The 2011 Revised West Virginia Phosphorus Index (ver. 2.0)

WV_CPA_WS_590_3
Worksheet 4/11/13

Overview

A Phosphorus Site Index or P-Index is just one of the many tools that can be used evaluate the relative risk of P loss to the environment when a P application is made. Its purpose is to help land owners, land managers and nutrient management planners identify areas and practices that are likely to result in P loss to ground and surface water from a P application. With this knowledge, management practices can be adjusted to minimize P losses. A P-Index is not a model; it does not predict how much P will reach a water source or when. It is simply a ranking of Low, Medium, High and Very High probability of P loss.

Guiding Principles

The revised WV P-Index is regionally consistent, scientifically defensible, meets federal P management guidelines and is applicable to all soils in the State. Anyone with formal training in an agricultural science should be able to understand the results of the P-Index. When data specific to the soils of West Virginia were not available to guide numeric criteria, we used information from surrounding states and our best professional judgment to infer these values. Recognizing the variability in soil properties, P sources and management practices that exist across the State, there is the option to substitute site-specific data, when appropriate. The current document represents our collective understanding of the present state of knowledge of the processes that govern the fate and transport of P in soils. It will change as our knowledge of these processes improves. In particular, we note an upcoming project to compare P-Indices in the Chesapeake Bay Watershed. Because this project will involve the collection of new data, it will likely result in improved coefficient estimates for all P-Indices in the region. We have also indicated areas where additional research using soils of the State could improve the WV P-Index. The form and structure of the WV P-Index is a combination of the NY P-Index (Cyzmmek *et al*., 2003) and the VA P-Index (Wolfe *et al*., 2005).

Structure

Soil P occurs in two general forms, dissolved and particulate, and can be transported by two general mechanisms, leaching and runoff. These combinations result in four potential mechanisms for P loss. However, leaching of particulate P is not likely to occur except in tile-drained fields with continuous no-till management where liquid dairy manure applications are planned. Therefore, the focus of the WV P-Index is dissolved and particulate P runoff and the leaching of dissolved P.

The WV P-Index has three sections. Section A is a preliminary evaluation to identify which fields or Management Units will need a P-Index determination. Section B is the P-Index with components for dissolved and particulate P in runoff and the leaching of dissolved P. Section C is an explanation of or justification for the criteria in Sections A and B. A list of acronyms and abbreviations (Appendix 1), glossary (Appendix 2) and supporting tables (Appendices 3 and 4) are also provided.

Section A. Preliminary Evaluation

Based on guidance from WV-NRCS, the risk of P-Loss (P-Index) is to be determined for each crop/year. According to the NRCS National 590 Practice Standard (NRCS, 2011) a "nutrient risk assessment for phosphorus must be completed when

1. phosphorus application rate exceeds land-grant university fertility rate guidelines (Appendix 3) for the planned crop(s), or
2. the planned area is within a phosphorus-impaired watershed (contributes to 303d-listed water bodies) or
3. the NRCS and State water quality control authority <u>have not</u> determined specific conditions where the risk of phosphorus loss is low."

Based on these conditions, a risk assessment for P loss (P-Index) must be completed if,

4. if the Soil Test P (STP) value for the Management Unit greater than 80 lb P_2O_5 acre^{-1}.

   Note 1: Phosphorus should not be applied to any 'Animal Concentration Area' (ACA) i.e. winter feeding areas, barnyards, feedlots, loafing areas, exercise lots or other similar animal confinement areas that will not maintain a growing crop or where deposited phosphorus in manure are in excess of crop needs. Pastures, cropland and pasture access ways that do not cause a direct flow of nutrients to surface or ground water are not considered ACAs. ACAs should be managed using Best Management Practices (BMPs).

Note 2: No P applications should be made to any field that exceeds 65% Degree of Phosphorus Saturation (DPS).

Section B. WV P-Index

Dissolved P in Runoff

The transport component for dissolved P in runoff (T_{diss}) is a surrogate for runoff. It is the sum of the contributions from the soil hydrologic group, flooding frequency and distance to receiving water body and is calculated as the sum of the factors given in Table 1 (Eq. 1) or 1.0, whichever is smaller.

$$T_{diss} = (\text{Hydrologic Soil Group}) + (\text{Flooding Frequency}) + (\text{Distance}) \qquad [1]$$

Note that no consideration is given to the presence or width of stream buffer strips because there is insufficient evidence that these reduce soluble P losses (Hoffman *et al*., 2009).

Table 1. Transport factors for dissolved P in runoff used to modify T_{diss} in Eq. 1.

Hydrologic Soil Group[1]	Factor	Flooding Frequency[1]	Factor	Distance[2]	Factor
A	0.2	Rare/Never	0	> 500 ft	0
B	0.4	Occasional	0.2	300 -499 ft	0.3
C	0.6	Frequent	1	200 – 299 ft	0.5
D	0.8			100 – 199 ft	0.6
				50 – 99 ft	0.8
				<49 ft	1

[1] From Soil Survey report. [2] the average straight-line distance length, in feet, as measured from the edge of field to nearest perennial or intermittent stream.

Three sources are used to account for dissolved P in surface runoff (P_{diss}). In soils where previous P applications have been made, some of that P will be water soluble in subsequent years (P_{soil}). Any inorganic fertilizer (P_{fert}) or organic P material (P_{manure}) applied in the current year will also contain soil water soluble P that must be considered in conjunction with the application method and timing.

$$P_{diss} = \left(P_{soil} + P_{fert} + P_{manure}\right) \qquad [2]$$

The contribution from soil (P_{soil}) is estimated from STP as (Wolfe *et al*., 2005)

$$P_{soil} = 0.00176 \times (STP) \text{ for pasture, hay and no-till crops, 2 inch sample} \qquad [3a]$$

or

$$P_{soil} = 0.00221 \times (STP) \quad \text{for all other crops} \qquad [3b]$$

or measured directly as water extractable P (Wolf *et al*., 2005). In equations 3a and 3b, STP is Mehlich 1 extractable P (lb P_2O_5 $acre^{-1}$). Equation 3b has been corrected for soil P stratification (Jesiek *et al*., 2005).

P_{fert} is calculated as (Cyzmmek *et al*., 2003)

$$P_{fert} = \left(\frac{\text{lb } P_2O_5}{\text{acre}}\right) \times (C_1) \times (PSC) \times (A_{timing}) \times (A_{method}) \qquad [4]$$

where

$$\left(\frac{\text{lb } P_2O_5}{\text{acre}}\right) = \text{fertilizer analysis}$$
$$C_1 = \text{unit conversion constant, 0.2185}$$
$$PSC = \text{P Source Coefficient (from Table 2)}$$
$$A_{timing} = \text{application timing factor (Table 3)}$$
$$A_{method} = \text{application method factor (Table 4)}$$

Table 2. Mid-Atlantic Region P Source Coefficients (PSC) for use in P Index site evaluations. (Table 1 in Coale *et al*., 2005).

P Source	Coefficient
Inorganic P Fertilizer	1.0
Swine manure	1.0
Other manures (beef, dairy, poultry, etc.)	0.8
Alum-treated manure	0.5
Biosolids	0.4

Table 3. Application timing factors for West Virginia (ARS Water Database, 2011) used to modify P_{fert} in Eq. 4 and P_{manure} in Eq. 5.

Application				
Timing	Dec. – Jan.	Feb. – Apr.	May – Aug.	Sept. – Nov.
Factor	0.7	0.9	0.4	0.5

Table 4. Application method factors (after Cyzmmek *et al*., 2003).

Application Method	Injected or subsurface banded	Hay and Pasture, long-term no-till[1]	Surface applied or broadcast AND incorporated within			Surface applied on frozen, snow covered or saturated ground
			1-2 days	3-5 days	>5 days	
Factor	0.2	0.4	0.4	0.6	0.8	1.0

[1.] Not part of the NY P-Index

and

$$P_{manure} = \left(\frac{\text{lb } P_2O_5}{\text{acre}}\right) \times (C_1) \times (PSC) \times (A_{timing}) \times (A_{method}) \qquad [5]$$

where

$$\left(\frac{\text{lb } P_2O_5}{\text{acre}}\right) = \text{manure analysis}$$
$$C_1 = \text{unit conversion constant, 0.2185}$$
$$PSC = \text{P Source Coefficient (from Table 2)}$$
$$A_{timing} = \text{application timing factor (Table 3)}$$
$$A_{method} = \text{application method factor (Table 4)}$$

The P Source Coefficient (PSC) accounts for the fact that only a fraction of the total manure P is water soluble and thus prone to runoff. Because there can be considerable variability in water soluble P in manure sources and alum-treated poultry litter, PSC can also be calculated from a water extractable water (WEP) test as (Elliot *et al*., 2006)

$$PSC = 0.1 \times WEP \qquad [6]$$

if WEP $\leq$ 10 mg L^{-1} when determined using the procedure described in Wolf *et al*., 2005. If WEP > 1 then PSC = 1. Note that the timing and method factors (A_{timing}, A_{method}) are currently the same for both fertilizer and manure P.

Therefore the index value for dissolved P in runoff is calculated as

$$(T_{diss} \text{ x } P_{diss}) \text{ x } B_1 \qquad [7]$$

where T_{diss} is determined from Eq. [1], P_{diss} is determined from Eq. [2], and B_1 is a constant to properly scale the magnitude of the dissolved P in the runoff component.

Particulate P Loss in Runoff

The transport of particulate P is calculated as the sum of the factors given in Table 5 and Table 6 (Eq. 8) or 1.0, whichever is smaller. Additionally, if the sum is less than zero, T_{part} will be set equal to zero.

$$T_{part} = T_{sed} = (\text{Flooding Frequency Factor}) + (\text{Distance Factor}) + (\text{Buffer Factor}) \quad [8]$$

where the Flooding Frequency Factors (Table 5) were taken from the NY P-Index (Cyzmmek *et al*., 2003),

Table 5. Flooding Frequency Factors used to modify T_{sed} in Eq. 8.

Flooding Frequency	Factor
Rare/Never (> 100 yrs)	0
Occasional (10-100 yrs)	0.2
Frequent (< 10 yrs)	1.0

and the distance from the edge of field to receiving water body and buffer width factors (Table 6) were based on relationships between return periods and contributing distances (Sharpley *et al*., 2008) and a recent literature review (Yuan *et al*., 2009).

Table 6. Sediment Delivery Factors for distance from edge of field to receiving water body and riparian buffer width used to modify T_{sed} in Eq. 8.

Distance from edge of field[1]	Factor	Riparian buffer width	Factor
---------------- ft --------------		------------- ft ----------	
> 500	0	> 100	-0.5
300 – 499	0.3	50 - 100	-0.4
200 – 299	0.5	35 – 49	-0.3
100 – 199	0.6	10 – 34	-0.2
50 – 99	0.7	<10	-0.1
0 – 49	1.0	No buffer	0

[1.] average straight-line distance length, in feet, as measured from the edge of field to nearest perennial or intermittent stream or concentrated flow path.

Particulate P is any phosphorus attached to, or part of, a solid particle. For the purposes of the WV P-Index, Particulate P is any P that would not pass through Whatman #40 filter paper. Conceptually, this could include eroded soil particles (P_{sed}) and manure or litter ($P_{organic}$).

$$\text{Particulate P} = P_{sed} + P_{organic} \qquad [9a]$$

Lacking a method to properly account for the runoff of particulate manure or litter, only the contribution from eroded sediment is considered here, so that

$$\text{Particulate P} = P_{sed} \qquad [9b]$$

and is calculated as

$$P_{sed} = (\text{Erosion}) \times (\text{Gully Erosion}) \times (\text{Total Soil P}) \times C_2 \qquad [10]$$

where P_{sed} is in units of lb P_2O_5 acre^{-1}, Erosion is the edge-of field soil loss calculated from RUSLE2 in units of ton acre^{-1}, Gully Erosion is taken from Table 7,

Table 7. Gully Erosion Factors used to modify T_{sed} in Eq. 10.

Gully Erosion	Factor
Yes	1.5
No	1

C_2 is a unit conversion factor(= 0.002) and Total Soil P (TSP) for pasture, hay or no-till fields is calculated from a two-inch soil sample as (Wolfe *et al*., 2005)

$$\text{TSP} = 102 + 0.40 \times (\text{STP}) \qquad [11a]$$

and for all other land uses as

$$\text{TSP} = 102 + 0.50 \times (\text{STP}) \qquad [11b]$$

where STP is a Mehlich 1 extract with units of lb P_2O_5 acre^{-1}. As in Equation 3b, Equation 11b accounts for soil P-stratification (Jesiek, 2005). Therefore, the index value for particulate P in runoff is calculated as

$$(T_{sed} \text{ x } P_{sed}) \text{ x } B_2 \qquad [12]$$

where T_{sed} is calculated using Eq. [8], P_{sed} from Eq. [10] and B_2 is a constant to properly scale the magnitude of the particulate P runoff component.

Dissolved P in Leachate

Dissolved P in leachate refers to any P that is lost as subsurface flow. This refers both to migration to groundwater and to the downward and horizontal movement to lower landscape positions (seeps) or surface water. It depends on the amount of water that moves through the soil and the P concentration of that water.

The transport component for dissolved P in leachate (T_{sub}) is a function of distance (Eq. 13) and is determined using Table 8.

$$T_{sub} = \text{Distance Factor} \qquad [13]$$

Table 8. Transport Factors used to modify T_{sub} in Eq. 13.

Distance[1]	Factor
> 200 ft	0
100 – 199	0.2
50 – 99	0.4
< 50	0.6

[1] average straight-line distance length, in feet, as measured from the edge of field to nearest perennial or intermittent stream or concentrated flow path. A tile-drained field has a distance of 0 ft.

Dissolved P in leachate (P_{sub}) comes from three sources; soil P from previous P applications (P_{soil}), applied fertilizer P (P_{fert}) and applied manure or litter P (P_{manure}).

$$P_{sub} = \left(P_{soil} + P_{fert} + P_{manure}\right) \qquad [14]$$

The WV P-Index assumes that P_{soil} is the dominant source of subsurface dissolved P and is modified by the soil Environmental Sensitivity Class (Table 9) as given in Eq. 15

$$P_{sub} = (P_{soil}) \text{ x } (\text{Environmental Sensitivity Class}) \qquad [15]$$

and P_{soil} is calculated as (Wolfe *et al*., 2005)

$$P_{soil} = -0.00168 + 0.000459 \times (\text{M1-P}) \qquad [16]$$

P_{soil} can also be measured directly as water extractable P as described above.

Table 9. Soil Environmental Sensitivity Class Factors used to modify P_{sub} in Eq. 15.

Environmental Sensitivity Class	Factor
Low	10
Medium	30
High	50

Therefore the index value for dissolved P in leachate is calculated as

$$(T_{sub} \text{ x } P_{sub}) \text{ x } B_3 \qquad [17]$$

where T_{sub} is calculated from Eq. 13 and P_{sub} is calculated from Eq. 15, and B_3 is a constant to properly scale the magnitude of the dissolved P in the leachate component.

Interpretation

The final P-Index value is the sum of the contributions from dissolved P in runoff, particulate P in runoff and dissolved P in leachate.

$$\begin{aligned} \text{P - Index Value} &= \text{Eq. 7} + \text{Eq.12} + \text{Eq.17} \\ &= \left(P_{diss} \times T_{diss}\right) \cdot B_1 + \left(P_{sed} \times T_{sed}\right) \cdot B_2 + \left(P_{sub} \times T_{sub}\right) \cdot B_3 \end{aligned} \qquad [18]$$

The P-index value is used to identify the recommended P-management guidance as described in Table 10.

Table 10. Potential Water Quality Impact and P Management guidance for each P-Index value.

P – Index Value	Potential Water Quality Impact	P- Management Guidance
0 to ≤ 35	Low	N-Based Plan
36 to ≤ 70	Medium	N-Based Plan. P application ≤ 1.5-times crop removal
71 to < 100	High	P-Based Plan at Crop Removal Rates/Remediation Practices Recommended
≥ 100	Very High	No P application/Remediation Practices Required

Section C. Explanations and Limitations

Preliminary Evaluation

Item 1: Land Grant University is West Virginia University (WVU), specifically the WVU Soil Test Laboratory (STL).

Item 4: The value of 80 lb P_2O_5 $acre^{-1}$ represents the largest STP value that a soil can test to be in the ‘High/Sufficient’ Category according to the West Virginia University Soil Test Laboratory (Appendix 3). Any P application above an agronomic recommendation needs to be evaluated. This is not the value that prohibits P application (a cutoff value). The goal is to not let STP values exceed the environmental threshold. Until data become available to determine what the environmental threshold should be, the conservative agronomic threshold is used. The value of 80 lb P_2O_5 $acre^{-1}$ and category ‘High/Sufficient’ may be adjusted in the future; field trials to evaluate/improve WVU Soil Test Laboratory fertilizer recommendations are in progress.

Note 1: The definition of ACA is from the Pennsylvania Nutrient Management Act (38) Regulations (83.201) with two modifications; winter feeding areas are added and ‘phosphorus’ is used instead of ‘nitrogen’. The purpose of this note is to prevent P applications to areas that are likely to have high STP because of previous management practices.

Note 2: The choice of 65% DPS is consistent with that chosen by Virginia (Wolfe et al., 2005) and preliminary data from WV (Sekhon, 2002) on the relationship between dissolved P and DPS. Until a DPS test is offered by the WVU Soil Test Laboratory, it will be calculated as

$$\mathrm{DPS} = 4.107 \times (\mathrm{M1} - \mathrm{P})^{0.2453 + 0.03217 \times \ln(\mathrm{M1}-\mathrm{P})} \qquad [19]$$

or determined directly from oxalate extracts. Equation 19 is the equation for VA Ridge and Valley soils from Beck et al., (2004). It was also a good fit in a preliminary study on a small set of WV soils (McDonald and Basden, 2006). The relationship between DPS, dissolved soil P and P loss is an area where the WV P-Index could be improved by expanding the data set for State-specific soils.

Equation 1 and Table 1

This is a standard approach for P-Indices in this region that considers runoff production, flooding, and distance to a surface water body. The Hydrologic Soil Group factor can be obtained from the Soil Survey, and is a relative estimation of a soil's propensity to generate surface runoff. When selecting the Hydrologic Soil Group (HSG) for a field, the dominant HSG within that field should be chosen for calculating the P-Index. Alternatively, portions of the field with varying HSGs can be treated as individual management units, and P-Index scores, and resulting management, can be determined separately.

The Flooding Frequency factor can also be found within the Soil Survey and is a relative classification of the likelihood of inundation of an area caused by overflowing streams or runoff from adjacent slopes. The dominant Flooding Frequency factor within a field should be selected when calculating the P-Index **except** when greater than 20% of the field area has a higher Flooding Frequency. In these situations, the higher Flooding Frequency factor should be used for calculations. Alternatively, portions of the field with varying Flooding Frequency factors can be treated as individual management units, and P-Index scores, and resulting management, can be determined separately.

The distance factors were based on relationships between rainfall event return periods and associated distances that contributed runoff to a water body (Sharpley *et al.*, 2008).

Note that each component of T is normalized to 1 and the overall contribution from T cannot be larger than 1. The rationale is that T is a scaling factor for P loss; it's not possible to lose more than 100% of the P-source. It would be more appropriate to normalize to some maximum to achieve a value between 0 and 1, however this would require an integrated analysis of HSG and distance and those data are not available. The upcoming project to compare P-Indices will likely provide a more objective basis for determining T. For now, the approach described is our best professional judgment.

Equation 2

This is a standard approach for P-Indices in this region.

Equation 3a and 3b

The concept is from the VA P-Index (Wolfe *et al.*, 2005). The equations were derived from data on West Virginia soils in Sekhon (2002). There are two important differences in the datasets used to generate these equations. First, the VA data set contained over three hundred field samples, collected by depth in three physiographic regions. The largest M1-P concentration was over 400 mg kg^{-1} and the largest dissolved P concentration was 4 mg L^{-1}. The WV data set consisted of four replications from four benchmark soils (Monongahela, Huntington, Lindside and Berks) collected by horizon (n=16) and then incubated in the laboratory to obtain different soil P concentrations. The maximum M1-P was 200 mg kg^{-1} and the maximum dissolved P concentration was just over 2 mg L^{-1}. The resulting equations were similar except that there is no intercept in the WV equations. For example, the equation in the VA P-Index equivalent (Wolfe *et al*., 2005) to Eq. 3a is,

$$P_{soil} = 0.124 + 0.0064 \times (M1 - P)$$

The equations yield equivalent results at 74.2 mg P kg^{-1} (340 lb P_2O_5 $acre^{-1}$). At the critical value of 80 lb P_2O_5 $acre^{-1}$ (~17.5 mg P kg^{-1}) the result is 0.24 with the Virginia equation and 0.14 with the West Virginia equation. The variability within and across these series suggests that there is an opportunity for improvement with additional research.

Incorporating Degree of P Saturation (DPS) is likely to provide a better estimate of dissolved P for runoff and leaching. This is another area where the WV P-Index could be improved by using State-specific data.

Equation 4

Adopted from the NY P-Index with WV specific adjustments to the timing (Table 3) and application method (Table 4) factors. The factor C_1 is the product of two conversion factors, P_2O_5 to P (0.437) and lb $acre^{-1}$ to mg kg^{-1} (0.5).

Table 2.

Generally accepted values for the Mid-Atlantic Region (Coale *et al*., 2005).

Table 3

Factors are based on the relative likelihood of runoff based on data from USDA-ARS Experimental Watershed in Moorefield, WV collected over a 10 year period on two sets of paired agricultural watersheds. Probability of runoff occurrence was determined for each month of the year. Months having similar probabilities were grouped and assigned a relative timing risk factor corresponding to their runoff occurrence probability. There was very little relative difference in seasonality of runoff occurrence between Moorefield, WV and Coshocton, OH and so no distinctions were made based on physiographic provinces.

Table 4

Adopted from the NY P-Index, with exception of 'Hay and pasture, long-term no-till' category. This category was added to make a clear distinction from the risk of surface application of nutrients on tilled soils. Long-term no-till refers to fields that have been in no-till systems long enough to distinguish P-loss characteristics from fields in continuous tillage. Lower runoff volumes are typically associated with non-tilled soils. Anything left on the surface for more than 5 days is considered 'not incorporated'.

Equation 5

Adopted from the NY P-Index with WV specific adjustments to the timing (Table 3) and application method (Table 4) factors. The factor C_1 is the product of two conversion factors, P_2O_5 to P (0.437) and lb $acre^{-1}$ to mg kg^{-1} (0.5).

Equation 6

The actual equation in Eliot *et al*., (2006) is

$$\mathrm{PSC} = 0.102 \times \mathrm{WEP}^{0.99} \ (r^2 = 0.80)$$

Equation 7

Typical P-Index formulation. The term B_1 is an empirical constant = 2, that is used to ensure that the results of the WV P-Index were consistent with other P-Indices in the region. Using our best-professional judgment we compared our outcomes to those obtained by VA-Tech. Again, the upcoming project to compare P-Indices will likely provide a more objective basis for determining B

Equation 8

Adopted from the NY P-Index with WV specific adjustments to the Flooding Frequency (Table 5), and Distance and Riparian buffer width (Table 6) Factors.

Table 5

The Flooding Frequency factor can be found within the Soil Survey and is a relative classification of the likelihood of inundation of an area caused by overflowing streams or runoff from adjacent slopes. The dominant Flooding Frequency factor within a field should be selected when calculating the P-Index **except** when greater than 20% of the field area has a higher Flooding Frequency. In these situations, the higher Flooding Frequency factor should be used for calculations. Alternatively, portions of the field with varying Flooding Frequency factors can be treated as individual management units, and P-Index scores, and resulting management, can be determined separately.

Table 6.

A recent synthesis of all buffer studies where sediment trapping efficiencies could be calculated was performed by the EPA and the USDA-ARS and published in September 2009 (Yuan *et al*., 2009). The results of this comprehensive literature review were used as guidance for developing relative risk rankings associated with varying buffer widths. Our selected P-transport structure assigns positive values to field characteristics that increase risk. Buffers decrease risk; therefore, increasingly negative values are assigned as buffer width increases.

Equations 9a and 9b

The factor $P_{organic}$ is used in Equation 9a so as not to cause confusion with P_{manure} in Equation 2; both account for contributions from manure or litter. For particulate P runoff (Equation 9a), there is no term equivalent to P_{fert} (Equation 2) because particulate inorganic fertilizer is water soluble and therefore not expected to move as a discrete particle. Equation 9b is the typical P-Index formulation.

Equation 10

The typical P-Index formulation.

Table 7

The gully erosion factor should be determined based on field inspection. If eroded channels deeper than 4” exist, then gully erosion is occurring and should be accounted for in risk calculation. Although a conservative estimate has been used in the WV P-Index, when present, this type of erosion often dominates sediment loss from a field.

Equation 11a and 11b

From Wolfe *et al.*, 2005 and used without modification because there is no equivalent data for WV soils. This is another area where the P-Index could be improved with additional research.

Equation 12

The standard P-Index formulation. The value for B_2 is 12. See explanation for B_1 above.

Equation 13 and Table 8

The Distance Factors used for subsurface P transport are abbreviated and reduced compared to surface transport (Table 6) to reflect the decreased flow velocities in the subsurface. These decreased velocities result in increased opportunity for subsurface P removal by the surrounding soil. Environmental Sensitivity Class factors account for potential for lateral flow and the presence of shallow groundwater. Distance is as defined previously and a tile-drained field has a distance of 0 ft.

Equation 14

A conceptual representation of all potential subsurface P sources. At present there is only data to support the inclusion of P_{soil} (Eq. 15).

Equation 15 and Table 9

Environmental sensitivity class refers to the susceptibility of a soil to nutrient loss by subsurface flow.

Equation 16

From Wolfe *et al.*, 2005 and used without modification because there is no equivalent data for WV soils. This is another area where the WV P-Index could be improved with additional research.

Equation 17

The standard P-Index formulation. The value for B_3 is 1. See explanation for B_1 above.

Equation 18

The standard P-Index formulation.

Table 10

Values, impacts and guidance are consistent with other P-Indices in the region.

Appendix 4

According to the Virginia Nutrient Management Standards and Criteria (2005), an *environmentally sensitive site* is defined as "any field [that] is particularly susceptible to nutrient loss to groundwater or surface water [because] it contains or drains to areas which contain sinkholes; or where at least 33% of the area in a specific field contains one or any combination of the following features:

1. Soils with high potential for leaching based on soil texture or excessive drainage;
2. Shallow soils less than 41 inches deep likely to be located over fractured or limestone bedrock;
3. Subsurface tile drains;
4. Soil with high potential for subsurface lateral flow based on soil texture and poor drainage;
5. Floodplains as identified by soils prone to frequent flooding in county soil surveys; or
6. Lands with slopes greater than 15%."

Based on these criteria, soils were judged to have Moderate or High environmental sensitivity risk if one of the following conditions was present:

- Soils with (i) a sandy particle size class, (ii) a rock fragment content greater than 35%, or (iii) a drainage class of excessively or somewhat excessively drained present a potential for **leaching** loss.
- Soils that are less than or equal to 40 inches deep over fractured or limestone bedrock are **shallow** and present a potential for subsurface loss.
- Soils with subsurface tile drains present a potential for **drainage** loss.

- Soils with a drainage class of somewhat poorly, poorly, or very poorly drained present a potential for subsurface lateral flow due to **wetness**.

Specifically, soils with a **Leaching** limitation are:

- Soils with a sandy particle size class are rated as having a High risk.
- Soils with a drainage class of excessively drained or somewhat excessively drained are rated as having a High risk.
- Soils with a rock fragment content greater than 35% formed from calcareous residual parent materials are rated as having a High risk.
- Other soils with a rock fragment content greater than 35% are rated as having a Moderate risk.
- Soils with a coarse-loamy particle size class are rated as having Moderate risk.

Soils with a **Shallow** limitation are:

- Soils that are less than or equal to 20 inches deep over bedrock are rated as having a High risk.
- Soils that are great than 20 inches but less than or equal to 40 inches over bedrock are rated as having a Moderate risk.

Soils with a **Drainage** limitation are:

- Soils with artificial subsurface drainage are rated as having a High risk.

Soils with a **Wetness** limitation are:

- Soils with a drainage class of poorly or very poorly drained are rated as having a High risk.
- Soils with a drainage class of somewhat poorly drained are rated as having a Moderate risk.

Adapted from the Virginia Nutrient Management Standards and Criteria, Revised October 2005. Virginia Department of Conservation and Recreation Division of Soil and Water Conservation 203 Governor Street, Suite 206 Richmond VA 23219

Reference the associated WVCPA-3 P Index Spreadsheet with Tables to assist with the computation of the above equations and final P-Index Score.

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Appendix 1.

P-Index List of Abbreviations and Acronyms

ACA: Animal Concentration Area

A_{method}: Manure application method scaling factor (see also Explanation and Justification section)

A_{timing}: Manure timing method scaling factor (see also Explanation and Justification section)

B_1: a constant in Eq. 2 (Provisional value = 2, see also Explanation and Justification section)

B_2: a constant in Eq. 10 (Provisional value = 12, see also Explanation and Justification section)

B_3: a constant in Eq. 15 (Provisional value = 1, see also Explanation and Justification section)

M1: Mehlich 1 extract and procedure

M1-P: Mehlich 1 extractable P (lb P_2O_5 acre^{-1})

P: Phosphorus

P_2O_5: the compound phosphorus pentoxide.

PSI: Phosphorus Site Index

STL: Soil Test Laboratory

STP: Soil Test Phosphorus (lb P_2O_5 acre^{-1})

T_{diss}: the transport component for dissolved P in runoff

T_{sed}: the transport component for particulate P in runoff

T_{sub}: the transport component for dissolved P in leachate

TSP: Total Soil Phosphorus (lb P_2O_5 acre^{-1})

P_{diss}: the source component for dissolved P in runoff

P_{sed}: the source component for particulate P in runoff

P_{sub}: the source component for dissolved P in leachate

WEP: Water Extractable Phosphorus

WVU: West Virginia University

Appendix 2. P-Index Glossary

Alum: potassium aluminum sulfate ($KAl(SO_4)_2$, is sometimes added to livestock wastes for odor control.

Biosolids: the solid residue remaining after waste water treatment.

Buffer width: minimum width of the riparian buffer measured perpendicular to the stream (VA Tech P-Index).

Buffer Width Factor: used to account for the positive effect of buffer strips on the transport component for particulate P runoff (Table 6).

Crop Removal: refers to the P-Management Guidance for a Medium P-Index Value and means a P application that will result in no net increase in STP per crop year.

Dissolved P: any P that is in solution. This could include inorganic P (the orthophosphate ion PO_4^{3-} or any of its complexes e.g. HPO_4^{2-}, H_2PO^{4-}) and organic molecules that contain P. Typically is defined by the pore size of the filter used

Distance Factor: used to scale the transport of dissolved P in runoff (Table 1), particulate P in runoff (Table 6) and dissolved P in leachate (Table 7).

Distance: the average straight-line distance length, in feet, as measured from the edge of field to nearest perennial or intermittent stream. (VA-Tech P-Index).

Edge of field: down slope end of the field (VA-Tech P-Index).

Erosion: in the context of the WV P-Index means the movement of soil by running water.

Flooding Frequency Factor: used to correct the transport of particulate P for soils that frequently flood. Flooding frequency classifications are available in NRCS Soil Survey reports.

Gully Erosion: eroded channels deeper than 4 inches.

Hydrologic soil group: refers to soils grouped by runoff-producing characteristics. Soils are assigned to four groups (A, B, C and D). Soils in group A have a high infiltration rate when thoroughly wet and a corresponding low runoff potential. At the other extreme, soils I group D have a very low infiltration rate and a corresponding high runoff potential (VA Tech P-Index).

Inorganic Phosphorus: The orthophosphate ion (PO_4^{3-}) or any of its dissolved complexes ($H_2PO_4^-$) or solid compounds; sometimes referred to as phosphate.

Land Grant University: in general – any state university established by the Morrill Act of 1862. For the purposes of the WV P-Index, refers specifically to West Virginia University.

Management Unit: any area of a field that is managed uniquely.

Mehlich 1: The amount of P extracted with the Mehlich 1 procedure and extract.

Organic Phosphorus: P that is an integral component of an organic (carbon)-containing molecule, examples include phospholipids and nucleic acids.

P stratification: The result of repeated surface P applications that are not incorporated with tillage.

Particulate P: Any P that is associated with or a part of a solid, including organic matter. Commonly defined by filter size; for the WV P-Index this is Whatman No. 40.

Phosphorus Index: an assessment of the relative risk of P loss from an agricultural field.

Phosphorus pentoxide: The unit for soil test P and fertilizer recommendations that are reported from the WV Soil Test Laboratory. P_2O_5 contains 43.7% P, explaining the term 0.437 in Equations 4 and 5. Fertilizer recommendations are usually and fertilizer labels are always expressed as % P_2O_5. Note that there is no P_2O_5 in soil, fertilizer or manure– it is simply used to indicate a P concentration.

Phosphorus Site Index: see Phosphorus Index.

Phosphorus: chemical element phosphorus; sometimes referred to as elemental P. When a concentration is indicated, the units are typically mg P/kg, lb P/acre or lb P_2O_5/acre for soil or sediment and mg P/L for water. Note that there is no elemental P in soil, manure or fertilizer – it is simply used to indicate P concentrations.

Riparian Buffer: see Riparian forest buffer or Riparian herbaceous buffer.

Riparian forest buffer: an area of predominantly trees and/or shrubs located adjacent to and up-gradient from watercourses or water bodies (definition from NRCS Virginia Conservation Practice Standard 391). Nutrient applications in strip should not exceed soil test recommendations (VA Tech P-Index).

Riparian herbaceous buffer (cover) an area of predominantly grass, forb and herbaceous vegetation located adjacent to and up-gradient from watercourses or water bodies (definition from NRCS Virginia Conservation Practice Standard 390). Nutrient applications in strip should not exceed soil test recommendations. watercourses or water bodies (definition from NRCS Virginia Conservation Practice Standard 391). Nutrient applications in strip should not exceed soil test recommendations (VA Tech P-Index).

Runoff: rainfall excess (difference between rainfall and infiltration during rainfall events) that flows over the ground surface and leaves a field. Watercourses or water bodies (definition from NRCS Virginia Conservation Practice Standard 391). Nutrient applications in strip should not exceed soil test recommendations (VA Tech P-Index).

Runoff dissolved P: the concentration of P in runoff water.

Soil Hydrologic Group: see Hydrologic Soil Group.

Soil Series: the lowest category of the national soil classification system. The name of a soil series is the common reference term, used to name soil map units. Soil series are the most homogenous classes in the system of taxonomy. “Official Soil Series Descriptions” define specific soil series in the United States, Territories, Commonwealths, and Island Nations served by USDA-NRCS. They are descriptions of the taxa in the series category of the national system of soil classification. They serve mainly as specification for identifying and classifying soils. The descriptions contain soil properties that define the soil series, distinguish it from other soil series, serve as the basis for the placement of that soil series in the soil family, and provide a record of soil properties needed to prepare soil interpretations. (USDA-NRCS).

Soil Test Laboratory: a laboratory that determines the concentrations of plant essential nutrients in soil and makes recommendations to correct deficiencies. These may be private commercial or public state university laboratories.

Soil Test Phosphorus: the concentration of phosphorus in a soil as determined by a specific soil test extractant. The results of any soil test are operationally defined (defined by the procedure and extractant used). The same soil will have different soil test phosphorus concentrations if different extractants are used.

Stream buffer: small areas of strips of land in permanent vegetation adjacent to streams. Stream buffers are designed to intercept pollutants. Buffers slow the flow rate, increase infiltration and sediment deposition, and reduce phosphorus delivered to an intermittent or perennial stream (VA Tech P-Index).

Total Soil Phosphorus: may have different meanings depending on the context. For the WV P-Index, it refers to the soil P concentration in eroded sediment as calculated from a recent M1-P soil test using Equations 11a and 11b.

Vegetated filter strip: strips of land in permanent vegetation, with at least 70% herbaceous ground cover, located at the downslope edge of a field. (VA Tech P-Index)

Water Extractable Phosphorus: the P concentration that can be extracted from a soil sample with water. There are several published procedures for determining WEP. The procedure in Wolf et al., 2005 is the most common and the one specified for the WV P-Index.

Appendix 3.

Relative Availability or Sufficiency Levels[1] for P, K, Ca and Mg

	P_2O_5	K_2O	Ca	Mg
	---------------------------- lb $acre^{-1}$	--------------------------------		
Low (deficient)	0 – 25	0 – 60	0 – 1000	0 – 100
Medium	25 – 50	60 – 120	1000 – 2500	100 – 250
High (sufficient)	50 – 80	120 – 240	2500 – 4000	250 – 500
Excessive	80 +	240 +	4000 +	500+

[1.] WVU Soil Testing Laboratory.

Appendix 4: West Virginia Soil Management Groupings with Environmental Sensitivity Ratings[1]

Soil Series	SMG	Sensitivity	Limitation
Airmont	BB	M	Wetness
Albrights	BB	M	Wetness
Albrights (drained)	W	H	Drainage
Allegheny	L	L	-
Alluvial Land, wet	NN	M	Leaching
Andover	BB	H	Wetness
Andover (drained)	W	H	Drainage
Ashton	L	L	-
Atkins	NN	H	Wetness
Atkins (drained)	H	H	Drainage
Bagtown	CC	M	Leaching
Barbour	CC	M	Leaching
Basher	HH	L	-
Basher (drained)	A	H	Drainage
Beech	HH	L	-
Beech (drained)	L	H	Drainage
Belmont	M	L	-
Benevola	M	L	-
Berks	FF	M	Leaching
Bethesda	FF	M	Leaching
Bigpool	L	L	-
Blackthorn	G	M	Leaching
Blago	Z	H	Wetness
Blago (drained)	P	H	Drainage
Blairton	AA	M	Shallow
Blairton (drained)	U	H	Drainage
Braddock	O	L	-
Brevard	L	L	-
Brickhaven	AA	L	-
Briery	FF	M	Leaching
Brinkerton	BB	H	Wetness
Brinkerton (drained)	W	H	Drainage
Brooke	Y	M	Shallow
Brooke (drained)	Y	H	Drainage
Brookside	HH	L	-
Brookside (drained)	L	H	Drainage
Buchanan	BB	M	Wetness
Buchanan (drained)	W	H	Drainage
Calvin	FF	M	Shallow
Caneyville	Y	M	Shallow
Captina	W	L	-

Soil Series	SMG	Sensitivity	Limitation
Captina (drained)	W	H	Drainage
Carbo	Y	M	Shallow
Cardova	U	M	Shallow
Cateache	U	M	Shallow
Catoctin	FF	M	Leaching
Cavode	AA	M	Wetness
Cavode (drained)	U	H	Drainage
Cedarcreek	FF	M	Leaching
Chagrin	A	L	-
Chavies	L	L	-
Chilhowie	Y	M	Shallow
Clarksburg	W	L	-
Clarksburg (drained)	W	H	Drainage
Clearbrook	AA	M	Shallow
Clearbrook (drained)	FF	H	Drainage
Clifftop	U	M	Shallow
Clifton	L	L	-
Cloverlick	FF	M	Leaching
Clymer	U	L	-
Combs	A	M	Leaching
Conotton	CC	M	Leaching
Cookport	W	L	-
Cookport (drained)	W	H	Drainage
Coolville	G	L	-
Coolville (drained)	G	H	Drainage
Cotaco	HH	M	Wetness
Cotaco (drained)	L	H	Drainage
Craigsville	CC	M	Leaching
Culleoka	U	M	Shallow
Dekalb	FF	H	Leaching
Dormont	HH	L	-
Dormont (drained)	L	H	Drainage
Downsville	CC	M	Leaching
Duffield	M	L	-
Duncannon	L	L	-
Dunmore	M	L	-
Dunning	NN	H	Wetness
Dunning (drained)	H	H	Drainage
Edgemont	U	L	-
Edom	M	L	-
Elk	L	L	-
Elkins	NN	H	Wetness
Elkins (drained)	H	H	Drainage
Elliber	GG	H	Leaching
Endcav	M	L	-

Soil Series	SMG	Sensitivity	Limitation
Ernest	W	L	-
Ernest (drained)	W	H	Drainage
Fairplay	NN	H	Wetness
Fairplay (drained)	H	H	Drainage
Fairpoint	FF	M	Leaching
Faywood	Y	M	Shallow
Fedscreek	CC	M	Leaching
Fenwick	AA	M	Shallow
Fiveblock	FF	H	Leaching
Frankstown	M	L	-
Frederick	U	L	-
Funkstown	HH	L	-
Gallia	L	L	-
Gallipolis	HH	L	-
Gallipolis (drained)	L	H	Drainage
Gauley	FF	M	Leaching
Gilpin	U	M	Shallow
Ginat	NN	H	Wetness
Ginat (drained)	H	H	Drainage
Glenford	L	L	-
Glenford (drained)	L	H	Drainage
Grigsby	CC	M	Leaching
Guernsey	AA	L	-
Gurensey (drained)	U	H	Drainage
Guyan	NN	M	Wetness
Guyan (drained)	H	H	Drainage
Guyandotte	CC	M	Leaching
Hackers	L	L	-
Hagerstown	M	L	-
Hazleton	FF	M	Leaching
Highsplint	CC	M	Leaching
Holly	NN	H	Wetness
Holly (drained)	H	H	Drainage
Huntington	A	L	-
Hustontown	W	L	-
Itmann	FF	H	Leaching
Janelew	FF	M	Leaching
Jefferson	L	L	-
Kanawha	L	L	-
Kaymine	FF	M	Leaching
Klinesville	JJ	H	Shallow
Laidig	W	L	-
Lakin	II	H	Leaching
Landes	A	M	Leaching
Lappans	A	H	Leaching

Soil Series	SMG	Sensitivity	Limitation
Latham	AA	M	Shallow
Latham (drained)	U	H	Drainage
Lawrence	BB	M	Wetness
Leatherbark	AA	M	Shallow
Leatherbark (drained)	U	H	Drainage
Leetonia	II	H	Leaching
Lehew	FF	H	Leaching
Lickdale	NN	H	Wetness
Lickdale (drained)	H	H	Drainage
Licking	HH	L	-
Licking (drained)	L	H	Drainage
Lily	U	M	Shallow
Linden	A	M	Leaching
Lindside	HH	L	-
Lindside (drained)	A	H	Drainage
Litz	FF	M	Leaching
Lobdell	HH	L	-
Lobdell (drained)	A	H	Drainage
Lodi	M	L	-
Lowell	M	L	-
Macove	CC	M	Leaching
Mandy	FF	M	Leaching
Markland	O	L	-
Markland (drained)	O	H	Drainage
Marrowbone	CC	M	Leaching
Matewan	FF	H	Leaching
McGary	Z	M	Wetness
McGary (drained)	P	H	Drainage
Meckesville	W	L	-
Melvin	NN	H	Wetness
Melvin (drained)	H	H	Drainage
Mertz	GG	H	Leaching
Middlebury	HH	L	-
Middlebury (drained)	A	H	Drainage
Monongahela	W	L	-
Monongahela (drained)	W	H	Drainage
Moshannon	A	L	-
Murrill	G	L	-
Muskingum	U	M	Shallow
Myersville	U	L	-
Myra	FF	M	Leaching
Nallen	U	M	Shallow
Nelse	A	M	Leaching
Nolin	A	L	-
Nollville	M	L	-

Soil Series	SMG	Sensitivity	Limitation
Nolo	BB	H	Wetness
Nolo (drained)	W	H	Drainage
Oaklet	KK	L	-
Omulga	W	L	-
Omulga (drained)	W	H	Drainage
Opequon	Y	H	Shallow
Orriville (drained)	H	H	Drainage
Orrville	NN	M	Wetness
Otwell	W	L	-
Otwell (drained)	W	H	Drainage
Peabody	U	M	Shallow
Pecktonville	M	L	-
Philo	HH	L	-
Philo (drained)	A	H	Drainage
Pineville	L	L	-
Poorhouse	AA	M	Wetness
Poorhouse (drained)	U	H	Drainage
Pope	A	M	Leaching
Poplimento	M	L	-
Potomac	II	H	Leaching
Purdy	Z	H	Wetness
Purdy (drained)	P	H	Drainage
Ramsey	JJ	H	Shallow
Rayne	U	L	-
Robertsville	BB	H	Wetness
Robertsville (drained)	W	H	Drainage
Rough	JJ	H	Shallow
Rushtown	FF	H	Leaching
Ryder	Y	M	Shallow
Schaffenaker	U	M	Shallow
Sciotoville	W	L	-
Sciotoville (drained)	W	H	Drainage
Secnecaville (drained)	A	H	Drainage
Sees	L	L	-
Senecaville	HH	L	-
Sensabaugh	A	L	-
Sensabaugh (drained)	A	H	Drainage
Sewell	FF	H	Leaching
Sharpcrest	U	L	-
Shelocta	L	L	-
Shelocta (drained)	L	H	Drainage
Shircliff	HH	L	-
Shircliff (drained)	L	H	Drainage
Shouns	G	L	-
Sideling	G	L	-

Soil Series	SMG	Sensitivity	Limitation
Simoda	W	L	-
Skidmore	CC	M	Leaching
Snowdog	W	L	-
Speedwell	A	L	-
Stumptown	FF	M	Leaching
Summers	FF	M	Leaching
Swanpond	KK	L	-
Swanpond (drained)	KK	H	Drainage
Sylvatus	JJ	H	Shallow
Taggart	HH	M	Wetness
Taggart (drained)	L	H	Drainage
Tarhollow	U	L	-
Thurmont	L	L	-
Tilsit	W	L	-
Tioga	A	L	-
Toms	Z	M	Wetness
Toms (drained)	P	H	Drainage
Trego	W	L	-
Trussel	BB	H	Wetness
Trussel (drained)	W	H	Drainage
Tygart	Z	M	Wetness
Tygart (drained)	P	H	Drainage
Tyler	BB	M	Wetness
Tyler (drained)	W	H	Drainage
Upshur	U	L	-
Vandalia	O	L	-
Vanderlip	II	H	Leaching
Vertrees	M	L	-
Vincent	HH	L	-
Vincent (drained)	L	H	Drainage
Weikert	JJ	H	Shallow
Wellston	U	L	-
Westmoreland	U	L	-
Weverton	G	M	Leaching
Wharton	U	L	-
Wharton (drained)	U	H	Drainage
Wheeling	L	L	-
Whiteford	U	L	-
Woodsfield	U	L	-
Yeager	II	H	Leaching
Zoar	HH	L	-
Zoar (drained)	L	H	Drainage

[1.] Prepared by James Thompson WVU Division of Plant & Soil Sciences, August 26, 2008, Revised May 29, 2012.