CAPTure™

Phosphorus

Compact Agricultural Phosphorus Treatment Structure *(Pat Pend)*

CAPTure^{TM} Box Siting Framework & Hotspot Analysis

Installation Considerations

CAPTure™ systems have been proven to remove soluble phosphorus from water, but require certain site-specific considerations in order to operate at optimal effectiveness. Hydraulically, there must be enough available head to drive water through the filter box's top-down gravity-fed design. These systems have a maximum treatment flow rate, meaning that the majority of installations will require flow control (such as a drainage water management structure) to be installed upstream of the filter box. For installations treating surface water, there must be adequate detention to drop out fine sediment that might reduce the effectiveness of filter media. Lastly, phosphorus concentrations in the water to be treated should meet a threshold for cost-effective treatment. While CAPTure™ systems can still bind phosphorus even at very low concentrations, from a management perspective it is best to deploy them where they can have the most impact.

Hydraulics

Hydraulically, there must be at least 2 feet of available head for a CAPTure™ installation. Hydraulic head is the difference in elevation between system influent and effluent. It can be thought of as the difference between the maximum allowable water elevation in the area to be treated and the surface elevation of the water body that the filter box discharges to. The maximum allowable elevation in the area to be treated is typically an elevation below the root zone so as to not flood the area or damage any crops. If this can be considered to be 1.5 feet below grade, the surface elevation of the water body being discharged to must be at least 3.5 feet below grade for a CAPTure™ installation to function without requiring a pump. Often, drainage ditches are at least 4 feet below grade and finding sufficient hydraulic head is not an issue.

For CAPTure™ installations targeting surface runoff, adequate detention must be provided to drop fine sediments out that might otherwise reduce filter media effectiveness. Adequate detention should be considered a storage volume that can accommodate surface runoff from a 2-year storm event. Runoff volumes can be calculated by either the rational method or curve number method, or from measurements if available. For example, if the curve number method estimates 1.5" of runoff from a 2-year storm on 20 acres of drainage, 2.5 ac-ft of storage would be required. If the storage area is 4 feet deep, the storage surface area would need to be 0.63 acres. This volume can then be drained out over time, allowing fine sediments to settle out prior to water going through the filter box.

Phosphorus Capture Potential

From a management perspective, it is important to deploy CAPTure™ systems in locations with elevated phosphorus loads. While the filter media can bind phosphorus at concentrations as low as 20 µg/L, treating concentrations this low is not an effective use of restoration funds. The NRCS conservation practice standard for phosphorus removal systems (#782) dictates that water to be treated must have a dissolved phosphorus concentration of 500 µg/L or greater.[1] It is possible that this value is somewhat elevated due to the range of potential filter media that qualify for this practice, some of which cannot dependably bind phosphorus at concentrations lower than 500 µg/L. If EQIP funding is being considered, or the installation is otherwise part of a project that requires NRCS practice adherence, this minimum concentration should be kept in mind. Otherwise, CAPTure™ installations should be prioritized based on estimated annual phosphorus loads to be treated. The minimum average load for a CAPTure™ filter box is considered to be 5 pounds of dissolved phosphorus per year. This can be calculated using the following equation:

$$W = 0.226 * \frac{A * I * C}{B}$$

Where:

- *W* is the annual dissolved phosphorus load (pounds per box per year)
- 0.226 is a conversion factor
- *A* is the drainage area (acres)
- *I* is the average depth of water to be treated (infiltration, runoff, or both, in inches/year)
- *C* is the average dissolved phosphorus concentration (mg/L)
- *B* is the number of CAPTure™ boxes

Treated water depth and phosphorus concentrations can be based on modeled values, but should use measured values whenever possible. An average load lower than 5 pounds per year could still be treated by a CAPTure™ system, but would face diminishing returns in terms of dollars spent per pound of phosphorus removed. If multiple locations are being prioritized for installations, locations with the highest loads should be chosen first assuming they meet hydraulic criteria as well.

Recent research has shown good correlations between soil test phosphorus (STP), soil composition (% silt), and dissolved phosphorus concentration in surface and subsurface runoff.[2] These provide a useful predictive capability as STP and soil composition are commonly tested by agricultural producers. In comparison, accurately measuring phosphorus concentrations in grab samples can be relatively costly. Relationships between soil values and estimated phosphorus concentrations are presented in Figures 1 and 2 in these regards. These concentrations can be used in the loading equation described previously.

[1] USDA-NRCS. (2023). Field office technical guide.
[2] Ebersbach, E. (2023). Impact of Soil Texture on Phosphorus Loss from Legacy-P Fields (Doctoral dissertation, The Ohio State University).

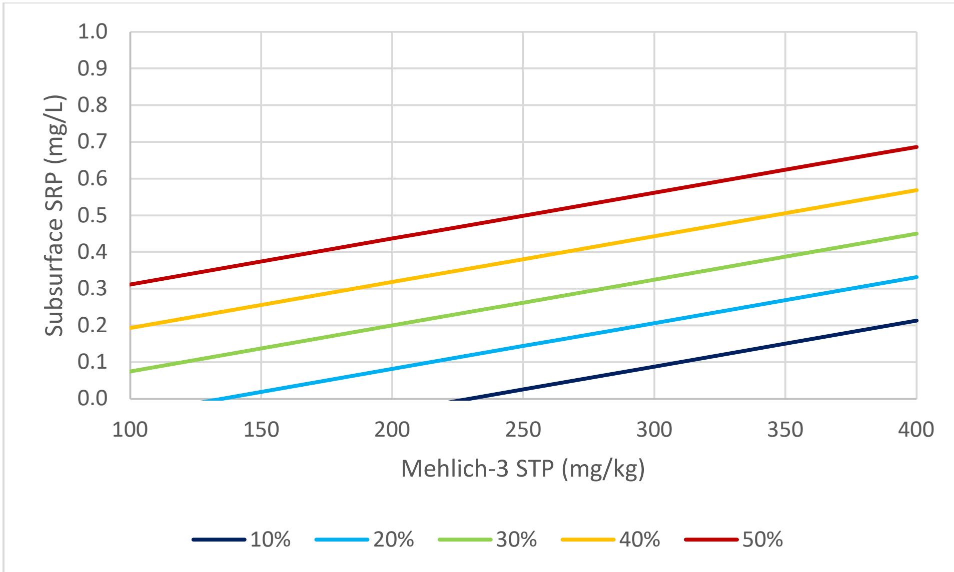

Figure 1 – Estimated Subsurface Soluble Reactive Phosphorus (SRP) Concentrations as a Function of Soil Test Phosphorus (STP) and Soil Silt Composition (%s noted in legend). Derived from Ebersbach, 2023.

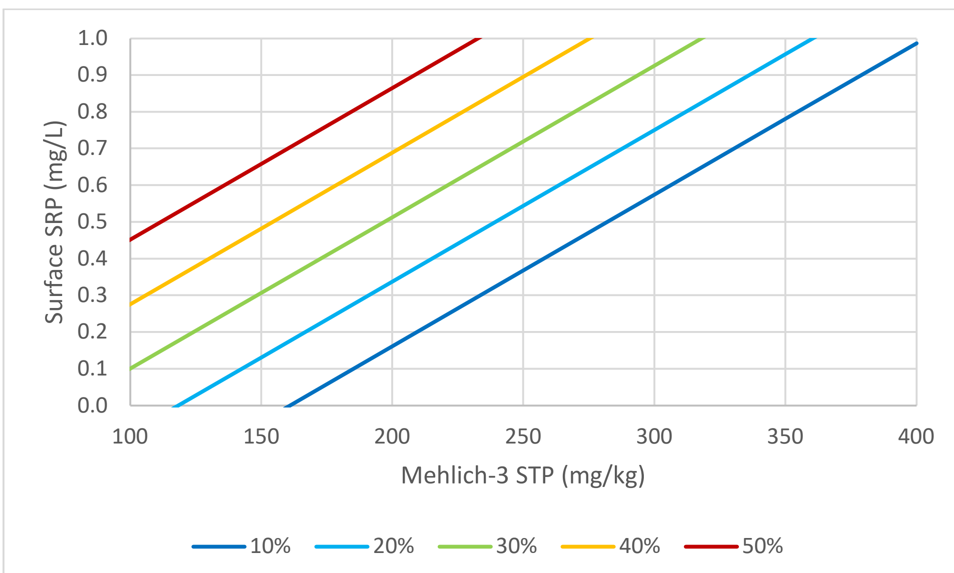

Figure 2 - Estimated Surface Soluble Reactive Phosphorus (SRP) Concentrations as a Function of Soil Test Phosphorus (STP) and Soil Silt Composition (%s noted in legend). Derived from Ebersbach, 2023.

If CAPTure™ systems are being considered for a watershed and specific installation locations are not yet known, there are certain analyses that can be performed to select sites with elevated phosphorus loss risks. The primary risk factors are soil characteristics, land use, and management practices. Hydrologic soil groups "C" and "D" should be prioritized, while "A" and "B" soils will produce less runoff and are not typically tile-drained. Areas used for corn and soybeans will typically see the highest phosphorus losses, though grain crops and pasture can still see elevated phosphorus loads under certain conditions. Management practices can reduce risks (conservation practices such as grass waterways or vegetated buffers), or increase risk (manure application) of elevated phosphorus losses. Using the USDA web soil survey tool can provide soil maps identifying areas with vulnerable soil groups as well as soil composition values.[3] The USDA cropland data layer tool can be used to identify areas with specific crops.[4]

Filter Box Calculations

Each CAPTure™ filter box can treat flows of up to 100 GPM. Typically, systems are designed with a drainage rate of 1/8 inch per day for the area being drained, which translates to roughly 2.5 GPM per acre. For projects where higher drainage rates are required, flow rates should be calculated as appropriate. The number of filter boxes required can be calculated by dividing the total project flow rate (in GPM) by 100 and rounding up to the nearest whole number.

When using activated aluminum, filter media should be replaced when the ratio of filter media to influent load drops below 50:1. In other words, a set of filter bags (640 pounds of total media) should be replaced after 13 pounds of phosphorus passes into the filter box. If this ratio is not surpassed, filter media should still be replaced yearly to prevent any potential clogging issues from sedimentation.

"Hot Spot" Analysis

Excess phosphorus loading is a widespread issue across the United States, particularly in agricultural areas. There exist hundreds of millions of acres of croplands, containing hundreds of thousands if not millions of subsurface drain outlets and surface runoff detention basins. However, not all of this acreage and its associated outlets are problematic. A common rule of thumb suggests within the conservation practice realm that "20% of the land can be 80% of the problem." When implementing a new practice such as the CAPTure™ system, it is imperative that locations likely to have elevated phosphorus loading rates can be readily identified. These "hot spots" can then be analyzed more thoroughly to select the specific installation sites that might provide the most benefit.

An analysis of phosphorus loading and subsurface drainage density was performed utilizing data from the USDA National Agricultural Statistics Service, Census of Agriculture[5] and its Canadian counterpart, the Canadian Census of Agriculture.[6] Subsurface drainage analysis is fairly straight forward as this is a reported category within the US Census. Phosphorus inputs were calculated using data for crop yields (corn, soybeans, and wheat) and animal head count (cattle, swine, and poultry). Values from the USDA-NRCS Nutrient Tracking Tool (NTT)[7] were used to convert crop yields and animal head counts into phosphorus inputs. Combined, these calculations provide an estimate of agricultural phosphorus inputs by county (or by reporting unit in Canada). Calculated values were then mapped utilizing QGIS.

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[3] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at the following link: http://websoilsurvey.sc.egov.usda.gov. Accessed 2023.

[4] Boryan, C., Yang, Z., Mueller, R., & Craig, M. (2011). Monitoring US agriculture: the US department of agriculture, national agricultural statistics service, cropland data layer program. Geocarto International, 26(5), 341-358.

[5] USDA. (2019). 2017 Census of Agriculture. Available online at the following link: https://www.nass.usda.gov/Publications/AgCensus/2017. Accessed 2023.

[6] Statistics Canada. (2023). 2021 Census of Agriculture. Available online at the following link: https://www.statcan.gc.ca/en/census-agriculture. Accessed 2023.

[7] Saleh, A., Gallego, O., Osei, E., Lal, H., Gross, C., McKinney, S., & Cover, H. (2011). Nutrient Tracking Tool—a user-friendly tool for calculating nutrient reductions for water quality trading. Journal of Soil and Water Conservation, 66(6), 400-410.

Phosphorus inputs were converted to loading estimates by comparing input totals against monitored loads for select watersheds,[8] as well as the Great Lakes Basin.[9,10] Total phosphorus (TP) loads were then split into particulate (PP) and dissolved (DP) fractions using data from past studies[11] and literature.[12] These studies were also used to estimate the fraction of phosphorus lost via subsurface drainage.

This analysis shows that high densities of both phosphorus losses and subsurface drainage are primarily clustered in and around the Corn Belt (Figures 3 and 4, respectively). Small additional hot spots can be seen in California, Idaho, North Carolina, and around Chesapeake Bay. Total loads estimated as a result of this analysis were 202,731 metric tons annually (MTA) of TP for the United States and Canada (from agricultural sources), with 45,193 of that being DP (Table 1). The United States is responsible for 90% of this load. Within the Great Lakes Basin, estimates were 12,520 MTA of TP with 3,051 of that being DP. Loading from Canada was more impactful here, with the United States being responsible for 76% of the total Great Lakes basin load. Great Lakes basin-specific hot spots can be seen in the Fox River basin, around Saginaw Bay, and in the Western Lake Erie Basin (Figure 5). Estimates for loads lost via subsurface drainage were 22,395 MTA of TP for the Continental US (12% of the total loss) and 2,392 MTA of TP for the US Great Lakes Basin (25% of the total loss).

Table 1 - Estimated Phosphorus Losses for Select Regions.

Region	**Annual Load (MT)**	
	TP	**DP**
Continental US	184,434	40,619
Canada	18,297	4,574
Great Lakes Basin (GLB)	12,520	3,051
US GLB	*9,556*	*2,310*
Canada GLB	*2,963*	*741*
Western Lake Erie Basin alone (Canada and US contributions)	*2,784*	*743*

8 Great Lakes Commission. (2021). Lake Erie Annual Tributary Data. Available online at the following link: https://blue-accounting-glcommission.hub.arcgis.com/documents/76bef23d9cce41f3809152b3f091bd9b/about. Accessed 2023.

9 Dolan, D. M., & Chapra, S. C. (2012). Great Lakes total phosphorus revisited: 1. Loading analysis and update (1994–2008). Journal of Great Lakes Research, 38(4), 730-740.

10 Maccoux, M. J., Dove, A., Backus, S. M., & Dolan, D. M. (2016). Total and soluble reactive phosphorus loadings to Lake Erie: A detailed accounting by year, basin, country, and tributary. Journal of Great Lakes Research, 42(6), 1151-1165.

11 Kieser & Associates, LLC. (2021). Strategic Water Quality Monitoring and Soil Sampling to Advance Systematic and Fundamental Changes in Agricultural Water Resources Management. Michigan USDA-NRCS EQIP Conservation Innovation Grant USDA-NRCS Agreement: 69-5D21-17-114.

12 Jarvie, H. P., Johnson, L. T., Sharpley, A. N., Smith, D. R., Baker, D. B., Bruulsema, T. W., & Confesor, R. (2017). Increased soluble phosphorus loads to Lake Erie: Unintended consequences of conservation practices? Journal of Environmental Quality, 46(1), 123-132.

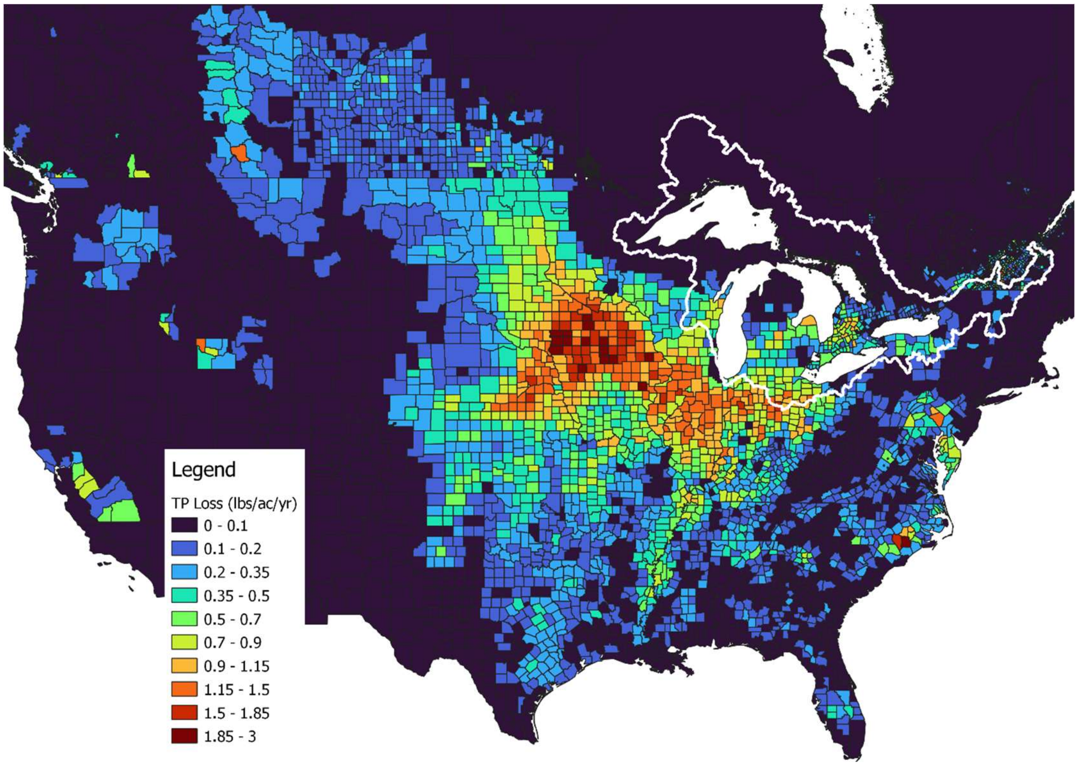


Figure 3 - Map of Estimated Total Phosphorus (TP) Losses Based on USDA and Statistics Canada Ag Census Data. The Great Lakes Basin is Outlined in White.

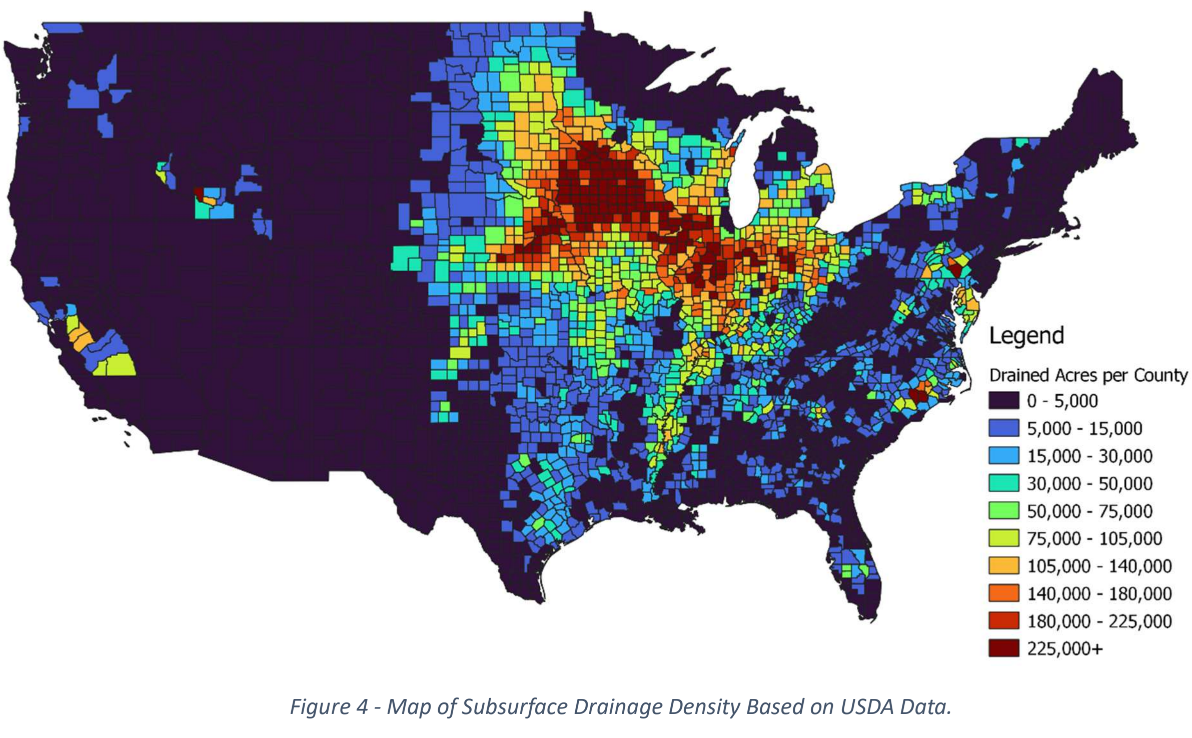


Figure 4 - Map of Subsurface Drainage Density Based on USDA Data.

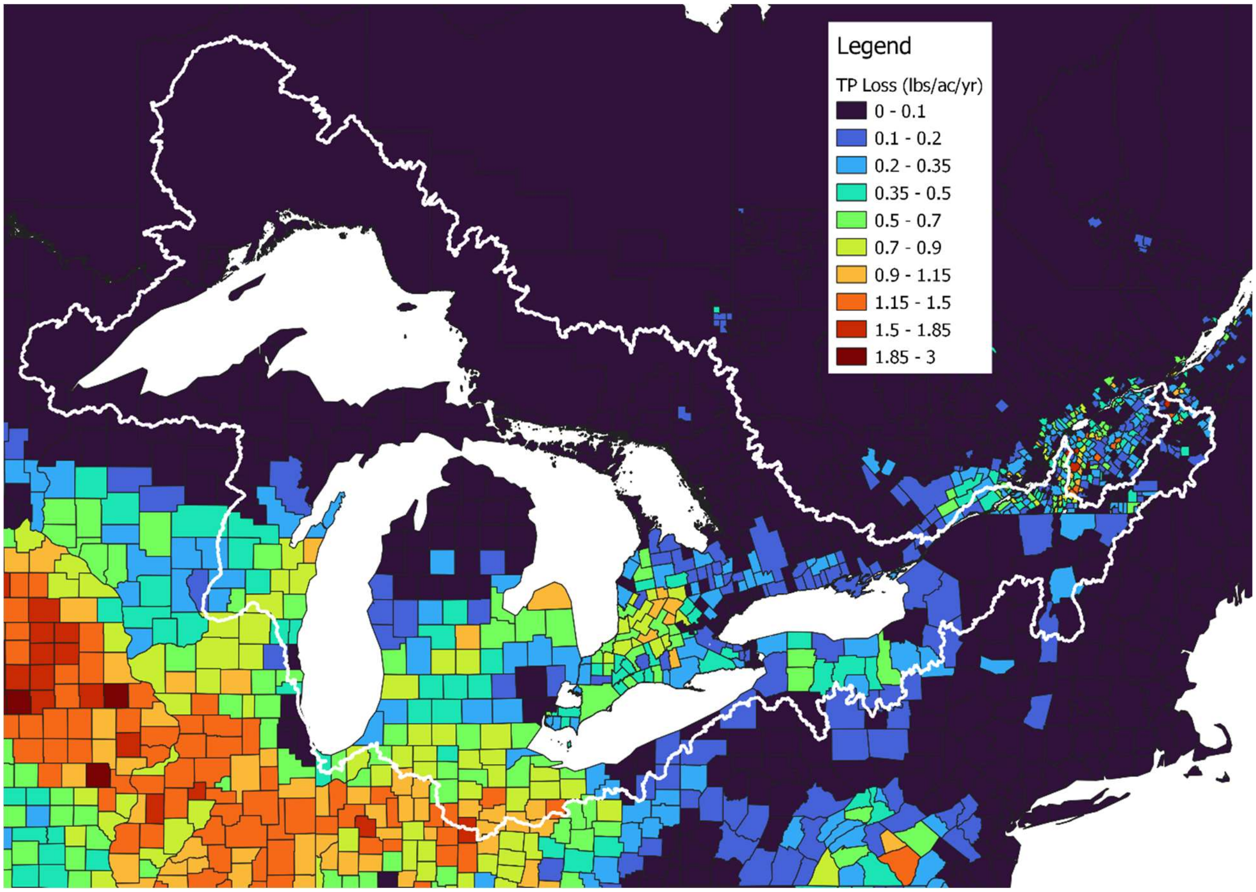


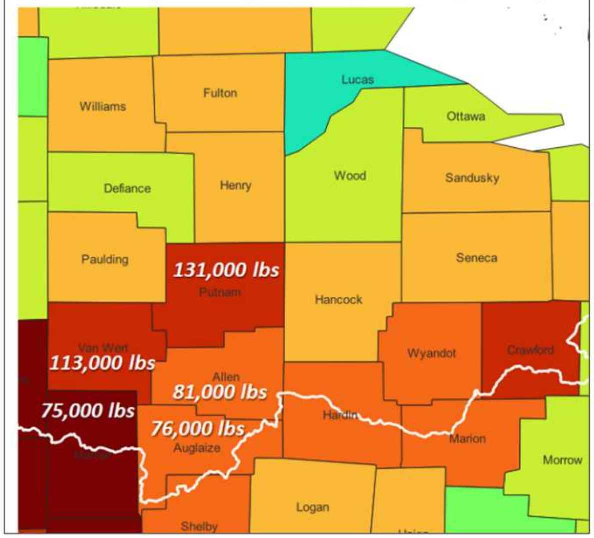
Figure 5 – Great Lakes Basin Map of Estimated Total Phosphorus (TP) Losses Based on USDA and Statistics Canada Ag Census Data. The Great Lakes Basin is Outlined in White.

Western Lake Erie Basin CAPTure™ Applications

A related K&A analysis was conducted for the Maumee River Watershed contributing to the WLEB. Figure 6 summarizes loading conditions using analyses described above, with the heat map depicting P inputs into the landscape and annual SRP loading estimates to the river from agriculture in headwater counties within the basin. The inset table identifies percent load contributions for these select headwater areas by county within the Maumee basin, and to the entire WLEB. Sensitivity analysis information in Table 6 identifies the most impactful elements for box siting in relationship to benefits. A siting approach that focuses on areas with high SRP loading provides the greatest return on benefits as illustrated in the related Monte Carlo analysis plot of Figure 7. This information emphasizes the importance of targeting select areas with the highest loads. For headwater applications in the Maumee River Basin, applying this technology throughout these areas could achieve significant reductions towards total phosphorus load reduction goals, most notably with SRP capture.

P Imports and Annual SRP Loading for Select OH Counties to WLEB

(K&A hotspot analysis; Chapra et al., 2015)



Loading by Counties	Maumee SRP	WLEB SRP
Top 2 (Putnam, VanWert)	24%	12%
Top 3 (+ Allen)	32%	16%
Top 5 (+ Auglaze, Mercer)	46%	23%

K&A Sensitivity Summary for Optimal CAPTure™ Cost-benefits

(Monte Carlo analysis)

Variable	R^2
Soil Test Phosphorus	0.053
Silt Fraction	0.266
SRP Concentration	0.337
SRP Load	0.707
Treatment Area	0.395
Treatment Target	0.001
Media Price	0.016
Box Price	0.031
Installation Cost	0.080
O&M Costs	0.034

Figure 6 – Maumee River Watershed Loading Conditions for Potential Scale-up Opportunities with CAPTure™ box applications.

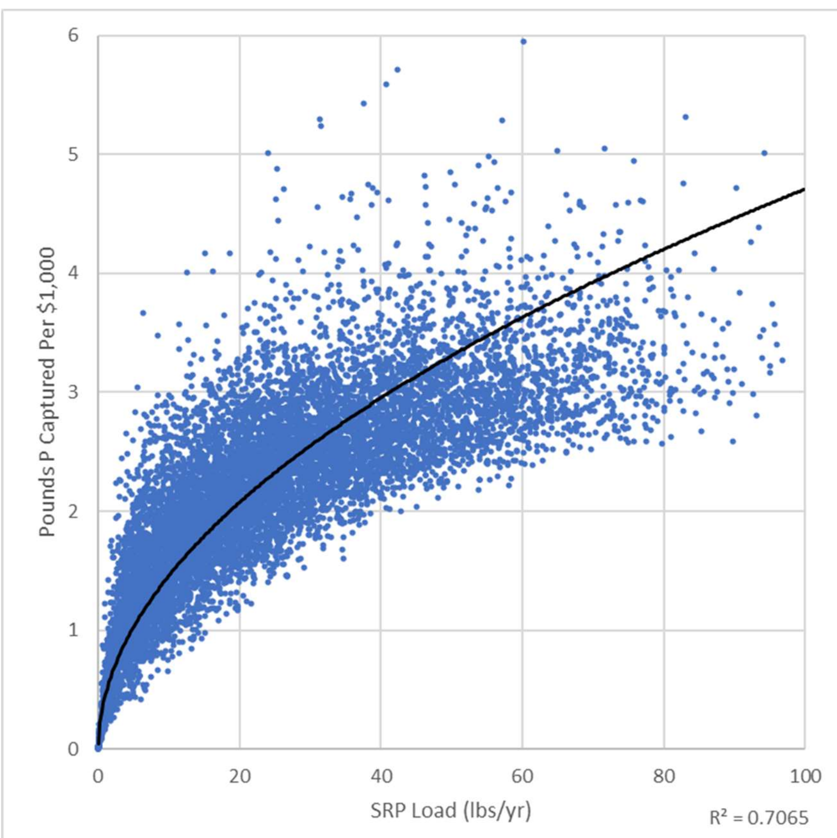


Figure 7 – Monte Carlo Analysis Results Reflecting Value of CAPTure™ Placement as a Function of SRP Loading and Pounds of Phosphorus Captured per $1,000 of Implementation Spending on Tile Drain Applications.