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

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Leaf Collection to Reduce Phosphorus - Pilot Study

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 municipal separate storm sewer systems (MS4) expect by collecting leaves?
- Are some leaf collection practices better than others?

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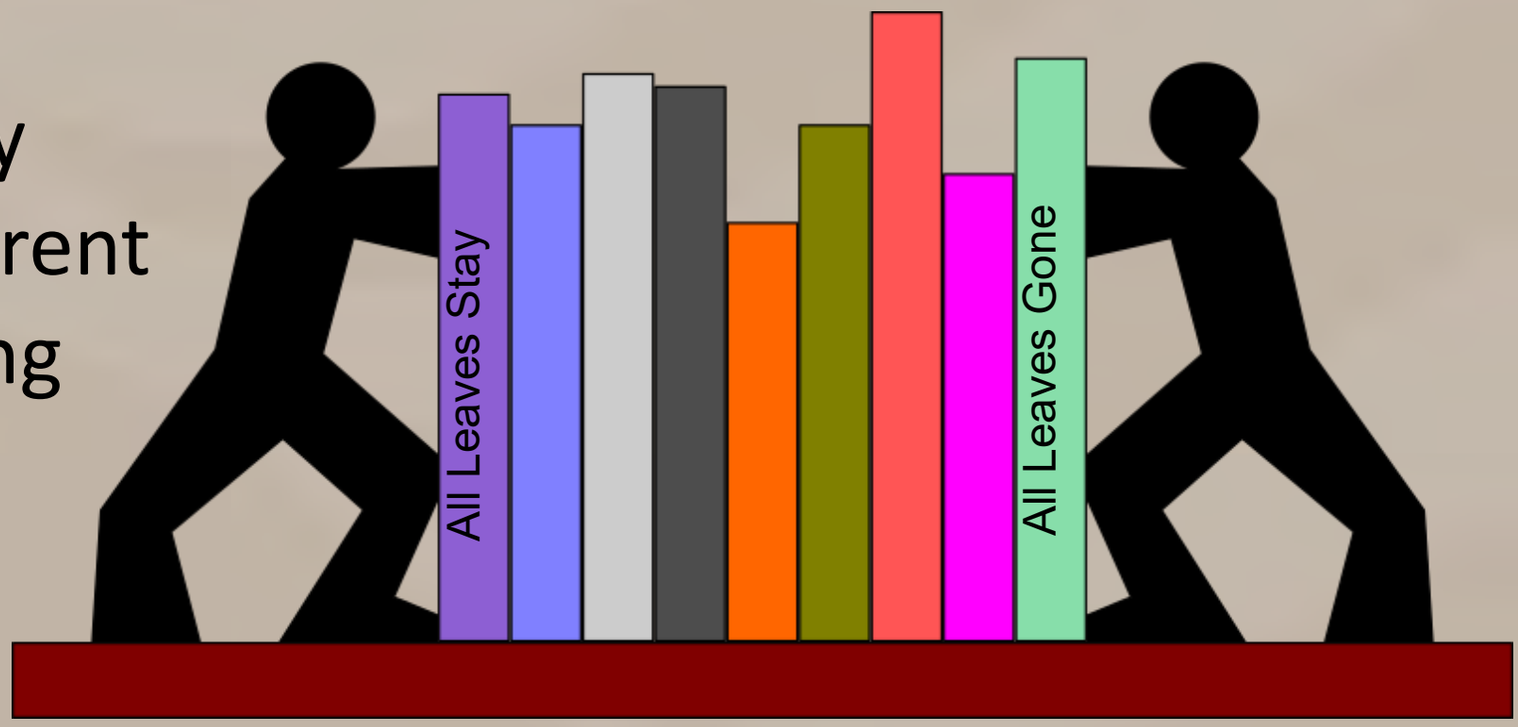
Study Objectives

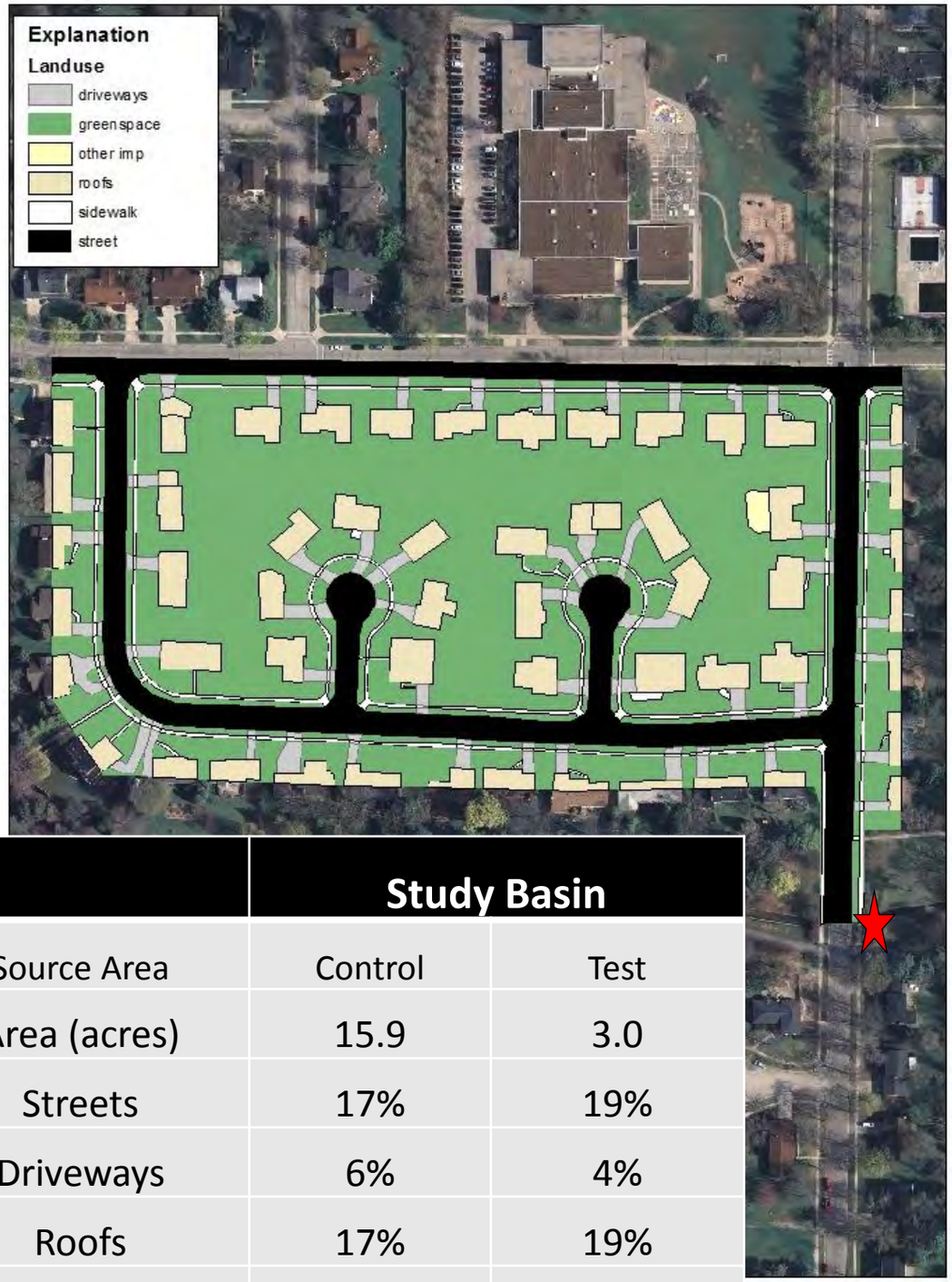
1. Collect water-quality samples from a control and test basin to determine if removing leaves will result in *detectable* changes in phosphorus [“book end approach”]

2. Develop criteria to rapidly assess effectiveness of different leaf collection practices using field survey techniques



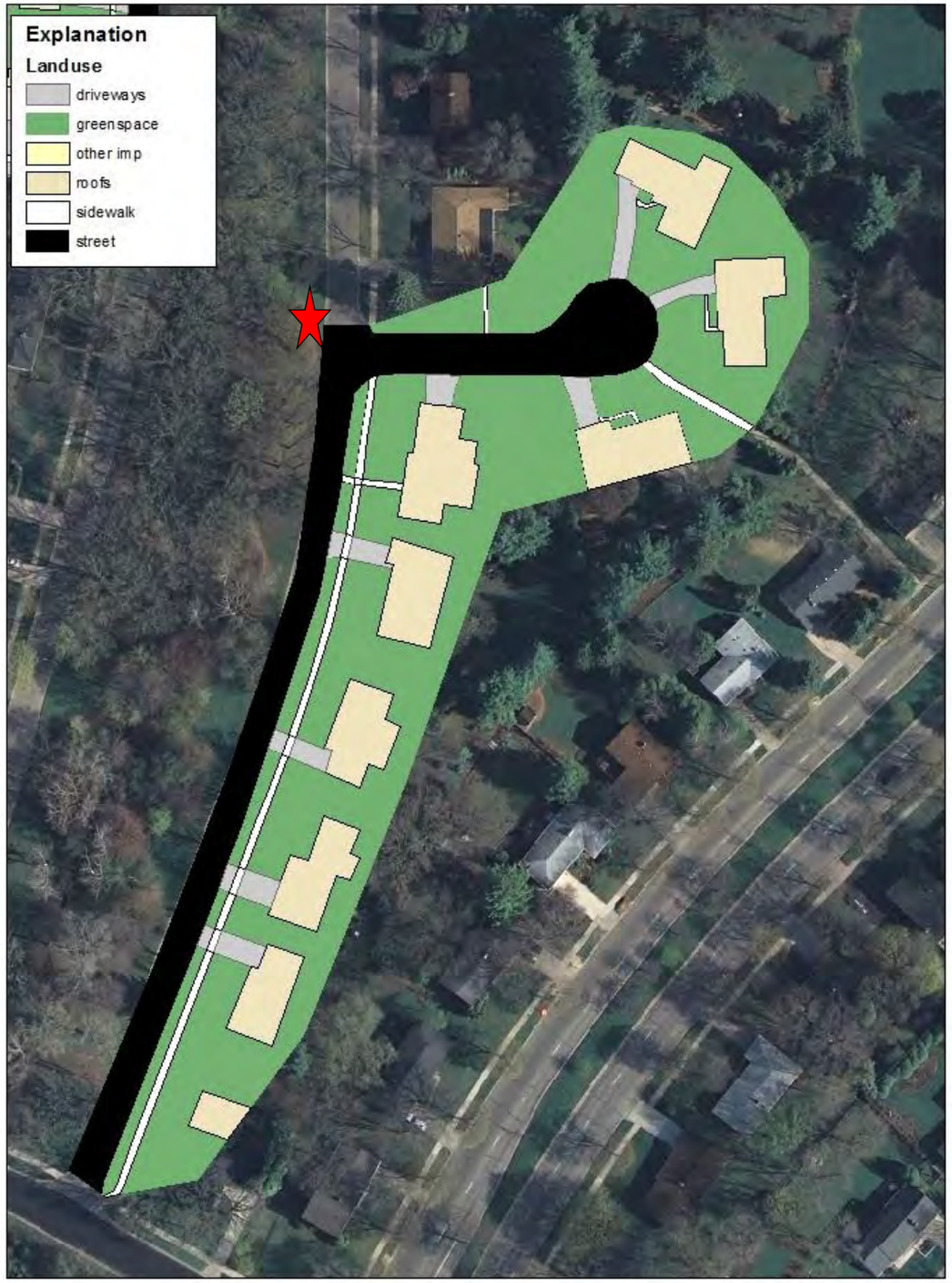
Paired Basin Study Design

Control



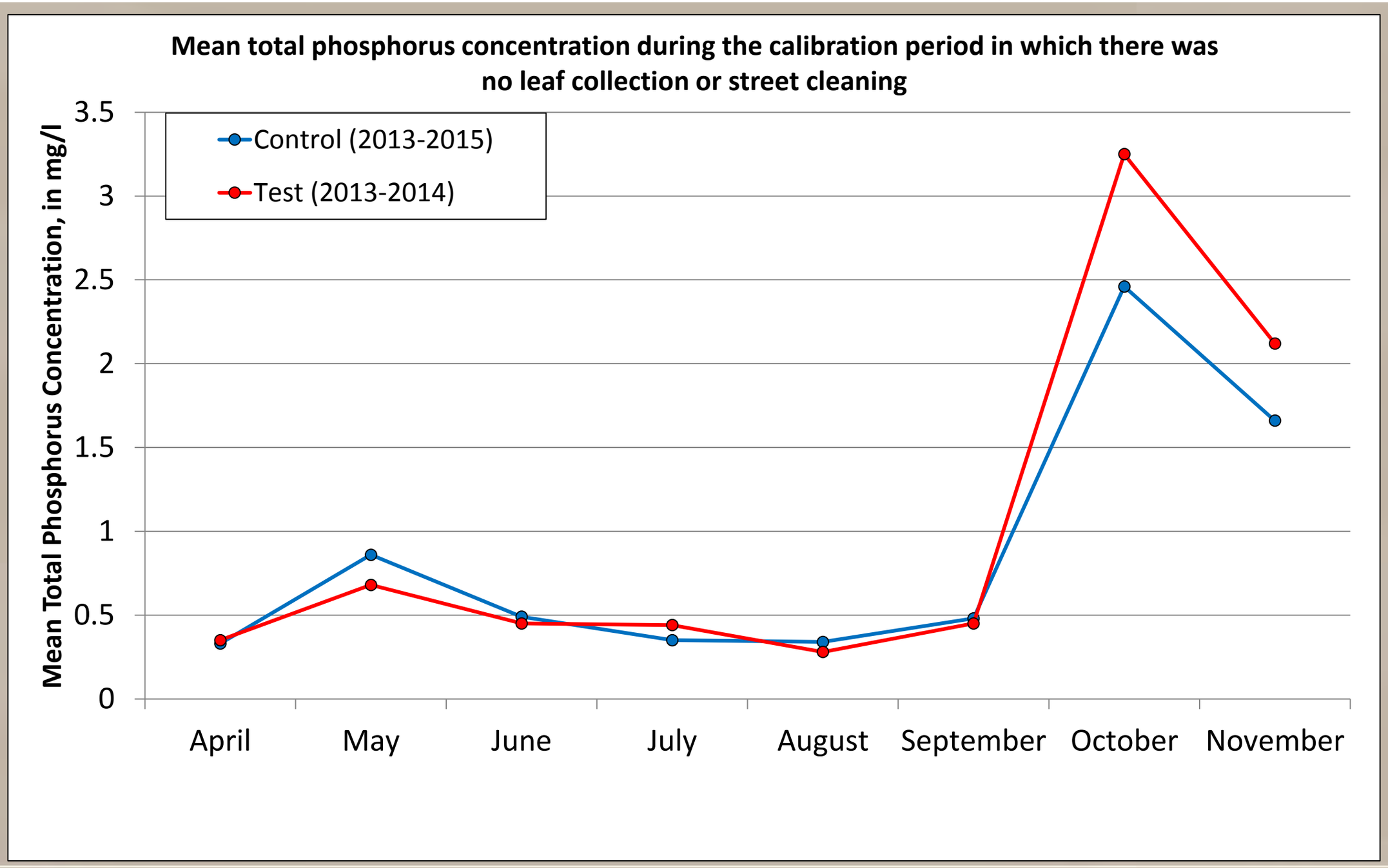
	Study Basin	
Source Area	Control	Test
Area (acres)	15.9	3.0
Streets	17%	19%
Driveways	6%	4%
Roofs	17%	19%
Sidewalks	5%	3%
Lawns/Open	55%	54%
Other Impervious	<1%	0%
Tree Cover	45%	68%

Test



USGS Monitoring Location

Photo Credit: USGS



“Escalated” Leaf Management in Test Basin

1. Weekly street cleaning in spring and summer
2. Weekly collection of leaf piles followed by street cleaning in fall

Photo Credit: USGS

Photo Credit: USGS

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

Photo Credit: USGS

Photo Credit: USGS

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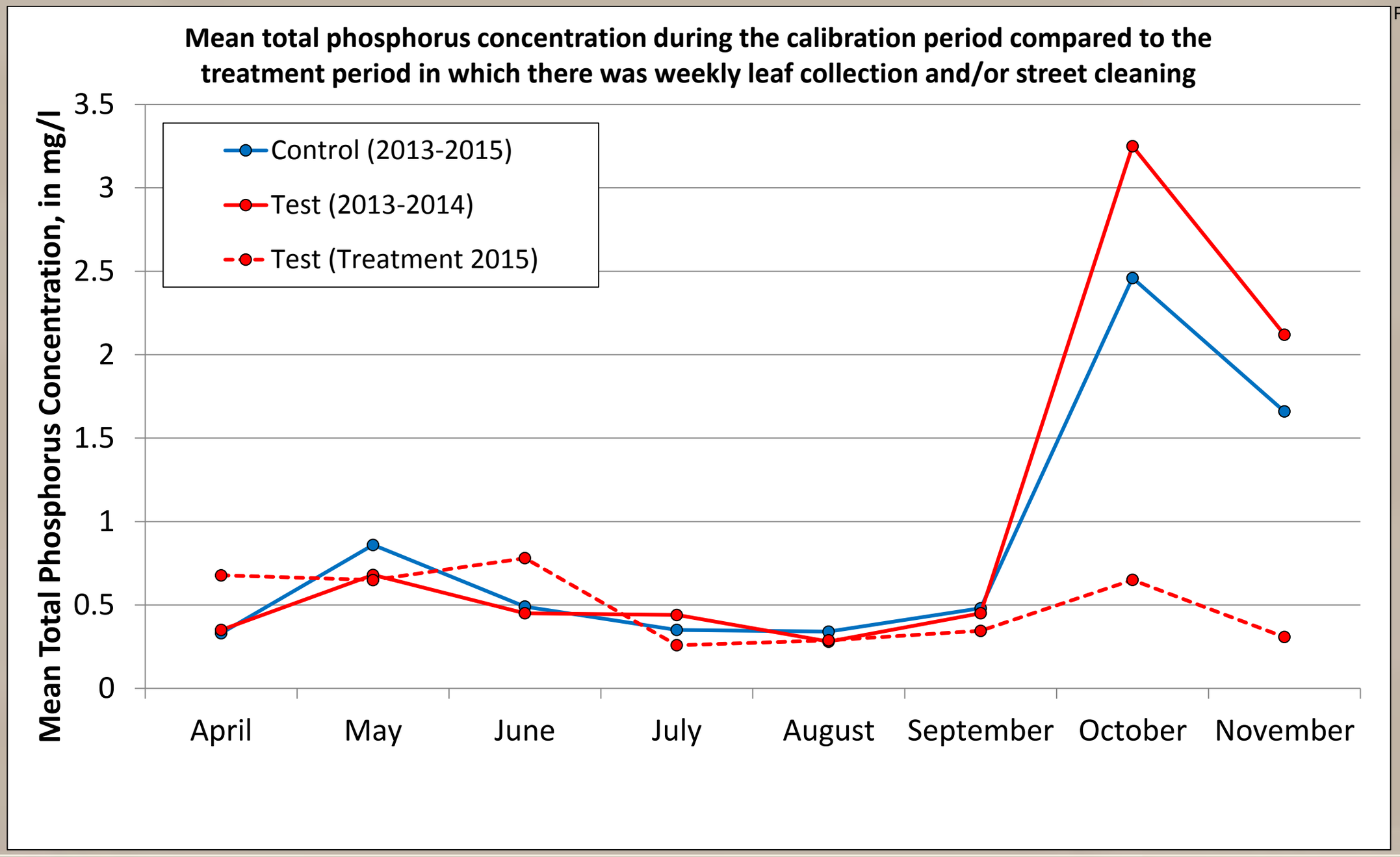
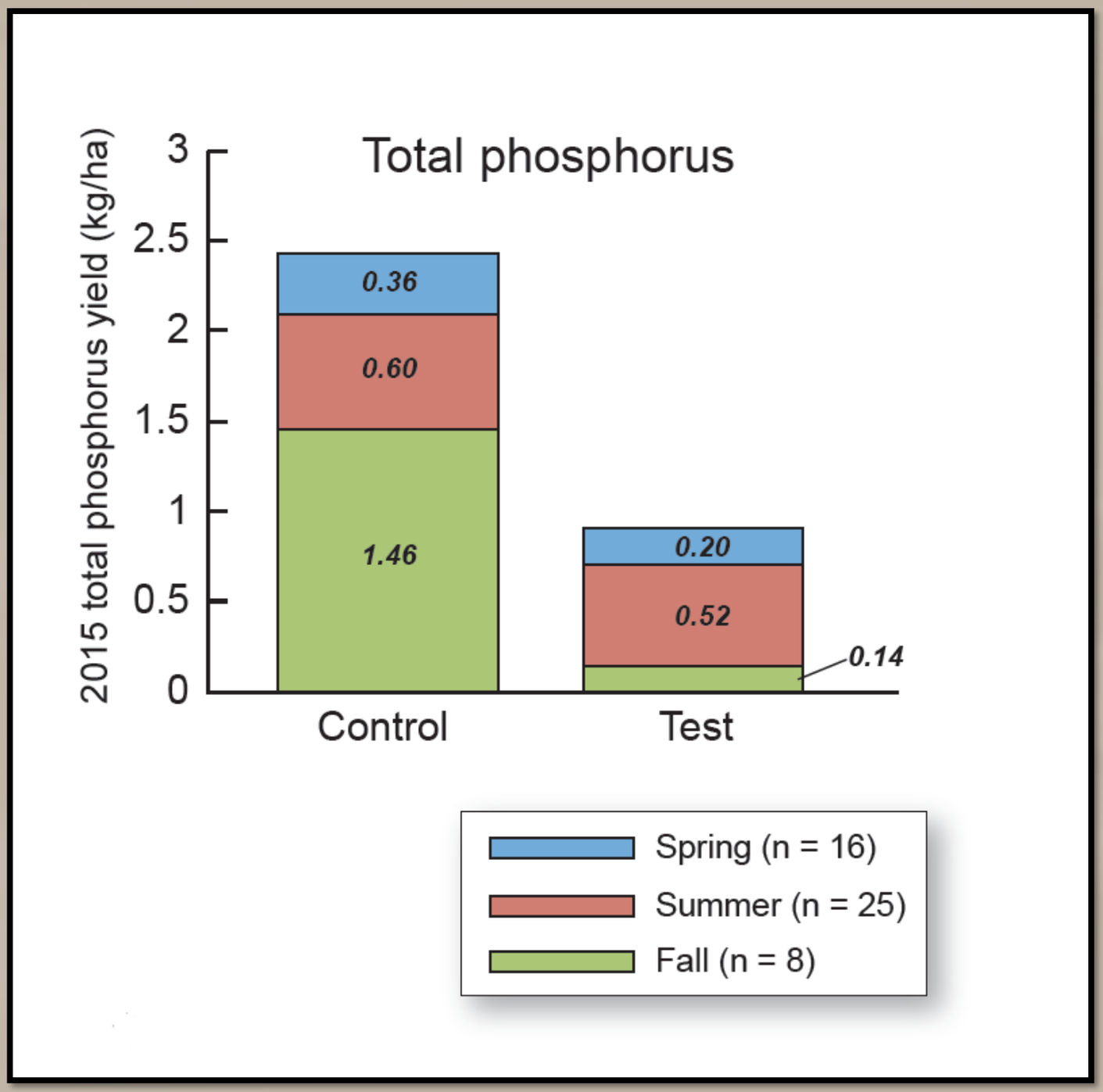
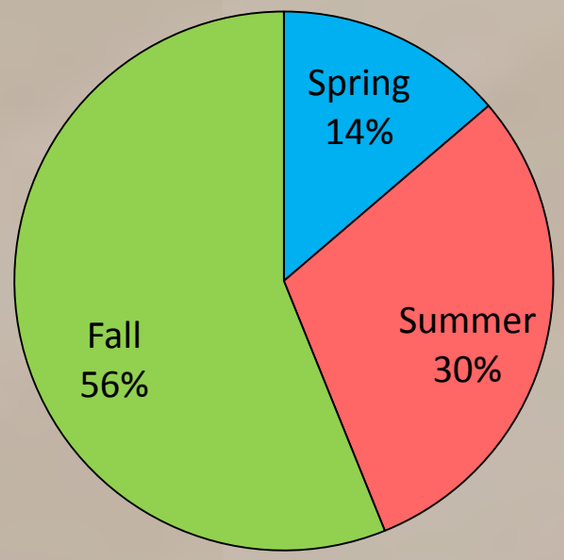
Photo Credit: USGS



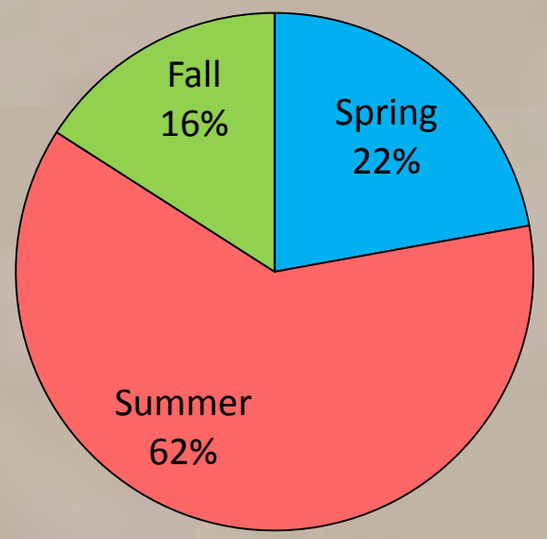
Seasonal Total Phosphorus Yield as a Percent of the 2015 Annual Yield (winter excluded)



Control

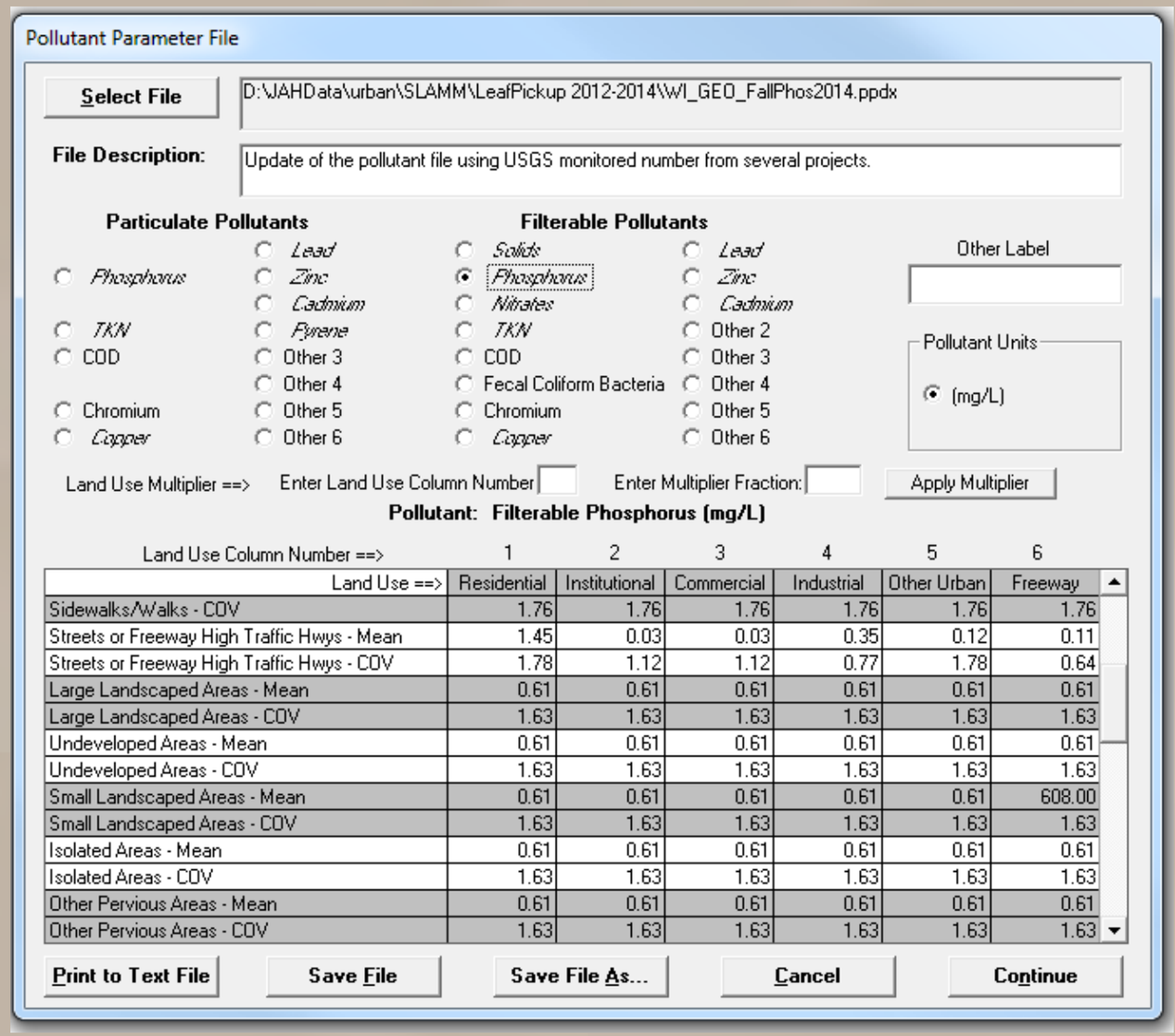


Test



How Representative Was 2015?

- 100 acres of medium density residential
- Standardized rainfall for Madison, WI (1980 – 1999)
- Source area concentrations, other than streets, used default values
- Streets were dominate source of runoff for range of precipitation depths measured
- Varied concentration of phosphorus by season

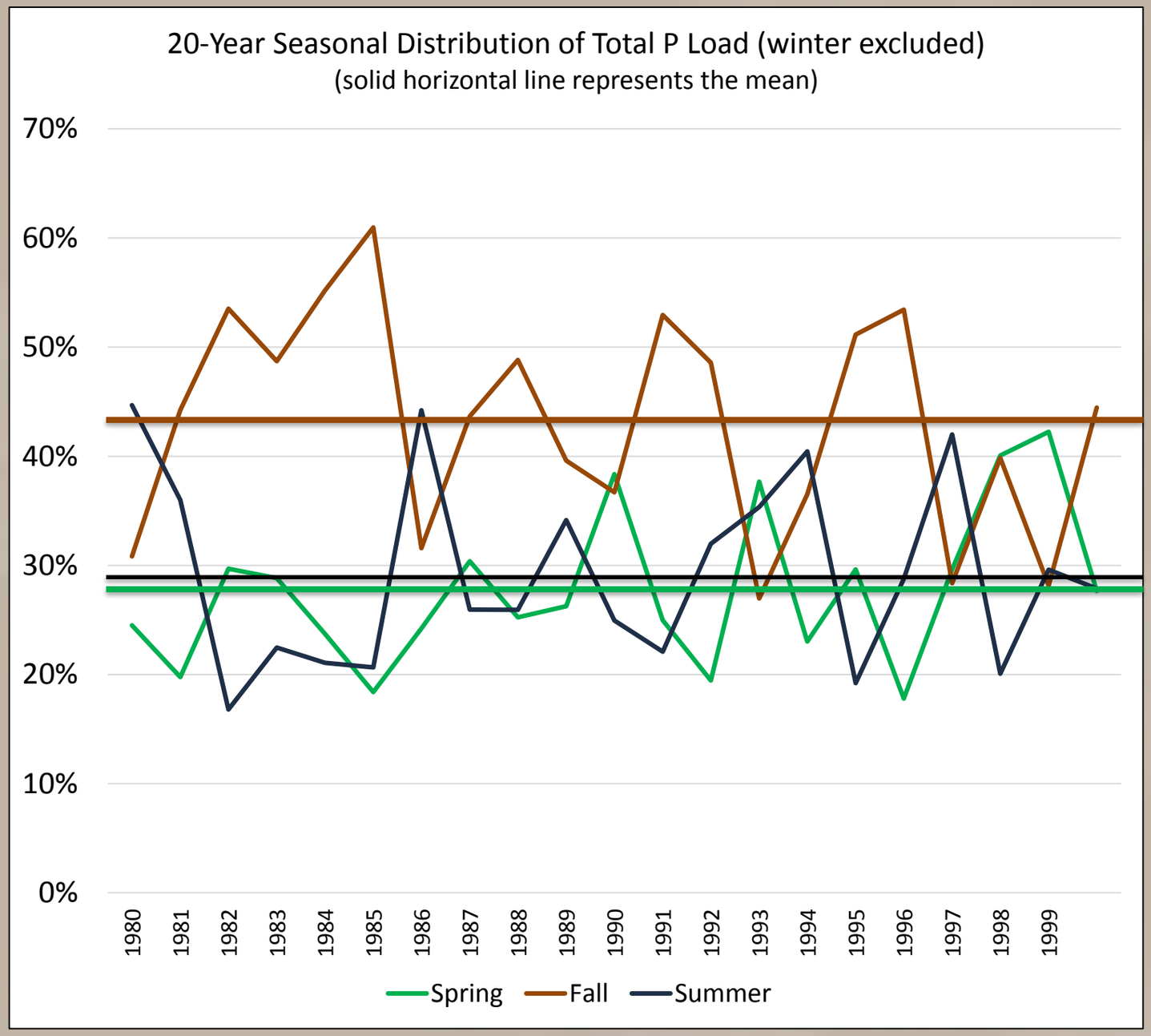


Land Use Column Number ==>	1	2	3	4	5	6
Land Use ==>	Residential	Institutional	Commercial	Industrial	Other Urban	Freeway
Sidewalks/Walks - COV	1.76	1.76	1.76	1.76	1.76	1.76
Streets or Freeway High Traffic Hwys - Mean	1.45	0.03	0.03	0.35	0.12	0.11
Streets or Freeway High Traffic Hwys - COV	1.78	1.12	1.12	0.77	1.78	0.64
Large Landscaped Areas - Mean	0.61	0.61	0.61	0.61	0.61	0.61
Large Landscaped Areas - COV	1.63	1.63	1.63	1.63	1.63	1.63
Undeveloped Areas - Mean	0.61	0.61	0.61	0.61	0.61	0.61
Undeveloped Areas - COV	1.63	1.63	1.63	1.63	1.63	1.63
Small Landscaped Areas - Mean	0.61	0.61	0.61	0.61	0.61	608.00
Small Landscaped Areas - COV	1.63	1.63	1.63	1.63	1.63	1.63
Isolated Areas - Mean	0.61	0.61	0.61	0.61	0.61	0.61
Isolated Areas - COV	1.63	1.63	1.63	1.63	1.63	1.63
Other Pervious Areas - Mean	0.61	0.61	0.61	0.61	0.61	0.61
Other Pervious Areas - COV	1.63	1.63	1.63	1.63	1.63	1.63

WinSLAMM v 10.2

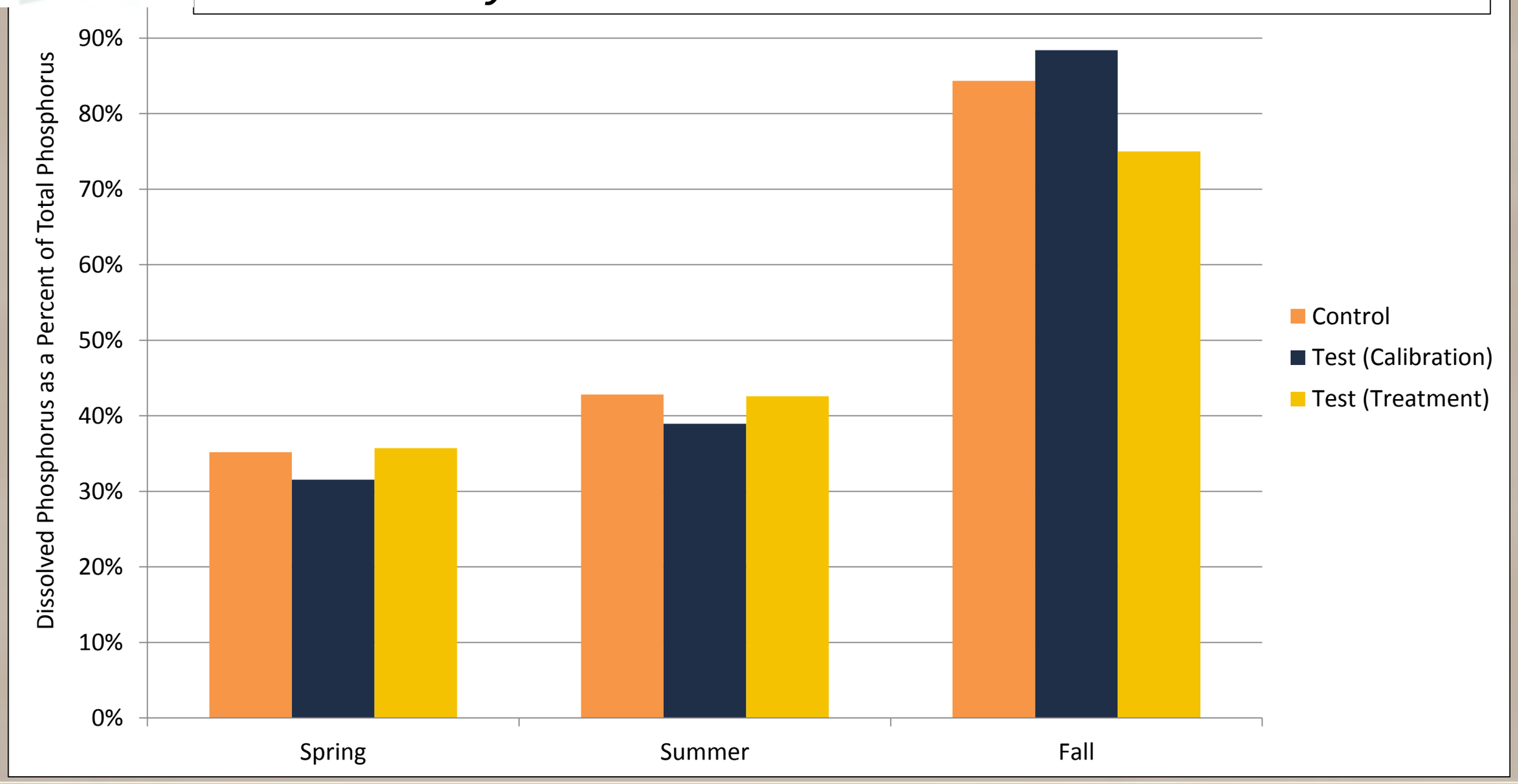
20-Year Distribution of Annual Phosphorus Load by Season

Season	Minimum %	Maximum %	Mean %
Spring	18	42	28
Summer	17	45	29
Fall	27	61	43

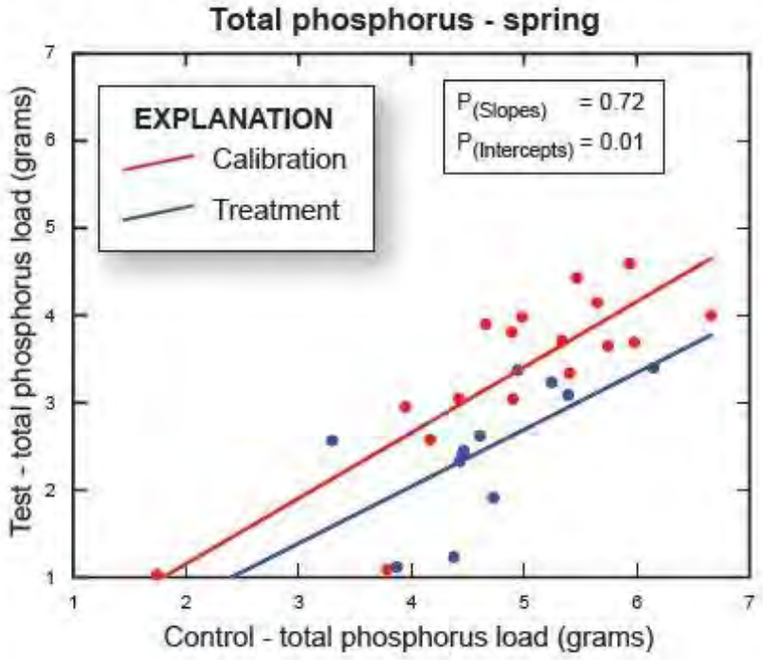


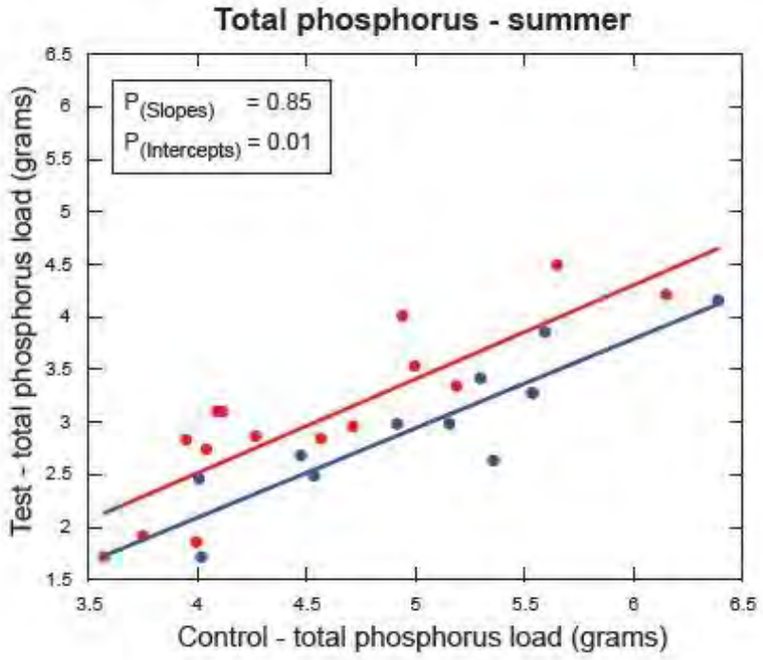
Leaf Collection One of few Options to Reduce Dissolved Phosphorus

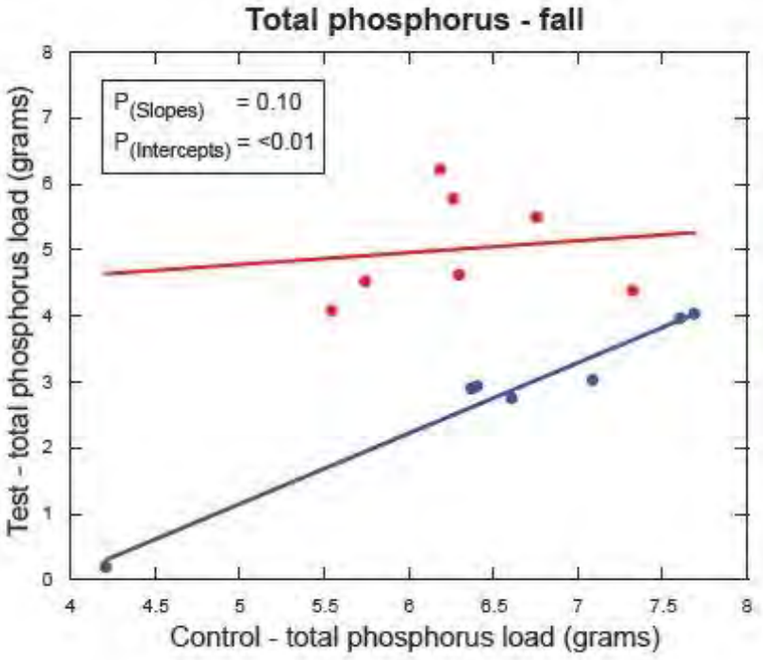
Leaf collection may be one of only a few options to reduce dissolved phosphorus since structural controls do not effectively remove the dissolved fraction.

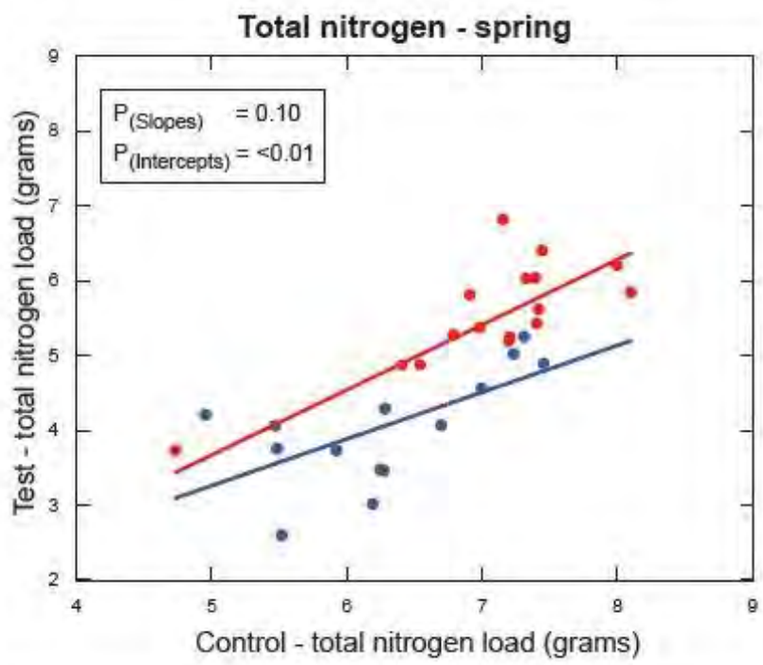


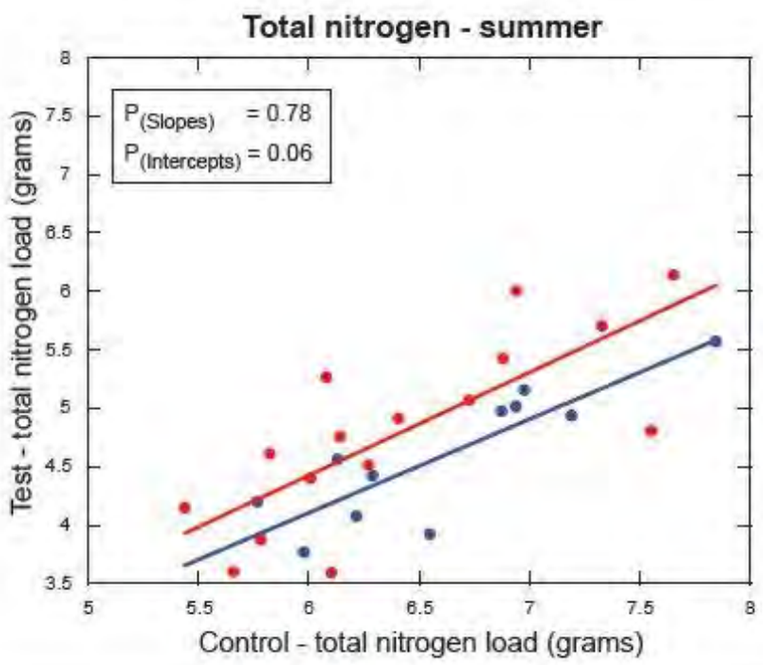
Paired Basin Results for Nutrient Load (Log), in grams

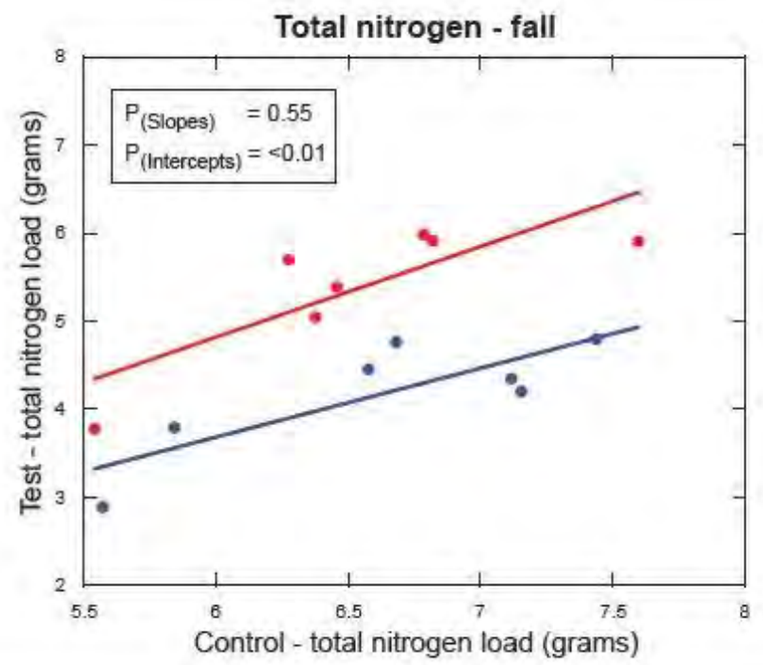












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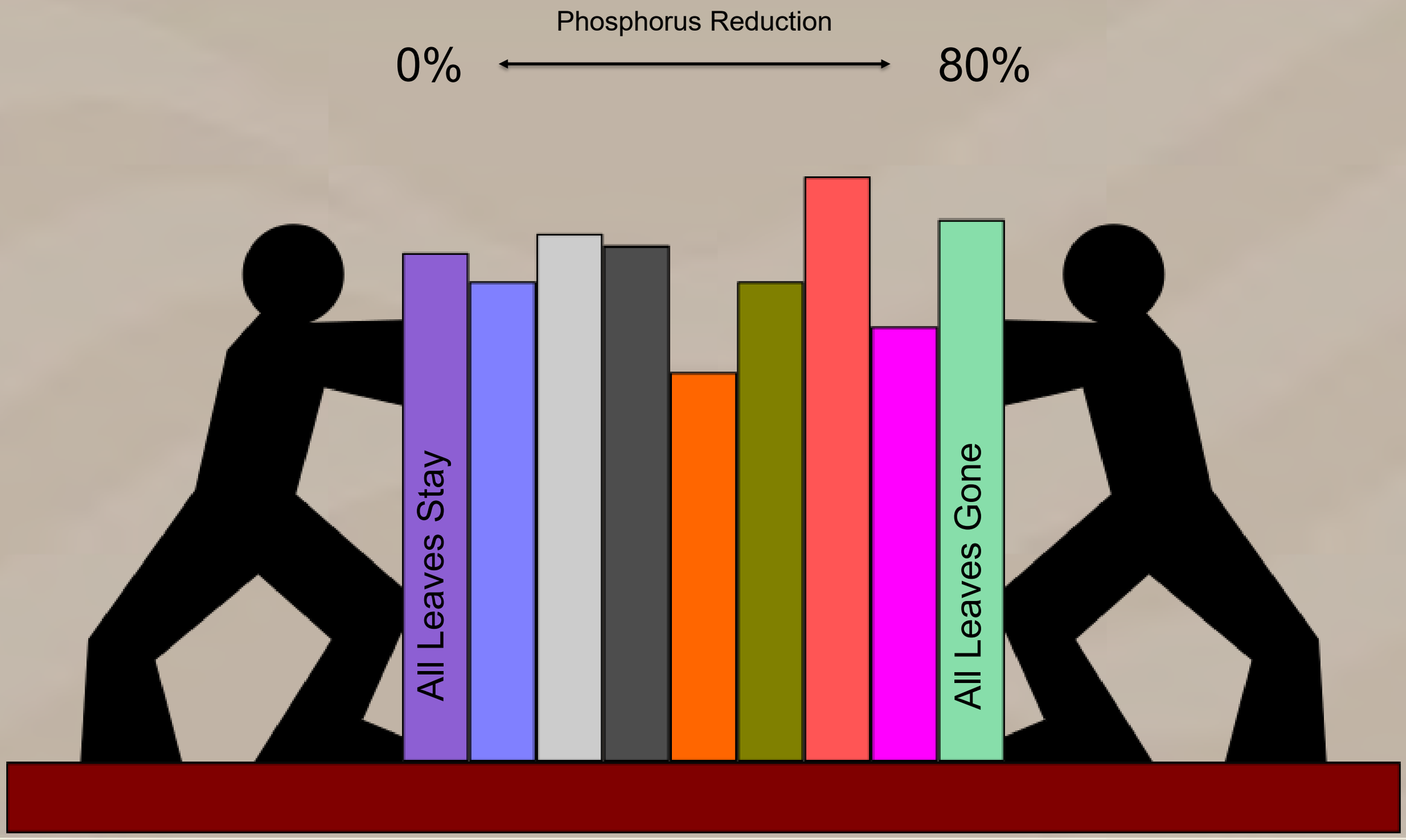
Percent Reduction in Nutrient Load - 2015

--, no statistical change

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

Photo Credit: USGS

How Does Your City Collect Leaves?



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City of Madison – Leaf Transfer plus Sweeping


Photo Credit: USGS

1. Transfer leaf piles from terrace into street then pick up with garbage truck
2. Leaf collection followed by street cleaning
3. Frequency = approximately 4x per season

Photo Credit: USGS

Photo Credit: USGS

Leaf Transfer and Street Cleaning Every ~20 Days

Nutrient	Percent Reduction
Total Phosphorus	40
Total Nitrogen	--
Dissolved Phosphorus	45
Dissolved Nitrogen	--

Preliminary Information – Subject to Revision. Not for Citation or Distribution

Photo Credit: City of Madison

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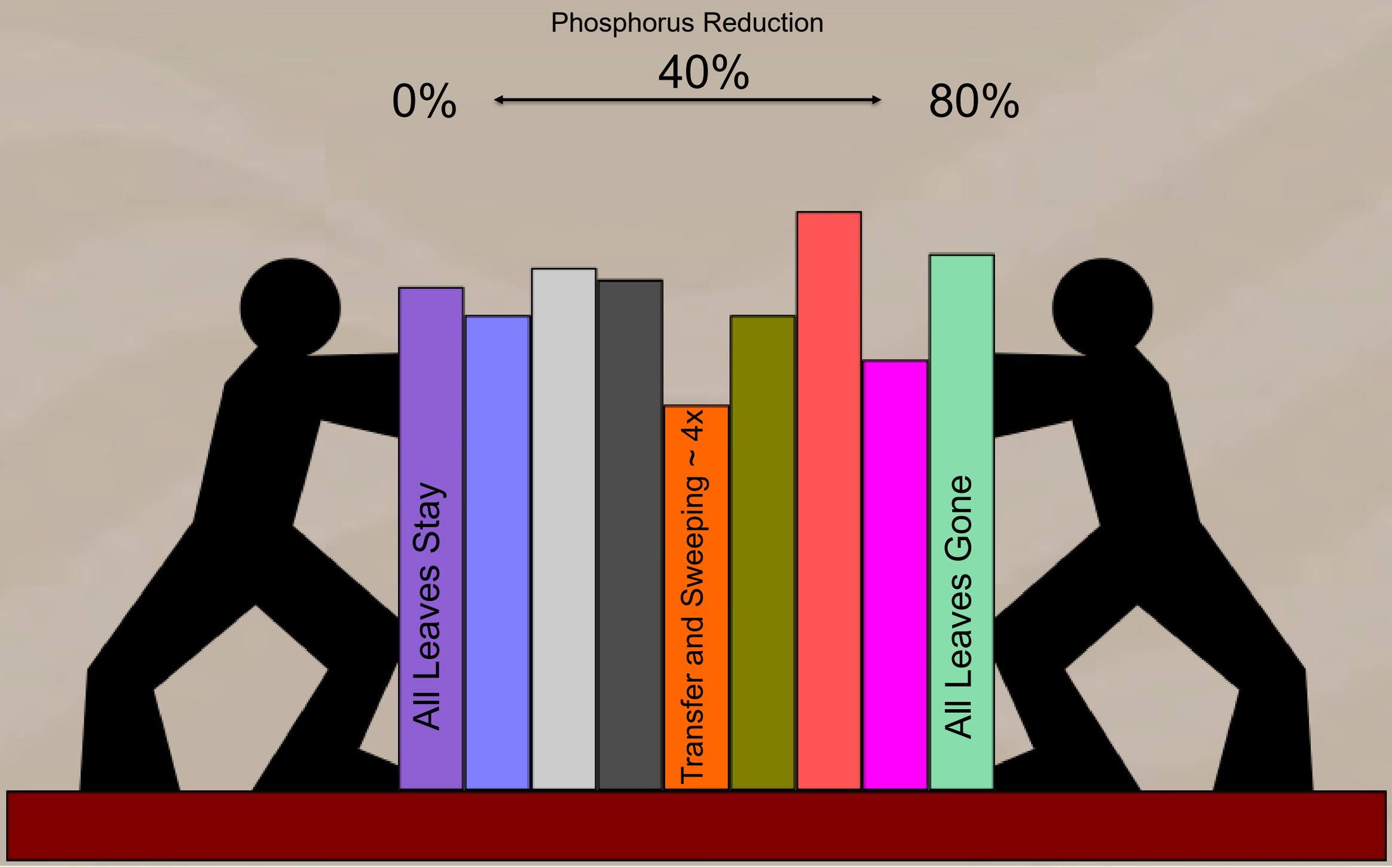
How Does Your City Collect Leaves?



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Next Steps…

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

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

Photo Credit: USGS

Estimating Phosphorus Load from Leaf Mass on Streets

Photo Credit: USGS

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


Photo Credit: USGS

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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

Photo Credit: USGS

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.

Dorney, 1986

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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Only the estimated leachable phosphorus prior to rain events were summed

Photo Credit: USGS

Survey Dates	Rain Date	Leachable Phosphorus per foot of curb (mg/ft)
		Test Area
10/4	10/5	0.5
10/6	Before Swept	1.7
10/6	10/7	0.5
10/11	10/12	3.9
10/15	10/16	2.3
10/18		5.1
10/25	10/26	3.2
10/28		0.5
11/2	11/2	2.8
11/8		4.2
11/17		0.5
11/22	11/23	1.0
11/22	11/28	1.0
11/30		0
Leachable P for Rainfalls		15.2 mg

Partial Leaf Collection Programs to be Evaluated in Study

Base Line:

No street cleaning in fall – home owners put their leaves on the terrace

Madison Program:

Leaf collection ~4x in fall & street cleaning after collection

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Average Leachable P

Baseline = 7.9 mg/ft
Madison = 5.0 mg/ft

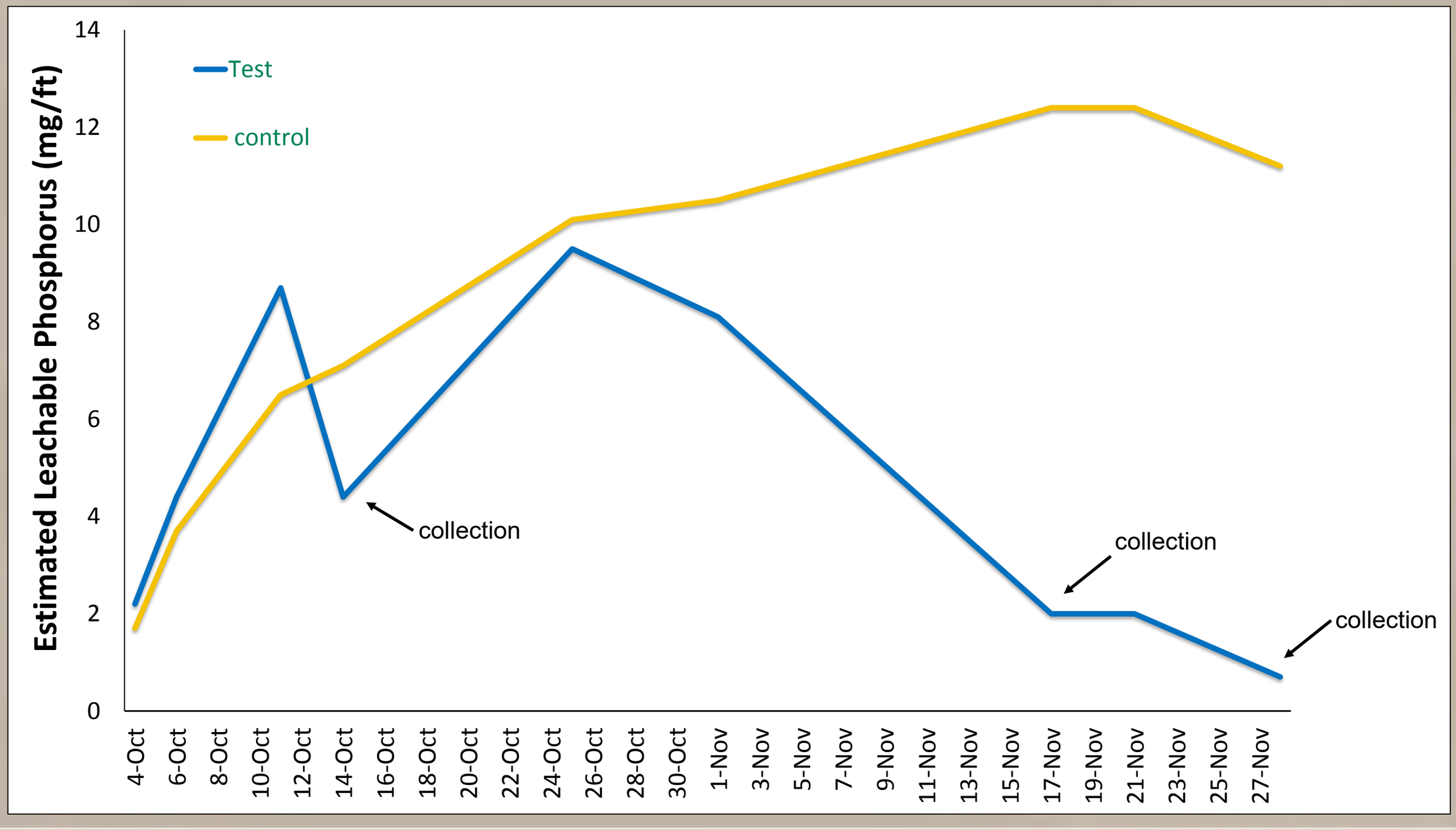
Percent Difference = 44%

Water-Quality Monitoring = 40%


Photo Credit: USGS

Survey Dates	Rain Date	Leachable P Normalized by Curb Length, mg	
		Baseline	Madison
Oct 4	10/5	1.7	2.2
Oct 6	10/7	3.7	4.4
Oct 11	10/12	6.5	8.7
Oct 14	10/16	7.1	4.4
Oct 25	10/26	10.1	9.5
Nov 1	11/2	10.5	8.1
Nov 17		12.4	2.0
Nov 21	11/23	12.4	2.0
Nov 28	11/28	11.2	0.7
Total Leachable P		75.5	42.0
Total Leachable P for Rain Dates		63.1	40.0
Avg. for Rain Dates		7.9	5

Comparison of Unit Loads Between Test and Control Areas



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How Could a Leaf Collection Program Relate to Phosphorus Reduction Credits for an Entire City?

EXAMPLE CALCULATION:

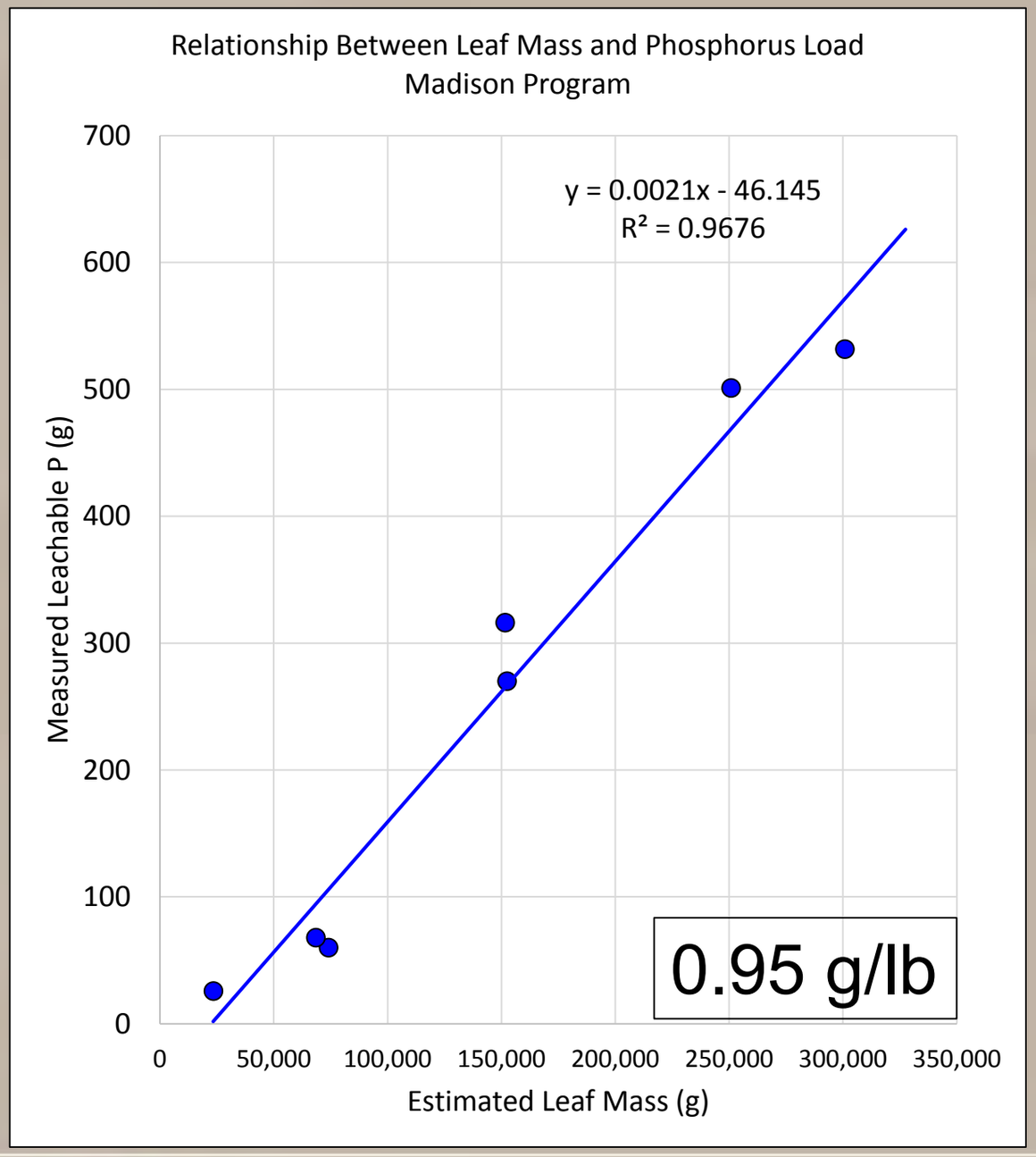
- **Madison Program (Leaf Collection and Street Cleaning ~4x) = 44%**
- **Residential Land Use with High Tree Canopy in Madison = 60%**
- **Modeled Annual Phosphorus Contribution in Fall = 43%**

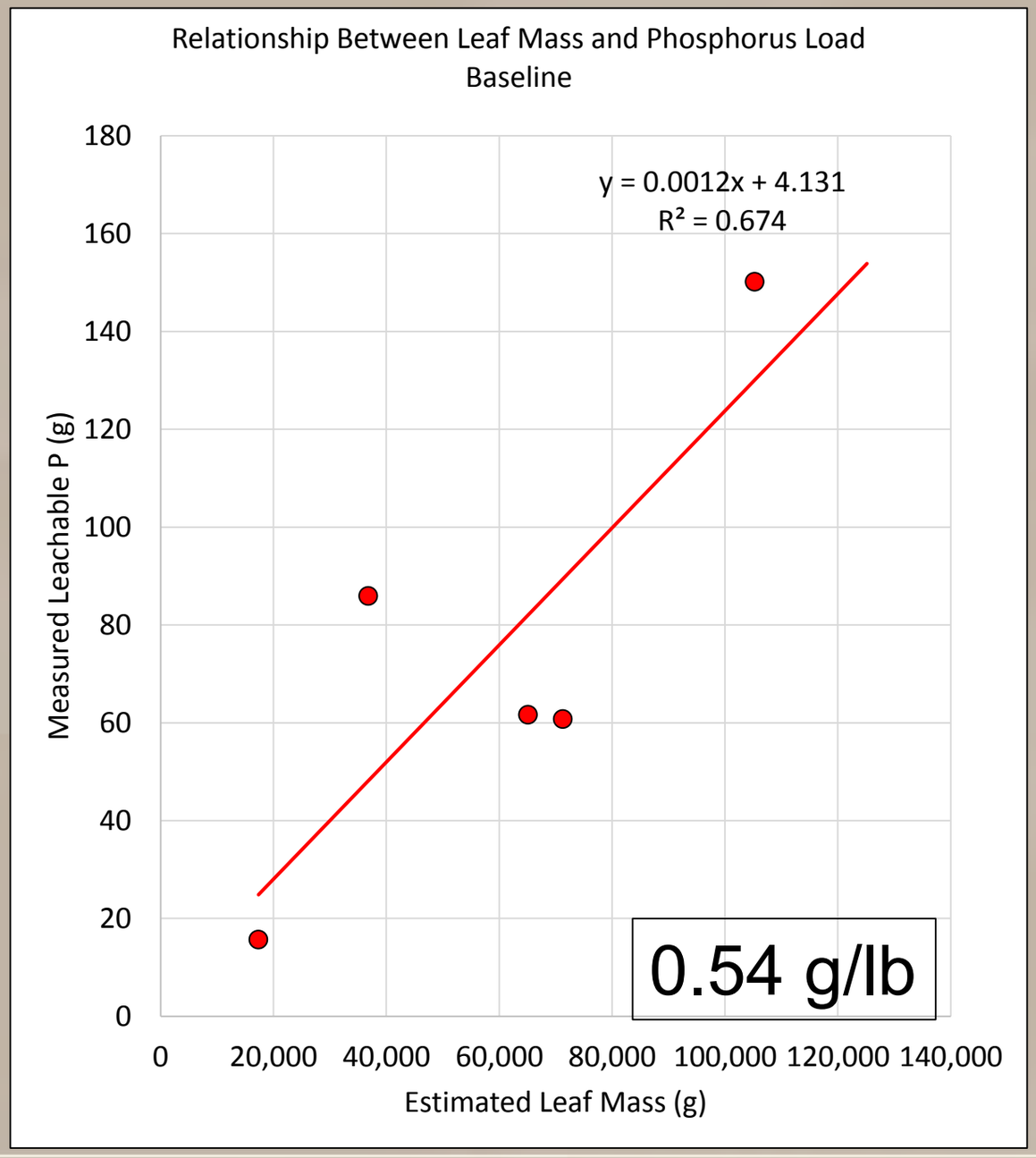
Annual Phosphorus Reduction Credit = 44% X 60% X 43% = *11 %*

Photo Credit: Roger Bannerman

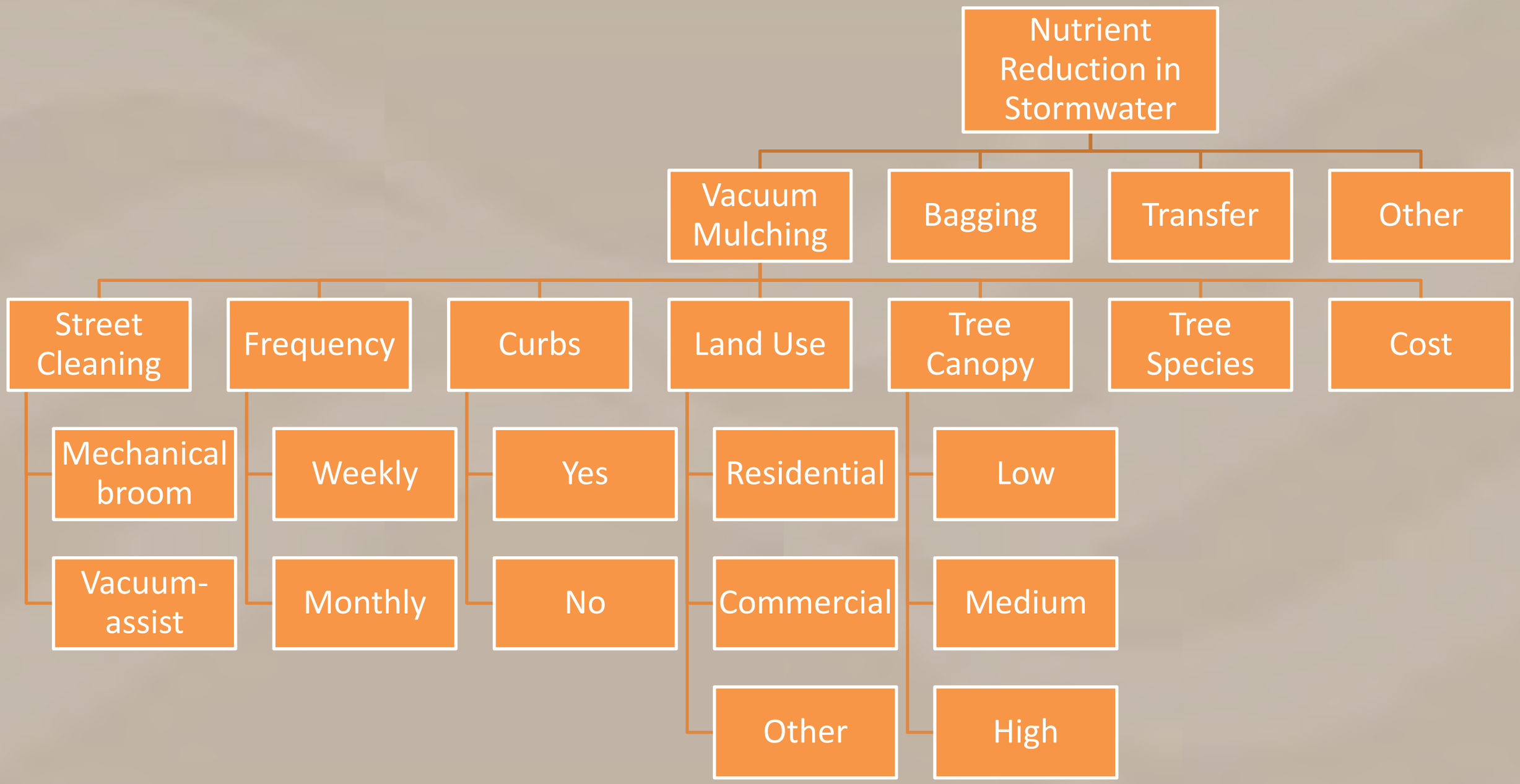
Still Much to Learn…..

Can we model the concentration of phosphorus in stormwater based on known parameters?





Still Much to Learn…



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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0048-9697/

References Cited:

Dorney, J.R., 1986. Leachable and total phosphorus in urban street tree leaves. Water Air Soil Poll. 28, 439-443.

Selbig, W.R., 2016, Evaluation of leaf removal as a means to reduce nutrient concentrations and loads in urban stormwater, *Science of the Total Environment*, 571, pp. 124 – 133.

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