



# REVISION OF THE 590 NUTRIENT MANAGEMENT STANDARD: SERA-17 RECOMMENDATIONS

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for Protection of the Water Resource

SERA 17

Organization to Minimize  
Phosphorus Loss from Agriculture





# Revision of the 590 Nutrient Management Standard: SERA-17 Recommendations

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## **ABSTRACT**

In late 2009, NRCS requested a Working Group within SERA-17 be established to review and revise the 590 Nutrient Management Conservation Standard. This was in response to growing concern in certain areas of the U.S., that current risk assessment tools were not bringing about as great a change in phosphorus (P) management or P load reductions from agricultural lands as deemed accepted by some action agencies and NGOs. The SERA-17 Working Group were given five charges by NRCS, related to P loss risk assessment as part of the 590 that were to define: (1) criteria establishing the range of soil test P (STP) values where a P Index risk assessment is needed; (2) upper P Index threshold that limits P application; (3) minimum requirements of P Indices; (4) a process to evaluate P Indices; and (5) long-term goals for development of the next generation P Indices. This report documents the findings and recommendations of the SERA-17 Working Group. This document was reviewed by SERA-17 members, NRCS, EPA, and NGOs, and represents to the best degree possible, a consensus statement of P loss risk assessment for agricultural sites.

## **FORWARD**

Since its introduction in the early 1990's, the P Index has morphed from an educational to an implementation, targeting, manure scheduling tool, and in some cases, a regulatory tool. A great deal of research has been conducted across the U.S. to derive, validate, and support components of the P Indexing concept, particularly those related to source factors. The general P Indexing concept has been modified state by state to consider their particular soil, land management, physiographic, and hydrologic controls influencing the potential for P loss. As a result, there are many variations in Indices now in use as part of the NRCS 590 Nutrient Management Conservation Standard. This variation is both a strength and weakness of the Indexing concept. Variability demonstrates the robustness of the approach but has led to differences in P management recommendations under relatively similar site conditions.

The inconsistency among Phosphorus (P) Indices in terms of level of detail and scientific underpinnings among states, as well as in recommendations and interpretations based on site risk, prompted this review of the P-Indexing approach as it is used in nutrient management planning. The need for revision has been heightened by a slower than expected decrease in P-related water quality impairment and, in some cases, an increase in soil P to levels several fold greater than agronomic optimum due to continued application of P with approval of the P Index.

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## Table of Contents

<a href="#"><u>Background</u></a> .....	2
<a href="#"><u>The Charge to SERA-17</u></a> .....	3
<a href="#"><u>Executive Summary</u></a> .....	4
<a href="#"><u>Criteria Establishing the Range of Soil Test Phosphorus Values where a Phosphorus Index Risk Assessment is needed</u></a> .....	5
<a href="#"><u>Defining an Upper Phosphorus Index Threshold that Limits Phosphorus Application</u></a> ..	16
<a href="#"><u>Defining the Minimum Requirements of Phosphorus Indices</u></a> .....	18
<a href="#"><u>Defining a Process to Evaluate Phosphorus Indices</u></a> .....	19
<a href="#"><u>Long-Term Goals for Development of Next Generation Phosphorus Indices</u></a> .....	21
<b><u>Appendices</u></b>	
<a href="#"><u>Current State of Land-Grant University Nutrient Recommendations</u></a> .....	25
<a href="#"><u>Relating Phosphorus Loss in Runoff to Soil Test Phosphorus, Soil Phosphorus Saturation and Phosphorus Index Risk</u></a> .....	26
<a href="#"><u>References</u></a> .....	28

## **REVISION OF THE 590 NUTRIENT MANAGEMENT STANDARD: SERA-17 RECOMMENDATIONS**

### **BACKGROUND**

In certain areas of the U.S., there is growing concern that phosphorus (P) based nutrient management was not bringing about as great a reduction in elevated soil P levels and P loss from agricultural lands as expected or desired. While a portion of the lack of response may reflect legacy effects of past management and a slow system response to change, there was indeed a need to address the approaches to determine and guide P-based nutrient management. As a result, NRCS undertook a revision of the 590 Nutrient Management Conservation Standard in mid 2009. A major component of this was to review and revise as necessary, the site risk assessment tool - P Index, used 590 nutrient management planning. In an effort to develop and science-based consensus on the nature of this revision and national standard for a P risk assessment tool, NRCS requested SERA-17 lead this task. In November, 2009, a SERA-17 Working Group was formed under guidance from NRCS and the SERA-17 Executive Committee.

NRCS's goals for a revised Phosphorus Index (P Index) or Phosphorus Risk Assessment Tool (PRAT) were to:

1. Prevent the gradual loading of phosphorus (P) to high water quality risk levels.
2. Assist producers in mitigating existing high water quality risk situations to lower sustainable P levels.
3. Determine and implement a "cutoff" to identify those conditions where no additional P shall be applied.
4. In order to accomplish the above goals, the P Index should include the following:
  - a. A tool built on a national platform with scientific underpinnings.
  - b. A tool to assess the potential for edge-of-field P runoff and leaching.
  - c. A tool based on the best available science that can be refined / improved as better technology or science becomes available.
  - d. A tool that can utilize local soil, hydrology, and climate data (these data already reside in wind and water erosion prediction tools used in NRCS field offices) that can track erosion and sediment transport to concentrated flow, to a point of deposition, or edge of field.
  - e. A tool that can address, where needed, irrigation-induced erosion, runoff, and leaching.
  - f. A tool that can assess risk from manure and/or P fertilizer.
  - g. Although the proposed P Index would be quantitative, it is not necessary that the results be delivered numerically. A narrative or category rating (Very Low, Low, Medium, High, Very High, etc.) would be satisfactory.
  - h. The minimum criteria for edge-of-field P runoff should be that nutrient concentrations in runoff reaching a stream or water body will not cause water quality impairment (algae,

aquatic habitat, etc.). The tool will also need to identify those fields/situations where even with the best conservation, no additional P should be applied.

### THE CHARGE TO SERA-17

Based on the above requirements the SERA-17 subgroup had the following charges (Figure 1):

1. Define criteria establishing the range of soil test P (STP) values where a P Index risk assessment is needed.
2. Define the upper P Index threshold that limits P application.
3. Define the minimum requirements of P Indices.
4. Define a process to evaluate P Indices.
5. Define long-term goals for development of the next generation P Indices.

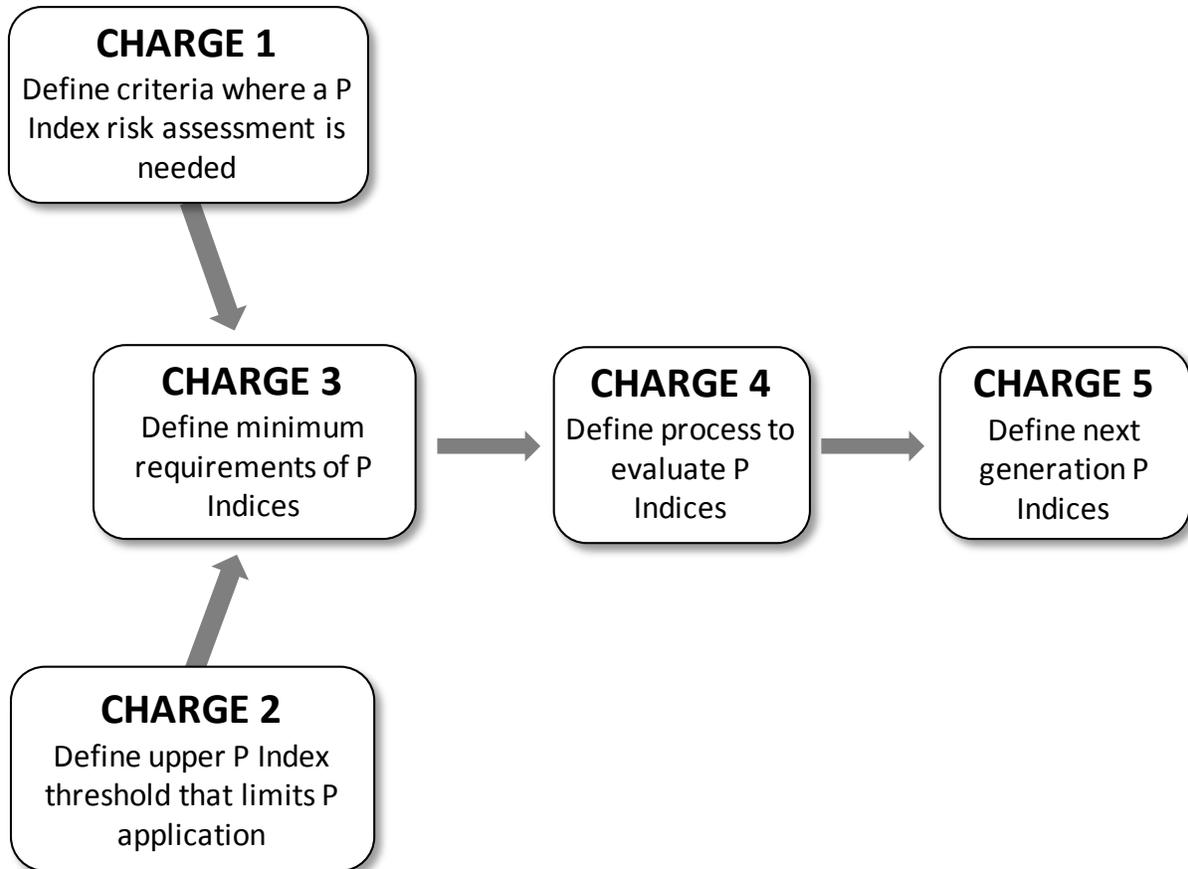


Figure 1. Organization scheme of the 590 revision charges.

## EXECUTIVE SUMMARY

- The goal of a P Index is to estimate the potential for P loss from any agricultural field. Phosphorus Indices were not designed to address or solve the broader issue of regional P surpluses. Many P Indices force a P balance approach on individual fields at some point; however, this point varies greatly and P Index cutoff values (the P Index value where no additional P is recommended) are not tied directly to water quality. A separate effort to address P balance (i.e., inputs equal to or less than outputs) at a watershed scale is needed. A P-balance approach will involve alternative technologies for manure utilization and export of manure from many farms in some watersheds.
- Many states have developed adequate tools to estimate the potential for P loss by describing the main factors and conditions controlling P loss in their state. However, there is substantial variation among P Indices in their structure, algorithms, and cutoff values used to delineate very low, low, medium, high, and very high risk of P loss. More importantly, there is a great deal of inconsistency in results and interpretation regardless of the details of the tool used.
- States may find it appropriate to eliminate the requirement of a P Index assessment when P applications are based on land-grant university nutrient recommendations and appropriate Best Management Practices (BMPs) for land application of P sources as defined by NRCS Conservation Practice Standards. For P application in excess of recommended rates, a P Index assessment will need to be conducted.
- All P Indices should “zero out” at some point. That is, there is a point above which the risk of P loss from a field is too great to warrant the application of P in any form. Each state should demonstrate that its P Index meets this criterion. We provide several approaches to determine this point, and where field-based research has been conducted to develop upper limits, state specific information should take precedence.
- There are too many legitimate differences in soils, climate, cropping systems, water body sensitivities, etc., and insufficient progress in modeling of all processes to support development and use of a single National P Index that addresses all of these differences, especially if a National Index must be user-friendly and require minimal input data and training for end-users at this time. Development of a National P Index will require a long-term commitment of time and resources similar to that required for the development of the USLE. Development of a P loss assessment tool that addresses the P loss issues specific to a physiographic region is desirable and should be a long-term goal of SERA-17 and NRCS collaboration.
- Although there is no scientific evidence to support the use of STP or P saturation alone to determine the risk of P loss; because P is a finite resource, states should consider establishing an upper limit of STP above which manure cannot be applied, regardless of P Index assessment.
- There needs to be a concerted training effort on how to use P Indices in the context of nutrient management planning and how to address any concerns identified by the P Index used during the planning/implementation process.

### **CHARGE 1**

## **CRITERIA ESTABLISHING THE RANGE OF SOIL TEST PHOSPHORUS VALUES WHERE A PHOSPHORUS INDEX RISK ASSESSMENT IS NEEDED**

### **Recommendation**

The lower limit of the range of STP values where a P Index risk assessment is needed can be based on land-grant university P application recommendations. States may find it appropriate to eliminate the requirement of a P Index assessment when P applications are based on land-grant university nutrient recommendations and appropriate Best Management Practices (BMPs) for land application of P sources (NRCS Conservation Practice Standards). For P application in excess of recommended rates, a P Index assessment will need to be conducted. States could develop a screening tool or other resources to identify high risk areas where a P Index assessment should be conducted even if STP results in a P application recommendation.

Because P is a finite resource, states should establish an upper limit of STP above which manure cannot be applied, regardless of P Index assessment. However there is no scientifically defensible way to set a uniform national upper STP bound based solely on water quality goals.

### **Considerations**

#### ***Setting the lower STP limit when no P Index assessment is required***

- The P Index (or pre-screening tool) should only be optional for fields with an agronomic need for P, based on STP and land-grant university nutrient recommendations.
- Producers are required to meet all other field-specific NRCS conservation objectives and standards, including erosion control, manure application setbacks, proper timing of manure application, and annual N limits for the crop. These conservation requirements apply to all nutrient applications independent of source according to the NRCS National Nutrient Management Standard.
- A low STP level does not mean there is no risk for P loss from manure or fertilizer application. For instance, the application of P to critical risk areas, such as fields adjacent to a stream with a high transport risk should be avoided. States that do not require the use of the P Index when an agronomic P need exists, could develop and use a screening tool to identify any local high risk situations (e.g., 303(d) listed waters for P or other state designated P-related impairment, erosion greater than T, high runoff potential, and within 30 m of flowing water) where the P Index should be used even when P applications are recommended.
- In some states, the P Index may allow repeated N-based applications, which can lead to a buildup of STP in excess of soil test P-driven nutrient recommendations. Because the recommended approach of Charge 1 never allows P applications to exceed crop rotation requirements, it is more restrictive than repeated N-based application rates.
- This approach promotes use of manure as a nutrient resource and ensures that farmers who manage manure P in this way can avoid conducting a P Index assessment when developing a

nutrient management plan or adjusting a manure application rate based on new information, such as information from regular and ongoing soil or manure test results. This allows limited planning resources to be targeted to higher priority areas.

- Manure P can be applied at a rate to meet the recommendation for multiple crop years (length to be determined by each state) without the need to do a P Index assessment. For example, with a three-year limit, a farmer could apply manure (based on the total P concentration of manure) in one year to meet three years of crop P need, as long as crop N requirements are not exceeded. No additional P is applied in the current and two additional years. However, given the short-term over application of P, states may want to provide additional guidance requiring agronomic practices that have been shown to minimize P runoff (e.g., subsurface placement, injection).
- It is theoretically possible that this approach would allow a manure or fertilizer application when the P Index recommends no application of manure. Reviewing current P loss assessment strategies from 21 states, shows that the P Indices in six of these states may indeed prevent manure application to fields when STP values are below the agronomic threshold (Table 1). In most cases, this would occur under specific and limited conditions (e.g., organic soils, high transport potential, proximity to a stream, specialty crops) for manure application and/or when manure application rate was high. Soil test P values at which no additional P is recommended are summarized in Table 2 for 24 states.
- Given the urgent need for improvements in P recommendations for environmental risk assessment purposes, continued efforts to use accurate data are essential. Private soil testing laboratories should be encouraged, if they are not already doing so, to participate in a laboratory certification program to verify that analytical procedures are performed correctly. They should also be encouraged to work with land-grant universities to ensure testing methods are consistent with extraction protocols established by the land-grant university in the state where the soil sample was taken. In addition, NRCS 590 standards should require soil test laboratories be certified and use land-grant university nutrient recommendations for both N and P. For states that do not have this requirement in their NRCS 590 standard, soil testing analysis and recommendations can vary significantly. See Appendix A for more information.

***Setting the upper STP limit when no more P should be applied because of limited P resources***

- There is no scientific evidence to support the use of STP or P saturation alone to determine the potential for P loss from a field. A wealth of scientific evidence is available documenting that agronomic STP or soil P saturation is only one of several factors influencing the risk of P loss from a field. Use of agronomic STP or P saturation alone will not capture a site's risk for P loss (see Appendix B for more information). Any effort to set regional or national limits based solely on STP or P saturation will encounter the following challenges:

1. Inability to define cutoff values based on water quality criteria because of the lack of a correlation between STP or P saturation and edge-of-field runoff water quality.
  2. Because several different STP methods and depths of soil sampling are used across the U.S., equivalent values for each method would have to be determined.
- There are legitimate reasons to set an upper STP boundary not directly associated with current P loss potential of a field:
    1. Phosphorus is a finite natural resource that needs to be conserved. Thus, we support achieving on-farm and regional P balance with the long-term goal of meeting agronomic requirements. The unlimited over-application of P to soils is not a sustainable use of this finite resource. Limited buildup of STP above agronomic thresholds (Table 2) can achieve both agronomic and economic goals by maintaining agronomic P levels through a rotation or as a hedge against volatile fertilizer prices. At some point, continued buildup of STP has no possible agronomic value and can only be classified as a waste disposal P application.
    2. There is no guarantee that conditions currently limiting P transport on low P index fields will be maintained in perpetuity.
  - The P index in many (if not all) states allows build up of STP above agronomic need on most fields. States should consider defining where STP buildup transitions above “insurance” applications. Such a boundary may be considered as a limit to P application to meet resource conservation goals or as an educational tool so farmers understand there is little or no expectation of utilization for applied P to fields with STP above that limit.

The following are possible approaches states may use if they choose to set an upper STP threshold above which no manure application is allowed:

1. **Select a multiple of agronomic STP optimum.** The resulting limit could be interpreted correctly independent of the extraction procedure. States using a specific extraction procedure could later translate the guidance into specific extract concentrations.
2. **Select a draw down STP level** that would require no more than a set number of years to be drawn down to optimum under normal cropping conditions.

Table 1. Conditions under which P Indices could limit P applications on a field with an agronomic need for P in selected states.

State	Can state P Index restrict P applications on soils with an agronomic need for P?	Basis of Determination	Reference
AK	Yes	Can limit agronomic applications where site, transport, methods of application and timing factors are all at very high or worst-case scenario levels.	NRCS Alaska PI Index. May 2002.
AR	No	Restrictions most likely to occur on soils with high rates of P application coupled with high transport potential.	Moore, P.A., Jr., A. Sharpley, W. Delp, B. Haggard, T. Daniel, K. VanDevender, A. Baber, and M. Daniel. 2010. The Revised Arkansas Phosphorus Index. Arkansas Natural Resources Commission Title 20. <a href="http://www.anrc.arkansas.gov/Title%2020%2012-10-09.pdf">http://www.anrc.arkansas.gov/Title%2020%2012-10-09.pdf</a> .
CO	No	P index does not need to be run if STP is less than 10 mg kg <sup>-1</sup> AB-DTPA, 30 mg kg <sup>-1</sup> Bray-I P, 40 mg kg <sup>-1</sup> Mehlich-3 P or 20 mg kg <sup>-1</sup> Olsen P. This will result in no restriction on agronomic P applications except for potatoes.	USDA-NRCS State of Colorado. Agronomy Technical Note No. 95 (revised). Colorado Phosphorus Index Risk Assessment (Version 4). October 1, 2008.
CT	No	State has no P-Index, but P applications are not restricted if soil test recommends P applications.	<a href="http://efotg.sc.egov.usda.gov/references/public/CT/CT_590_2010_F.pdf">http://efotg.sc.egov.usda.gov/references/public/CT/CT_590_2010_F.pdf</a>
DE	No	The State of Delaware’s Nutrient Management Commission has established a Mehlich 3 P threshold of 150 mg kg <sup>-1</sup> (3 times the University of Delaware M3 P critical value of 50 mg kg <sup>-1</sup> ) as the basic definition of a “high P” soil. By state law (Delaware Nutrient Management Act of 1999), soils that are “high” in P can continue to receive manure or fertilizer P in any given year at the rate that will	Sims, J. T. and Leytem, A. B. 2002. The Phosphorus Site Index: A phosphorus management strategy for Delaware’s agricultural soils. Nutrient Management Fact Sheet No. 5. University of Delaware College of Agriculture and Natural Resources, Newark, DE 19717-2303.

		<p>be removed by crop harvest in the next 3 years, but no additional P can then be applied for 3 years (i.e., P is applied once at a "3-year crop P removal" rate, then again 3 years later). However, farmers are given the option to use a P Site Index for soils with M3-P &gt; 150 mg kg<sup>-1</sup> and to apply manure and fertilizer P in accordance with the recommendations of the P Site Index. The University of Delaware recommends that no manure or fertilizer P be applied if a field has a "Very High" P Index rating. For soils with a "High" P Index value, the recommendation is that "...fertilizer P, other than a small amount used in starter fertilizers, will not be needed. Manure may be in excess on the farm and should only be applied to fields with a lower P Site Index value." It is possible, but highly unlikely, that soil erosion or artificial drainage could result in a Very High P Index value and restrict manure applications to a soil with an agronomic need for P.</p>	
GA	Yes	<p>P Index could restrict agronomic applications in soils with high transport potential.</p>	<p>Cabrera, M.L., D.H. Franklin, G.H. Harris, V.H. Jones, H.A. Kuykendall, D.E. Radcliffe, L.M. Rise, and C.C. Truman. 2002. The Georgia Phosphorus Index. Cooperative Extension Service, Publications Distribution Center, University of Georgia, Athens, Georgia, 4pp.</p>
IN	No	<p>Application rate bases for nutrient applications are determined by STP according to Chart B if the Indiana off-site risk pre-screening tool value is &lt;6. If the Indiana off-site risk pre-screening tool is &gt;6, the Indiana Off-Site Risk Index (ORI) must be completed and all risk components identified must be addressed. After all risk components identified by the ORI have been addressed nutrient applications are determined by STP according to Chart B.</p>	<p>Indiana Nutrient Management Standard. July 2001.</p>
KS	No	<p>There is no restriction in P application when STP less than 50 mg kg<sup>-1</sup> Mehlich 3 P regardless of the P index rating.</p>	<p>Kansas Nutrient Management Standard, November 2009.  <a href="http://efotg.sc.egov.usda.gov/references/public/KS/590st.pdf">http://efotg.sc.egov.usda.gov/references/public/KS/590st.pdf</a></p>

KY	No	P Index is not required until Mehlich-3 STP values exceed 200 mg kg <sup>-1</sup> which is ~ 7 times greater than the agronomic recommendation for most crops.	Kentucky Nutrient Management Standard, May 2001.
MD	Yes	P Index may restrict agronomic applications for sites with very high off-site transport potential (e.g. high erosion potential) and close proximity to surface water and/or surface application of manure.	Coale, F.J. 2005. The Maryland Phosphorus Site Index Technical Users Guide. Soil Fertility Management Series, SFM-7. Maryland Cooperative Extension. <a href="http://www.anmp.umd.edu/files/SFM-7.pdf">http://www.anmp.umd.edu/files/SFM-7.pdf</a> .
ME	No	Restrictions affect soils with soil test P greater than 20 mg kg <sup>-1</sup> where no P application is recommended.	
MO	No	P Index is designed to insure rating of no higher than “medium” on fields with agronomic need and soil loss less than 2T. Therefore, the P index should never limit agronomic applications on fields where erosion limits of the 590 standard are being met.	Lory, J.A., R. Miller, G. Davis, D. Steen and B. Li. 2007. The Missouri Phosphorus Index. MU Extension Pub. G9184.
NC	Yes	P Index almost always restricts agronomic applications on organic soils at the agronomic cutoff for P. Most manure, however, is not applied to organic soils.	Johnson, A.M., D.L. Osmond, and S.H. Hodges. 2005. Predicted impacts of North Carolina’s Phosphorus Loss Assessment Tool. <i>J. Environ. Qual.</i> 34:1801-1810.
NY	No	Restrictions most likely to occur on soils with high rates of P application coupled with high transport potential.	Czymmek, K.J. Q. M. Ketterings, L. D. Geohring, G. L. Albrecht. 2003. The New York Phosphorus Runoff Index. User’s Manual and Documentation. CSS Extension Publication E03-13. 64 pages.
OK	No	Nutrient Management Standard states that no manure application only on fields with Mehlich3-P >150 mg kg <sup>-1</sup> (STP Index >300).	Oklahoma Nutrient Management Standard. March 2007.
PA	Yes	Using all the worst-case scenarios leads to no application if the P application rate from all sources exceeds 100 lbs acre <sup>-1</sup> . Result only applicable in special protection watersheds and applications within 150 feet of receiving water.	2007. The Pennsylvania Phosphorus Index, Version 2.

SC	No	P Index cannot be used to limit or deny applications of P when it is recommended for crop growth through soil test results	The Phosphorus Index: South Carolina. 210-AWMFH, SC Supplement, July 2004.
TN	No	The P Index assessment is required for P applications where no further P additions are agronomically needed as defined by Mehlich-1 soil test P.	Tennessee Phosphorus Index: A Planning Tool to Assess & Manage P Movement. 2001.
TX	No	When the Mehlich-3 soil test P reaches 200 mg kg <sup>-1</sup> in East Texas (counties with greater than 25 inches of precipitation) or 350 mg kg <sup>-1</sup> (counties with less than 25 inches of precipitation and named streams greater than 1 mile away), the maximum application would be 1.0X P annual crop removal rate, not to exceed the annual N rate of application for PI ratings of Very Low, Low, Medium, or High and for Very High it is 0.5X the annual P crop removal rate.	Texas Nutrient Management Practice Standard. July, 2007.
UT	No	Nutrient management guidance states that Olsen-P of 50 mg kg <sup>-1</sup> manure can be applied according to the agronomic N need. Between 50 and 100 mg kg <sup>-1</sup> , manure should be applied according to the agronomic P need. Above 100 mg kg <sup>-1</sup> Olsen P, manure should only be applied at 50% of agronomic P need.	Utah 590 Standard: <a href="http://extension.usu.edu/files/publications/publication/AG_Soils_2008-01pr.pdf">http://extension.usu.edu/files/publications/publication/AG_Soils_2008-01pr.pdf</a>
VA	No	P Index does not come into effect until Mehlich 1 P above agronomic optimum	<a href="http://p-index.agecon.vt.edu/">http://p-index.agecon.vt.edu/</a>
WI	Yes	It is possible to have particulate P loss that exceeds the WI target P Index value with STP in the optimum range for high P demand crops (e.g., potato) even when erosion is below T; these crops rarely receive manure.	2010. The Wisconsin Phosphorus Index, <a href="http://wpindex.soils.wisc.edu/">http://wpindex.soils.wisc.edu/</a>

Table 2. Soil test P at which land-grant universities recommend no additional P be applied.

State	Method	Soil sampling depth	Soil test P where no additional P recommended	References
		inches	mg kg <sup>-1</sup>	
AK	Mehlich-3	Plow depth to a maximum of 6 inches	15-66 Starter P typically recommended	USDA NRCS Alaska Technical Note 16 - Making fertilizer recommendations from soil test reports-October 2008.
AR	Mehlich-3	4 (pastures) or 6 (row crops)	36-50	Espinosa, L., N. Slaton, and M. Mozaffari. 2006. The soil test report. University of Arkansas Division of Agriculture, Cooperative Extension Service Fact Sheet FSA2153. <a href="http://www.uark.edu/depts/soiltest/NewSoilTest/pdf_files/FSA-2153.pdf">http://www.uark.edu/depts/soiltest/NewSoilTest/pdf_files/FSA-2153.pdf</a>
CO	AB-DPTA Olsen	Plow depth or 4 inches	8-11 15-22 P always recommended for potatoes	Davis, J.G. and D.G. Westfall, Fertilizing corn. CSU Ext. Pub. No. 0.538. Oct.. 2009. Davis, J.G. and D.G. Westfall, Fertilizing sugar beets. CSU Ext. Pub. No. 0.542. Apr. 2009. Davis, J.G., R.D. Davidson and S.Y.C. Essah. Fertilizing potatoes. CSU Ext. Pub. No. 0.541. May 2009.
CT	Modified Morgan	6-8	10	University of Connecticut Soil Nutrient Analysis Laboratory Recommendations for Agronomic Growers
DE	Mehlich-3	4 pastures 8 row crops	100 <sup>†</sup>	Sims, J. T. A. B. Leytem, and K. L. Gartley. 2002. Interpreting soil phosphorus tests. Nutrient Management Fact Sheet No. 4. University of Delaware College of Agriculture and Natural Resources, Newark, DE 19717-2303. Sims, J. T., and K. L Gartley. 1996. Nutrient management handbook for Delaware. Coop. Bull. 59. Univ. Delaware, Newark, DE.
GA	Mehlich-1	4 (pastures) 6 (row crops vegetables)	14-70	Kissel, D.E. and L.S. Sonon. 2008. Soil test handbook for Georgia. <a href="http://aesl.ces.uga.edu/publications/soil/STHandbook.pdf">http://aesl.ces.uga.edu/publications/soil/STHandbook.pdf</a>

IN	Bray 1	8	40-50	Vitosh, M.L., J.W. Johnson, and D.B. Mengel. 1996. Tri-state fertilizer recommendations for corn, soybeans, wheat and alfalfa. Ohio State Univ. Bulletin E-2567
KS	Bray 1	6	20-30	Leikam, D.F., R.E. Lamond, and D.B. Mengel. 2003. Soil test interpretations and fertilizer recommendations. Kansas State Univ. Agricultural Experiment Station and Cooperative Extension Service Pub. MF-2586. Manhattan, KS.
KY	Mehlich 3	3-4 (consv till) 6-7 (conv till)	30-40	Murdock, L. and G. Schwab. 2010. Lime and fertilizer recommendations. University of Kentucky Extension Publication AGR-1
MI	Bray 1	8	40-50	Vitosh, M.L., J.W. Johnson, and D.B. Mengel. 1996. Tri-state fertilizer recommendations for corn, soybeans, wheat and alfalfa. Ohio State Univ. Bulletin E-2567
MD	Mehlich-3	8	50	McGrath, J. 2010. Agronomic crop nutrient recommendations based on soil tests and yield goals. Soil Fertility Management Series, SFM-1. Maryland Cooperative Extension. <a href="http://www.anmp.umd.edu/files/SFM-1.pdf">http://www.anmp.umd.edu/files/SFM-1.pdf</a> .
ME	Morgan	6	20	Hoskins, B.R. 1997. Soil Testing Handbook. Revised 2001. Available at <a href="http://anlab.umesci.maine.edu/soillab_files/faq/handbook.pdf">http://anlab.umesci.maine.edu/soillab_files/faq/handbook.pdf</a> .
MO	Bray 1	6	35	Soil Test and Interpretations Handbook. Revised 5/2004. Available at <a href="http://aes.missouri.edu/pfcs/soiltest.pdf">http://aes.missouri.edu/pfcs/soiltest.pdf</a>
MS	Lancaster	4-6 pastures, 6 crops	36	Oldham, J.L., and K.K. Crouse. Soil test-based inorganic fertilizer nutrient recommendations for Mississippi agronomic crops. MSU Extension Service Soil Testing Laboratory.
NC	Mehlich 3	4 (consv till) or 8 (conv till)	60	Hardy, D.H., M.R. Tucker, C.E. Stokes. 2009. Crop fertilization based on soil test report. <a href="http://www.ncagr.gov/agronomi/pdffiles/oobook.pdf">http://www.ncagr.gov/agronomi/pdffiles/oobook.pdf</a> . NCDA&CS, Raleigh, NC
NY	Morgan	6-8	20	Ketterings, Q.M., K.J. Czymmek and S.D. Klausner. 2003. Phosphorus guidelines for field Crops in New York. Second Release. Department of Crop and Soil Sciences Extension Series E03-15. Cornell Univ., Ithaca NY. 35 pp.

OH	Bray 1	8	40-50	Vitosh, M.L., J.W. Johnson, and D.B. Mengel. 1996. Tri-state fertilizer recommendations for corn, soybeans, wheat and alfalfa. Ohio State Univ. Bulletin E-2567
OK	Mehlich 3	6	41 ¶	Zhang, H. and B. Raun. 2006. Oklahoma Soil Fertility Handbook. 6 <sup>th</sup> Edition. OSU Extension Publication.
PA	Mehlich 3	8	50	AASL.psu.edu Penn State Soil Fertility Handbook
SC	Mehlich 1	6 (crops) 3 (pasture)	27.5 - 40	
TN	Mehlich 1	6	>15	<a href="http://soilplantandpest.utk.edu/pdf/files/soiltestandfetrecom/chap2-agronomic_mar2009.pdf">http://soilplantandpest.utk.edu/pdf/files/soiltestandfetrecom/chap2-agronomic_mar2009.pdf</a>
TX	Mehlich 3	6	50	Provin, Tony. 2010. Soil, water and forage testing laboratory methods and recommendations. <a href="http://soiltesting.tamu.edu">http://soiltesting.tamu.edu</a> .
UT	Olsen P	12 ‡	15	Cardon, G.E., J. Kotuby-Amacher, P, Hole, R. Koenig. 2008. Understanding your soil test report. Utah State Cooperative Extension Service AG/Soils/2008-01pr. <a href="http://extension.usu.edu/files/publications/publication/AG_Soils_2008-01pr.pdf">http://extension.usu.edu/files/publications/publication/AG_Soils_2008-01pr.pdf</a>
VA	Mehlich 1	4 no-till, 6-8 conventional till	55	Maguire, R.O., and S.E. Heckendorn. 2009. Soil test recommendations for Virginia (Update of 1994 version). Virginia Cooperative Extension.
WI	Bray 1	6-8	17-80 § P always recommended for potatoes	Laboski, C.A., J.B. Peters, L.G. Bundy. 2006. Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin. UW-Extension A2809.

† Optimum range for M3-P in Delaware is 50-100 mg kg<sup>-1</sup> by Mehlich 3 P. In almost all cases, only starter P is recommended when M3-P values are > 50 mg kg<sup>-1</sup>.

‡ Value is 32.5 mg kg<sup>-1</sup> if P is measured colorimetrically.

¶ Recommendation is that the sample be confined to the upper foot. Most will focus on extracting from 6 to 10 inches deep.

§ Value within range depends on crop and soil type.

**CHARGE 2**  
**DEFINING AN UPPER PHOPSHORUS INDEX THRESHOLD THAT LIMITS PHOSPHORUS APPLICATION**

**Recommendation**

All P Indices should “zero out”, which means they must identify a critical risk of P loss from a field beyond which no P in any form should be applied. Each state must demonstrate that its P Index meets this criterion for combinations of parameters that influence P loss potential. The upper criteria or threshold should be determined based on local water quality criteria where available, or on a basic set of conditions that in combination lead to an unacceptable risk of P loss. The upper threshold should be used to establish the minimum standard for restricting P applications on a field and should not be used to justify raising limits on P applications in states with more restrictive P Indices.

**Considerations**

Possible methods for establishing an upper P Index threshold are detailed below and outlined in Table 3.

1. Define P loss limits for a field based on quantitative water quality criteria for the target water body.
  - This approach is similar to that for establishing TMDLs, and provides a quantitative measure justified directly by water quality standards for a specific region. Essentially, the following are estimated: (a) how much total P a specific water body can assimilate without adverse water quality impacts; (b) how much of that total acceptable P load can come from agriculture in the watershed; and (c) an allowable field scale P loss based on the total allowable agricultural P load to the water body.
  - Unfortunately, there are significant technical challenges to setting field-level P limits based on numeric water quality criteria. Currently, numeric criteria for P water quality standards only exist for a limited number of water bodies; and methods to establish field-specific limits on P loss based on numeric water quality limits are not well developed.
  - This approach requires use of a P Index that estimates field scale P loss in lb/ac so P Index results can be directly related to water quality estimates.
2. Run a range of scenarios and estimate P loss for each of them using an appropriate model. Use professional judgment to set runoff P limits that clearly limit risky management and/or prevent levels of P loss likely to degrade water quality.
  - This approach integrates professional judgment and local management into the establishment of P limits. However, subjective criteria are used to connect P loss limits with water quality criteria.

3. Run a comprehensive set of representative P runoff scenarios for a state or region using an appropriate model and set P limits to eliminate application on a specified upper percentile of the scenarios (e.g., top 20%).
  - This approach provides a limit based on local scenarios that will reliably establish and identify the worst situations. However, there is no connection between the limit and any water quality criteria. The limit could be either more restrictive or more liberal than needed.
  - To be successful, this approach requires knowing and running the full range of real field scenarios, from the lowest to the highest P loss rating.

Table 3. Potential strategies to identify field P loss limits in runoff where a P risk assessment strategy should zero out P applications.

Approach Description	Strengths	Weaknesses
Set field runoff P limits based on water quality criteria of the target watershed.	<ul style="list-style-type: none"> <li>• Quantitative measure justified directly by water quality standards for a specific region.</li> <li>• Preferred approach in TMDL watersheds and when other water quality criteria are available.</li> </ul>	<ul style="list-style-type: none"> <li>• Requires quantitative water quality criteria to be in place and a mechanism to convert to field –level P loss limits. There is insufficient information in place to calculate such limits in many locations.</li> </ul>
Run a range of scenarios and estimate P loss for each of them using an appropriate model. Use professional judgment to set runoff P limits that clearly limits risky management and/or prevents levels of P loss likely to degrade water quality.	<ul style="list-style-type: none"> <li>• Integrates professional judgment and local management into the establishment of P limits.</li> </ul>	<ul style="list-style-type: none"> <li>• Subjective criteria used to connect P loss limit with water quality criteria.</li> </ul>
Run a comprehensive set of representative P runoff scenarios for a state or region using an appropriate model and set P limits to eliminate application on a specified upper percentile of the scenarios (e.g., top 20%).	<ul style="list-style-type: none"> <li>• Provides a limit based on local scenarios that will reliably establish and identify the worst situations.</li> </ul>	<ul style="list-style-type: none"> <li>• No connection between the limit and any water quality criteria. Limit could be either more restrictive or more liberal than needed.</li> <li>• Requires that the full range of real field scenarios be known and run, from the lowest to the highest loss rating, to be successful.</li> </ul>

**CHARGE 3**  
**DEFINING THE MINIMUM REQUIREMENTS OF PHOSPHORUS INDICES**

**Recommendations**

1. Soil test P, P additions, runoff, and erosion should be continuous variables in all P Indices.
2. The risk assigned by all Indices must increase with increasing STP, P additions, runoff, erosion, and leaching where applicable.
3. Management interpretations of P Indices should provide clear direction, and have at a minimum P-based and no P application categories. Narrative statements of management recommendations (e.g., “conservation measures should be considered to decrease the risk of P loss”) have limited specificity in terms of nutrient management and implementation and, therefore, have no place in P Index interpretations.

**Considerations**

Differences in category boundaries and how those categories affect management are separate issues from differences in calculation. Even using similar calculation methods, there are a wide range of management interpretations for a given risk. Having different categories for management response to the same risk interpretation does not necessarily mean that one P Index is less protective of local water quality than another. Ideally for water quality protection, the interpretation of different levels of risk would not be uniform across all watersheds. Rather, the risk categories and the limits should be assigned based on water quality targets and the assimilative capacity of the receiving water body. However, some P Indices never reach a risk level assessment that restricts manure application to a field (Osmond et al., 2006), and this situation must be addressed.

Clearly, the fact that there is not a framework for establishing risk categories based on water quality is problematic. Without such a framework, the determination of “how much is too much” is generally a value judgment. At present, few states have established numeric P water quality standards. Even with numeric standards in place, it is difficult to make the connection between a field-based risk assessment and P concentrations or loads in receiving waters. We recommend that where water quality criteria are available, such as in TMDL areas, the process used in evaluating P Indices in Charge 4, also be used for setting management interpretation categories. Requirements related to each interpretation category should be clear and descriptive. As stated under Charge 2, all indices should have a no P application interpretation category.

## **CHARGE 4**

### **DEFINING A PROCESS TO EVALUATE PHOSPHORUS INDICES**

#### **Recommendations**

1. Ideally, local water quality data should be used to evaluate P Indices and to establish thresholds based on local water quality criteria.
2. Given that there are limited edge-of-field water quality data available, an alternative approach is to use a nonpoint source model to estimate P loss from a range of conditions consistent with P Index assessment for each state.
3. Where states have already used and validated a regionally appropriate model, that model should be used. Examples of default models are provided below.
4. Reference to any specific model to evaluate P Indices does not imply a recommendation that the model be used as an alternative risk assessment tool to the P Indexing approach.

#### **Recommended Approach to Evaluate P Indices: Using Data and Models**

Local water quality standards should be used to evaluate the P Index and to establish P application rate thresholds based directly on these water quality criteria. Unfortunately, these data are limited or unavailable in many states, particularly at scales required to validate the P Index. However, where measured data do exist (e.g., local research sites, National Resource Inventory [NRI] sites) they should be used to validate P indices; and SERA-17 should be encouraged to maintain a database of benchmark fields where water quality data are available for P Index validation (e.g., Harmel et al., 2008). As an alternative to direct evaluation with measured data, appropriate models could be used to provide information for evaluating P Indices, as long as the model selected has been validated to reliably predict field-scale P loss (e.g., Veith et al., 2005). This could also be used as the basis for justifying and documenting if P Index risk assessment does in fact limit P application at a certain specific pre-approved set of threshold conditions (see Charge 2 earlier).

We envision that in a state, or better yet a physiographic region, a model that has been evaluated for local conditions could be used to run simulations on a broad range of scenarios that would cover the expected conditions and management in that region. The P Index would then be run on the same scenarios using the same inputs that were used in the model and that apply to that particular Index. The results of model simulations and P Index evaluations would then be compared. At the present time, a nationally applicable model does not exist to use as the standard against which to compare all P Index assessments. Until a consensus driven alternative is selected, the following models are suggested as an interim option;

- Spreadsheet P runoff model of Vadas et al. (2005 and 2009) to estimate P loss in surface runoff from a range of source conditions consistent with P Index assessment for each state. This spreadsheet operates on an annual time step and is appropriate to evaluate the

source components of a P Index for a user-defined set of runoff and erosion conditions. The spreadsheet does not itself predict runoff or erosion.

- Agricultural Policy Environmental eXtender (APEX; Gassman et al., 2009), which is a daily time step model that predicts runoff, erosion, and P loss for a user-defined set of field, management, and weather scenarios. APEX has been run as part of the Conservation Effects Assessment Project (CEAP). More than 22,000 sites across the nation have been modeled. The NRI sites could serve as evaluation points for the model, and where appropriate, can be used as actual data points for evaluating a P Index.
- Where locally calibrated / validated models are available, such as the quantitative P loss assessment tool for agricultural fields developed by White et al. (2010), their use would be appropriate.

This approach should be used to evaluate P Indices across the country to determine the directional and proportional integrity of P Indices with increasingly “risky” management scenarios. The model used must appropriately simulate the P loss processes under evaluation. For example, a model without a well-developed manure application or P leaching routine may not be appropriate for assessing the risk of P loss from surface applied manures or artificially drained soils, respectively. Regardless of the model used, conditions must still be defined that result in both unacceptable P loss within the model and high or very high P Index ratings that limit or preclude P applications run under the same set of conditions. Comparisons could be based on P loss estimates from the model but would not depend on any particular quantitative result for the P Index being evaluated as many P Indices are qualitative tools.

The primary criteria for comparison would be that the model and the P Index agree directionally and proportionally for an appropriate range of management, runoff, and erosion conditions. For use in regulatory programs, it is likely that more rigorous statistical criteria will need to be developed for this comparison. This evaluation approach would allow the use of existing P Indices as long as they meet the evaluation criteria. This approach can also be used to identify and support changes to existing P Indices to improve the assessment and could help in designing a new P Index. It is important to note however, that use of any model to evaluate a P Index does not imply use of the model as an alternative to existing P risk assessment tools / P Indices.

Because of the innate variability of natural systems, methods should be developed to estimate the uncertainty in predictions by P-indices and models. An example of a tool that could be used for this is @RISK commercial software which is a plug-in for Excel spreadsheets ([http://www.palisade.com/decisiontools\\_suite/](http://www.palisade.com/decisiontools_suite/)). Uncertainty in predictions should be considered when using models to test P Indices.

## **CHARGE 5**

### **LONG-TERM GOALS FOR DEVELOPMENT OF NEXT GENERATION PHOSPHORUS INDICES**

#### **Recommendations**

1. Development of a National P Risk Assessment Tool should be considered. Information needed to represent all situations, soils, management, physiographic settings, etc., must be compiled. This will require a major investment of resources and infrastructure, particularly for a reliable representation of landscape hydrology, surface runoff and leaching generation, and flow pathways.
2. NRCS should use a P loss assessment approach based on physiographic regions or NRCS Major Land Resource Areas (MLRAs) rather than national or state boundaries.
3. Next generation Indices should be constructed on a GIS platform to facilitate integration of current and future information databases.
4. There needs to be a concerted training effort on how to use P Indices in the context of nutrient management planning and how to address any concerns identified by the P Index used during the plan development/implementation process.

#### **Considerations**

The initial P Index ranked transport and source factors and added them together (Lemunyon and Gilbert, 1993). Because individual states were allowed to write their own NRCS 590 standard and modify the original P Index to address local priorities and conditions, there are large structural variations in P Indices. In addition, each state's P Index was developed for a slightly different purpose, and thus variations between them are apparent. Most states have made one or more of the following changes to the original design and formula proposed by Lemunyon and Gilbert (1993): 1) source and transport factors are multiplied rather than added; 2) distance from water resources is considered; and 3) some factors, such as soil loss, STP and P application rate, are quantified continuous inputs (Sharpley et al., 2003).

#### ***Developing a National P Index***

We currently do not have the science, technologies, hydrological models, political will, resources, or infrastructure to implement a single approach to P loss risk assessment that covers all situations, soils, management, and physiographic settings. It would take an effort similar to that invested in USLE to develop and implement a national P risk assessment tool. There are several important factors influencing categorization and interpretation of P Index risk assessment, which vary greatly among states. This variation influences the outcomes and management recommendations as a result of an Index assessment and many are independent of the functionality of Indices in general. These factors include the spatial and temporal resolution and representation of Indices, multiplicative versus additive approaches, and state

fertilizer recommendations. While some of this variability can be addressed during the Index revision process, external factors will have to be evaluated separately.

### ***Spatial Representation***

Most P Indices are state specific. This is primarily due to the requirements of state regulations and state 590 standards. Predominant mechanisms of P loss vary widely depending on soil and climate conditions, which are certainly not uniform across the country and rarely follow state boundaries. Consequently physiographic regions would be the more logical basis for regionalization of P Indices than state boundaries.

In the Chesapeake Bay watershed for example, which only represents a small area of the country, there are five main distinctly different physiographic regions; Coastal Plain, Piedmont, Great Valley, Appalachian Mountains, and Appalachian Plateau (Figure 2). Most of the states in this watershed contain three or more of these physiographic regions. It is very difficult to develop a practical P loss assessment tool that will work equally well for all these physiographic regions. Consequently, compromises are often necessary which are usually less than ideal in any of these regions.

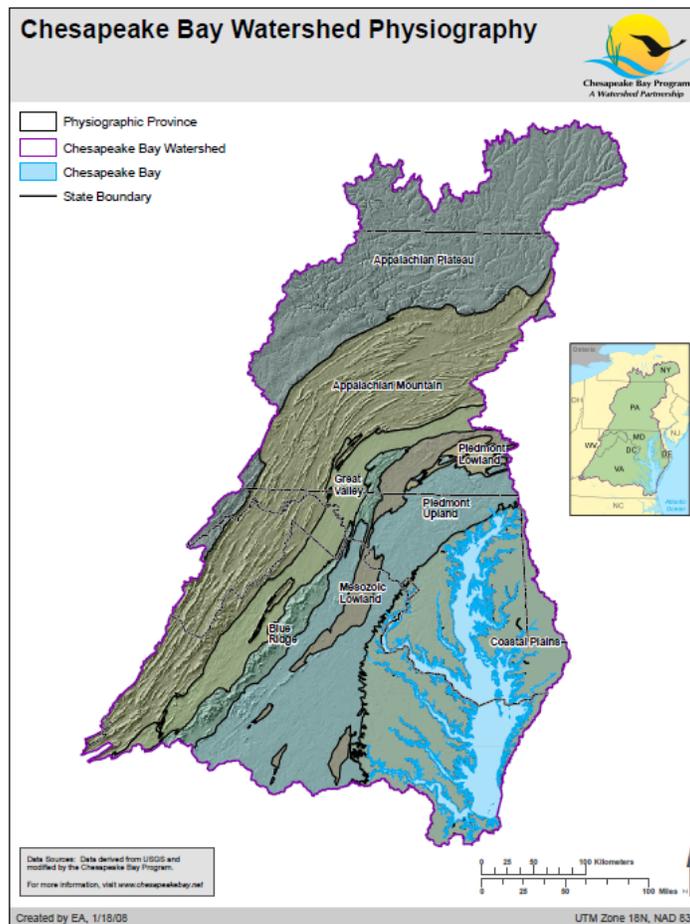


Figure 2. Physiographic regions of the Chesapeake Bay Watershed (courtesy of the Chesapeake Bay Program Resource Library - <http://www.chesapeakebay.net/maps.aspx?menuitem=16825>).

For example, how do you develop a P risk assessment tool that adequately addresses the predominantly leaching-driven losses of P in the Coastal Plain, where erosion is only a minor mechanism and the predominantly erosion- and runoff-driven losses in the Appalachian Mountains where leaching is much less of a factor? Indices in Maryland and Virginia attempt to do this. Because of these widely varying conditions and different relative areas of these physiographic regions in these two states, the approach to compromise varies enough that there are often significant differences in the P loss risk assessments from these states even on the same field.

Thus, in the Chesapeake Bay Watershed for example, a better approach would be to have an Index for each of the physiographic regions rather than one for each state (i.e., Delaware, Maryland, New York, Pennsylvania, and Virginia). These would be specifically tailored to the soils, climate, and management systems in these regions and be used within each physiographic region across all of the states. The challenge is to get acceptance within government programs of P Indices that cross state lines. States are generally reluctant to base regulations on something that they do not completely control.

### ***GIS and Database Interfacing***

The NRCS and EPA require the use of the Revised Universal Soil Loss Equation, Version 2 (RUSLE2) to determine soil erosion when developing nutrient management plans (NMPs). The standard approach to estimating a crop field's soil loss with RUSLE2 involves selecting a single soil type in the field. If the field has more than one soil type, the field's "dominant critical area" is supposed to be used as a "surrogate" to determine soil loss for the entire field in the conservation plan. However, the dominant critical area soil may not be the predominant soil in the field and it may not be the soil that should be used in making nutrient recommendations or in assessing the risk of nutrient and sediment loss from the field. A "spatial" approach to estimating soil loss for a field with RUSLE2 involves estimating soil loss for all digitized soil survey polygons whose boundaries overlap with the field's boundary. This would eliminate the need to select a single soil for a field to run RUSLE2, while allowing traditional conservation planning to be done on the basis of a single soil. Similarly, the P Index could be also calculated for each soil polygon in the field, using each polygon's underlying soil properties as inputs to the P Index.

### ***Training and Support***

Next generation P Index development plans need to include funding and resources to ensure effective implementation and long term support for the tool that is developed. Resource requirements for implementation are likely to be greater than those for initial development. An on-going training effort for NRCS staff, technical service providers and farmers on the use of the P Index in nutrient management planning will be needed. Planners and farmers need to understand the P Index as an indicator of P loss risk to find appropriate

solutions to high P loss areas during the planning process and to be able to make appropriate adjustments when needed as the plan is implemented.

To be effective, any P loss assessment tool must be completely integrated with the nutrient management planning process. Nutrient management takes place in an agricultural landscape that is constantly changing, and ongoing funding for updates will be needed to maintain this integration. This will be especially true of assessment tools using computer software.

## **APPENDIX A**

### **CURRENT STATE OF LAND-GRANT UNIVERSITY NUTRIENT RECOMMENDATIONS**

Agronomic soil testing for P has been conducted for many years. These tests were initially developed to identify soils where plant-available P is insufficient to support maximum crop growth and where further addition of fertilizer was not needed. In many situations, P may not be recommended where the relative yield is >95% of the maximum yield or the likelihood of crop response to applied P is less than 5%. Soil test P where no additional P is recommended will vary with soil properties, crop type, and yield goal. Also, many states include a crop removal recommendation for STP just above this crop response critical level, as most farmers only test their soils periodically (every 2 to 5 years). This is to ensure that STP levels will not drop below the crop response critical level between soil tests. Soils are typically categorized (i.e., Very Low P, Low P, or below optimum P; Sufficient, Moderate P, or optimum P; High P, Very High P or above optimum P) based on the probability of crop response to additional P.

Soil testing to assess the potential environmental impact of P is a relatively recent development. Agronomic soil P tests were developed to assess the potential for crop response to applied P. The crop response categories / agronomic interpretations should not be equated to environmental risk interpretations. A number of tests and relationships of these P tests with runoff P have been developed for this purpose. However, there are too many other variables independent of soil P, such as P application, runoff and erosion potential, and distance to a stream or concentrated flow channel, for agronomic STP to be used as the sole indicator of the risk for P loss from a field.

Most P fertilizer recommendations for crops were established by scientists associated primarily with land-grant universities. Much of this work was done when commercial fertilizers first became widely available beginning in the 1950's. In the recent past, much less emphasis has been given to this type of research by public institutions and once-common publicly funded soil testing laboratories are now rare. This can be problematic when government programs refer to university recommendations for a standard but the land-grant university can no longer support soil test calibration research and updates. Thus, updating nutrient recommendations should be supported as new crop varieties and yield response data become available.

## **APPENDIX B**

### **RELATING PHOPSHORUS LOSS IN RUNOFF TO SOIL TEST PHOPSHORUS, SOIL PHOPSHORUS SATURATION AND PHOPSHORUS INDEX RISK**

There is no scientific evidence to support the use of STP or soil P saturation alone to determine the amount of P loss from a field. A wealth of scientific evidence is available documenting that STP and/or soil P saturation are one of several factors influencing the risk of P loss from a field. Use of STP or soil P saturation alone will not capture a site's risk for P loss and may be less restrictive than a well designed P Index, thereby increasing the potential for P runoff and leaching (Figure 3). The data in Figure 3 is from the FD-36 watershed on south-central Pennsylvania and is adapted from that presented in Sharpley et al. (2001). Runoff was collected from 2-m<sup>2</sup> plots subject to 70 mm hr<sup>-1</sup> rainfall (to create 30 minutes of runoff) across the watershed and related to plot Mehlich-3 STP and soil P saturation of 0 to 5 cm samples collected after rainfall, as well as P Index ratings determined by the Pennsylvania P Index (Sharpley et al., 2001). Of the three methods, the P Index rating best represented the loss of P in runoff over the various soil, management, hydrology, and topographic conditions across the watershed (Figure 3).

More importantly, there were sites with "low" STP and soil P saturation, which had high losses of P due to a combination of factors that include high runoff volumes and / or application of fertilizer or manure. It should be noted that these "low" P sites are above the agronomic response range (i.e., >50 mg P kg<sup>-1</sup> as Mehlich-3 soil P). On the other hand, there were sites with low P loss but had high STP or soil P saturation values (Figure 3). A similar lack of a strong relationship between STP and runoff P loss was demonstrated by Butler et al. (2010) for runoff from several fields in Georgia, which had received varying amounts and forms of P (Figure 4).

In summary, we recognize that the relationship between STP or P saturation and runoff dissolved P concentration is well established (e.g., Vadas et al., 2005). However, this relationship can vary as a function of soil type and land cover, and P loss is influenced by many site factors such as applied P (type, rate, method, and timing) runoff, erosion, landscape position, etc. Further, use of soil P saturation in place of STP is only suitable for noncalcareous soils where Fe and Al dominate soil P reactions. In light of these factors, it is inappropriate to use STP or soil P saturation alone to estimate P loss in runoff from a given site.

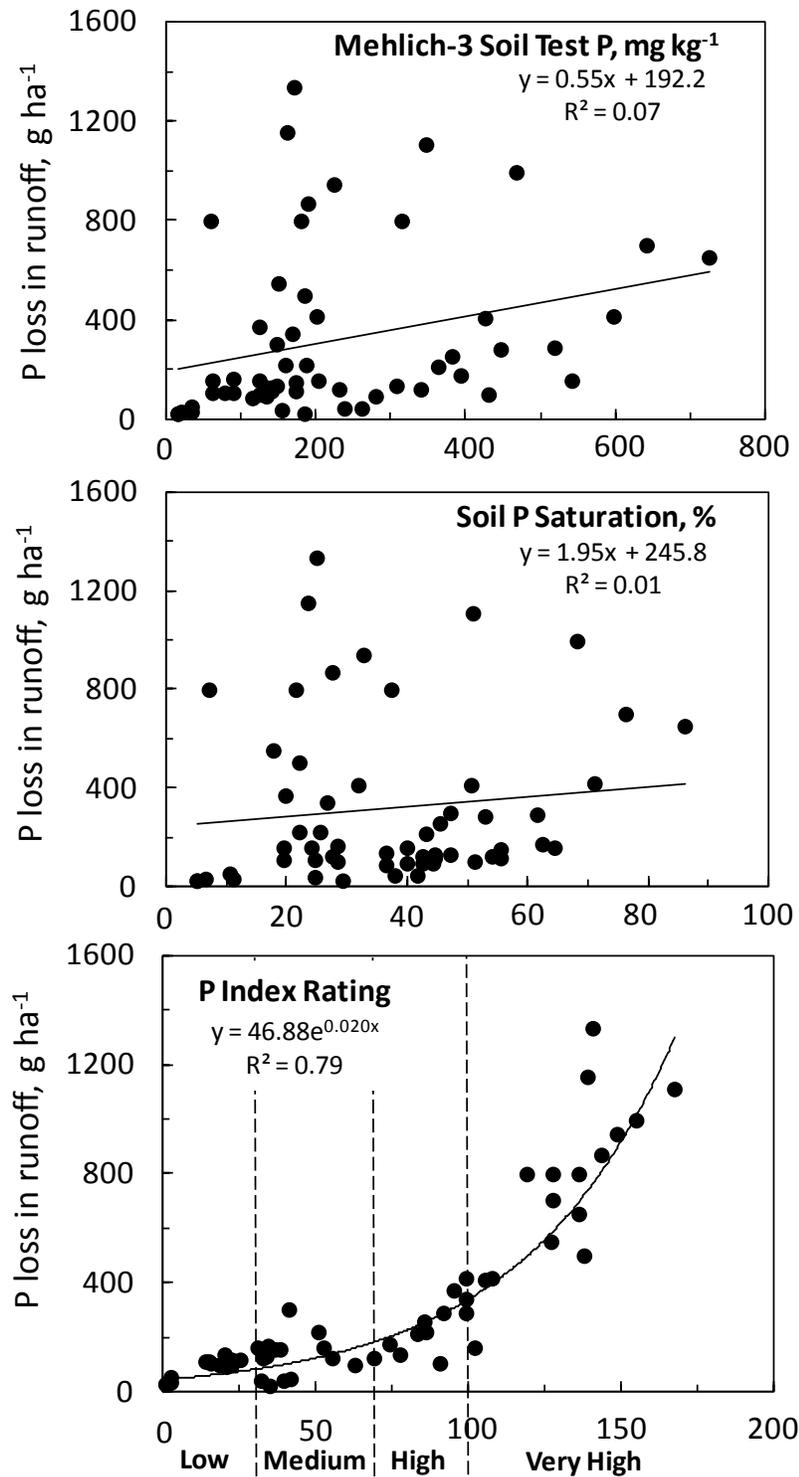


Figure 3. Relationship between the loss of total P in runoff and Mehlich-3 soil test P, soil P saturation, and the Pennsylvania P Index ratings for the plots in the FD-36 watershed, PA (adapted from Sharpley et al., 2001).

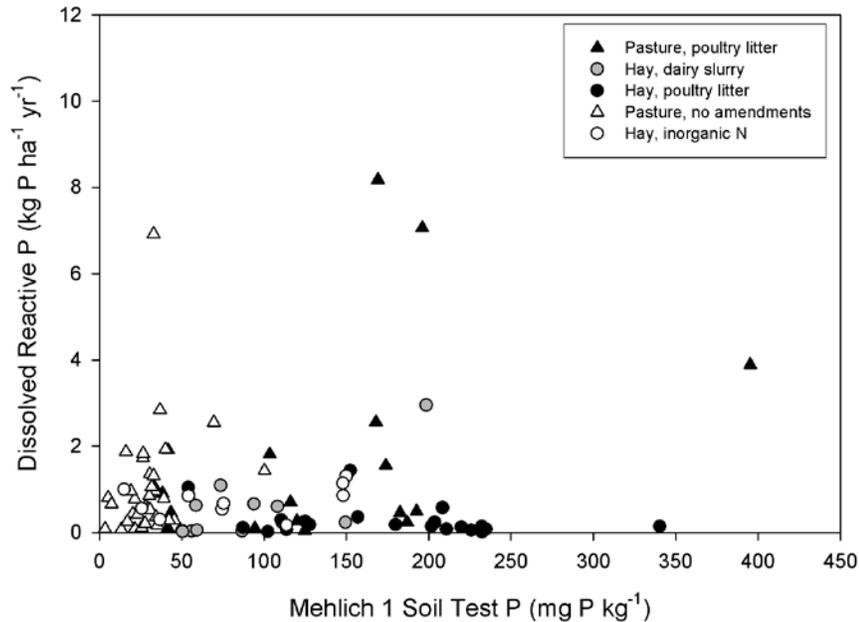


Figure 4. Relationship between Mehlich-1 soil test P and the loss of total P in runoff for several fields in Georgia (adapted from Butler et al., 2010).

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