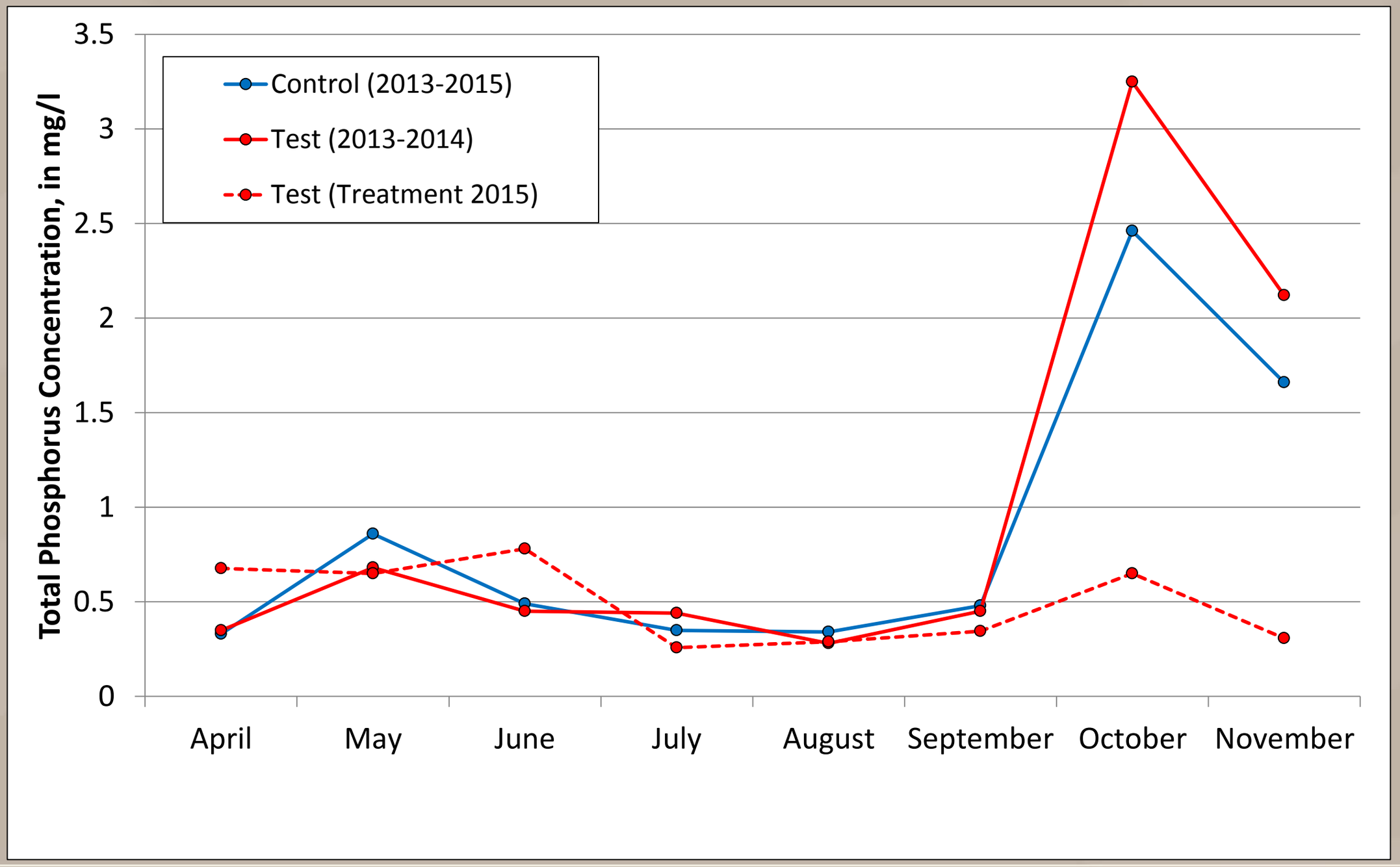
“Escalated” Leaf Management

In addition to municipal efforts, USGS field crews would clear all organic debris from street surface prior to rain event



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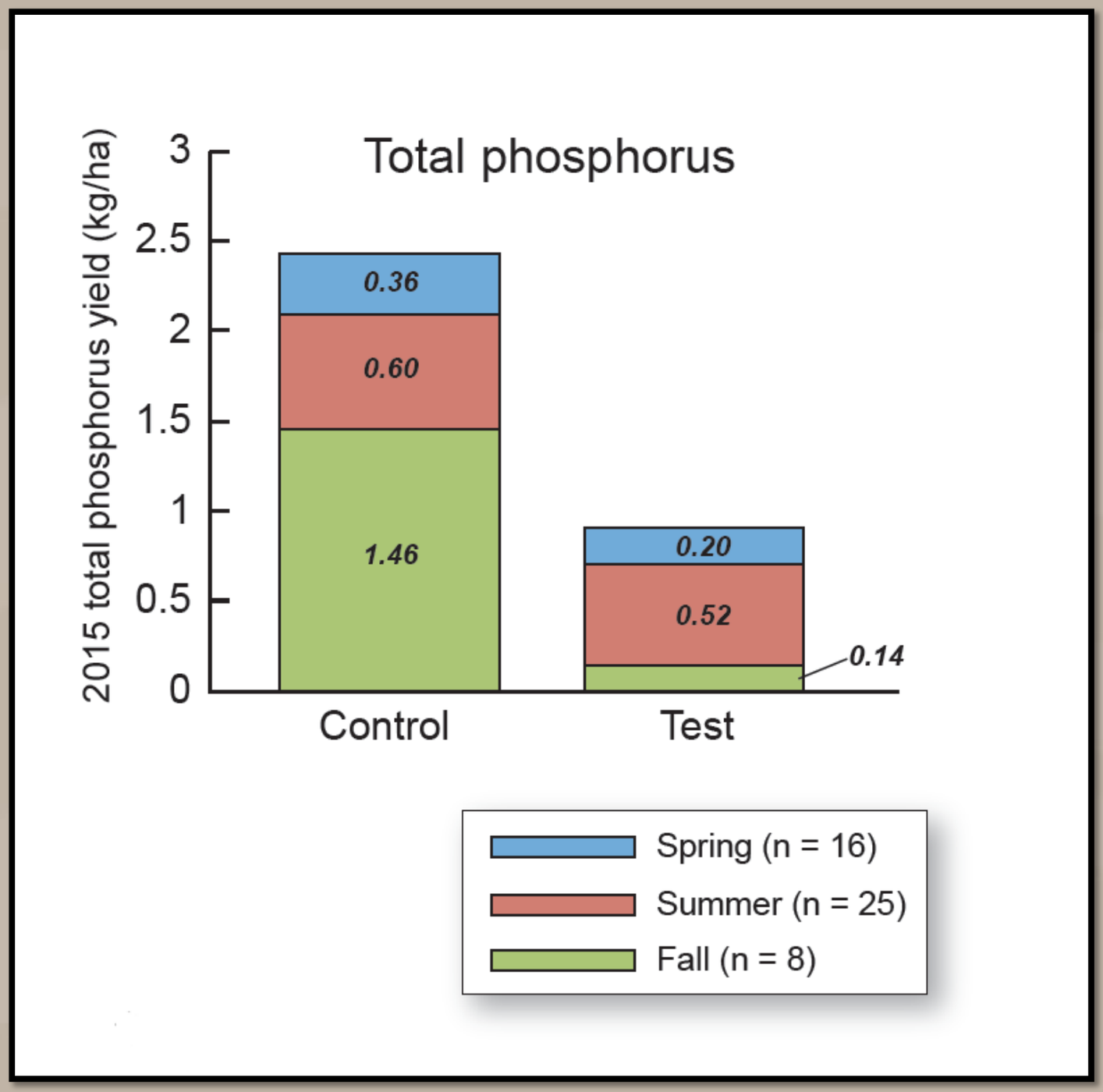
Seasonal Total Phosphorus Yield as a Percent of the 2015 Annual Yield (winter excluded)



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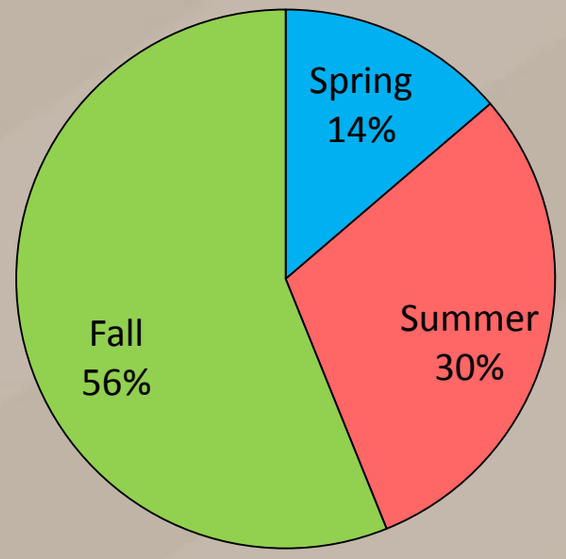

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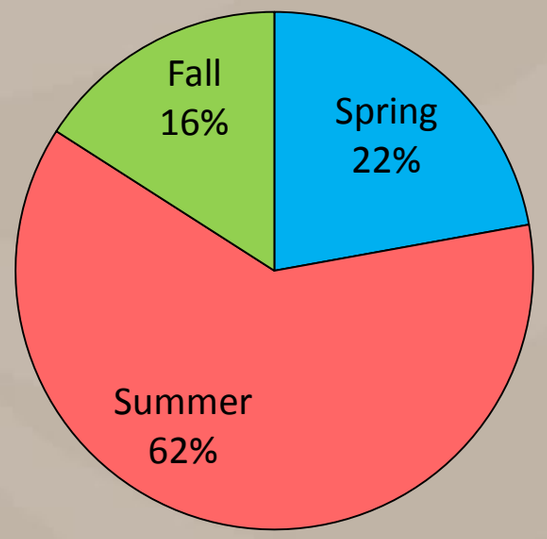

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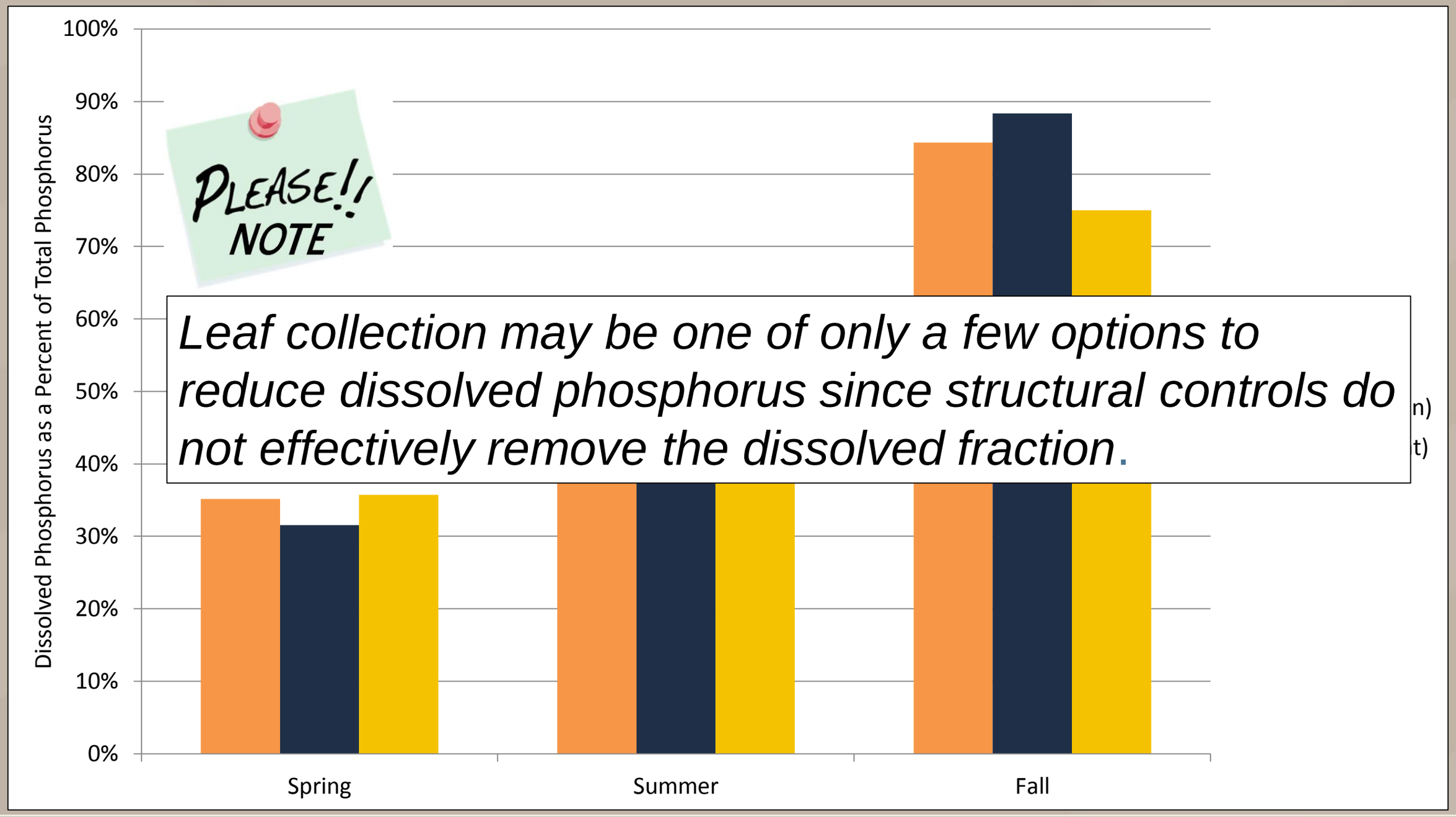
Seasonal Phosphorus Partitioning

Charts show the range of dissolved P as a percent of total P



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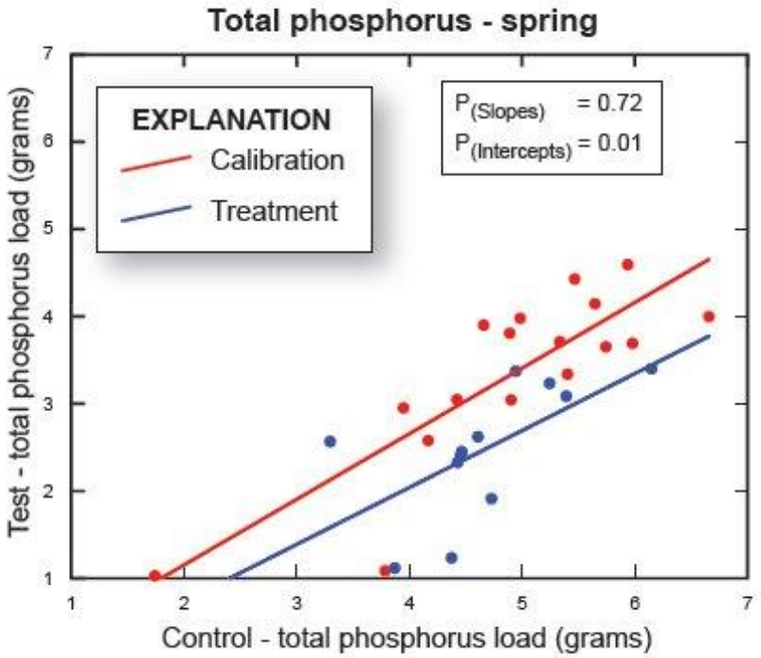
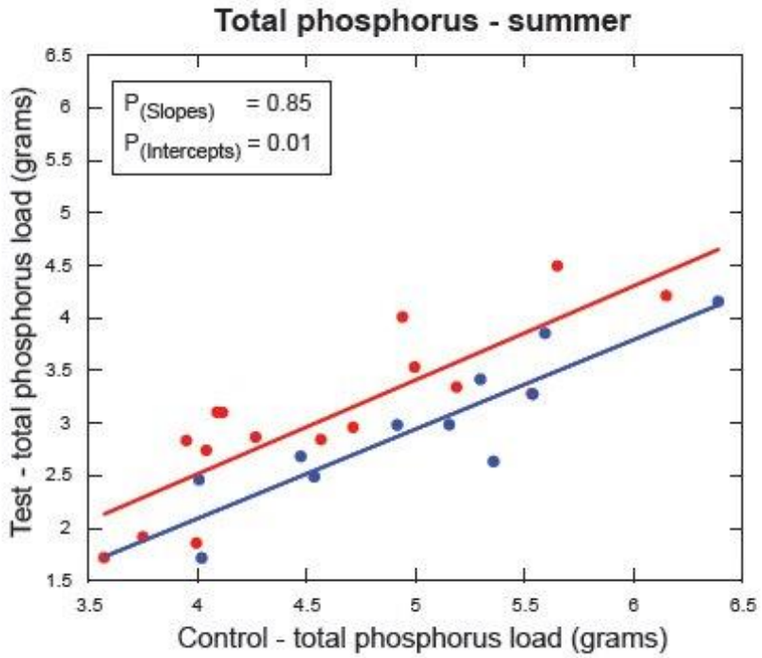
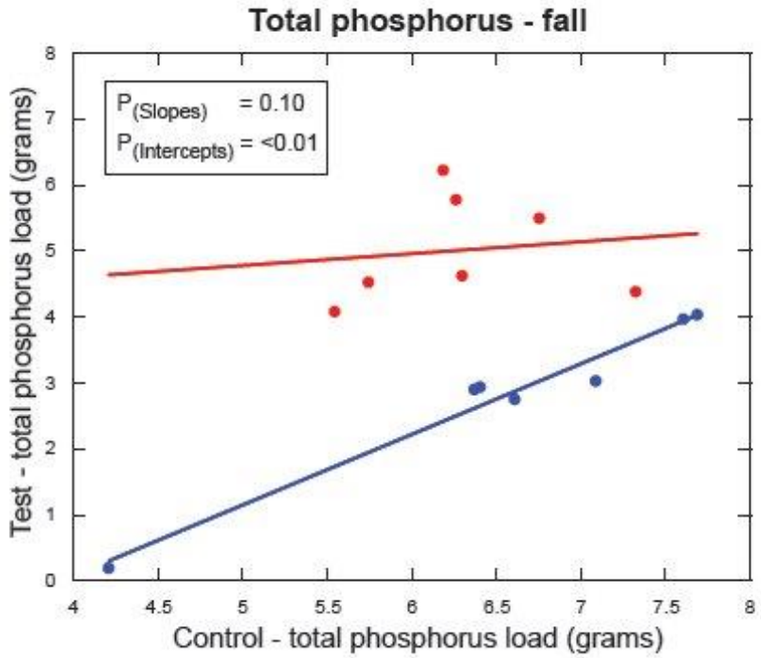
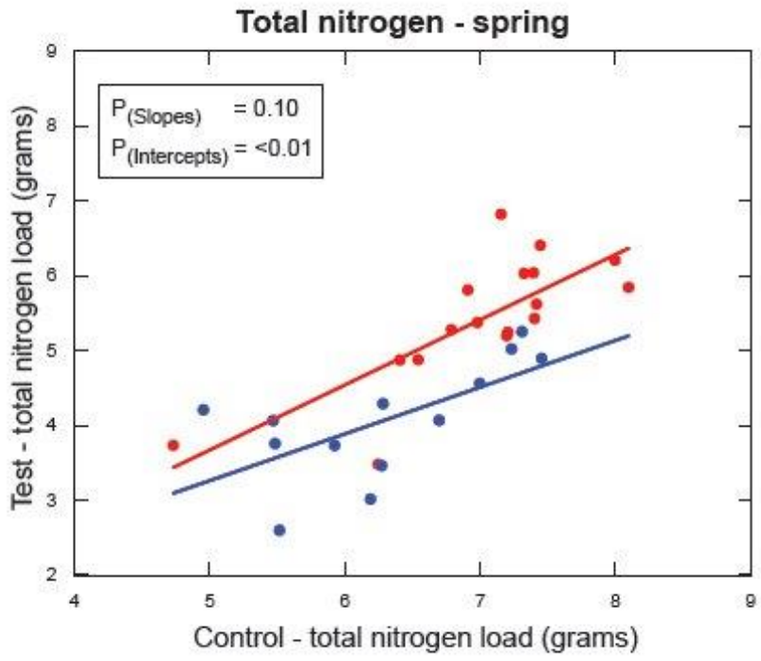
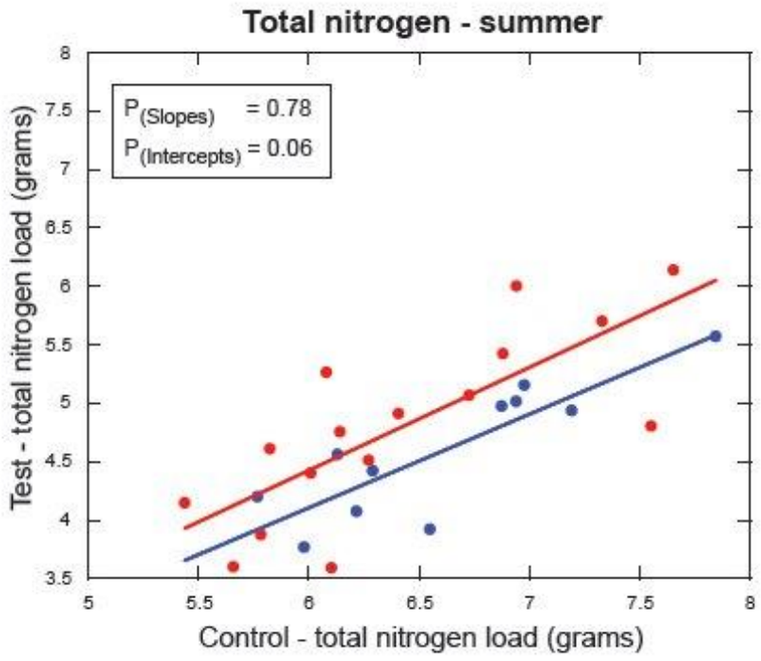
Paired Basin Results for Nutrient Load (Log), in grams

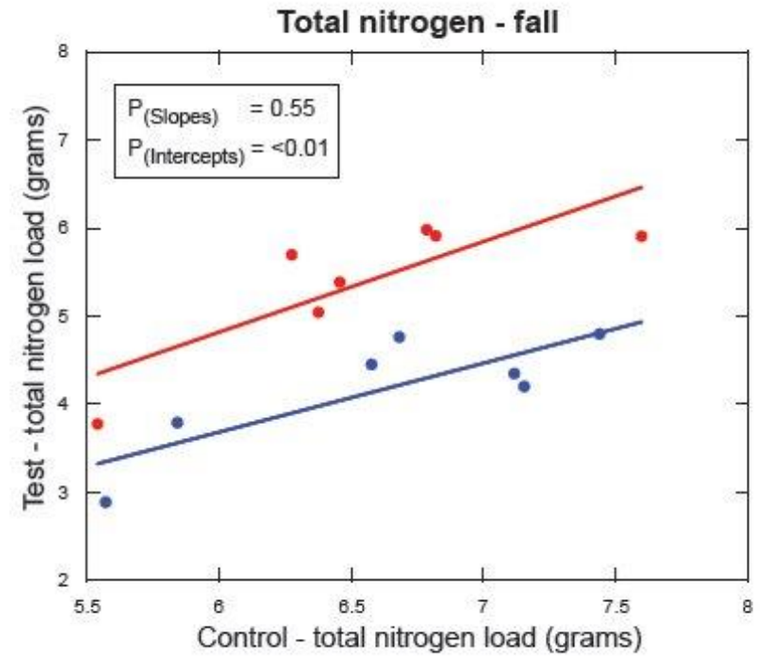












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Percent Reduction in Nutrient Load - 2015

Parameter	Spring	Summer	Fall
Total Phosphorus	-45	-36	-84
Total Nitrogen	-52	--	-74
Dissolved Phosphorus	-51	--	-83
Dissolved Nitrogen	-44	--	-71

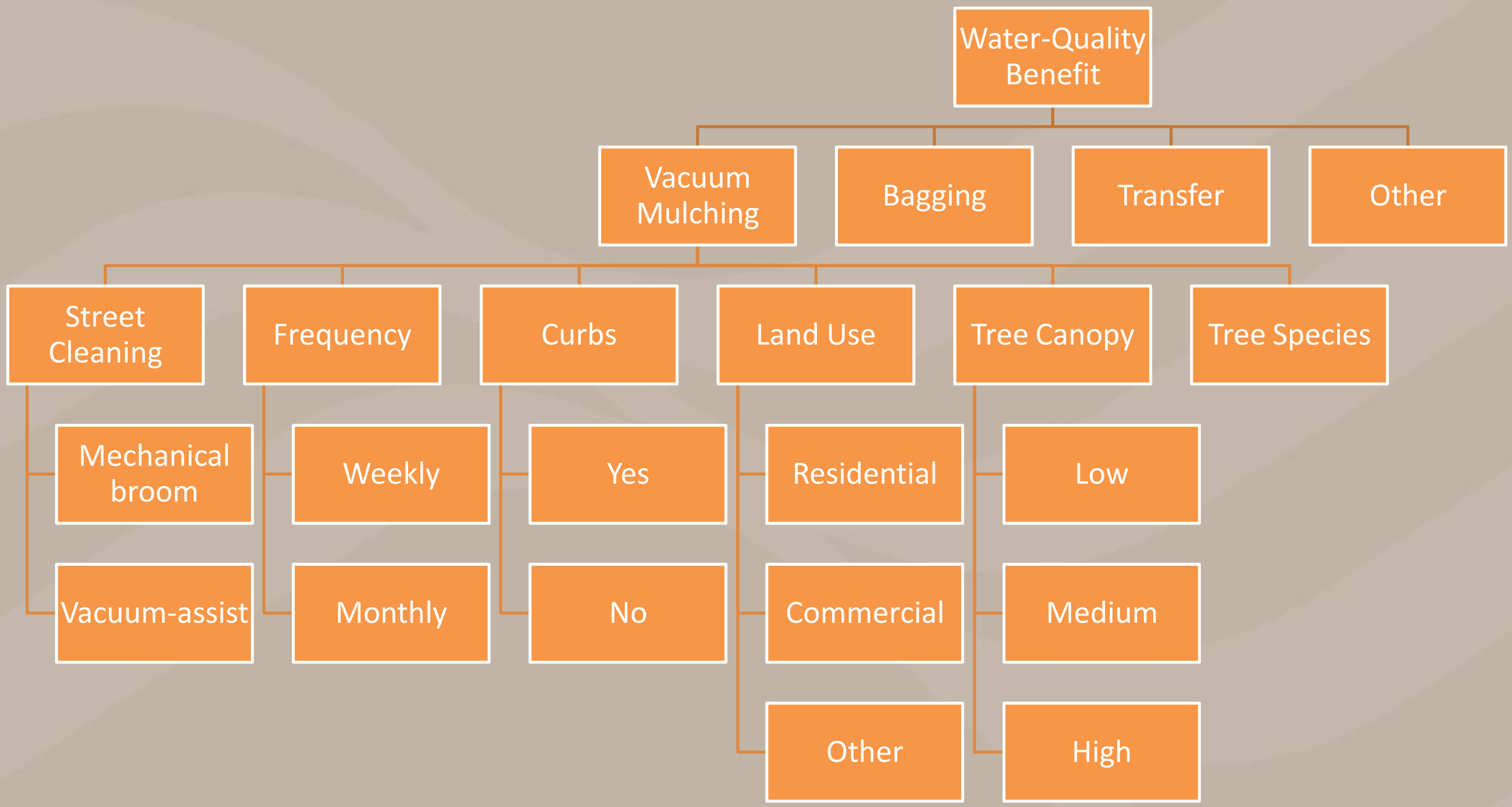
--, no statistical change

Next Steps…

- Evaluate commonly used municipal leaf collection programs
  - Vacuum mulching
  - Bagging
  - Transfer
  - Frequency

- Develop semi-quantitative method to predict phosphorus load in stormwater based on estimate of leaf mass on streets

Leaf Collection Benefits can be Highly Parameterized



Estimating Phosphorus Load from Leaf Mass on Streets

Develop method to rapidly assess the potential benefit of different leaf collection practices without the time and cost of water-quality monitoring

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Survey of Test and Control Sites in Madison

Test Site **:**

- **Clean Streets Once/Week with Vacuum Street Cleaner**

Control Site:

- **Pickup Every 20 Days By Pushing into Garbage Truck**

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Estimating Phosphorus Load from Leaf Mass on Streets

Category	Average Net Weight, lbs. (80 ft frontage)	Lbs. of Leaves Per Foot of curb
1	5	0.05
2	10	0.13
3	16	0.20
4	25	0.35

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Estimating Phosphorus Load from Leaf Mass on Streets

TABLE 1

Leachable P, total P and % of total P leachable (and standard deviation) from urban street tree leaves and seeds

Species name		Leachable P	Total P	% of total P leachable	Number of samples	
Common name	Scientific name	µg gm^{-1}	%		Leachable P	Total P
Leaves						
Sugar Maple	Acer saccharum Marsh.	259.9 (113.1)	0.20 (0.032)	13.43 (6.2)	6	3
Silver Maple	Acer saccharinum L.	232.7 (117.6)	0.13 (0.040)	17.7 (6.3)	3	3
Green Ash	Fraxinus pensylvanica Fern.	188.4 (75.1)	0.24 (0.049)	7.0 (0.43)	7	2
Honey Locust	Gleditsia tricanthos L.	176.0 (101.1)	0.44 (0.117)	4.5 (2.3)	8	5
White Ash	Fraxinus americana L.	161.9 (137.9)	0.14 (0.042)	9.6 (0.04)	4	2
American Elm	Ulmus americana L.	158.5 (66.8)	n.d.[b]	n.d.	2	0
Basswood	Tilia americana L.	95.7 (32.1)	0.15 (0.045)	7.8 (2.1)	5	3
Chinese Elm	Ulmus pumila L.	88.6 (36.1)	n.d.	n.d.	2	0
Little Leaf Linden	Tilia cordata L.	86.5 (22.5)	0.09 (n.d.)	6.7 (n.d.)	3	1
Pin Oak	Quercus palustris Muenchh.	81.5 (29.3)	n.d.	n.d.	2	0
Norway Maple	Acer platanoides L.	80.1 (53.9)	0.08 (0.035)	8.4 (3.63)	5	2
Hessian Ash	Fraxinus excelsior L.	66.1 (40.0)	n.d.	n.d.	3	0
Weeping Willow	Salix babylonica L.	38.1 (1.1)	n.d.	n.d.	2	0
All Leaves		148.1 (99.4)	0.22 (0.147)	9.3 (5.4)	52	21
LSD[a]		38.8	0.06	3.4		
Seeds						
Green Ash	Fraxinus pensylvania Fern.	77.6 (n.d.)	0.26 (n.d.)	3.0 (n.d.)		
Sugar Maple	Acer saccharum Marsh.	40.8 (12.5)	0.35 (n.d.)	1.4 (n.d.)		
Little Leaf Linden	Tilia cordata L.	39.2 (11.6)	0.26 (n.d.)	1.8 (n.d.)		
All Seeds		47.5 (18.9)	0.29 (0.052)	2.1 (0.8)		

[a] Least significant difference ($P \leq 0.05$).
[b] n.d. = not determined.

Average = 0.076 g/lb

Category	Average Net Weight, lbs. (80 ft frontage)	Lbs. of Leaves Per Foot of curb	Leachable P per foot of curb (g)
1	5	0.05	0.004
2	10	0.13	0.01
3	16	0.20	0.015
4	25	0.35	0.026

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Estimating Phosphorus Load from Leaf Mass on Streets

updated Control Site Spread Sheet 2016.xlsx - Excel

File Home Insert Page Layout Formulas Data Review View Developer Add-ins ACROBAT XLSTAT Tell me what you want to do...

Cut Copy Format Painter Paste — Clipboard

Calibri 11 — Font

Wrap Text Merge & Center — Alignment

General — Number

Conditional Formatting Format as Table

Normal Bad Good Neutral Calculation Check Cell Explanatory T... Input Linked Cell Note — Styles

Insert Delete Format — Cells

AutoSum Fill Clear Sort & Filter Find & Select — Editing

E94

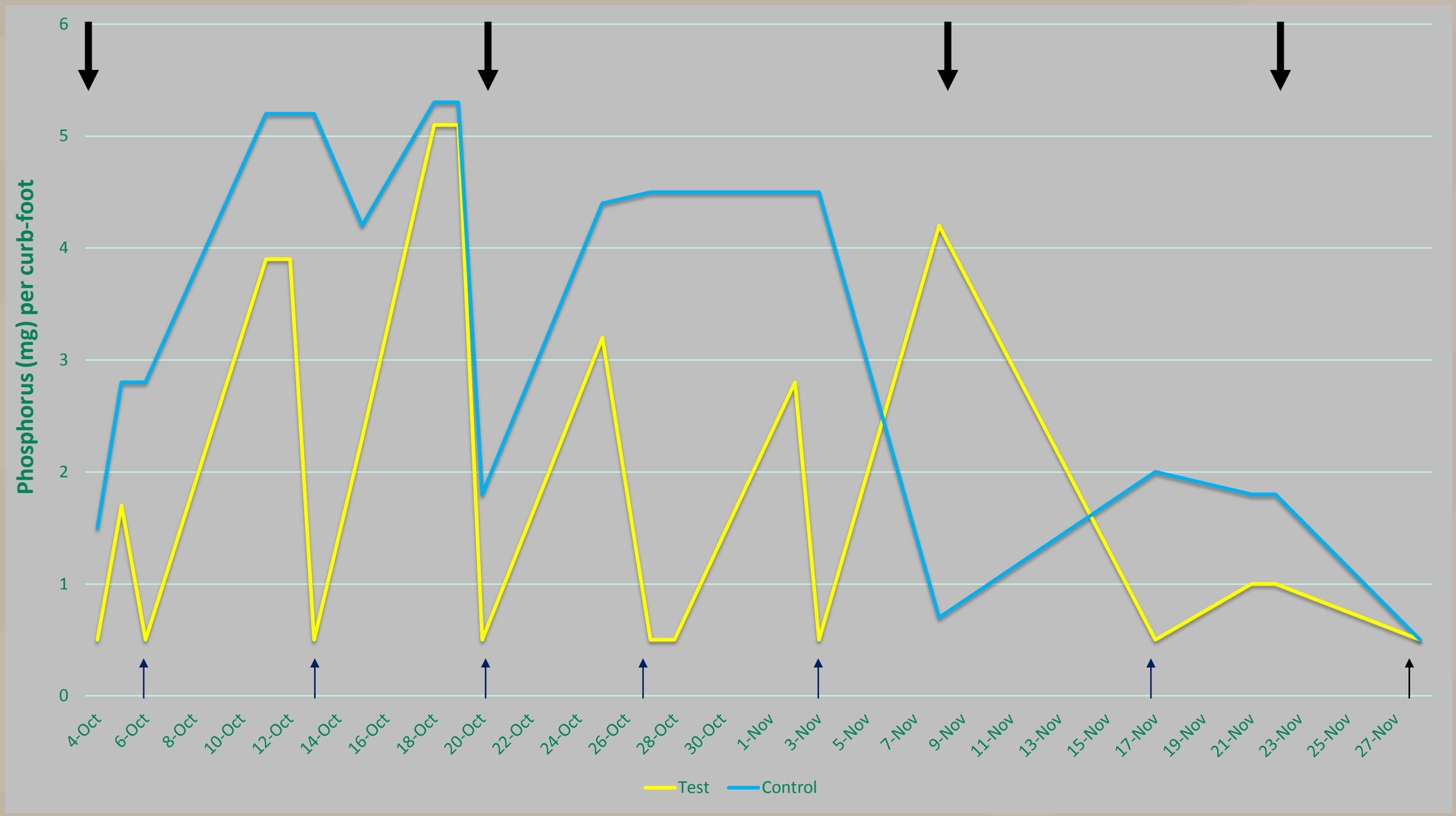
SURVEY SHEET FOR RECORDING LEAF WEIGHT

KEY		Address	Frontage	Oct.4	lbs/frontage	g of P	Oct. 6	lbs/frontage	g of P	Oct. 11	lbs/frontage	g of P	Oct. 15	lbs/frontage	g of P	Oct. 18	lbs/frontage	g of P	25-Oct	lbs/frontage	g of P
Category	Lbs of leaves																				
0	0																				
1	5	4906 Sherwood	97		0	0.00		0	0.00		0	0.00		0	0.00	2	12.61	0.96	1	4.85	0.37
2	13	4910 Sherwood	97		0	0.00		0	0.00		0	0.00		0	0.00	1	4.85	0.37	0	0	0.00
3	20	4918 Sherwood	80		0	0.00		0	0.00		0	0.00		0	0.00	1	4	0.30	0	0	0.00
4	35	4922 Sherwood	81		0	0.00		0	0.00		0	0.00		0	0.00	0	0	0.00	0	0	0.00
		4926 Sherwood	81		0	0.00		0	0.00		0	0.00		0	0.00	1	4.05	0.31	1	4.05	0.31
ms of Phosphorus per lb		5002 Sherwood	70	0	0	0.00	1	3.5	0.27	1	3.5	0.27	0	0	0.00	1	3.5	0.27	1	3.5	0.27
		5006 Sherwood	66	0	0	0.00	0	0	0.00	0	0	0.00	0	0	0.00	0	0	0.00	1	3.3	0.25
		5010 Sherwood	67	0	0	0.00	0	0	0.00	1	3.35	0.25	0	0	0.00	0	0	0.00	1	3.35	0.25
		5014 Sherwood	67	0	0	0.00	0	0	0.00	1	3.35	0.25	0	0	0.00	1	3.35	0.25	1	3.35	0.25
		5018 Sherwood	67	0	0	0.00	0	0	0.00	1	3.35	0.25	0	0	0.00	0	0	0.00	1	3.35	0.25
		5022 Sherwood	67	0	0	0.00	0	0	0.00	1	3.35	0.25	1	3.35	0.25	0	0	0.00	1	3.35	0.25
		5026 Sherwood	67	0	0	0.00	0	0	0.00	1	3.35	0.25	0	0	0.00	1	3.35	0.25	1	3.35	0.25
		5102 Sherwood	67	0	0	0.00	0	0	0.00	0	0	0.00	0	0	0.00	0	0	0.00	1	3.35	0.25
		5106 Sherwood	65	0	0	0.00	0	0	0.00	0	0	0.00	0	0	0.00	0	0	0.00	1	3.25	0.25
		5110 Sherwood	77	0	0	0.00	3	15.4	1.17	0	0	0.00	0	0	0.00	0	0	0.00	0	0	0.00
		5114 Sherwood	77	1	3.85	0.29	2	10.01	0.76	1	3.85	0.29	1	3.85	0.29	1	3.85	0.29	1	3.85	0.29
		5118 Sherwood	77	1	3.85	0.29	1	3.85	0.29	2	10.01	0.76	2	10.01	0.76	1	3.85	0.29	1	3.85	0.29
		5122 Sherwood	80	0	0	0.00	1	4	0.30	1	4	0.30	1	4	0.30	1	4	0.30	1	4	0.30
		5121 Sherwood	80	1	4	0.30	2	10.4	0.79	2	10.4	0.79	1	4	0.30	2	10.4	0.79	1	4	0.30
		5117 Sherwood	77	1	3.85	0.29	1	3.85	0.29	1	3.85	0.29	1	3.85	0.29	2	10.01	0.76	1	3.85	0.29
		5113 Sherwood	77	2	10.01	0.76	2	10.01	0.76	3	15.4	1.17	2	10.01	0.76	3	15.4	1.17	1	3.85	0.29
		5109 Sherwood	77	0	0	0.00	0	0	0.00	1	3.85	0.29	1	3.85	0.29	1	3.85	0.29	0	0	0.00
		5105 Sherwood	65	0	0	0.00	0	0	0.00	1	3.25	0.25	0	0	0.00	1	3.25	0.25	2	8.45	0.64
		5101 Sherwood	66	0	0	0.00	0	0	0.00	2	8.58	0.65	1	3.3	0.25	1	3.3	0.25	1	3.3	0.25
		5025 Sherwood	67	1	3.35	0.25	1	3.35	0.25	2	8.71	0.66	2	8.71	0.66	1	3.35	0.25	0	0	0.00
		5021 Sherwood	67	1	3.35	0.25	2	8.71	0.66	2	8.71	0.66	2	8.71	0.66	1	3.35	0.25	1	3.35	0.25
		5017 Sherwood	67	0	0	0.00	0	0	0.00	1	3.35	0.25	1	3.35	0.25	0	0	0.00	2	8.71	0.66
		5013 Sherwood	67	1	3.35	0.25	1	3.35	0.25	2	8.71	0.66	1	3.35	0.25	1	3.35	0.25	1	3.35	0.25
		5009 Sherwood	66	0	0	0.00	0	0	0.00	1	3.3	0.25	2	8.58	0.65	2	8.58	0.65	2	8.58	0.65
		5005 Sherwood	66	0	0	0.00	0	0	0.00	0	0	0.00	0	0	0.00	1	3.3	0.25	1	3.3	0.25
		5001 Sherwood	70	0	0	0.00	0	0	0.00	0	0	0.00	1	3.5	0.27	1	3.5	0.27	1	3.5	0.27
		4925 Sherwood	81		0	0.00		0	0.00		0	0.00		0	0.00	1	4.05	0.31	1	4.05	0.31
		4921 Sherwood	81		0	0.00		0	0.00		0	0.00		0	0.00	1	4.05	0.31	1	4.05	0.31
		4917 Sherwood	81		0	0.00		0	0.00		0	0.00		0	0.00	1	4.05	0.31	1	4.05	0.31
		4909 Sherwood	98		0	0.00		0	0.00		0	0.00		0	0.00	1	4.9	0.37	1	4.9	0.37
		4905 Sherwood	98		0	0.00		0	0.00		0	0.00		0	0.00	2	12.74	0.97	1	4.9	0.37
					0	0.00		0	0.00		0	0.00		0	0.00		0	0.00		0	0.00
		4910 Holiday	73		0	0.00		0	0.00		0	0.00		0	0.00	3	14.6	1.11	1	3.65	0.28
		4914 Holiday	73		0	0.00		0	0.00		0	0.00		0	0.00	1	3.65	0.28	0	0	0.00

Sheet1 Sheet2 Sheet3

Ready

Comparison of Unit Loads Between Test and Control Areas – Mg of P per Ft of Curb



Test Cleaned = ↑

Control Cleaned = ↓

Leachable P in mg/ft of Curb - Test and Control Site

Collection and Cleaning:

- **Weekly = 15.2 mg/ft**
- **20 Days = 26.2 mg/ft**

Percent Change = 42%

Survey Dates	Rain Date	Leachable Phosphorus , mg/ft. of curb	
		Test Area	Control Area
10/4	10/5	0.5	1.5
10/6	Before Swept	1.7	2.8
10/6	10/7	0.5	2.8
10/11	10/12	3.9	5.2
10/15	10/16	2.3	4.2
10/18		5.1	5.3
10/25	10/26	3.2	4.4
10/28		0.5	4.5
11/2	11/2	2.8	4.5
11/8		4.2	0.7
11/17		0.5	2.0
11/22	11/23	1.0	1.8
11/22	11/28	1.0	1.8
11/30		0	0
Leachable P for Rainfalls		15.2 mg/ft	26.2 mg/ft

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Questions

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Evaluation of leaf removal as a means to reduce nutrient concentrations and loads in urban stormwater

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HIGHLIGHTS

- Leaves are a significant source of phosphorus to urban stormwater.
- Phosphorus and nitrogen were measured in basins with and without leaf removal.
- Nearly 60 percent of the annual phosphorus yield comes from leaf litter in the fall.
- Timely removal of leaf litter can reduce phosphorus concentrations by 80%.
- Leaf removal is one of a few options available to reduce dissolved phosphorus.

GRAPHICAL ABSTRACT

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ABSTRACT

While the sources of nutrients to urban stormwater are many, the primary contributor is often organic detritus, especially in areas with dense overhead tree canopy. One way to remove organic detritus before it becomes entrained in runoff is to implement a city-wide leaf collection and street cleaning program. Improving our knowledge of the potential reduction of nutrients to stormwater through removal of leaves and other organic detritus on streets could help tailor more targeted municipal leaf collection programs. This study characterized an upper ideal limit in reductions of total and dissolved forms of phosphorus and nitrogen in stormwater through implementation of a municipal leaf collection and street cleaning program in Madison, WI, USA. Additional measures were taken to remove leaf litter from street surfaces prior to precipitation events.

Loads of total and dissolved phosphorus were reduced by 84 and 83% ($p < 0.05$), and total and dissolved nitrogen by 74 and 71% ($p < 0.05$) with an active leaf removal program. Without leaf removal, 56% of the annual total phosphorus yield (winter excluded) was due to leaf litter in the fall compared to 16% with leaf removal. Despite significant reductions in load, total nitrogen showed only minor changes in fall yields without and with leaf removal at 19 and 16%, respectively. The majority of nutrient concentrations were in the dissolved fraction making source control through leaf removal one of the few treatment options available to environmental managers when reducing the amount of dissolved nutrients in stormwater runoff. Subsequently, the efficiency, frequency, and timing of leaf removal and street cleaning are the primary factors to consider when developing a leaf management program.

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