Phosphorus Management: An Analysis of the Virginia Phosphorus Index

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Abstract

Excess phosphorus (P) that is transported into water bodies can cause water quality problems. A high potential for P delivery occurs when there is a high transport potential from erosion, runoff, and/or leaching coupled with high soil test P and/or high rate of fertilizer P application. A management tool is needed to identify those fields that have a high transport and source potential to deliver P to surface water. The Virginia P-Index is a mass-based tool that estimates the annual risk of delivery of P from a given field to surface water. Guidelines on P application rates are then given based on the level of risk. This is a new tool and additional research and testing are needed to determine the dependability and validity of the index.

The overall goal of the research was to contribute to the continued development of the Virginia P-Index as an effective P management tool. A sensitivity analysis was completed to identify the parameters to which the P-Index was most sensitive under a range of conditions. In low erosion and runoff conditions, the P-Index was most sensitive to P management factors including application rate. As erosion and runoff potential increased, the P-Index was most sensitive to the erosion risk factors including soil loss. Under conditions with subsurface leaching, the P-Index was most sensitive to the subsurface leaching factors and Mehlich I soil test P. A stochastic analysis was also conducted to determine the effects of parameter variability. Variability of the P-Index output was greater as the risk of P delivery increased and this could affect management recommendations.

A survey was completed to determine expert opinion as to the appropriateness of parameter estimation methods used in the Virginia P-Index. Thirty-eight surveys were returned, representing a diverse range of participants within and outside of Virginia. Comments from the respondents were used to evaluate the appropriateness of the parameter methods. All factors were determined to be appropriate given the state of the science. Estimation methods for the following factors were determined to be less appropriate than the other sub-factors by the survey respondents: soil texture/drainage class, subsurface dissolved reactive orthophosphate (DRP), runoff delivery, and sediment delivery. The Virginia P-Index was determined to be a well thought out management tool and implementation should identify fields with the greatest risk of P delivery to surface water. Recommendations for improvement were identified including a need for additional analysis and studies.

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Table of Contents

List of Tables

List of Figures

1.0 Introduction

Phosphorus (P) is an essential element for plant and animal growth and is widely applied in crop and pasture systems. It is well documented that applying fertilizer P will increase crop yields in soil that is low in P. However, application of P in excess of crop requirements can cause P buildup in soils. Phosphorus buildup in soils has occurred mainly in areas where animal manures have been applied to crops and pastures based on nitrogen (N) requirements of crops. This can lead to excess P in the soil since the N:P ratio is much lower in animal manures than required by most crops. For example, a recommended N:P fertilization ratio for corn silage (yield 1540 kg/ha) is 7.4, while the N:P ratio of poultry litter is 2.8 (Virginia DCR, 1995). If fertilizer application is based on N needs of the crop, over 1.6 times more P will be applied than needed for crop growth.

A general consensus of the past was that P was stable in the soil system as long as soil erosion was minimized. However, recent studies have shown that soil high in P is more susceptible to runoff and leaching losses (Sharpley et al., 1994). Excess P that is transported into water bodies can cause water quality problems. Phosphorus is a limiting nutrient in freshwater systems (Sharpley et al., 1994), so excess P from agricultural sources accelerates eutrophication. Reducing P losses in any given area may slow eutrophication.

Phosphorus soil tests, including the Mehlich (1984), Bray (1945), and Olsen (1954), have long been used to determine plant available P in soils. Studies have shown that there is a relationship between soil test P and P in runoff (Sharpley 1995a; Pautler and Sims, 2000). However, a high soil test P does not necessarily mean there is a high probability of P loss from a particular field. A high potential for P loss occurs when there is a high transport potential from erosion, runoff, and/or leaching coupled with high soil test P.

Phosphorus management tools can aid in improving water quality. A management tool that could identify areas with a high potential for P loss is desirable. These areas can then be targeted and management practices implemented to decrease the overall P loss.

The P index is such a tool, developed by the United States Department of Agriculture - Natural Resources Conservation Service (USDA-NRCS) as a field level assessment tool that integrates soil, management, environmental, and hydrological characteristics to determine the risk of P loss to surface water (USDA-SCS, 1994). The USDA-NRCS P-Index was developed from professional estimates as a general structure or approach for assessing the potential for P losses and was not derived from any observed field data (Beegle et al., 1998). Since P management is site-specific, the USDA-NRCS encourages development of this approach on a more regional or state level (Lemunyon and Gilbert, 1993).

The USDA-NRCS revised its nutrient management policy in May 1999, requiring each state to revise the Nutrient Management (590) standard in its Field Office Technical Guide (Mullins et al., 2002a). An assessment of P loss from agricultural fields must be included in the new standard and include one of the following: agronomic soil test interpretations, environmental soil P thresholds, or a P loss index. The Virginia NRCS has chosen to use a P-Index as a P management tool for NRCS programs in Virginia.

A multidisciplinary team at Virginia Tech has developed a P-Index for Virginia, which is a mass-based tool that estimates the annual risk of delivery of P to surface water from a given field. The Virginia P-Index includes site-specific erosion, runoff, and leaching risk factors that are used to categorize the overall risk of P delivery to surface water from a field under a given management system. To calculate the P-Index, various input parameters are determined for a field, which are then used to determine the factors within the index. Some input parameters include average annual soil loss from a field, Mehlich I soil test P, and curve number. Factor values are determined based on the input parameters from developed tables and equations. Examples of different factors in the P-Index include total average annual runoff, sediment delivery to the nearest intermittent or perennial stream, and soil texture/drainage class. Management factors are also included in the index, including method and rate of fertilizer P application. Computed P-Index values range from 0 to >100. Management guidelines for P application are recommended based on P-Index values that relate to potential water quality impact.

According to the (590) Virginia Nutrient Management Standard, the P-Index should be implemented at all sites with P saturation levels between 20% and 65% (NRCS-VA, 2001). Phosphorus saturation is based on the soil's capacity to sorb P. Below 20% P saturation, nutrient requirements recommended by NRCS can be based on crop N requirements. For fields with greater than 65% P saturation, NRCS will not recommend application of any P. This standard applies to all land receiving organic sources with the exception of poultry waste. The Virginia Code (VAC 9 25-630-10) requires P application to fields receiving poultry waste to be based on P by either soil test recommendations or by crop nutrient removal (NRCS-VA, 2001).

The P-Index can be used by agricultural professionals and state and federal agencies within Virginia to assess the vulnerability of agricultural fields to P losses. Once the risk is assessed, the P-Index could then be used to identify practices or strategies for reduction of P losses from a site, specifically, fields that are in a high or very high risk category. Furthermore, the P-Index could be used as an educational tool to demonstrate to producers how changes in management practices can reduce the potential for P losses from agricultural soils.

The Virginia P-Index was developed over the past three years. The Virginia Department of Conservation and Recreation (DCR) and Virginia NRCS will begin using the P-Index for their projects in the immediate future. The Virginia P-Index is a new tool for P management and limited evaluation has been completed to determine if the P-Index will be effective in recognizing fields that have a high risk of P delivery to surface water. It is important that the P-Index be dependable for any site-specific setting in Virginia so that results are consistent anywhere within the state. It is also important that the factors and the methods to quantify the factors in the P-Index are based on the best scientific information, while accommodating the practicalities of field implementation. Various parameter estimation methods are used in the Virginia P-Index including the revised universal soil loss equation (RUSLE) to estimate average annual soil loss from a field and the curve number (CN) approach to estimate average annual runoff from a field. The appropriateness of these methods, and all other methods used in the Virginia P-Index, needs to be evaluated. Additional research and testing are needed to determine the dependability and validity of the index. Identifying strengths and weaknesses in the P-Index is important to aid developers and policy makers in focusing their time and efforts on P management more efficiently.

1.1 Research Objective

The overall goal of the research was to contribute to the continued development of the Virginia P-Index as an effective P management tool. The research focused on determining which parameters require additional analysis and evaluation.

The following specific objectives were:

1. to determine the sensitivity of the Virginia P-Index to input parameters including assessment of output variability across a range of climate, soil, and management conditions; and
2. to determine the appropriateness of the parameter estimation methods used in the Virginia P-Index.

2.0 Literature Review

2.1 Introduction

The literature review summarizes research identifying P buildup in soils, which defines the overall problem of P loss that contributes to water quality problems. An overview of P management and the P-Index is also presented to provide background and basis for completing the research objectives. The literature review also includes the topics of sensitivity analysis and expert opinion surveys since both were conducted to meet the research objectives. The following specific topics are included in the literature review: 1) environmental implications of P, 2) P saturation in soils, 3) P-index, 4) Virginia P-Index, 5) other state P-Indexes, 6) sensitivity analyses, and 7) expert opinion surveys.

2.2 Environmental Implications of Phosphorus in Agriculture

Soil P exists in inorganic and organic forms, with 50-75% of the P as inorganic (Sharpley and Rekolainen, 1997). Phosphorus is transported in dissolved and particulate forms. Particulate P includes P sorbed by soil particles and organic matter that is eroded during flow events. Typically, 60-90% of P transported from cultivated land is associated with sediment (Sharpley et al., 1992). Runoff from grass or forested land carries little sediment, and P losses are generally dominated by dissolved forms (Sharpley and Rekolainen, 1997). Dissolved P in runoff is mostly bioavailable (available for uptake by aquatic biota) (Peters, 1981; Walton and Lee, 1972), while bioavailable particulate P can vary from 10-90% (Sharpley, 1993). Phosphorus loss can occur via various pathways including soil erosion, runoff, and subsurface leaching. Several studies have shown that P loss can occur through subsurface leaching in some soil conditions including drainage in areas with a high water table (Gaynor and Findlay, 1995; Grant et al., 1996; Haygarth et al., 1998).

Research has shown that an increase in the transport of P in agricultural runoff increases or promotes eutrophication (Sharpley et al., 1994). Eutrophication is increased since P is the limiting nutrient in most freshwater systems and a primary nutrient in saltwater systems and thereby accelerates aquatic plant growth, oxygen depletion, pH variability, and plant species quality (Sharpley et al., 1994). Algae blooms have been reported to be caused by P concentrations ranging from 0.01 to 0.03 mg/L (Sharpley et al., 1996; USEPA, 1994).

2.3 Phosphorus Saturation in Soils

It has been shown that application of animal manures including poultry litter has increased the level of P in soils (Kingery, 1994). It is well known that soils vary in their capacity to retain P due to differences in the amount of clay, aluminum/iron oxides, and carbonates present (Sims, 2000). The capacity of the soil to hold P is not infinite and soils have a given P sorption capacity, or ability to hold or fix P, based on those individual characteristics. As soils become more saturated with P, the risk of P losses increases. Studies have shown that soil high in P is more susceptible to runoff and leaching losses of P (Sharpley, 1994; Sharpley, 1995a). According to data collected in the late 1980s by the Potash and Phosphate Institute (1989), over 58% of soils tested in Virginia were considered above agronomic P (Sims, 1993). Data collected by the Virginia Tech Soil Testing Laboratory from January 1997 to June 1998 for Mehlich I soil test P for three Virginia counties showed that over 70% of the fields had a high to very high soil test rating (Table 2.1).

Table 2.1: Distribution of agricultural soil samples analyzed by Virginia Tech Soil Testing Laboratory from January 1997 to June 1998 by Mehlich I soil test from three Virginia Counties having intensive animal and row crop agriculture (Mullins et al., 2002a).

County	Number of Fields	Soil Test Rating, Virginia Tech			
		Low (< 12 lbs P/acre)	Medium (12-35 lbs P/acre)	High (36-110 lbs P/acre)	Very High (> 110 lbs P/acre)
		% of fields			
Accomack	405	1.0	14.1	39.5	45.4
Amelia	99	5.1	23.2	37.4	34.3
Rockingham	179	6.7	22.3	39.1	31.9

Gartley and Sims (1994) reported that upper critical limits of soil test P for increased risk of P loss vary among states, however, are typically between three to six times the value accepted as adequate for optimum crop yields. Sharpley (1996), however, suggested that critical values of soil test P are less than cited by Gartley and Sims (1994) and have been defined as the break-point between a medium soil test P value, where crop response to fertilizer is likely, and a high soil test P value, where adding fertilizer will usually not produce an economic yield increase (Sharpley et al., 1996). Typical critical agronomic soil test P values for Mehlich-1, Mehlich-3, and Bray-1 in the eastern United States are 30, 50, and 15 mg kg^{-1}, respectively (Sharpley et al., 1996).

Research was conducted by the Virginia P-Index development team to evaluate and characterize soil conditions in Virginia. Soil samples were collected in Rockingham (n=28), Accomack (n=19), and Amelia (n=15) counties from a range of soil textures and cover including crop, pasture, and forested land. Soil tests determined Mehlich I soil test P, water extractable P, ammonium oxalate extractable P, total P, organic P, active mineral P, stable soil P, and P sorption for each site (P-Index development team, unpublished data, 2000). Based on the results of the soil testing, relationships were developed between Mehlich I extractable P (soil test P) and P saturation (Figure 2.1), Mehlich I P and P sorption capacity (Figure 2.2), and P saturation and P sorption capacity (Figure 2.3).

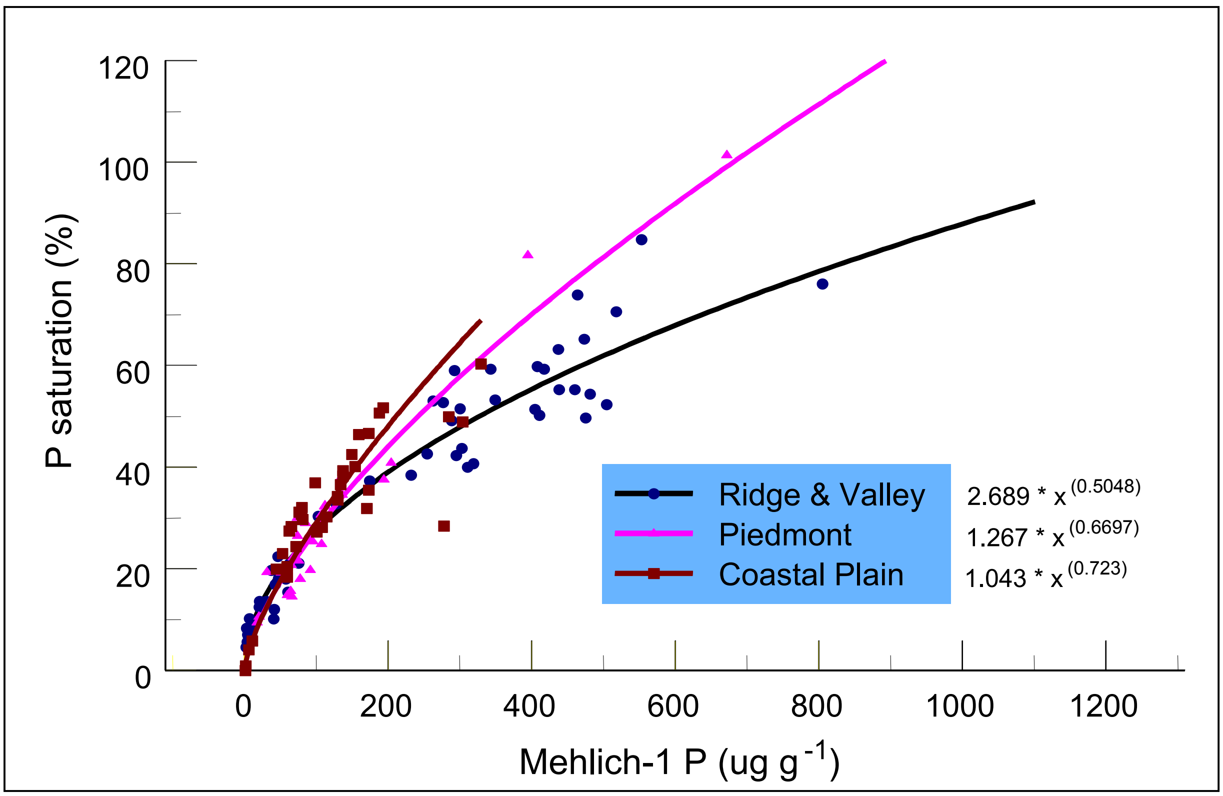

Figure 2.1: Relationship of Mehlich-I P and P saturation for three physiographic regions of Virginia based on soil samples collected in Rockingham, Accomack, and Amelia Counties (P-Index development team, unpublished data, 2000)

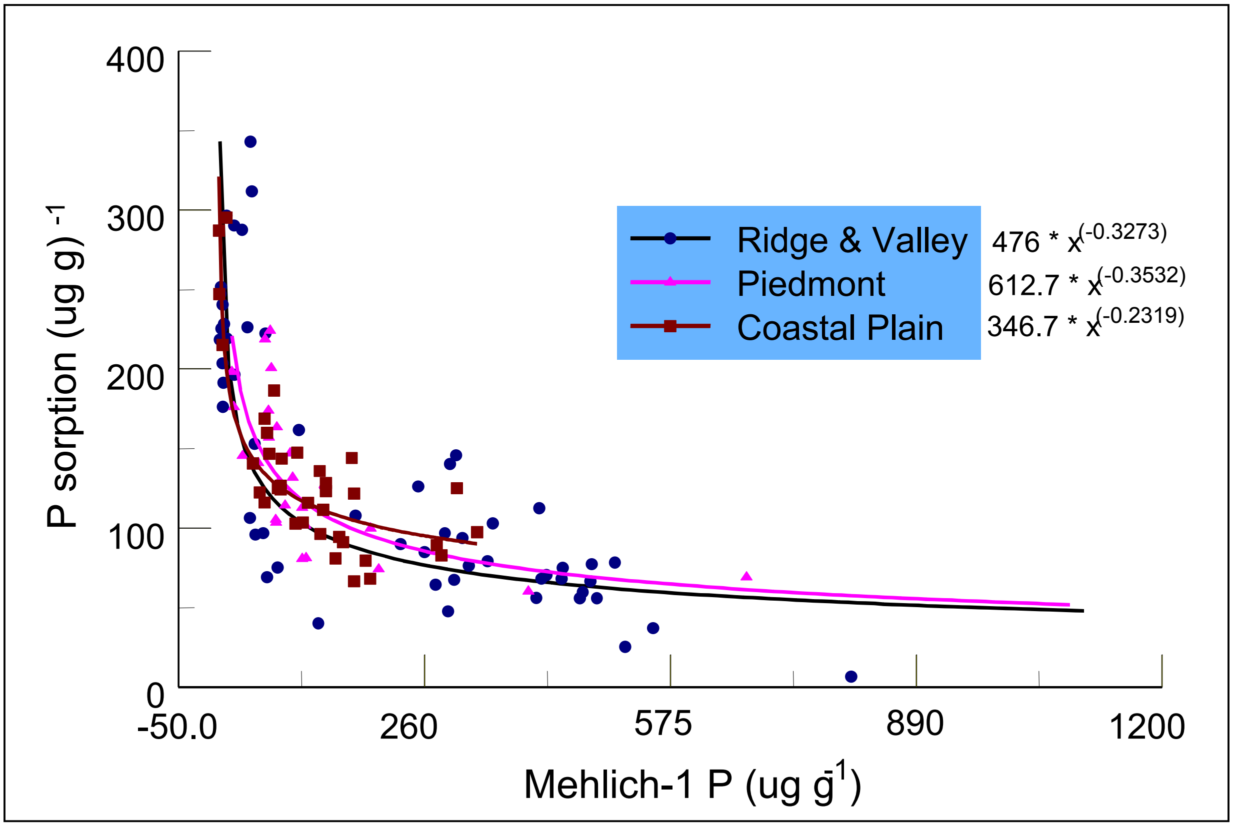

Figure 2.2: Relationship between Mehlich-1 P and P sorption capacity for three physiographic regions of Virginia based on soil samples collected in Rockingham, Accomack, and Amelia Counties (P-Index development team, unpublished data, 2000)

Regional differences were identified due to varying predominant soil texture/class. These results show that as Mehlich I P increases, P saturation increases and the available P sorption capacity is less since more P is sorbed to the soil. Thus, the potential for P loss increases as P in the soil increases.

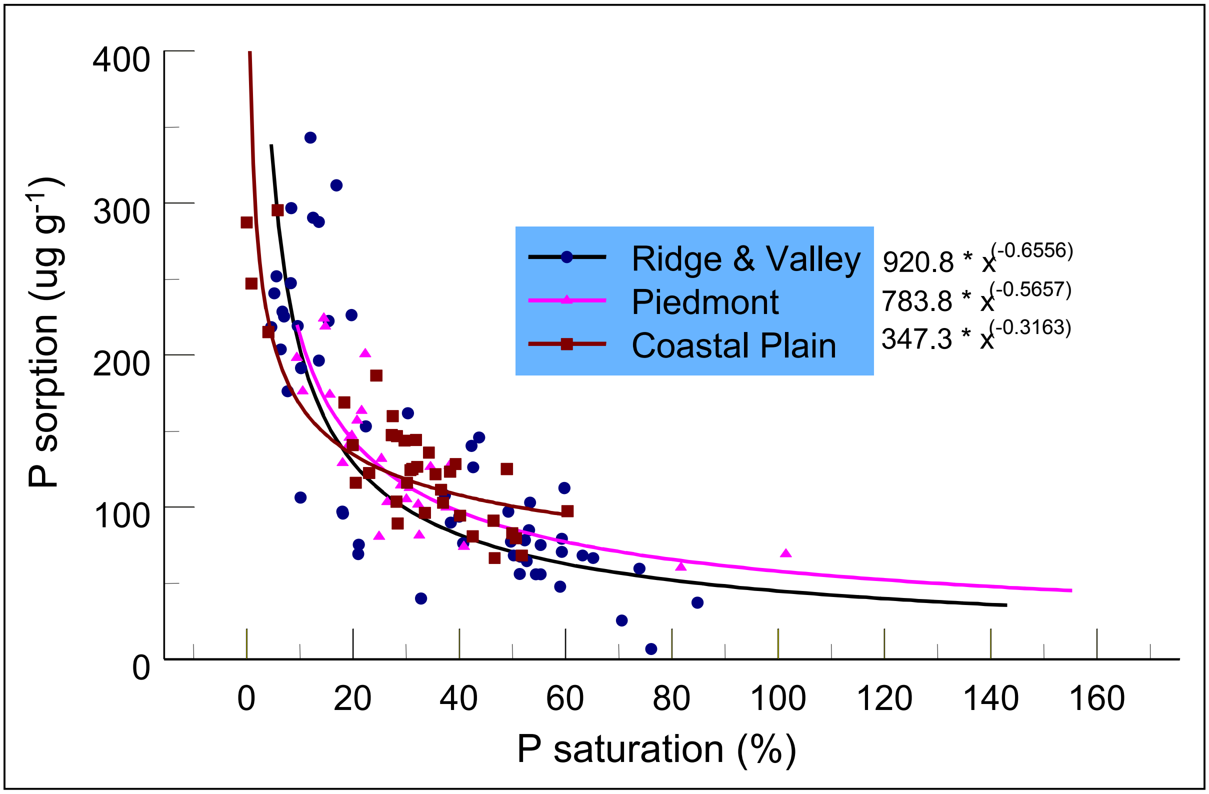

Figure 2.3: Relationship between P saturation and P sorption capacity for three physiographic regions of Virginia based on soil samples collected in Rockingham, Accomack, and Amelia Counties (P-Index development team, unpublished data, 2000)

Environmental soil P thresholds, or critical levels of soil P above which the risk of P delivery to surface water is unacceptable, have been determined by different approaches. Approaches have related to agronomic or water quality criteria. The agronomic approach established soil P standards based on the rationale that soil P in excess of crop requirements may be vulnerable to removal by surface runoff or leaching (Sharpley et al., 1996). This approach has been widely adopted by state agencies due to the readily available soil test P data currently being used for crop growth (Kleinman et al., 2000). The major problem with this method is that the processes by which plants assimilate soil P are much different from the processes by which soil P is removed by runoff (Kleinman et al., 2000).

A second approach to determining soil P thresholds is by correlating soil P with measurements of P in runoff and groundwater (Pote et al., 1996, 1999). Sharpley (1995a) developed a relationship between runoff P and soil P saturation using data for ten different soils. Further studies have determined upper critical limits for soil test P by correlating increases in extractable or desorbable soil P to significant losses of P in runoff and drainage (Heckrath et al., 1995; Pote et al., 1996). Heckrath et al. (1995) determined that P remained strongly in the plow layer in silt loam and silty clay loam soils with concentrations below 60 mg Olsen-P/kg. Above this level, there was a rapid increase in total P in drainage water. Pote et al. (1996) indicated that a Mehlich-3 soil test P level of 200 mg kg^{-1} resulted in a dissolved P concentration in runoff near 1000 µg L^{-1} for a silt loam in fescue. Pote et al. suggested that level of 200 mg kg^{-1} as an upper limit for dissolved P, which corresponds to a level of 25% P saturation for that soil. This limit coincides with research conducted by Breeuswma et al. (1995) that showed P saturation greater than 25% in the soil profile to the depth of the mean high water table would contribute to shallow groundwater pollution.

A third, more detailed approach, based on the second approach for setting environmental thresholds of soil P, involves the soil chemical behavior relating to P soil saturation. A linear relationship was developed between P saturation and calcium chloride ($CaCl_2$) extractable P (a soil test P method) from soil samples collected from the New York Delaware watershed (Kleinman et al., 2000). At some P saturation level, dissolved losses of P increase dramatically; that P saturation level is referred to in literature as the change point. McDowell et al. (2001) determined that there is a linear relationship between soil test P and the concentration or release of P on either side of a change point for the soils they tested, including clay and silt loam soils from England and the United States. Their research showed that the linear relationship is significantly different ($p<0.05$) above and below the change point (McDowell et al, 2001).

In summary, research has shown that the potential for P loss increases as the P saturation increases in the soil. Relationships can be developed to identify critical soil test P levels, however, are site specific and, therefore, must be developed for individual soil textures.

2.4 Development of P-Index

Due to the high level of P saturation in some soils, an approach is needed to identify areas where more intensive P management practices should be applied in order to protect surface waters (Sims et. al, 2000). The P-Index is a tool to identify the risk of P delivery from a field. The information from the P-Index can then be used to target fields with the highest risk of P delivery to surface water. A reduction of P applied to the site is recommended for those sites with a high risk of P delivery.

The P-index tool was developed by the Natural Resources Conservation Service (NRCS) as a field scale assessment tool to rank the vulnerability of fields as sources of P loss in runoff (Lemunyon and Gilbert, 1993; USDA-SCS, 1994). The NRCS P-Index incorporates soil characteristics (soil test P), management characteristics (fertilizer and manure inputs), and transport characteristics (runoff and erosion) at the field scale and assigns a P-Index value based on an additive and weighting format. Each of the characteristics is assigned a rating value (low-1, medium-2, high-4, or very high-8) based on the relationship between the characteristic and the potential for P loss from a site. Each characteristic is also assigned a weighting factor that reflects its relative importance to P loss (Sims et al., 2000). For example, the erosion weighting factor is 1.5, which is more important to P loss than the P fertilizer application method, which has a weighting factor of 0.5. The P-Index value can then be compared on a field by field basis to rank P-loss potential for each site.

Sharpley (1995b) applied the NRCS P-Index to 30 small watersheds of about 2 ha each in Texas and Oklahoma and results were compared with measured data for P runoff and erosion losses. The P-Index rankings correlated well with total P loss from the watersheds (r=0.79) (Sharpley, 1995b). Sharpley (1995b) also showed that when measured runoff and erosion data were used to calculate the P-Index, the relationship between the P-Index and total P loss from the watershed strengthened (r=0.89). This further emphasized the importance of transport related to P loss. However, when the NRCS P-Index was applied at the field scale to a larger watershed in Pennsylvania having dynamic and variable source areas of runoff, the field ranking did not reflect all the watershed areas having combinations of high soil P and high runoff probability that had a documented impact on the stream (Gburek et al., 1996).

Gburek et al. (2000) suggested an approach for P management that incorporates the interactions between soil P and surface runoff at the plot/field scale with P transport processes applicable to the multifield/watershed scale where impacts of P loss are evaluated. Gburek et al. (2000) modified the NRCS P-Index to incorporate these interactions. The modified P-Index was then applied to a watershed and P loss risk was improved for identifying those fields with the highest source and transport potentially relating to connectivity to a surface water body.

2.5 State P-Indexes

Two basic approaches have been used by states in developing a state specific P-Index: a mass-based approach and a weighting/rating scheme. A mass-based approach assesses risk of P delivery by quantifying P losses while a weighting/rating scheme uses ratings or categories to define overall risk. An overview of state P-Indexes is given in Table 2.2 followed by brief descriptions of individual state indexes. A detailed description of the Virginia P-Index is included in Section 2.6.

Table 2.2: Summary of some state P-Indexes

State	Approach	P-Index categories and recommendation for P application	
Florida	Ratings and values for soil loss/soil test P/application rate	<75	Low - N based
		75-150	Medium - N based w/conservation practices
		151-225	High - P based
		>225	Very high - P based w/conservation practices
Iowa	Mass-based (values)	0-2	Very low & low - no actions
		2-5	Medium - P management considered
		5-15	High - P management/remedial action required
		>15	Very high - immediate action required, may require discontinuing P application
Maryland	Ratings and values for soil loss/soil test P	0-50	Low - N based
		51-75	Medium - 1 yr N based, 2 yr P crop removal or soil test recommendation
		76-100	High – P based
New York	Ratings and values for soil loss/application rate	0-50	Low - N based
		50-74	Medium - N based w/BMPs
		75-99	High - P crop removal
		≥ 100	Very high - no P application allowed
North Carolina	Ratings and values for soil loss/soil test P/application rate	0-50	Low & medium - N based
		51-100	High - P crop removal
		>100	Very high - no additional P applied
Pennsylvania	Ratings and values for soil loss/soil test P/application rate	<60	Low - N based
		60-80	Medium - N based
		80-100	High - P based w/ conservation practices
		>100	Very high - no P application, conservation practices
Vermont	Rating/weighting & values soil loss/soil test P	0-50	Low & medium - N based
		51-100	High - P crop removal
		>100	Very high - no additional P applied
Virginia	Mass-based (values)	0-30	Low - N based
		31-60	Medium - 1.5 P crop removal
		61-100	High - P crop removal
		>100	Very High - No P can be applied

2.5.1 Florida

Florida's P-Index uses eight site characteristics to calculate an overall rating for P loss at a site (Florida Phosphorus Work Group, 2000). The four P transport characteristics are soil erosion, runoff potential, leaching potential, and potential to reach water body. The characteristics are added together to obtain a total site value. The four P management characteristics are a fertility index value, P application rate, application method, and wastewater application volume. The characteristics are added together to obtain a total management value. The overall rating is then calculated by multiplying the site value by the management value. Site management recommendations are based on the P-Index output within the low, medium, high, and very high categories.

2.5.2 Iowa

The Iowa P-Index is comprised of three components, erosion, runoff, and subsurface, that are summed to determine an overall value for risk of P delivery from a site (NRCS-IA, 2001). Sub-factors comprise each of the factors and are multiplied together to obtain the overall value for risk of P delivery. The erosion component is calculated by multiplying together the following factors: gross erosion, sediment trap factor, a buffer factor, an enrichment factor, and total P. The runoff component includes a runoff factor, precipitation, a soil test P runoff factor, and a P application factor. The first two factors are multiplied together and added to the multiplication of the third and fourth factors to yield the runoff component. The subsurface drainage component is calculated by multiplying precipitation, a flow factor, and a soil test P drainage factor. Site management recommendations are based on the P-Index output within the low, medium, high, and very high categories.

2.5.3 Maryland

The Maryland P-Index is comprised of twelve site characteristics or management factors within two parts (Coale, 2001). Part A is the site and transport characteristics and Part B is the management practice and source characteristics. The site characteristics for Part A include soil erosion, soil runoff class, subsurface drainage, leaching potential, distance from edge of field to surface water, and priority of receiving water. These factors are added together and multiplied by a scaling factor so that transport potential is expressed on a relative scale from 0 to 1. The site characteristics for Part B include a soil test P fertility index value, P fertilizer application rate, P fertilizer application method, organic P application rate, and organic P application method. These factors are added together to obtain an overall P loss potential due to management practice and source characteristics. Part A and B are then multiplied to get an overall P-Index rating within low, medium, high, and very high P loss risk categories corresponding to P management recommendations.

2.5.4 New York

The New York P-Index is comprised of two parts, a dissolved P Index and a particulate P Index (Czymmek et al., 2001). Both P-Indexes are determined by multiplying a P source factor by a P transport factor. Adding a soil test P factor, fertilizer P factor, and organic P factor determines the P source factor. The dissolved P transport factor is calculated by adding a soil drainage factor, flooding frequency, and flow distance to a stream rating. The particulate P transport factor is calculated by adding soil erosion, flooding frequency, flow distance to stream, and concentrated flow ratings. Site management recommendations are based on the P-Index output within the low, medium, high, and very high categories.

2.5.5 North Carolina

North Carolina has developed a Phosphorus Loss Assessment Tool (PLAT) ("Nutrient Management Information for North Carolina", 2002). PLAT ratings are determined by summing site-specific ratings for four loss pathways: particulate P, runoff soluble P, subsurface soluble P, and source P (based on soil test P). Management options are then based on the overall PLAT rating, corresponding to low, medium, high, and very high ratings. Some factors included in PLAT are soil erosion calculated using RUSLE, soil test P (Mehlich 3), estimated clay content, receiving slope width, runoff, application rate, application method, and a delivery factor.

2.5.6 Pennsylvania

In Pennsylvania, if the soil test P value for a field is greater than 200 ppm or the field is located within 150 feet of a channel, the Pennsylvania Phosphorus Index should be used (Pennsylvania Phosphorus Index, 2001). The Pennsylvania P-Index is comprised of transport and source factors defined by ratings of various subfactors. The transport factor is determined by adding the soil erosion, runoff class, subsurface drainage, and contributing distance ratings and then dividing by 22. The transport factor is then multiplied by a modified connectivity rating to obtain the final transport factor. The source factor is determined by adding a soil test rating, fertilizer rating, and manure rating. The P-Index is calculated by multiplying the transport and source factors and then multiplying the product by two. Site management recommendations are based on the P-Index value within the low, medium, high, and very high categories.

2.5.7 Vermont

The P-Index for Vermont includes ten site characteristics grouped into P source and P transport potential categories (Jokela, 2001). The site characteristics that comprise the P source potential are soil test P, fertilizer P, fertilizer P application method/timing, organic P rate, organic P application method/timing, and reactive aluminum. The factors that comprise the P transport potential are soil erosion, soil runoff class, flooding frequency, and buffer width. The P-Index is calculated by multiplying the P source potential by the P transport potential. Site management recommendations are based on the P-Index output within the low, medium, high, and very high categories.

2.5.8 Summary of Other State P-Indexes

In summary, many states have developed a P- Index, tailoring it to be site-specific for their state. The same general approach of source and transport components is used for all states under guidance suggested by NRCS. Most states have chosen to adopt a rating system using values for soil loss, soil test P, and P application rate. Only Iowa and Virginia have opted for a mass-based approach. Some states multiply factors together, some add and then multiply factors, and some multiply factors and then add these together. Overall, all management recommendations (Table 2.2) are similar for the states between N-based and P-based with some differences in risk categories and values. Some states have only chosen to recommend P application management, while others also require conservation practices to be implemented for the field. In most states, the switch to P-based management from N-based management is at the high risk of P loss level. Application rates in an N-based management system are based on N nutrient recommendations. In a P-based management system, application rates are based on crop removal of P.

2.6 *Virginia P-Index*

The Virginia P-Index (Figure 2.4) was developed by a multidisciplinary research team at Virginia Tech to quantify the risk of P delivery to surface water. The index is based on site-specific erosion, runoff, and subsurface risk factors. Source and transport factors included in the index were determined from data collected on selected Virginia soils, reference to published literature, and professional judgment of the P-Index development team (Mullins et al., 2002a).

Phosphorus Risk = Erosion Risk Factor + Runoff Risk Factor + Subsurface Risk Factor

P Index = 6.3 * Phosphorus Risk

Erosion Risk Factor = Edge of field soil loss (million lbs/ac) X Sediment P delivery factor (dimensionless) X Sediment total P factor (ppm)

Runoff Risk Factor = Runoff from field (million lbs/ac) X Runoff P delivery factor (dimensionless) X Runoff DRP[*] factor (ppm) + Applied fertilizer DRP[*] factor (lb/ac)

Subsurface Risk Factor = Percolation (million lbs/ac) X Soil texture/drainage factor (dimensionless) X Subsurface DRP[*] factor (ppm)

[*]DRP is dissolved reactive orthophosphate.

Figure 2.4: Version 1 of the Virginia P-Index (Mullins et al., 2002b)

The erosion risk factor is calculated by multiplying the edge of field loss by a sediment delivery factor by the sediment total P factor. The edge of field soil loss is calculated using RUSLE, a soil erosion model developed by USDA (Renard and Ferreira, 1993). If a vegetative filter strip is located at the downslope edge of the field, results from RUSLE are multiplied by a vegetated filter strip adjustment factor. The sediment delivery factor relates to the distance from a field to an intermittent or perennial stream and to the width of a buffer next to the stream. The sediment total P factor is based on region-specific equations relating to site-specific Mehlich I soil test results. Region specific source factors were developed for the following three regions: 1) Ridge and Valley, 2) Piedmont and Middle and Upper Coastal Plain (referred to as Piedmont hereafter), and 3) Eastern Shore and Lower Coastal Plain (referred to as Eastern Shore hereafter).

The runoff risk factor includes the following subfactors: 1) runoff from field based on the site curve number and regional average annual rainfall; 2) runoff delivery factor that relates to the distance from a field to an intermittent or perennial stream and buffer width next to the stream; 3) runoff dissolved reactive orthophosphate (DRP) factor, which is region-specific and is based on the dissolved P potentially available to runoff based on a Mehlich I soil test; and 4) the applied fertilizer DRP factor based on annual application rate of fertilizer, source availability of fertilizer, and method of fertilizer application. The first three subfactors are multiplied together and added to the fourth to yield the runoff risk factor.

The subsurface risk factor is calculated by multiplying average annual percolation, the soil texture/drainage factor, and the subsurface DRP factor. The average annual percolation is determined based on region, crop category, and curve number for the site. The soil texture/drainage factor was developed to account for the potential for P movement through subsurface transport based on the effects of soil texture and drainage. The soil texture/drainage factor was developed to assign a maximum risk of subsurface P losses to soils that (1) are very coarse textured to the minimum depth of drainage and (2) are so wet in their natural state that intensive agricultural practices are not possible without drainage. The subsurface DRP factor represents the dissolved P potentially available for subsurface loss and is determined from Mehlich I soil test results.

The P-index is then calculated by adding the erosion, runoff, and subsurface risk factors and multiplying by a scaling factor. The addition of the three risk factors estimates the potential P that could be delivered to surface water in lbs/acre/yr (without the scaling factor). A scaling factor is included in the P-Index to expand the P-Index scale such that the threshold for the very high category is 100. The specific value of the scaling factor was determined by the P-Index development team through evaluation of scenarios that yielded unacceptably high levels of P delivery to surface waters. Expanding the scale also helped to account for uncertainty in estimation of some parameter values. P-Index values are divided into four classes, low, medium, high or very high potential water quality impact, with associated P management guidelines (Table 2.3).

Version I of the Virginia P-index is now available for use as a fully automated spreadsheet (Mullins et al., 2002c). A technical guide has also been developed to support the spreadsheet (Mullins et al., 2002b). Index developers at Virginia Tech have trained some NRCS, Virginia Department of Conservation and Recreation (DCR), Virginia Department of Environmental Quality, and Virginia Cooperative Extension personnel in the use of the Index.

Table 2.3: General interpretation of the Virginia Phosphorus Site Index (Mullins et al., 2002b)

P Index Value	Potential Water Quality Impact	Phosphorus Management Guidance Based on Proposed Management Practices
0 – 30	Low	Phosphorus application according to N-based nutrient management is acceptable.
31 – 60	Medium	Phosphorus application for this site should not be more than 1.5 times crop removal.
61 – 100	High	Phosphorus application should not be greater than crop removal.
> 100	Very High	No phosphorus should be applied.

2.7 Sensitivity Analysis

Lane and Ferreira (1980) defined sensitivity analysis as determining the rate of change in one factor with respect to change in another factor. It can also be defined as the process of identifying and quantifying the magnitude of expected changes. A sensitivity analysis ranks parameters based on their contribution to overall changes in model predictions (Renard and Ferreira, 1993). A component of a sensitivity analysis of a model is the change in the output caused by changes in a model input. A sensitivity analysis identifies which input variables have the greatest effect on a particular output.

Sensitivity analyses are performed for a number of reasons. Objectives include determining the following: (a) which parameters require additional research for strengthening the knowledge base, thereby reducing output uncertainty; (b) which inputs contribute most to output variability; (c) which parameters are insignificant and can be eliminated from the final model; and (d) which parameters correlate most significantly to the output (Hamby, 1994). Meier et al. (1971) indicated that the sensitivity of a model's responses to variations in input data can be used to determine the relative importance of input information. This can place emphasis on developing and refining data that have the greatest influence on model output. A sensitivity analysis should be designed to include the range of expected errors of the input parameters under different conditions (Renard and Ferreira, 1993). This allows for a systematic means of determining the response of a model independent of errors in parameter estimation.

Sensitivity analysis techniques can be grouped into two categories, deterministic and stochastic approaches. All values are known in a deterministic approach; therefore, parameters are chosen to give the best model predictions for a particular situation. In the deterministic approach only one value is given for the input and the analysis is for one scenario. A stochastic sensitivity analysis is used when there is uncertainty in the values of various parameter inputs. A stochastic sensitivity analysis assesses the effect a parameter has on an output variable over the range of parameter values that are likely to be exhibited. The stochastic sensitivity analysis attempts to partition the variance observed in the output variable to multiple parameters (Renard and Ferreira, 1993). Tiscareno-Lopez (1991) used a stochastic approach to evaluate the erosion model WEPP where a range of values could represent an input parameter. Frequency distributions were determined for the input parameters by applying the Monte-Carlo approach to a set of empirical regression equations and from reported means and standard deviations when available. The output distribution was then determined through a Monte-Carlo sampling approach based on the distributions of the combined inputs to determine sensitivity. A step-wise regression approach was also completed to determine which input parameters the output of WEPP was most sensitive to.

There are different techniques or methods to quantify sensitivity of a model. Outlined below are some of the methods used, with a focus on analyses conducted for environmental models. The most basic method is differential analysis, or the direct method determined from simple partial derivatives (Morisawa and Inoue, 1974; Dickinson and Gelinas, 1976; Helton et al., 1985). When an explicit algebraic equation describes the relationship between the independent variables and the dependent variable, the sensitivity coefficient or relative sensitivity, ϕ_i, can be determined for any independent variable by calculating the partial derivative of the dependent variable Y, with respect to the independent variable, X (Artherton et al., 1975):

$$\phi_i \equiv \frac{\partial Y}{\partial X_i}\left(\frac{X_i}{Y}\right) \qquad [2.1]$$

where (X_i/Y) is used to normalize the coefficient by removing the effect of units. When a solution cannot be determined by the solution to the partial differential, relative sensitivity can also be calculated for any point as defined by James and Burges (1982) as follows:

$$S_r = \frac{\partial R}{\partial P}\frac{P}{R} \quad \text{or} \quad S_r = \frac{(R - R_b)}{(P - P_b)}\frac{P_b}{R_b} \qquad [2.2]$$

where S_r is relative sensitivity, R is the result or output, P is the model input parameter, and subscript b indicates values of the base scenario. The method uses a first-order approach in which one input is varied at a time.

Model sensitivity can be evaluated by ranking parameters from resultant output changes or by developing criteria to characterize parameter sensitivity. For example, Storm et. al. (1998) evaluated model sensitivity for a nonpoint source pollution model, ANSWERS, using relative sensitivity as: insensitive ($S_r < |0.01|$), slightly sensitive ($|0.01| \le S_r < |0.10|$), moderately sensitive ($|0.10| \le S_r < |1.00|$), sensitive ($|1.00| \le S_r < |2.00|$), and extremely sensitive ($S_r \ge |2.00|$).

Another sensitivity analysis method is the sensitivity index, or % difference in output when varying one input parameter from its minimum value to its maximum value (Hoffman and Gardner, 1983). Hoffman and Gardner (1983) advocated utilizing each parameter's entire range of possible values in order to assess true parameter sensitivities. Other sensitivity analysis methods utilize random sampling methods such as Monte Carlo or Latin hypercube to generate input and output distributions useful in assessing model and parameter uncertainties (Hamby, 1994). The model sensitivity depends on the range and distribution of an individual input parameter and on other parameters to which the model is sensitive (Iman et al., 1981). Some methods of evaluation include scatter plots, correlation coefficients of regression analysis, Pearson's r, and the relative deviation method (Hamby, 1994). The relative deviation method is the ratio of the standard deviation to the mean of the output density function when parameters are varied one-at-a-time, according to each parameter's probability density function (Hamby, 1994).

Heinen and Lydon (1989) performed a sensitivity analysis for a wildlife habitat index. Sensitivity was characterized as the impact of the contribution of individual variables on the model ratings. The index is based on a habitat analysis technique for use with raster-format data to assess impacts on habitat quality. Their method included analysis at two thresholds or baselines, low and median index values and medium and high index values. Weighting factors were assigned to base maps to determine the changes in the index. A chi-square test for homogeneity was used to test the null hypothesis that changing the different weighting factors does not change the threshold. The results of the threshold tests were determined to be highly dependent on the original input data and small changes in the input data led to significantly different output values, therefore, the hypothesis was rejected. This study shows that conducting a sensitivity analysis on an index can be useful for determining which factors result in the most change in the output and, thus, could be modified to improve the results.

2.8 Expert opinion surveys

Useful information can be obtained by eliciting expert opinion and experiences (Cooke, 1991). Expert opinion surveys have been used for various applications including evaluation of models and decision criteria and identifying model parameters and estimates (Lawrence et al., 1997; Fried and Gilless, 1989; Prins and Wind, 1993; Stark, 1998a; van der Fels-Klerz, 2000).

The Delphi method is the most well known method for eliciting and synthesizing expert opinions (Ayyub, 2001). The Delphi technique uses a systematic procedure for soliciting the advice of a number of experts and forging a consensus from that advice (Richey et al., 1985). The Delphi method was used extensively in the 1960s and 1970s, primarily for technological forecasting and policy analysis (Linstone and Turoff, 1975).

A decision support system (DSS) developed by scientists at the USDA-ARS Southwest Watershed Research Center used measured data and expert opinion to quantify eight decision criteria in the evaluation of four management systems for semiarid rangelands (Lawrence et al., 1997). The preferred management system chosen by the DSS was different than if only measured data or physical characteristics of the watershed were used. Information was obtained from nine experts from the University of Arizona and USDA who have professional experience in watershed management, erosion processes, rangeland management, wildlife management, and resource economics from a written survey. Stark et al. (1998a) used expert opinion to evaluate

EpiMAN-SF, a DSS used for managing swine fever epidemics. A written questionnaire was used to elicit expert opinion on classifying the outbreak events. Experts were asked to rank risk of fabricated contacts with swine on and off an imaginary property to assess salmonella outbreaks (Stark et al., 1998b). It was determined from the analysis that EpiMAN-SF is a valid alternative to traditional data management during exotic disease epidemics.

Fried and Gilless (1989) used an expert opinion survey to obtain estimates of fireline production rates for use in stochastic simulations of initial attack on wildland fires. The survey was conducted by having participants visit various sites and then asking them on a written sheet to estimate the time it would take to complete the fireline. The procedure was used due to deficiencies in literature on the subject and was determined to be a cost-effective method of quickly obtaining useable information. Pooled expert opinion was used to set priorities for evaluating nature management in Southeast Asia (Prins and Wind, 1993). Questionnaires were sent to 12 experts working on Indonesian nature projects and experts employed with the government to rank nature management techniques. Ranks were calculated from arithmetic means and were used to calculate priority values. The priority values were calculated by dividing the rank values by the total number of items in a topic, subtracting 1 from each result, and multiplying by the inverse of the value of the highest ranking item. The priority value was expressed on a scale of 0 (least important) to 1 (most important).

Morgan and Keith (1995) used expert elicitation methods drawn from decision analysis to obtain quantitative, probabilistic judgments about a number of key climate variables and about the nature of the climate system. They designed elicitation protocols for the format of the survey to minimize the effects of biases. They developed the assessment over a nine-month period using influence diagrams to evaluate which questions should be included in the interviews. Through the use of expert opinion they were able to obtain probabilistic results on unknown variables and determined that the overall uncertainty about the geophysics of climate change is not likely to change.

2.9 Summary of Literature Review

The reviewed literature has shown that there is a need for further evaluation of the Virginia P-Index. Increased P in soils from over application increases the risk of P delivery to surface water and a tool such as the P-Index could be used to identify fields with an increased risk. States including Virginia have developed P-Indexes as a P management tool. However, this is a new tool, and further evaluation is needed. As shown in the literature, a sensitivity analysis is a standard tool used to evaluate models and there are many approaches that can be used. The direct method appears to be the best method to be used since an explicit algebraic equation describes the relationship between the independent variables and the dependent variable. The literature review has shown that using opinions solicited from experts is an effective approach for gaining information and insight in areas where less information about the science or subject is available. A ranking system or scaling system can be useful for obtaining opinions of methods used in a system or approach. Expert opinion can be used for determining decision support systems. Although some bias might be present in solicitation of opinions from experts, useful information can be obtained in a prompt manner through written or telephone questionnaires.

3.0 Sensitivity Analysis

3.1 Introduction

A sensitivity analysis is a widely recognized procedure to determine significant inputs, identify sources of input error, and determine parameter precision or estimation. Completion of a sensitivity analysis is important to establish a sense of robustness of the recommendations generated by the index and will aid in continual development of the index and identification of any improvements that may be needed. The objective of the sensitivity analysis was to identify and numerically rank parameters based on relative sensitivity (eq. 2.1 and 2.2) whose changes have an impact on the P-index value. The following steps were completed for the sensitivity analysis:

1) identified parameters whose changes have an impact on the P-Index value and subsequent management recommendations in terms of relative sensitivity of the P-Index;
2) numerically ranked parameters based on results of relative sensitivity;
3) evaluated input variability and uncertainty using a probability distribution method; and
4) assessed the P-Index output distribution of baseline scenarios within the low, medium, high, and very high risk categories for water quality impact.

3.2 Methodology

3.2.1 Baseline Scenarios

Sensitivity of the P-Index output to inputs was determined based on three baseline scenarios for each of the three regions: 1) Ridge and Valley, 2) Piedmont and Middle and Upper Coastal Plain (Piedmont hereafter), and 3) Eastern Shore and Lower Coastal Plain (Eastern Shore hereafter). The analysis was conducted based on these three distinct regions since region-specific factors are included in the P-Index. The baseline scenarios were related to the interpretation of the P-Index as having low, medium, and high risk of P delivery to surface water and were based on field conditions and characteristics.

The following factors were used to establish low, medium, and high risk baseline scenarios: soil loss, Mehlich I soil test P, distance to stream, soil texture, curve number, and P application rate. To encompass the low, medium, and high risk of P delivery within regions, different baseline scenarios were used. For example, within the Ridge and Valley region of Virginia, a high risk is likely due to erosion potential, while in the Eastern Shore area of Virginia a high risk is more likely due to subsurface P loss potential.

Baseline scenarios for P delivery risk were developed based on typical fields within Rockingham, Amelia, and Accomack counties in the Commonwealth of Virginia (Figure 3.1), the three counties in which data were collected for development of the P-Index. The baseline scenarios (low, medium, and high) for each of the three regions are outlined in Table 3.1 with parameter inputs listed in Table 3.2.

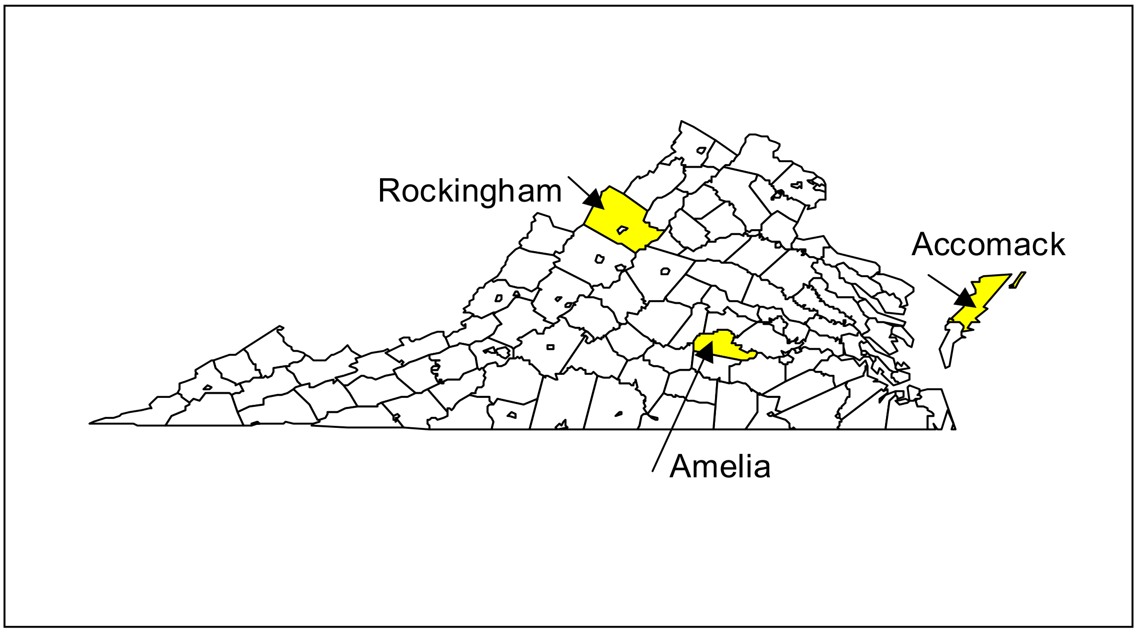

Figure 3.1: Location of Rockingham, Amelia, and Accomack Counties

Table 3.1: Baseline scenario characteristics

Ridge and Valley - Rockingham County
Low P delivery risk scenario: Hay with inorganic fertilizer, 10 acres, 6% slope, Silt Loam, Hydrologic group B, well drained
Medium P delivery risk scenario: Corn/Small Grain rotation, No-till corn, Poultry litter applied, 10 acres, 4% Slope, Silt Loam, Hydrologic group B, moderately to well drained
High P delivery risk scenario: Corn with conventional tillage: dairy manure applied, 10 acres, 5% slope, Silt loam, Hydrologic group B, moderately to well drained
Piedmont & Middle/Upper Coastal Plain - Amelia County
Low P delivery risk scenario: Hay with inorganic fertilizer, 10 acres, 4% slope, Silt Loam, Hydrologic group B, well drained
Medium P delivery risk scenario: Corn/Small Grain Rotation, No-till corn, Poultry litter applied, 10 acres, 6% Slope, Silt Loam, Hydrologic group B, moderately to well drained
High P delivery risk scenario: Corn, conventional tillage, dairy manure applied, 10 acres, 6% slope, Silt loam, Hydrologic group B, moderately to well drained
Eastern Shore & Lower Coastal Plain – Accomack County
Low P delivery risk scenario: Corn/Bean Rotation w/cover, inorganic fertilizer, 10 acres, 0.5% slope, sandy loam, hydrologic group B, well drained
Medium P delivery risk scenario: Corn/Small Grain Rotation, No-till corn, Poultry litter applied, 10 acres, 1% Slope, Fine Sandy Loam, Hydrologic group C , Somewhat poorly drained
High P delivery risk scenario: Corn, conventional tillage, poultry litter applied, 10 acres, 2% slope, Sandy loam, Hydrologic group D, poorly drained

Table 3.2: P delivery risk baseline scenario factors for the three regions

	Ridge and Valley: Rockingham County			Piedmont & Middle/Upper Coastal Plain: Amelia County			Eastern Shore & Lower Coastal Plain: Accomack County		
	Scenarios for P delivery risk			Scenarios for P delivery risk			Scenarios for P delivery risk		
Baseline Factors	Low	Medium	High	Low	Medium	High	Low	Medium	High
Annual soil loss (t/acre)	0.12	2.3	4.5	0.2	2.4	4.3	0.01	0.2	1.5
Mehlich I soil test P (ppm)	30	175	400	30	175	350	30	75	125
Distance to stream (ft)	400	275	225	400	290	150	400	100	12
Soil texture	0	0	0	0	0	0	0	0.25	0.75
Curve number (CN)	58	75	78	58	75	75	72	78	89
P application rate (P/acre)	43	95	105	43	95	105	43	95	105
P-Index	**14**	**46**	**89**	**14**	**41**	**79**	**14**	**42**	**101***

* P-Index output for this scenario is within the very high management category recommendation

Annual soil loss was determined based on typical fields and crops within each county using RUSLE (USDA-NRCS-VA 1997). Calculations of RUSLE soil loss for each baseline scenario are included in Appendix A. NRCS conservationists from each county provided information on crops, soil, and slope length. Mehlich I soil test P was determined from a distribution of soil samples collected for each of the three counties (P-Index development team, 2000). The soil texture was typical according to the county soil survey for each county. Phosphorus application corresponded to a low rate or crop removal P-based rate and rates just lower than rates based on N requirements for the crop. For the low P risk scenarios, a low P rate was chosen to represent supplemental nutrients added to pasture where inorganic fertilizer was used based on a crop removal P-based rate. Other rates were based on crop removal of N when manure was applied. Since a sensitivity analysis would vary the value a percentage from the baseline, a slightly lower P application rate than recommended N-based rates was used so that in the high case the P application rate would not be unrealistic when the parameter was varied +/- 35%. For example, in a corn and rye rotation a recommended N application rate for the silt loam may be 325 lbs N as poultry litter corresponding to a rate of 116 lbs P/acre. Therefore, a slightly lower application rate (105 lbs P/acre) was used as the baseline. To maintain consistency among the scenarios, all fields were 10 acres in size.

Inorganic fertilizer was chosen for the low baseline scenarios for all three counties. Inorganic fertilizer was chosen over manure for this baseline to represent a field where only required nutrients have been applied and thus nutrient levels in the soil are not built up from over application. Poultry litter was applied for the medium scenarios and the high scenario for Accomack county. This was representative of agricultural land within the three counties. Dairy is also present in Amelia and Rockingham counties; therefore, dairy manure was applied for the high risk scenarios for both of those counties. The distance to the stream is representative of conditions from data collected in a study by Virginia Tech (P-Index development team, 2000) for fields within each county and interviews with local NRCS conservationists.

3.2.2 Sensitivity Analysis Procedure

The sensitivity analysis included multiple scenarios within the P-Index output range based on the low, medium, and high risk of P delivery baseline scenarios. A first-order sensitivity analysis was used with one input varied at a time and sensitivity quantified in terms of relative sensitivity (eq. 2.1 and eq. 2.2). A direct method, or differential analysis, was used to calculate relative sensitivity by determining the derivative of the P-Index equation with respect to the parameter of interest for all parameters except curve number and distance to stream. For those two parameters, relative sensitivity was calculated by varying each parameter +/- 15 and 35% and/or within categories from its base value (eq. 2.2). The percentages of 15 and 35 % were selected to represent the range of interest of the parameters. Figure 3.2 shows a schematic of the sensitivity analysis procedure.

The magnitude of relative sensitivity indicates the sensitivity of the P-Index to a corresponding parameter and measures the proportional change between the input and the output. Therefore, if relative sensitivity is +/-1, the output changes proportionally with changes in model input. Categories for relative sensitivity were defined as used by Storm et al. (1998): insensitive ($S_r < |0.01|$), slightly sensitive ($|0.01| \leq S_r < |0.10|$), moderately sensitive ($|0.10| \leq S_r < |1.00|$), sensitive ($|1.00| \leq S_r < |2.00|$), and extremely sensitive ($S_r \geq |2.00|$).

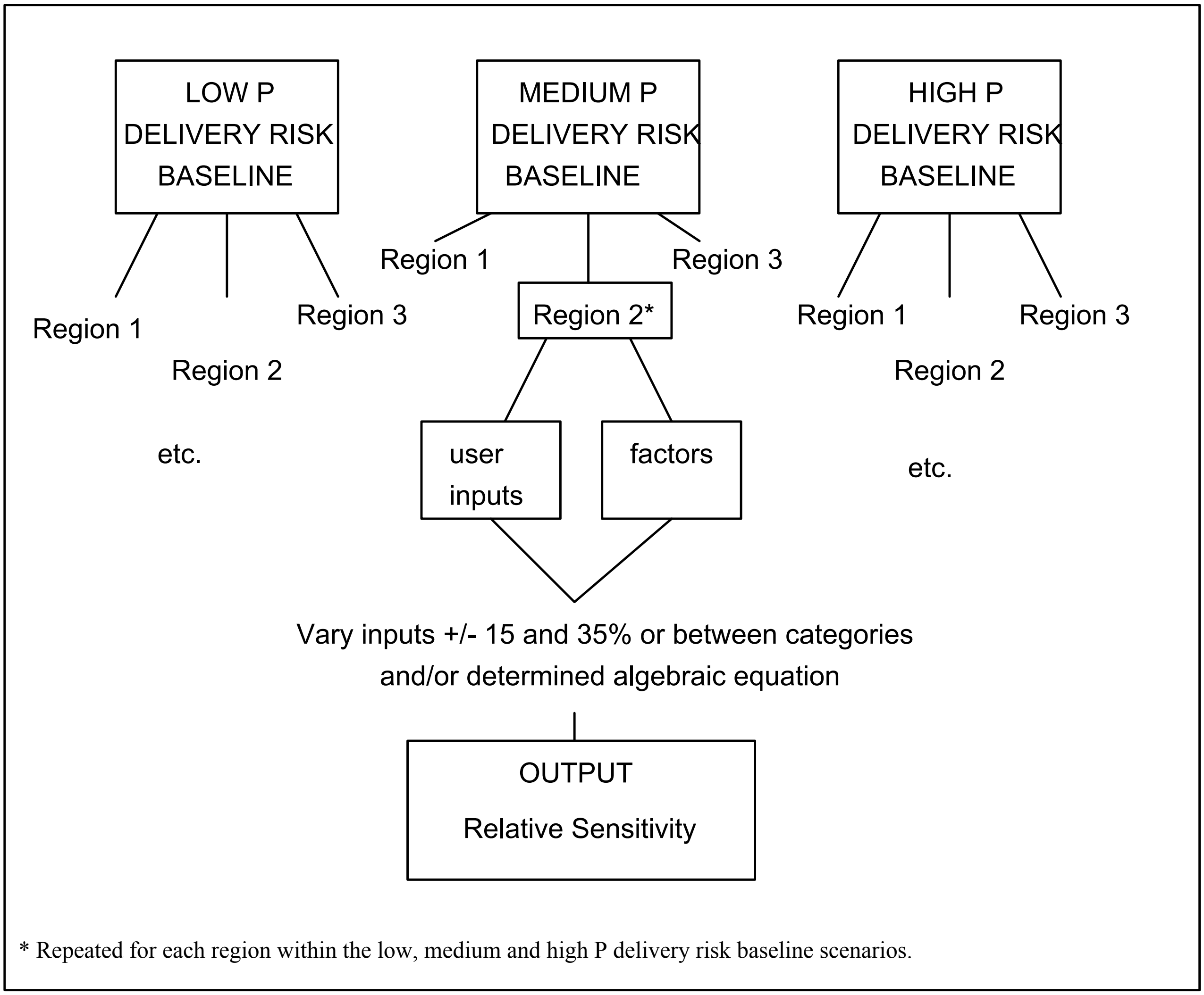

Figure 3.2: Sensitivity analysis procedure

Changes in P management recommendation categories due to varying parameters from the baseline were evaluated. For example, if the index changes 10 units from 45 to 55, there is no change in the management guideline (Table 2.3), however, a change from 55 to 65 results in a change in the management category from medium to high. Parameters were varied +/- 15 and 35% and/or within categories for those that have distinct categories such as method of fertilizer application. Table 3.3 lists the input parameters and subfactors developed from those inputs and whether they were varied a percentage or within categories.

Table 3.3: Input parameters and developed subfactors used in sensitivity analysis and varied a percentage or within a category

Varied a percentage from base values	
Input parameters	edge of field soil loss, Mehlich I soil test P, distance to stream, curve number, and P application rate
Developed subfactors	vegetated filter strip adjustment factor, sediment delivery factor, sediment total P factor, runoff from field, runoff delivery factor, runoff DRP factor, applied DRP factor, percolation, and subsurface DRP factor
Varied by categories from base values	
Input parameters	soil texture, method of application, and type of fertilizer
Developed subfactors	soil texture/drainage factor, sediment delivery factor, and runoff delivery factor

3.2.3 Probability Distribution Procedure

When model input values are uncertain, stochastic methods are recommended to complete a sensitivity analysis (Tiscareno-Lopez, 1991). The program @Risk (Palisade Corp.), a risk analysis software package that uses a Monte Carlo or Latin Hypercube random sampling method, was employed to evaluate input variability. The objective of this analysis was to identify the impact on the P-Index output of parameters that could vary largely due to user and site variability. The direct method and relative sensitivity analysis identified which parameters the P-Index is most sensitive to under various soil, management, and transport scenarios.

Probability distributions were defined for the following inputs: average annual soil loss, distance to stream, and Mehlich I soil test P. These values were chosen since a range of possible values could be used in the calculation due to various sources of error including variability in calculating RUSLE, different interpretations or measurements of distance to stream, and sampling variability for soil test P. For this analysis, it was assumed that specification of hydrologic soil group, soil texture, region, application rate, crop, and management of the crop did not vary among users. Although it is possible a field would have different textures and hydrologic soil groups within the field, it was assumed that the majority soil type would be evaluated and thus all users would enter the same texture and hydrologic soil group.

A method was needed to evaluate the distribution or range of values for soil loss, distance to stream, and Mehlich I soil test P. The best way to identify the range and distribution of the values of these parameters would be for many different users to calculate the P-Index for a field. This was not possible due to timing and financial constraints since the P-Index has not been implemented. Further, it would have been very difficult to get enough people to test the P-Index for a field that would have been statistically appropriate in the time frame to complete this objective. Instead, a distribution of values for each of these parameters was determined based on a review of published values and professional judgment. A truncated triangular distribution was used to represent the variability of soil loss, a discrete distribution was used to represent the variability of distance to stream, and a lognormal distribution was used to represent the variability of soil test P. Determination of the appropriate distributions for each parameter is described in the following paragraphs.

Soil loss is estimated with RUSLE by multiplying the following factors:

$$A = R\ \text{Factor} * K\ \text{Factor} * LS\ \text{Factor} * C\ \text{Factor} * P\ \text{Factor} \qquad [3.1]$$

where, R = the factor for climatic erosivity
K = the factor for soil erodibility
LS = the factor for slope length/slope steepness
C = the factor for cover management
P = the factor for support practices
A = average annual soil loss (tons/acre/yr)

David Lightle (personal communication), a RUSLE researcher and developer with NRCS, indicated that he was not aware of any studies addressing user interpretation and variability of RUSLE. He did describe efforts to develop a national database for RUSLE2, an updated version of RUSLE with improved values that is more user-friendly (University of Tennessee et al., 2002), for crop and field operations, climate, and soil data to reduce the variability among different users. According to David Lightle (personal communication), considerable variability related to individual judgments that could impact RUSLE results include the following: choosing the slope steepness and length; choosing the soil component and corresponding soil erodibility (K) value; defining the farming system and yield level; and choosing values to account for practice (P) effects of contouring, terraces or strips. Boyce Harvey (personal communication), who works on regional cropping (C) values for RUSLE with NRCS in Virginia, indicated that determination of slope steepness and length could vary among users or the individual from day to day and contributes to the greatest variability in determining soil loss.

Of the components of RUSLE, the LS factor contributes the majority of the user error (USDA-NRCS-VA, 1997) since this factor is determined subjectively using different approaches. According to the Virginia RUSLE technical guide (USDA-NRCS-VA, 1997), the LS factor could be based on the steepest slope or on a combination of segments within the field and averaged based on weighting of the segments. Therefore, estimation of the LS factor could vary significantly from user to user. RUSLE is more sensitive to slope steepness than to slope length (Renard and Ferreira, 1993). Slope is also considered in the R adjustment factor for ponding for slopes less than 4%.

User variability could also occur in choosing C factors, however, since the Virginia RUSLE guide contains C factors for many different cropping/management combinations for each region and new factors can be developed by request (Boyce Harvey, personal communication), error within this factor was not considered. User variability could also occur in choosing the correct K factor, but for this analysis it was assumed that the correct soil was identified. Since contouring, terracing, and strips were not considered in the baseline scenarios, user variability in the P factor was not considered.

The range of values for soil loss for each of the baseline scenarios was based on variability of slope steepness and slope length. Since fields in the baseline were not actual fields, it was assumed that slope steepness and slope length were fairly uniform for the field. Therefore, a combination of segments was not used to calculate the LS factor. The ranges of soil loss values for all baseline scenarios are listed in Table 3.4. These ranges corresponded to annual soil loss based on estimated values for the LS and R ponding factors when the slope was varied +/- 1.0 % and slope length was varied +/- 50 feet.

Table 3.4: Range of edge of field soil loss values used in the P-Index sensitivity analysis

Baseline Scenario	Slope Steepness (%)	Slope Length (ft)	Length Slope Factor	R Ponding Factor	Soil loss (ton/acre)
Range	min-baseline-max	min-baseline-max	min-baseline-max	min-baseline-max	Min-baseline-max
Low P Risk Ridge and Valley	3-4-5	100-150-200	0.38 - 0.54 - 0.73	na	0.09 – 0.12 - 0.19
Medium P Risk Ridge and Valley	3-4-5	100-150-200	0.39 - 0.6 - 0.86	na	1.5 - 2.3 - 3.3
High P Risk Ridge and Valley	4-5-6	100-150-200	0.52 - 0.76 - 1.05	na	3.1 - 4.6 - 6.3
Low P Risk Piedmont	3-4-5	125-175-225	0.39 - 0.57 - 0.93	na	0.12 – 0.18 - 0.29
Medium P Risk Piedmont	5-6-7	125-175-225	0.60 - 0.99 - 1.45	na	1.5 - 2.4 - 3.5
High P Risk Piedmont	5-6-7	125-175-225	0.60 - 0.99 - 1.46	na	2.6 - 4.3 - 6.3
Low P Risk Eastern Shore	0.2-0.5-1	200-250-300	0.05 - 0.09 - 0.17	0.62 - 0.68 - 0.77	0.05 - 0.1 - 0.2
Medium P Risk Eastern Shore	0.5-1-2	250-300-350	0.09 - 0.17 - 0.35	0.68 - 0.77 - 0.84	0.08 – 0.17 - 0.39
High P Risk Eastern Shore	1-2-3	250-300-350	0.17 - 0.35 - 0.55	0.77 - 0.87 - 0.93	0.62 – 1.45 - 2.43

na-not applicable

A truncated triangular distribution was then used to fit the data distribution. This distribution was chosen since it places the most emphasis on the baseline value, which would be more likely chosen by the user (@ Risk, 2000). Further, this distribution is simple and can be used when the variability is unknown. In a triangular distribution, the probability of both the minimum and maximum value is zero. This does not represent the data since the minimum and maximum values are considered possible values, therefore, the distribution was fitted for a larger range and truncated at the minimum and maximum values. In a triangular distribution, the most likely value is chosen 1.5 times more than the other values (@Risk, 2000). Figure 3.3 is an example of the fitted distribution for soil loss for the medium risk of P delivery Ridge and Valley baseline scenario.

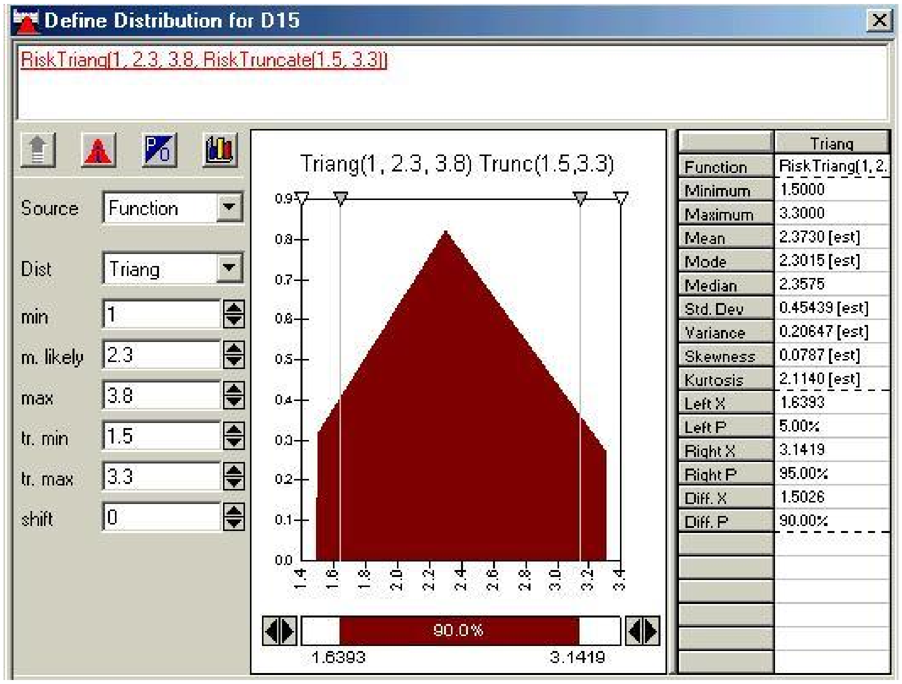

Figure 3.3: Screen from @Risk of the distribution for soil loss for the Ridge and Valley medium risk of P delivery scenario

Estimates of distance to stream could also vary from user to user. Depending on the situation in the field, the user may pace out the distance if close, measure the distance, estimate from observation, or obtain a value from a topographic or soil survey map. Furthermore, the distance is based on flow length distances, which could also vary in user interpretation. Distance to stream affects both the sediment and runoff delivery factors. Since distinct categories are the only possibilities, a discrete distribution was used to define distance to stream variability. Variability between categories would only occur if distances were close to a different category. Values of the sediment and runoff delivery factors are provided in Table 3.5 and Table 3.6, respectively.

Table 3.5: Sediment delivery factor for the Virginia P Index

Flow Distance from Edge of Field to an Intermittent or Perennial Stream/ Stream Buffer Width	Sediment Delivery Factor
> 500 ft OR stream buffer width > 100 ft	0.3
300-500 ft OR stream buffer width of 75-100 ft	0.5
200-300 ft OR stream buffer width of 50-75 ft	0.7
100-200 ft OR stream buffer width of 25-50 ft	0.8
25-100 ft AND stream buffer width < 25 ft	0.9
< 25 ft	1.0

Table 3.6: Runoff delivery factor for the Virginia P Index

Flow Distance from Field to an Intermittent or Perennial Stream/Stream Buffer Width	Runoff Delivery Factor
> 500 ft OR stream buffer width > 100 ft	0.4
300-500 ft OR stream buffer width of 75-100 ft	0.6
200-300 ft OR stream buffer width of 50-75 ft	0.8
100-200 ft OR stream buffer width of 25-50 ft	0.9
0-100 ft AND stream buffer width < 25 ft	1.0

It was assumed that the baseline scenarios with a distance to stream of 400 feet, 150 feet, and 12 feet would have no category change. For all others there would be a possibility of choosing a different category than the baseline value. Therefore, discrete distributions were defined as outlined in Table 3.7 based on reasonable probabilities. While sediment and runoff delivery factors were evaluated only with respect to varying distance to stream, the same type of variability could occur with buffer widths (Table 3.5 and Table 3.6).

Table 3.7: Probability distributions for distance to stream

Distance to Stream (ft)	Sediment Delivery Factor		Runoff Delivery Factor	
	Probability	Value	Probability	Value
400	100%	0.5	100%	0.6
290	65%	0.7	65%	0.7
	35%	0.5	35%	0.5
275	80%	0.7	80%	0.8
	20%	0.5	20%	0.6
225	80%	0.7	80%	0.8
	20%	0.8	20%	0.9
150	100%	0.8	100%	0.9
100	60%	0.9	60%	1.0
	40%	0.8	40%	0.9
12	100%	1.0	100%	1.0

Variability of soil test P in a field is due to many different factors including uniformity of fertilizer application, variability of soil type/texture within the field, crop yields, water holding capacity, tillage, slope, and rate of P fertilizer application. Therefore, composite soil sampling is done based on various guidelines in order to obtain representative results. Different sampling techniques could be used to determine soil test P for a field, including one composite soil sample per area in field, composite sampling by soil type in a field, or grid sampling. The most common sampling technique is composite soil sampling for a uniform field (Havlin et. al, 1999). Soil sampling instructions are provided by the Virginia Tech Soil Testing Laboratory on the sample box and are listed in Table 3.8.

Table 3.8: Virginia Tech Soil Testing Laboratory soil sample collection instructions (from sample box)

1.	Equipment needed: sampling tube, spade, trowel, or auger and clean plastic pail
2.	Samples should be made up of at least 5 subsamples or cores from each acre represented by the sample. Sample to plow depth in cropland and the top two to four inches in pasture, or sod. Mix sample thoroughly in the pail before the sample carton is filled with soil. Sample should not represent much over 10 acres.
3.	If there are visible differences in soils or crop growth in a field, a separate sample should be taken from each uniform area. Do not take subsamples from eroded spots, back furrows, or small depressions. Large areas in a field that have been manured, limed, fertilized, or otherwise treated differently should be sampled separately.

These instructions are provided to facilitate obtaining representative results. However, variability of composite soil results will still occur due to reasons such as the soil sampler not adequately following instructions and randomness of sample collection locations. Furthermore, soil samples collected for the entire plow layer may not be representative of the surface layer soil if fertilizer was not incorporated, thus adding to variability. For 164 soil samples collected by the P-Index development team within the three regions, Mehlich I soil test P varied between the surface layer (0-1 inches) and plow layer (0-6 inches) from 2 ppm to 400 ppm (P-Index Development Team, 2001). Therefore, it is difficult in general to estimate error.

In a study by Schmidt et al. (2002), soil samples (5, 10, 20, 30, or 50 per field) were randomly collected from eight fields to obtain frequency distributions of soil test P. It was determined from the study that the lognormal population distribution best represented the population of soil test P from a field (Schmidt et al., 2002). Therefore, a lognormal population distribution was used for Mehlich I soil test P variability. Compiled in Table 3.9 are results for Mehlich I soil test P soil samples from grid sampling within fields within Virginia. Limited data were available but sites included fields from each of the three regions (Ridge and Valley-Augusta County, Piedmont- Goochland County, Coastal Plain). Much of the variability in soil test P within the fields can be attributed to different soil types that have different abilities to hold P. For example, in the Anderson-Cook et al. (1999) study, field two had more soil variability than field one corresponding to a greater variability of soil test P.

Table 3.9: Grid sampling Mehlich I soil test P results for some fields within Virginia

Source	Region	Site ID	Range for Mehlich 1 soil test P (ppm)
Anderson-Cook et al. (1999)	Coastal Plain	Field 1	Composite: mean 14 ppm Comp by soil-type: mean 16 ppm range 14-21 ppm 0.83 ha grid size: mean 15 ppm range 9-22 ppm 0.33 ha grid size: mean 13 ppm range 8-18 ppm
Anderson-Cook et al. (1999)	Coastal Plain	Field 2	Composite: mean 22 ppm Comp by soil-type: mean 23 ppm range 17-32 ppm 0.83 ha grid size: mean 21 ppm range 3-62 ppm 0.33 ha grid size: mean 22 ppm range 6-63 ppm
Raines, Unpublished data (2002)	Ridge & Valley-Augusta County	Field D1	mean: 60 ppm range: 10 –127 ppm # grid samples: 28
Raines, Unpublished data (2002)	Ridge & Valley-Augusta County	Field D2	mean: 32.5 ppm range: 4 -117 ppm # grid samples 29
Raines, Unpublished data (2002)	Ridge & Valley-Augusta County	Field D3	mean: 32.8 ppm range: 5 –110 ppm # grid samples: 19
Raines, Unpublished data (2002)	Piedmont-Goochland County	Field S901	mean: 28.7 range: 7-93 ppm # grid samples: 50

The baseline scenario fields were fictional, thus soil variability within a field was not known. It was assumed that some soil texture differences were present within a field leading to some variability within soil test P but not as much as the Raines (2002) fields since the size of the fields in the study were generally larger than the baseline scenarios of ten acres. Thus ranges within more uniform soil types were used. The variability of composite sampling is of importance. However, since there were no studies available to address variability of composite sampling of soil test P, estimates of variability were lower than the range of grid sampling to account for the averaging effect of composite sampling. The distributions for soil test P for each of the baselines for composite soil sampling are given in Table 3.10.

Table 3.10: Distributions for soil test P for each of the baselines for composite soil sampling for each of the baseline scenarios

Region and baseline scenario	Baseline Mehlich I P (ppm)	Range and Distribution	
Ridge and Valley			
Low risk of P delivery	30	15-45	Lognormal distribution (mean=30, SD* = 5)
Medium risk of P delivery	175	140-210	Lognormal distribution (mean=175, SD= 10)
High risk of P delivery	400	370-430	Lognormal distribution (mean=400,SD= 10)
Piedmont			
Low risk of P delivery	30	15-45	Lognormal distribution (mean=30, SD= 5)
Medium risk of P delivery	175	155-195	Lognormal distribution (mean=175, SD= 7.5)
High risk of P delivery	350	330-370	Lognormal distribution (mean=350, SD= 7.5)
Eastern Shore			
Low risk of P delivery	30	15-45	Lognormal distribution (mean=30, SD= 5)
Medium risk of P delivery	75	60-90	Lognormal distribution (mean=75, SD= 5)
High risk of P delivery	125	110-140	Lognormal distribution (mean=125, SD= 5)

*standard deviation from the mean

Once all probability distributions were defined for the inputs, the overall P-Index distribution was determined based on the probability input distributions. The program @Risk was used to calculate the distribution of the P-Index output using the Latin Hypercube random sampling method (Iman et al., 1981) to generate the output. The Latin hypercube sampling method was chosen over the Monte Carlo sampling method. The sampling methods differ in the number of iterations required until sampled values approximate input distributions (Palisade, 2000). In the Monte Carlo sampling method, a large number of samples is required to approximate the input distribution, especially if the input has values of low probability. The Latin Hypercube sampling method forces the samples drawn to correspond more closely with the input distribution, converging faster on the true statistics of the input distribution.

A regression analysis of the P-Index output was also completed for the parameters where a probability distribution was used. The parameters with the highest regression coefficients contributed most to the variability of the output. This procedure was used for each of the three baseline scenarios for all three regions. This analysis determined which of the parameters defined by a probability distribution had the largest impact on changes in the overall P-Index output under the baseline scenarios.

The probability of being in each P management category was also determined based on the results of user/parameter variability. The distribution of the output was used to calculate the probability of being in each P management category by determining the portion of the probability distribution that was within each P management category.

3.3 Results and Discussion

3.3.1 P-Index Sensitivity

The sensitivity analysis was conducted for the nine baseline scenarios. Equation 3.1 is the algebraic equation for the P-Index. Sediment total P factor, runoff DRP factor, and subsurface DRP factor vary among the regions and are defined by equations 3.2 through 3.10. Equation 3.11 is the sensitivity coefficient for soil loss and Equation 3.12 is the sensitivity coefficient for Mehlich I P for the Ridge and Valley region low risk of P delivery scenario. The sensitivity was calculated by determining the derivative with respect to the parameter of interest. The relative sensitivity was computed for each of the factors in equation 3.1.

$$PI \equiv \left[(SL * VFSA * SDF * STP) + (R * RDF * RDRP + (SAF * MA * APR)) + (P * STF * SDRP)\right] * 6.3 \quad [3.1]$$

where, PI = Virginia P-Index output
SL = soil loss (million lbs/ac)
VFSA = vegetative filter strip adjustment factor (dimensionless)
SDF = sediment delivery factor (dimensionless)
STP = sediment total P Factor (ppm)

$$STP = 642 + 1.89 * MEHI \quad \text{Ridge and Valley} \quad [3.2]$$

$$STP = 305 + 2.04 * MEHI \quad \text{Piedmont} \quad [3.3]$$

$$STP = 239 + 2.51 * MEHI \quad \text{Eastern Shore} \quad [3.4]$$

R = runoff from field (million lbs/ac)
RDF = runoff delivery factor (dimensionless)
RDRP = runoff DRP factor (ppm)

$$RDRP = 0.35 + 0.0057 * MEHI \quad \text{Ridge and Valley} \quad [3.5]$$

$$RDRP = -0.32 + 0.0093 * MEHI \quad \text{Piedmont} \quad [3.6]$$

$$RDRP = 0.0088 * MEHI \quad \text{Eastern Shore} \quad [3.7]$$

SAF = source availability factor (dimensionless)
MA = method of P application factor (dimensionless)
APR = annual application rate of P (lbs P/ac)
P = percolation (million lbs/ac)
STF = soil texture/drainage factor (dimensionless)
SDRP = subsurface DRP factor (ppm)

$$SDRP = 0.34 + 0.021 * MEHI \quad \text{Ridge and Valley} \quad [3.8]$$

$$SDRP = -1.72 + 0.034 * MEHI \quad \text{Piedmont} \tag{3.9}$$

$$SDRP = 0.07 + 0.02 * MEHI \quad \text{Eastern Shore} \tag{3.10}$$

The sensitivity coefficient for soil loss for the Ridge and Valley low risk of P delivery baseline scenario is:

$$\phi = \frac{\partial PI}{\partial SL}\left(\frac{SL}{PI}\right) = VFSA * SDF * (642 + 1.89 * MEHI) * 6.3 * \left(\frac{SL_i}{PI}\right) \tag{3.11}$$

$$\phi = 1 * 0.5 * (642 + 1.89 * 30) * 6.3 * \left(\frac{0.000248}{14.2}\right) = 0.03$$

where, VFSA = vegetative filter strip adjustment factor = 1
SDF = sediment delivery factor = 0.5
MEHI = Mehlich I soil test P = 30 ppm
SL_i = soil loss baseline value = 0.000248 million lbs/ac
PI = P-Index Output = 14.2

The sensitivity coefficient for Mehlich I P for the Ridge and Valley low risk of P delivery baseline scenario is:

$$\phi = [(SL * VFSA * SDF * (0 + 1.89)) + (R * RDF * (0 + 0.0057)) + (P * STF * (0 + 0.021))] * 6.3 * \left(\frac{MEHI_i}{PI}\right) \tag{3.12}$$

$$\phi = [(0.000248 * 1 * 0.5 * 1.89) + (0.4 * 0.6 * 0.0057) + (6.55 * 0 * 0.021)] * 6.3 * \left(\frac{30}{14.2}\right) = 0.005$$

where, SL = soil loss = 0.00248 million lbs/ac
VFSA = vegetative filter strip adjustment factor = 1
SDF = sediment delivery factor = 0.5
MEHI = Mehlich I soil test P = 30
R = runoff from field = 0.4 million lbs/ac
RDF = runoff delivery factor = 0.6
P = percolation = 6.55 million lbs/ac
STF = soil texture/drainage factor = 0
PI = P-Index output = 14.2

Relative sensitivities were calculated as defined by partial derivatives for all parameters except curve number and distance to stream. These parameters are not explicit within eq. 3.1 but are inputs for specific subfactors. Runoff and percolation are functions of curve number; sediment and runoff delivery factors are functions of distance to stream. Relative sensitivity of the P-Index to curve number and distance to stream was calculated by varying each parameter +/- 15 and 35% from its base value (eq.2.2). Relative sensitivity values are given in Table 3.11. The relative sensitivity of the P-Index to the various parameters is ranked in Table 3.12 from highest to lowest for each of the nine baseline scenarios. Within each column, relative sensitivity is ranked for a particular baseline. Because relative sensitivity was the same for some parameters, those parameters have the same ranking. Additional results of the relative sensitivity analysis are included in Appendix B including the output values when parameters were varied +/- 15 and 35% or +/-1 and 2 categories from their baseline values.

The sensitivity analysis was conducted to identify and rank parameters whose changes have an impact on the P-Index value and subsequent management recommendations. There were differences in relative sensitivity between the low, medium, and high P delivery risk scenarios within each of the regions. Relative sensitivity results were more similar between the Ridge and Valley and Piedmont regions compared to the Eastern Shore region. Differences in sensitivity compared to the other regions were observed for the Eastern Shore region where an effect of poor or artificial drainage contributes to P-Index results. The P-Index was most sensitive in the low and medium scenarios to the management subfactors including annual application rate, method of fertilizer application, applied fertilizer DRP, and source availability factor. The P-Index was moderately sensitive to the erosion subfactors for the medium risk of P delivery scenarios for the Ridge and Valley and Piedmont regions.

The P-Index was moderately sensitive to sensitive to curve number for all baseline scenarios except the Ridge and Valley and Piedmont low P delivery risk scenarios. In the Ridge and Valley and Piedmont low P delivery risk scenarios, the P-Index was insensitive to curve number; annual runoff was 1.5 to 2 inches less in the low scenario than the other scenarios. The P-Index was moderately sensitive ($|0.10| \leq S < |1.00|$) to distance to stream when there was a change between categories. When there was no change between categories, there was no change in the P-Index output and thus the P-Index was insensitive to the parameter.

Table 3.11: Relative sensitivity for all parameters for each of the baseline scenarios within the three regions

<table>
<tr><th rowspan="4">Parameters</th><th colspan="18">Relative Sensitivity</th></tr>
<tr><th colspan="6">Ridge and Valley</th><th colspan="6">Piedmont & Upper Coastal Plain</th><th colspan="6">Eastern Shore & Lower Coastal Plain</th></tr>
<tr><th colspan="6">P Risk Delivery Scenarios</th><th colspan="6">P Risk Delivery Scenarios</th><th colspan="6">P Risk Delivery Scenarios</th></tr>
<tr><th colspan="2">Low</th><th colspan="2">Medium</th><th colspan="2">High</th><th colspan="2">Low</th><th colspan="2">Medium</th><th colspan="2">High</th><th colspan="2">Low</th><th colspan="2">Medium</th><th colspan="2">High</th></tr>
<tr><td>Erosion Risk Factor</td><td colspan="2">0.039</td><td colspan="2">0.43</td><td colspan="2">0.62</td><td colspan="2">0.033</td><td colspan="2">0.34</td><td colspan="2">0.56</td><td colspan="2">0.010</td><td colspan="2">0.023</td><td colspan="2">0.10</td></tr>
<tr><td>Edge of field soil loss (RUSLE) (million lbs/ac)</td><td colspan="2">0.039</td><td colspan="2">0.43</td><td colspan="2">0.62</td><td colspan="2">0.033</td><td colspan="2">0.34</td><td colspan="2">0.56</td><td colspan="2">0.010</td><td colspan="2">0.023</td><td colspan="2">0.10</td></tr>
<tr><td>Vegetated Filter Strip Adjustment Factor</td><td colspan="2">0.039</td><td colspan="2">0.43</td><td colspan="2">0.62</td><td colspan="2">0.033</td><td colspan="2">0.34</td><td colspan="2">0.56</td><td colspan="2">0.010</td><td colspan="2">0.023</td><td colspan="2">0.10</td></tr>
<tr><td>Sediment Delivery Factor</td><td colspan="2">0.039</td><td colspan="2">0.43</td><td colspan="2">0.62</td><td colspan="2">0.033</td><td colspan="2">0.34</td><td colspan="2">0.56</td><td colspan="2">0.010</td><td colspan="2">0.023</td><td colspan="2">0.10</td></tr>
<tr><td>Sediment Total P (ppm P in soil)</td><td colspan="2">0.039</td><td colspan="2">0.43</td><td colspan="2">0.62</td><td colspan="2">0.033</td><td colspan="2">0.34</td><td colspan="2">0.56</td><td colspan="2">0.010</td><td colspan="2">0.023</td><td colspan="2">0.10</td></tr>
<tr><td>Runoff Risk Factor</td><td colspan="2">0.961</td><td colspan="2">0.57</td><td colspan="2">0.38</td><td colspan="2">0.967</td><td colspan="2">0.66</td><td colspan="2">0.44</td><td colspan="2">0.990</td><td colspan="2">0.647</td><td colspan="2">0.42</td></tr>
<tr><td>Runoff from field (million lbs water/ac)</td><td colspan="2">0.005</td><td colspan="2">0.056</td><td colspan="2">0.081</td><td colspan="2">0</td><td colspan="2">0.081</td><td colspan="2">0.11</td><td colspan="2">0.027</td><td colspan="2">0.074</td><td colspan="2">0.16</td></tr>
<tr><td>Runoff Delivery Factor</td><td colspan="2">0.005</td><td colspan="2">0.056</td><td colspan="2">0.081</td><td colspan="2">0</td><td colspan="2">0.081</td><td colspan="2">0.11</td><td colspan="2">0.027</td><td colspan="2">0.074</td><td colspan="2">0.16</td></tr>
<tr><td>Runoff DRP (ppm)</td><td colspan="2">0.005</td><td colspan="2">0.056</td><td colspan="2">0.081</td><td colspan="2">0</td><td colspan="2">0.081</td><td colspan="2">0.11</td><td colspan="2">0.027</td><td colspan="2">0.074</td><td colspan="2">0.16</td></tr>
<tr><td>Applied Fertilizer DRP Factor</td><td colspan="2">0.96</td><td colspan="2">0.52</td><td colspan="2">0.30</td><td colspan="2">0.97</td><td colspan="2">0.58</td><td colspan="2">0.33</td><td colspan="2">0.96</td><td colspan="2">0.57</td><td colspan="2">0.26</td></tr>
<tr><td>Annual Application Rate (lbs P/ac)</td><td colspan="2">0.96</td><td colspan="2">0.52</td><td colspan="2">0.30</td><td colspan="2">0.97</td><td colspan="2">0.58</td><td colspan="2">0.33</td><td colspan="2">0.96</td><td colspan="2">0.57</td><td colspan="2">0.26</td></tr>
<tr><td>Method of Fertilizer Application Factor</td><td colspan="2">0.96</td><td colspan="2">0.52</td><td colspan="2">0.30</td><td colspan="2">0.97</td><td colspan="2">0.58</td><td colspan="2">0.33</td><td colspan="2">0.96</td><td colspan="2">0.57</td><td colspan="2">0.26</td></tr>
<tr><td>Source Availability Factor</td><td colspan="2">0.96</td><td colspan="2">0.52</td><td colspan="2">0.30</td><td colspan="2">0.97</td><td colspan="2">0.58</td><td colspan="2">0.33</td><td colspan="2">0.96</td><td colspan="2">0.57</td><td colspan="2">0.26</td></tr>
<tr><td>Subsurface Risk Factor</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0.33</td><td colspan="2">0.48</td></tr>
<tr><td>Percolation (million lbs/ac)</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0.33</td><td colspan="2">0.48</td></tr>
<tr><td>Subsurface DRP Factor (ppm P in solution)</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0.33</td><td colspan="2">0.48</td></tr>
<tr><td>Soil Texture/Drainage Class Factor</td><td colspan="2">0*</td><td colspan="2">0*</td><td colspan="2">0*</td><td colspan="2">0*</td><td colspan="2">0*</td><td colspan="2">0*</td><td colspan="2">0*</td><td colspan="2">0.33</td><td colspan="2">0.48</td></tr>
<tr><td>Mehlich I P (ppm)</td><td colspan="2">0.005</td><td colspan="2">0.19</td><td colspan="2">0.41</td><td colspan="2">0.009</td><td colspan="2">0.28</td><td colspan="2">0.51</td><td colspan="2">0.030</td><td colspan="2">0.40</td><td colspan="2">0.68</td></tr>
<tr><td>Varied within baseline†</td><td>15%</td><td>-15%</td><td>15%</td><td>-15%</td><td>15%</td><td>-15%</td><td>15%</td><td>-15%</td><td>15%</td><td>-15%</td><td>15%</td><td>-15%</td><td>15%</td><td>-15%</td><td>15%</td><td>-15%</td><td>15%</td><td>-15%</td></tr>
<tr><td>Curve Number (CN)</td><td>0.097</td><td>0.028</td><td>0.91</td><td>0.29</td><td>1.43</td><td>0.40</td><td>0</td><td>0</td><td>1.19</td><td>0.41</td><td>1.56</td><td>0.54</td><td>0.40</td><td>0.14</td><td>0.48</td><td>0.32</td><td>na</td><td>-0.60</td></tr>
<tr><td>Distance to Stream (ft)</td><td>0</td><td>0</td><td>-0.91</td><td>0</td><td>0</td><td>-0.66</td><td>0</td><td>0</td><td>-0.78</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>-0.07</td><td>0</td><td>0</td><td>0</td></tr>
</table>

* Relative sensitivity is zero since baseline is zero, but a change in the output was observed when parameter was varied.

† Relative sensitivity was calculated varying within +/- 15% of the baseline value since the P-Index equation was not differentiable with respect to these parameters.

Table 3.12: Relative sensitivity rankings for each region and baseline scenario from high to low sensitivity

Parameters	Relative Sensitivity Ranking*																	
	Ridge and Valley						Piedmont & Upper Coastal Plain						Eastern Shore & Lower Coastal Plain					
	P Risk Delivery Scenarios						P Risk Delivery Scenarios						P Risk Delivery Scenarios					
	Low		Medium		High		Low		Medium		High		Low		Medium		High	
Edge of field soil loss (RUSLE) (million lbs/ac)	6		7		2		5		8		2		11		15		13	
Vegetated Filter Strip Adjustment Factor	6		7		2		5		8		2		11		15		13	
Sediment Delivery Factor	6		7		2		5		8		2		11		15		13	
Sediment Total P (ppm P in soil))	6		7		2		5		8		2		11		15		13	
Runoff from field (million lbs water/ac)	10		13		13		10		13		12		8		11		10	
Runoff Delivery Factor	10		13		13		10		13		12		8		11		10	
Runoff DRP (ppm)	10		13		13		10		13		12		8		11		10	
Applied Fertilizer DRP Factor	1		3		9		1		3		8		1		1		6	
Annual Application Rate (lbs P/ac)	1		3		9		1		3		8		1		1		6	
Method of Fertilizer Application Factor	1		3		9		1		3		8		1		1		6	
Source Availability Factor	1		3		9		1		3		8		1		1		6	
Percolation (million lbs/ac)	14		16		16		10		16		15		15		7		3	
Subsurface DRP Factor (ppm P in solution)	14		16		16		10		16		15		15		7		3	
Soil Texture/Drainage Class Factor	14		16		16		10		16		15		15		7		3	
Mehlich I P (ppm)	13		12		7		9		12		7		7		6		1	
Varied within baseline	15%	-15%	15%	-15%	15%	-15%	15%	-15%	15%	-15%	15%	-15%	15%	-15%	15%	-15%	15%	-15%
Curve Number (CN)	5	7	1	11	1	8	10	10	1	7	1	6	5	6	5	10	na	2
Distance to Stream (ft)	14	14	2	16	16	6	10	10	2	16	15	15	15	15	14	19	17	17

* 1= most sensitive

The low, medium, and high baseline scenarios for the Ridge and Valley and Piedmont regions were very similar. The main difference between baseline scenarios was that Mehlich I P was lower for the high P delivery risk scenario for the Piedmont region and distance to stream varied somewhat between regions (Table 3.2). Distance to stream varied slightly due to differences between the typical fields within the two regions. In the low P delivery risk scenarios for the Ridge and Valley and Piedmont regions, hay was grown on a slope of 4%. Typically in a grass system, dissolved P dominates losses because less sediment-bound P is lost from the field compared to other crops such as corn. There is less soil detachment and sediment is filtered out at a higher deposition rate for grass compared to row crops since grass has a higher cover percentage. Since erosion subfactors were not dominant in the low risk scenarios for Ridge and Valley and Piedmont regions, the P-Index output was not sensitive to those parameters (<0.04).

There was a low P source in the soil for the low scenarios. Since Mehlich I P levels in soil were low, the P-Index was not as sensitive to parameters that were multiplied by Mehlich I P. These factors included runoff from field, runoff delivery factor, and STDRP in runoff. If the value is at the low end of the spectrum initially, an increase of this parameter to another low value will not change the P-Index output more than one unit. The P-Index output was moderately sensitive to P management subfactors including annual application rate, method of fertilizer application, applied fertilizer DRP factor, and source availability factor and were ranked the highest. In a field where there is a low P source (<30 ppm Mehlich I P) initially, additional P sources due to applications during the year will contribute to the highest delivery of P.

Results for the medium and high P delivery risk scenarios were similar for the Ridge and Valley and Piedmont regions. Rankings were almost identical for both medium scenarios as well as for both high scenarios (Table 3.12). The only difference was that relative sensitivity to curve number was larger for the Piedmont medium risk of P delivery baseline than for the Ridge and Valley region. There were some differences between the medium and high baseline scenarios. For the medium scenarios, conservation tillage was practiced compared to conventional tillage in the high scenario. Other differences between the medium and high scenarios were that Mehlich I P concentration in the soil was higher and the distance to the nearest stream was closer in the high P delivery risk scenarios for both regions. These differences correspond to differences in P-Index sensitivity. The P-Index had a higher sensitivity to the erosion subfactors including soil loss, sediment delivery factor, sediment total P, and Mehlich I P in the high P delivery risk scenarios. Since the P-Index was less sensitive to Mehlich I P in the medium scenario, the P-Index was more sensitive to the management subfactors relating to application rate than the erosion subfactors for the medium P risk scenarios in the Ridge and Valley and Piedmont regions. This also corresponds to conservation or no-till versus conventional tillage between the medium and high scenarios. A no-till cropping system will have less soil erosion overall than a conventional cropping system with a higher proportion of losses as dissolved P.

Results of the low P delivery risk scenario for the Eastern Shore region were similar to the other low risk scenarios. However, differences were observed since a no-till row crop was grown instead of hay. However, since it was no-tillage and there was low erosion or soil loss, the P-Index was more sensitive to the runoff subfactors. The major difference in the Eastern Shore low P delivery risk scenario was that the P-Index had a higher sensitivity to runoff, runoff delivery factor, and STDRP in runoff since there was a higher curve number used for a no-till system compared to hay. Runoff increases with increasing curve number.

Results for the medium and high P delivery risk scenarios were similar for the Eastern Shore. In both scenarios, the soil texture and drainage class (somewhat poorly drained to poorly drained) contributed to subsurface losses within the P-Index. The P-Index was determined to be very sensitive to Mehlich I P in both scenarios. Since subsurface risk of P loss was included, Mehlich I P concentration affected results of all three factors that comprise the P-Index, thus, it was expected that the output would be sensitive to this parameter. Within these scenarios, the P-Index was second most sensitive to the P management subfactors including P application rate, method of application factor, and source availability of P factor. In comparison, leaching had less impact in the medium scenarios compared to the high risk of P delivery scenario for the Eastern Shore region since the medium scenario had better drainage characteristics (a somewhat poorly drained soil compared to a poor drained soil). For the high risk of P delivery scenario for the Eastern Shore, the P-Index output was more sensitive to percolation and the leachate DRP factor than to the management subfactors, including P application rate, source availability factor, and method of application factor, since soil/texture drainage effects were greater, as shown in Table 3.12.

Most of the relative sensitivity results appeared to be reasonable. The P-Index was insensitive to slightly sensitive to the runoff subfactors (Table 3.11). Typically, P loss associated with sediment is estimated to contribute 60-90% of P transported from cultivated land (Sharpley et al. 1992). However, losses from dissolved P in runoff are a concern typically in grass, pasture, and no-till cropping where soil losses are lower than in conventional systems. In no-till systems, a higher concentration of P could be dissolved in runoff compared to conventional systems since P might build up in the surface. In the medium risk of P delivery scenarios, where no-till cropping was in place in fields across all regions, greater variability or impact due to changes in runoff delivery factor should have been observed. For instance, changing the runoff delivery factor from 0.2 to 1 for the medium risk of P delivery scenarios for the Ridge and Valley region resulted in a change in the output from 44.3 to 46.9. For this scenario, there is very little difference between a field that is located >500 feet from a stream and a field located adjacent to a stream. This result does not appear to be representative of the risk of P delivery at the medium level. This effect seems more representative at the higher and lower risk levels.

The output was determined to be moderately sensitive to P application rate. Although the output should be sensitive to this parameter, since the amount of runoff does not affect the value of this factor (applied fertilizer factor is added to the runoff factor), it is possible this factor is being overemphasized in situations where there is little to no runoff. This effect could become a concern at the low to medium category when P application recommendation switches from N-based to 1.5 times P crop removal. Although P in runoff may be very low, the amount of P application may be N-based as defined by the low risk of P delivery category. Since the P-Index is sensitive to P application rate, the N-based rate could change the category to a higher P management category, although there is very little to no P loss in runoff.

For the soil texture/drainage factor, relative sensitivity was calculated to be zero for all cases since the baseline value was zero. However, when the soil texture/drainage factor was varied + 1 and + 2 categories, the P-Index output changed. Thus, relative sensitivity was not actually zero. For these cases, the P-Index output changes between categories were compared (Table 3.13). For most of the scenarios, the P-Index output changed at a greater rate when the soil texture/drainage factor was varied compared to the other parameters. Thus, the P-Index was most sensitive to the soil texture/drainage class factor. However, when the parameter was varied +/- 1 and 2 categories, the factor was really varied 25 and 50%. Proportionally, the change in output was greater in these scenarios compared to the other parameters. Soil texture was less important in the Eastern Shore region where the subfactor value was not zero (ranked 7 in medium and 2 and 3 in the high risk scenarios).

Table 3.13: P-Index Output for all regions for changes in the soil texture/drainage class factor

P Delivery Risk Scenarios	Baseline Output	Baseline Soil/Texture Value	Output +1 category (0 to 0.25)	% Change to Output	Output +2 category (0 to 0.5)	% Change to Output
Ridge and Valley Low	14	0	24	71	34	142
Ridge and Valley Medium	46	0	80	74	113	146
Ridge and Valley High	89	0	160	80	230	158
Piedmont Low	14	0	14	0*	14	0*
Piedmont Medium	41	0	86	110	130	217
Piedmont High	79	0	186	135	293	271
Eastern Shore Low	14	0	25	79	35	150
Eastern Shore Medium	42	0.25	56	33	69	64
Eastern Shore High	101	0.75	118	17	na†	na

* There was no change in the output because the subsurface DRP value was zero.
† na-not applicable

The P-Index output for all baseline scenarios when subfactors were varied +/- 15% or +/- 1 category from the baseline value is included in Table 3.14. In the low scenarios, the output did not change very much (< +/- 2 units from the baseline) when the sub-factors were varied +/- 15 %. Figure 3.4, Figure 3.5, and Figure 3.6 show the range of values of the P-Index output when the subfactors were varied +/- 35% from their baseline value for the high P delivery risk scenarios for each of the three regions. Since there was a high Mehlich I P level and fields with high soil loss, the erosion subfactors resulted in the greatest changes from the baseline output. As shown by Figure 3.4, Figure 3.5, and Figure 3.6, the ranges of the output were similar for the Ridge and Valley and Piedmont regions with differences observable in the Eastern Shore region. The greatest change of the output in the Eastern Shore high risk region was due to Mehlich I P and subsurface subfactors.

Table 3.14: Values of the P-Index output for all baseline scenarios when parameters were varied +/- 15% or +/- 1 category from the baseline value

Parameters	P-Index Output																	
	Ridge and Valley						Piedmont & Upper Coastal Plain						Eastern Shore & Lower Coastal Plain					
	P Risk Delivery Scenarios						P Risk Delivery Scenarios						P Risk Delivery Scenarios					
	Low		Medium		High		Low		Medium		High		Low		Medium		High	
Baseline Output Value	**14.2**		**46.3**		**89.1**		**14.0**		**41.3**		**79.0**		**14.07**		**41.8**		**101.2**	
Varied within baseline	**15%**	**-15%**	**15%**	**-15%**	**15%**	**-15%**	**15%**	**-15%**	**15%**	**-15%**	**15%**	**-15%**	**15%**	**-15%**	**15%**	**-15%**	**15%**	**-15%**
Edge of field soil loss (RUSLE) (million lbs/ac)	14.2	14.1	49.3	43.3	97.5	80.8	14.1	13.9	43.4	39.2	85.7	72.4	14.1	14.1	41.9	41.6	102.8	99.7
Vegetated Filter Strip Adjustment Factor	14.2	14.1	49.3	43.3	97.5	80.8	14.1	13.9	43.4	39.2	85.7	72.4	14.1	14.1	41.9	41.6	102.8	99.7
Sediment Delivery Factor	14.2	14.1	49.3	43.3	97.5	80.8	14.1	13.9	43.4	39.2	85.7	72.4	14.1	14.1	41.9	41.6	102.8	99.7
Sediment Total P (ppm P in soil)	14.2	14.1	49.3	43.3	97.5	80.8	14.1	13.9	43.4	39.2	85.7	72.4	14.1	14.1	41.9	41.6	102.8	99.7
Runoff from field (million lbs water/ac)	14.2	14.2	46.7	45.9	90.2	88.1	14.0	14.0	41.8	40.8	80.6	78.0	14.1	14.1	41.3	42.9	103.7	98.9
Runoff Delivery Factor	14.2	14.2	46.7	45.9	90.2	88.1	14.0	14.0	41.8	40.8	80.3	77.8	14.1	14.1	41.3	42.9	103.7	98.9
Runoff DRP (ppm)	14.2	14.2	46.7	45.9	90.2	88.1	14.0	14.0	41.8	40.8	80.3	77.8	14.1	14.1	41.3	42.9	103.7	98.9
Applied Fertilizer DRP Factor	16.2	12.1	49.9	42.7	93.1	85.2	16.0	12.0	44.9	37.7	83.0	75.1	14.1	16.1	38.2	50.2	105.2	97.3
Annual Application Rate (lbs P/ac)	16.2	12.1	49.9	42.7	93.1	85.2	16.0	12.0	44.9	37.7	83.0	75.1	14.1	16.1	38.2	50.2	105.2	97.3
Method of Fertilizer Application Factor	16.2	12.1	49.9	42.7	93.1	85.2	16.0	12.0	44.9	37.7	83.0	75.1	14.1	16.1	38.2	50.2	105.2	97.3
Percolation (million lbs/ac)	14.2	14.2	46.3	46.3	89.1	89.1	14.0	14.0	41.3	41.3	79.0	79.0	14.1	14.1	39.7	46.6	108.5	93.9
Subsurface DRP Factor (ppm P in solution)	14.2	14.2	46.3	46.3	89.1	89.1	14.0	14.0	41.3	41.3	79.0	79.0	14.1	14.1	39.7	46.6	108.5	93.9
Mehlich I P (ppm)	14.2	14.2	47.6	45.0	94.6	83.7	14.0	14.0	43.0	39.5	85.1	73.0	14.1	14.0	44.3	39.3	111.6	90.9
Curve Number (CN)	14.4	14.10	52.5	44.3	108.7	83.6	14.0	14.0	48.5	38.8	97.2	72.8	14.9	13.8	44.9	39.7	na	110.1
Distance to Stream (ft)	14.2	14.2	40.0	46.3	89.1	98.0	14.0	14.0	36.5	41.3	79.0	79.0	14.1	14.1	41.4	41.8	101.2	101.2
Varied within categories	**+1**	**-1**	**+1**	**-1**	**+1**	**-1**	**+1**	**-1**	**+1**	**-1**	**+1**	**-1**	**+1**	**-1**	**+1**	**-1**	**+1**	**-1**
Source Availability Factor	na*	11.5	52.3	40.30	95.7	82.5	Na	11.30	47.3	35.3	85.7	72.4	na	11.4	47.8	35.8	107.9	94.62
Soil Texture/Drainage Class Factor	24.2	na	79.7	na	159.6	na	14.01	na	85.7	na	186.0	na	24.7	na	55.6	28.0	117.5	85.01
Baseline Output Value	**14.2**		**46.3**		**89.1**		**14.0**		**41.3**		**79.0**		**14.1**		**41.8**		**101.2**	

* not applicable

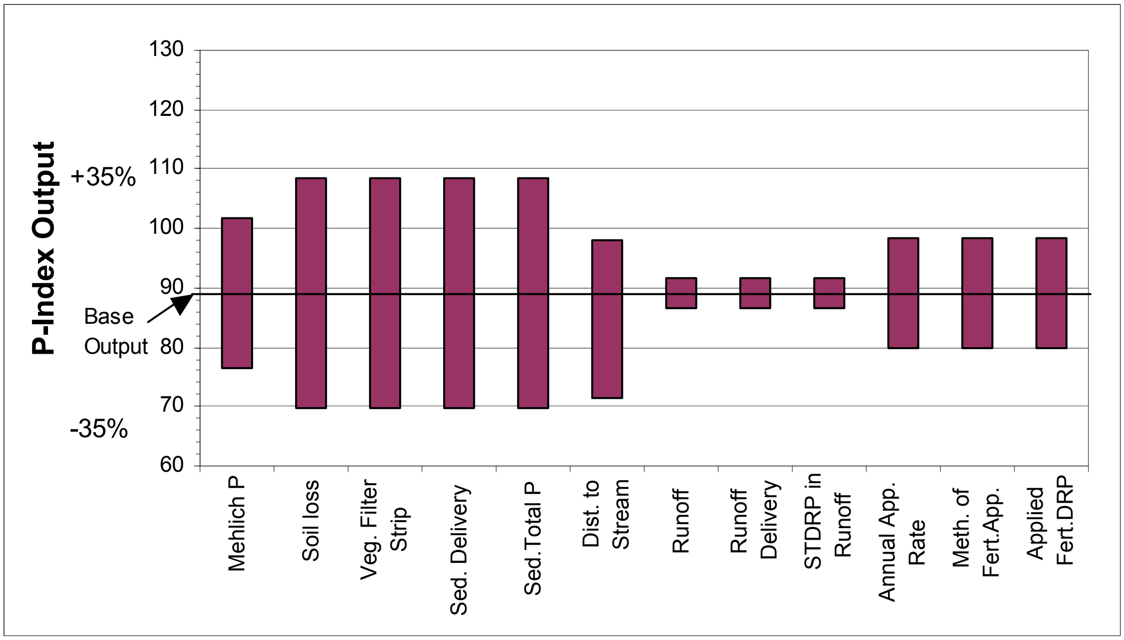

Figure 3.4: Change in P-Index from varying +/- 35% each sub-factor for the high P delivery risk scenario for the Ridge and Valley Region

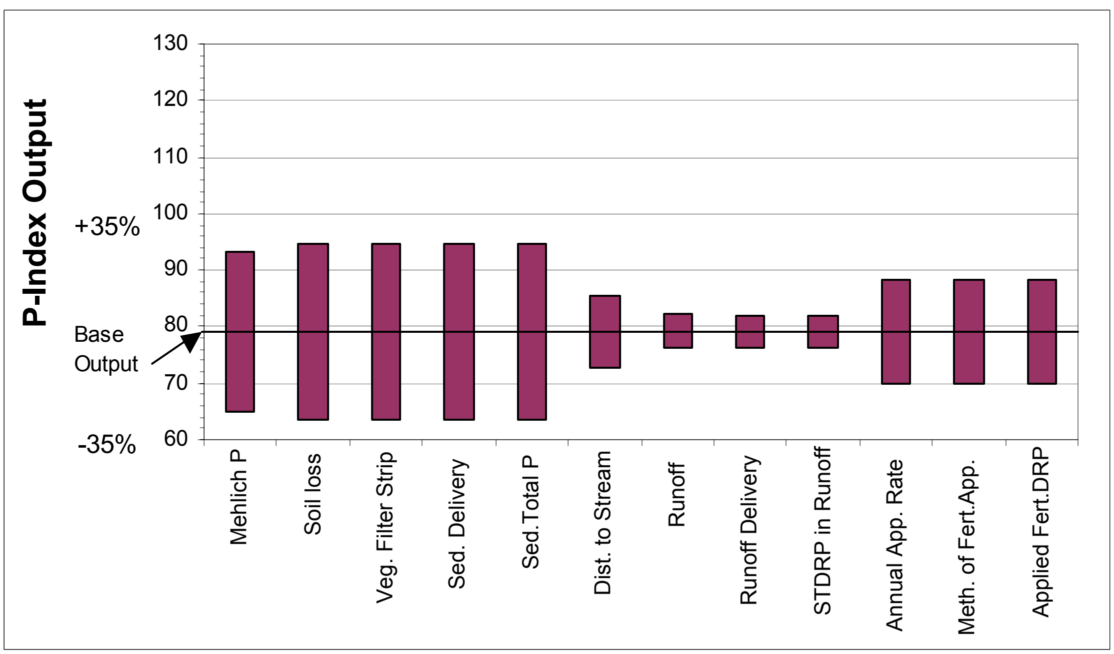

Figure 3.5: Change in P-Index from varying +/- 35% each sub-factor for the high P delivery risk scenario for the Piedmont and Upper Coastal Plain Region

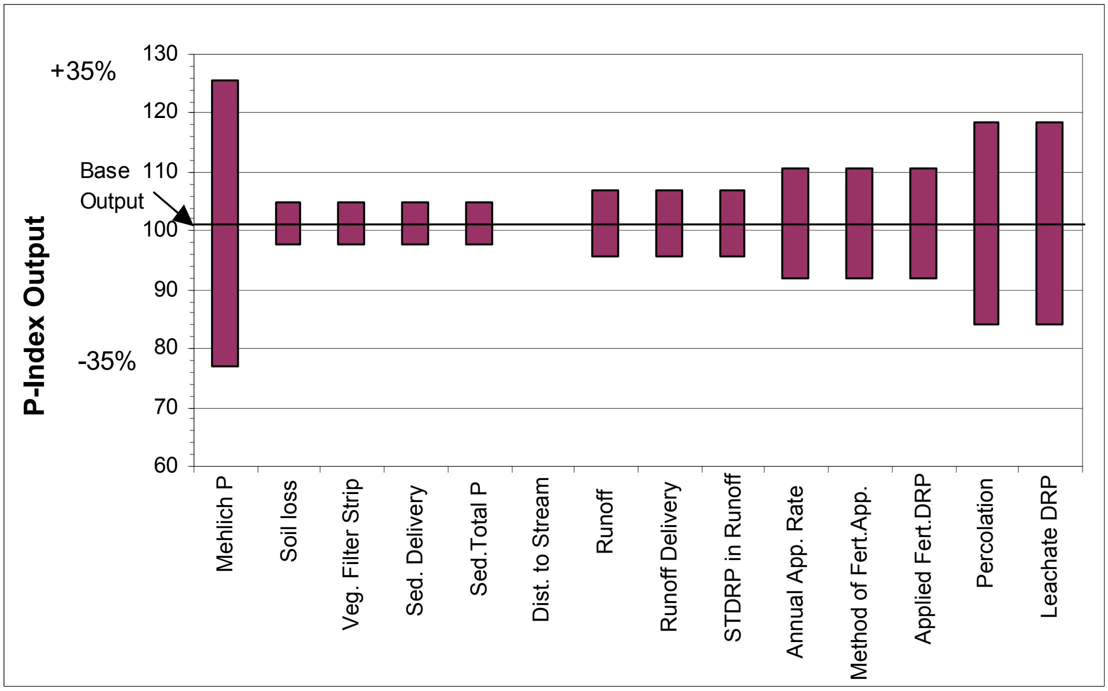

Figure 3.6: Change in P-Index from varying +/- 35% each sub-factor for the high P delivery risk scenario for the Eastern Shore and Lower Coastal Plain Region

3.3.2 Probability Distribution

Distributions of the P-Index output for each of the baselines were generated using the program @Risk. A Latin Hypercube random generator sampling technique was used to generate the output and 500 iterations (convergence of the output was met before this iteration for all runs) were completed for each of the runs. The probability distributions for distance to stream, Mehlich I P, and soil loss defined in Section 3.2.3 were used along with baseline values to generate the output. The output distributions for the nine baseline scenarios are given in Figures 3.7 through 3.15 and a summary of the results is provided in Table 3.15. The potential variability of the inputs was represented by using distributions for the three parameters. The output distributions are the results of that variability.

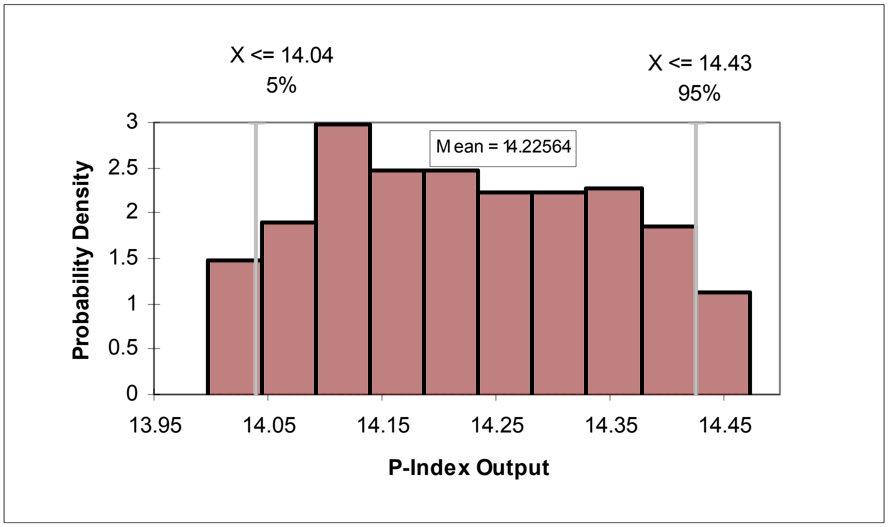

Figure 3.7: Distribution of P-Index output for the Ridge and Valley low P delivery risk scenario

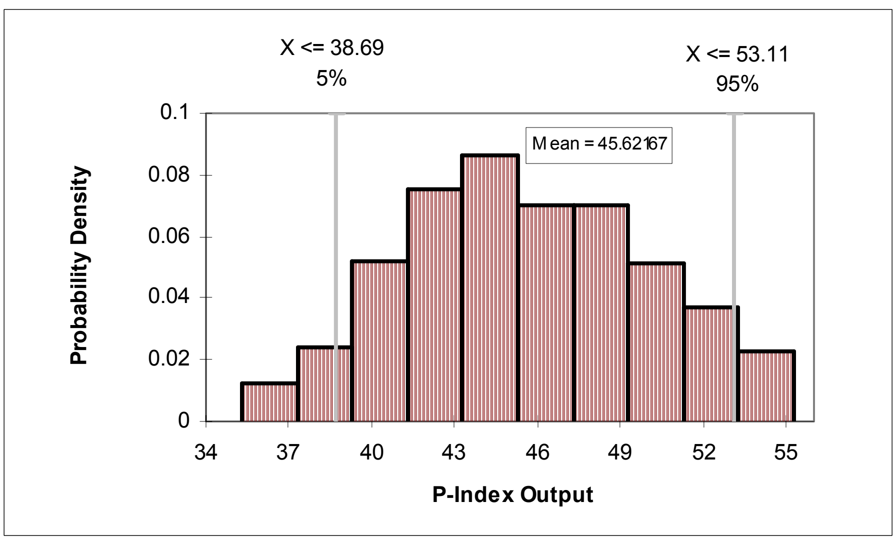

Figure 3.8: Distribution of P-Index output for the Ridge and Valley medium P delivery risk scenario

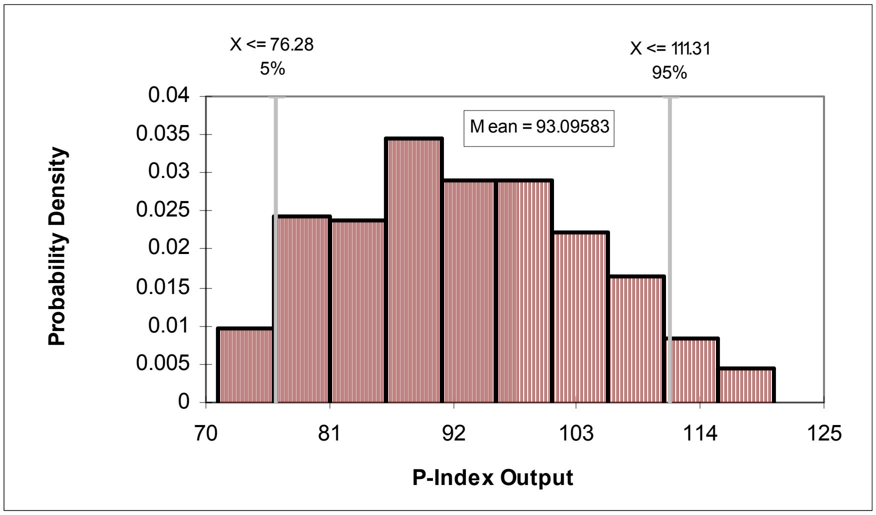

Figure 3.9: Distribution of P-Index output for the Ridge and Valley high P delivery risk scenario

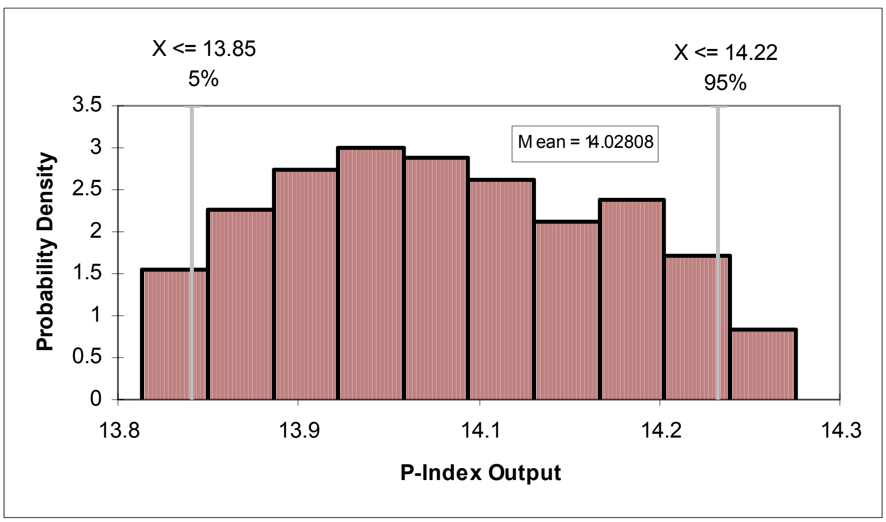

Figure 3.10: Distribution of P-Index output for the Piedmont low P delivery risk scenario

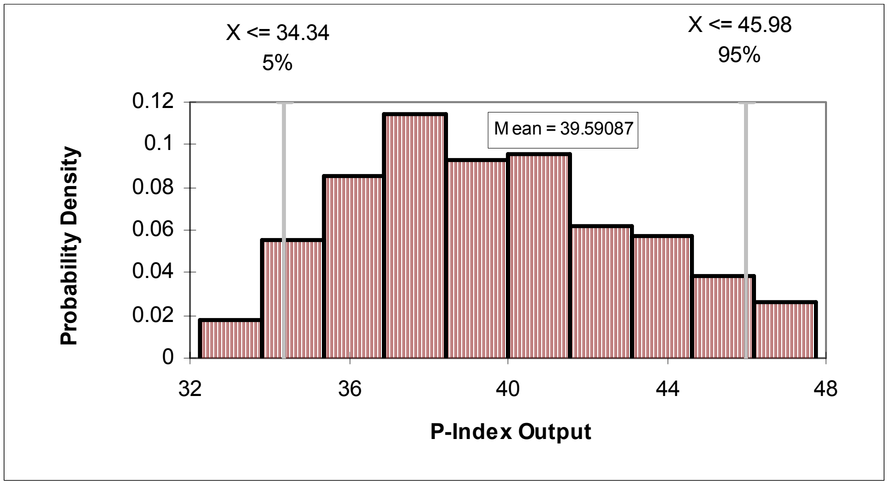

Figure 3.11: Distribution of P-Index output for the Piedmont medium P delivery risk scenario

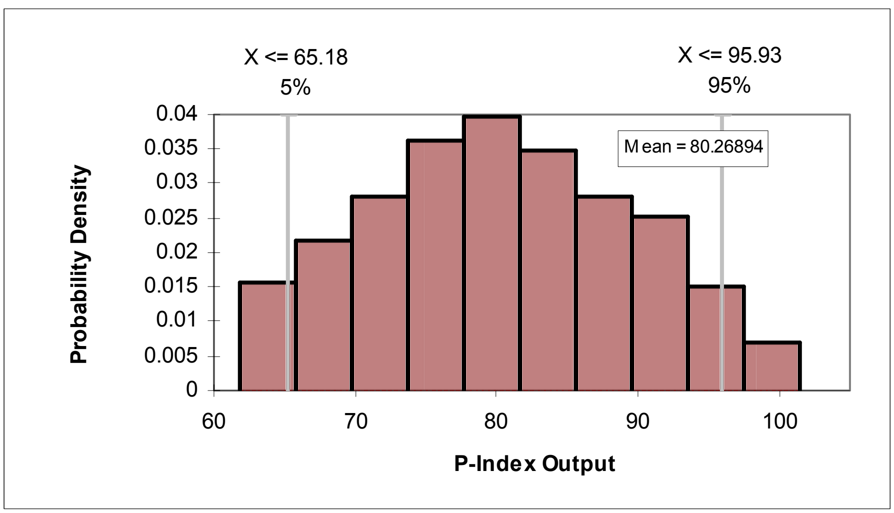

Figure 3.12: Distribution of P-Index output for the Piedmont high P delivery risk scenario

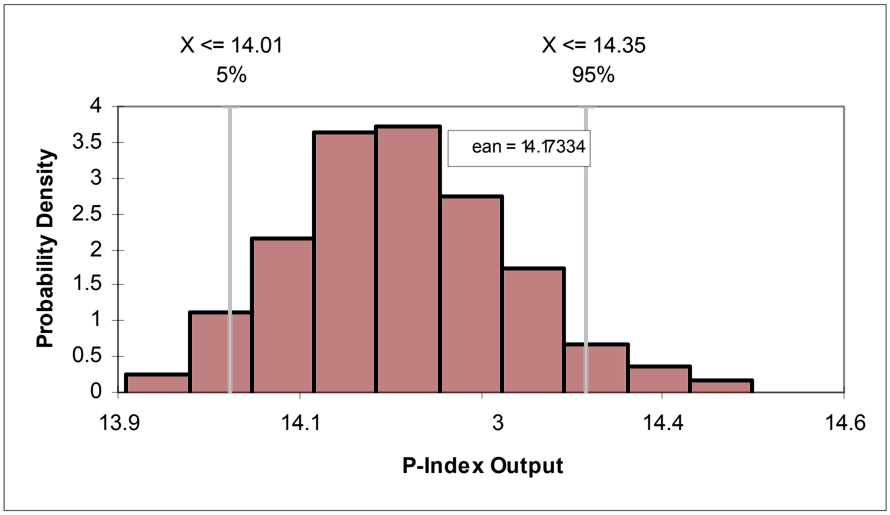

Figure 3.13: Distribution of P-Index output for the Eastern Shore low P delivery risk scenario

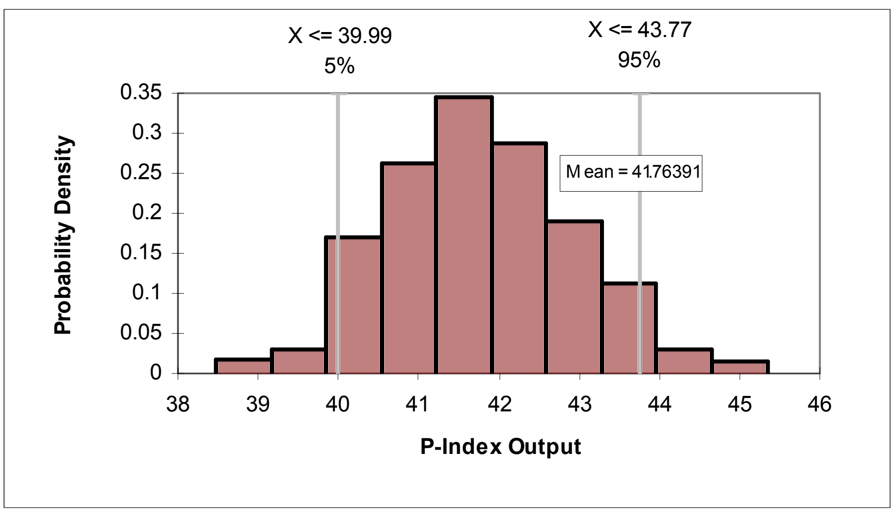

Figure 3.14: Distribution of P-Index output for the Eastern Shore medium P delivery risk scenario

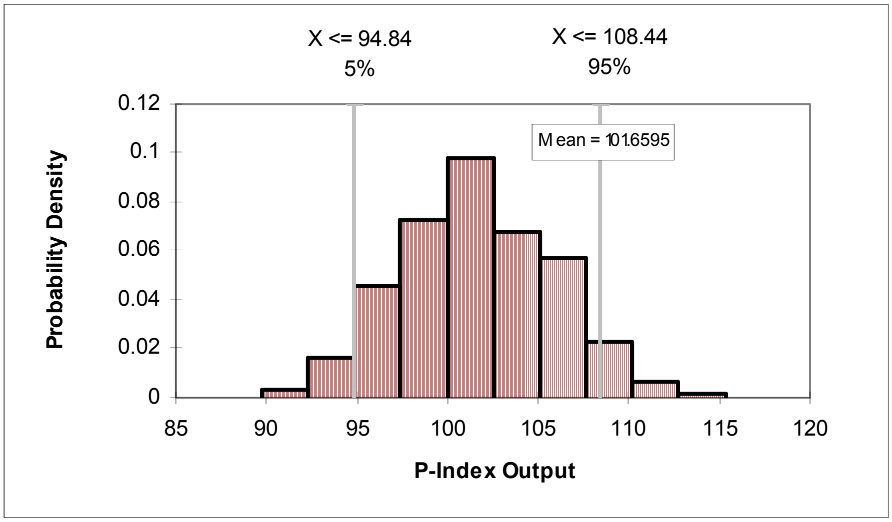

Figure 3.15: Distribution of P-Index output for the Eastern Shore high P delivery risk scenario

Table 3.15: Summary of the distribution for the nine baseline scenarios

Baseline Scenario	Baseline Output	Mean	Minimum	Maximum	Standard Deviation	5% Quantile	95% Quantile
Ridge and Valley low risk of P delivery	14	14.23	14.00	14.47	0.12	14.04	14.43
Ridge and Valley medium risk of P delivery	46	45.62	35.30	55.27	4.43	38.69	53.11
Ridge and Valley high risk of P delivery	89	93.10	71.15	120.60	10.98	76.28	111.31
Piedmont low risk of P delivery	14	14.03	13.82	14.27	0.11	13.85	14.22
Piedmont medium risk of P delivery	41	39.59	32.25	47.75	3.52	34.34	45.98
Piedmont high risk of P delivery	79	80.27	61.81	101.46	9.31	65.18	95.93
Eastern Shore low risk of P delivery	14	14.17	13.91	14.51	0.11	14.01	14.35
Eastern Shore medium risk of P delivery	42	41.76	38.48	45.34	4.23	39.99	43.77
Eastern Shore high risk of P delivery	101	101.66	89.74	115.32	4.99	94.84	108.44

According to the analysis, variability as defined by the distributions has a greater impact on the P-Index output as P risk increases over each of the three regions. Within the low risk of P delivery scenarios, changes in the P-Index output were minimal (<1) and did not affect the overall output value. The range of the P-Index output distributions for the medium risk of P delivery were between 6 and 20 units among the regions, an increase over the low risk of P delivery scenarios. The Ridge and Valley medium risk of P delivery region exhibited the greatest variability among the medium scenarios with 90% of the distribution between 39 and 53 (Figure 3.8). Ninety percent of the output distribution in the Piedmont medium risk of P delivery region fell between 34 and 46 (Figure 3.11), which is similar in range to the Ridge and Valley medium risk of P delivery region. Ninety percent of the output distribution in the Eastern Shore medium risk of P delivery region was between 40 and 44 (Figure 3.14), which is much smaller than the ranges in other regions. Since the distribution range was much less, it is less likely that variability of the inputs will affect the overall management recommendation for P application rate within this scenario.

Variability within the high risk of P delivery regions was observed and resulted in changes in management guidance of P application for some cases. Within the Ridge and Valley high risk of P delivery region, 90% of the output distribution was between 76 and 111 indicating differences in management recommendations (Figure 3.9). In the Piedmont high risk of P delivery region, 90% of the output distribution was between 65 and 96 and, therefore, it was not likely that a change in management recommendation would occur (Figure 3.12). Ninety percent of the output distribution for the Eastern Shore high risk of P delivery region was between 95 and 108 (Figure 3.15). Variability within this region had less impact on the output compared to the other regions. However, since the baseline value (101) was at the low end of the very high management recommendation, variability of the subfactors could impact the overall management recommendation approximately 50% of the time.

A multivariate stepwise regression analysis with respect to the output was conducted using @Risk to determine which of the factors that contributed to the variability had the greatest impact on the P-Index output. In the multivariate regression analysis, the input parameters were fit to a planar equation. The results are given in Table 3.16. Within the Ridge and Valley and Piedmont low risk of P delivery regions, soil loss contributed more to the variability of output than Mehlich I soil test P. Within the Eastern Shore low risk of P delivery region, soil loss and Mehlich I P contributed equally to the variability of P-Index output. In the Ridge and Valley and Piedmont medium risk of P delivery scenarios, soil loss followed by sediment delivery factor contributed the most to the variability of the P-Index. In the Eastern Shore medium risk of P delivery scenario, Mehlich I soil test P contributed the most to variability of the P-Index output followed by soil loss. Within the Ridge and Valley and Piedmont high risk of P delivery scenarios, soil loss contributed the most to the variability of the P-Index output. In the Eastern Shore high risk of P delivery scenario, soil loss contributed the greatest to the variability of the P-Index output followed closely by Mehlich I P.

Table 3.16: Normalized regression coefficients of factors with input distributions

Baseline Scenario	Regression coefficients			
	Soil Loss	Mehlich I	Sediment Delivery	Runoff Delivery
Ridge and Valley low risk of P delivery	1.000	0.096	na	Na
Ridge and Valley medium risk of P delivery	0.832	0.108	0.524	0.052
Ridge and Valley high risk of P delivery	0.945	0.088	0.3	0.035
Piedmont low risk of P delivery	0.991	0.140	na	Na
Piedmont medium risk of P delivery	0.780	0.129	0.557	0.113
Piedmont high risk of P delivery	0.993	0.096	na	Na
Eastern Shore low risk of P delivery	0.753	0.701	na	Na
Eastern Shore medium risk of P delivery	0.336	0.949	0.053	0.131
Eastern Shore high risk of P delivery	0.757	0.661	na	Na

Subfactors that had a higher relative sensitivity also had regression coefficients that were higher except for the Eastern Shore high risk of P delivery region. In that region, Mehlich I P had a higher relative sensitivity ($R_s = 0.68$) than soil loss ($R_s = 0.10$), but the regression coefficient was higher for soil loss. This can be attributed to a larger variability of soil loss than Mehlich I P for this scenario.

3.3.3 Probability of Being in Each P Management Category

The probability distribution analysis showed the P-Index could have a range of values as a result of user and parameter variability with respect to Mehlich I P, soil loss, and distance to stream. The resulting probability distribution has the potential to extend into multiple P management categories. The P management categories are low (0-30), medium (31-60), high (61-100), and very high (>100) (Table 2.3). The probability of being in each P management category for each baseline scenario was calculated by summing the output distribution that fell inside of the respective management categories (Table 3.17). For example, for the Ridge and Valley low P delivery risk scenario, the entire distribution fell within the low management category and thus the probability of being in that category would be 1. For the Ridge and Valley high P delivery risk scenario, 73% of the distribution was in the high P management category and 27% of the distribution was in the very high P management category as shown in the cumulative probability distribution (Figure 3.16). Therefore, there is a 0.73 probability of being in the high P management category and a 0.27 probability of being in the very high P management category. Since all the values for the baseline scenarios were near the middle of a P management category except for the Eastern Shore high P delivery risk scenario, the majority of the distributions were within one category.

Table 3.17: Probability of being in each P management category for each baseline scenario

Baseline Scenario	P Management Category: Low (0-30)	Medium (31-60)	High (61-100)	Very High (>100)
Ridge and Valley low risk of P delivery	1	0	0	0
Ridge and Valley medium risk of P delivery	0	1	0	0
Ridge and Valley high risk of P delivery	0	0	0.73	0.27
Piedmont low risk of P delivery	1	0	0	0
Piedmont medium risk of P delivery	0	1	0	0
Piedmont high risk of P delivery	0	0.996	0.004	0
Eastern Shore low risk of P delivery	1	0	0	0
Eastern Shore medium risk of P delivery	0	1	0	0
Eastern Shore high risk of P delivery	0	0	0.35	0.65

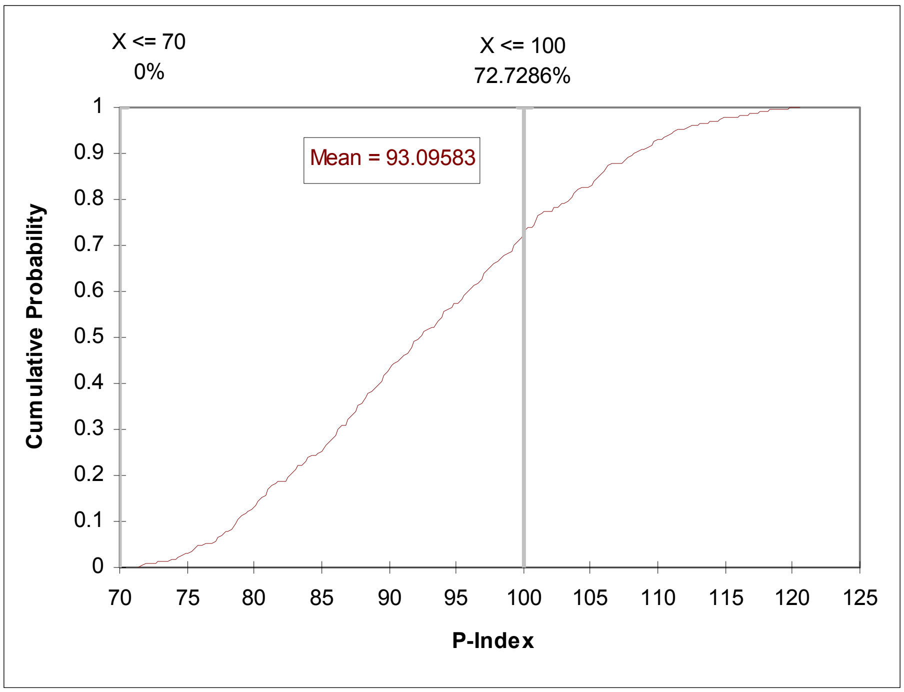

Figure 3.16: Cumulative probability distribution for the Ridge and Valley high risk of P delivery scenario

This approach could also be used to estimate the probability of being in each P management category for other scenarios using the baseline scenario distributions within the low, medium, and high risk of P delivery. Specifically of concern are those values near the threshold values (values near a different management category). The probability distributions should be defined when the threshold values are the baseline values to obtain an accurate probability for each P management category. However, further characterization and additional scenarios would be needed to define distributions at the threshold values. The current baseline distributions can be used as an initial estimate of the probability of being in each P management category. The distributions for the medium P risk of delivery scenarios were used to define the probability for each P management category at the medium to high level of impact to surface water. The distributions for the high P delivery scenarios were used to define the probability of being in each P management category at the high to very high level of impact to surface water. The low to medium categorical change was not evaluated since none of the baseline distributions represented the distribution for that level.

The probability of being in each P management category when the computed P-Index value is near the threshold between the medium and high level of impact to surface water was calculated for each of the three regions assuming that the computed value is at or near the mean of the distribution (Table 3.18). Specifically, each distribution was shifted so that the mean of the distribution was equal to the baseline value. The probabilities were then calculated by summing the distribution that is in each P management category. Similar probabilities were calculated for the Ridge and Valley and Piedmont regions with the Ridge and Valley region having a higher probability of being in a different P management category. For the Eastern Shore region, unless the value is within 3.5 from the threshold, there is no chance of being in a different P management category assuming the computed P-Index value is located near the mean.

The probability of being in each P management category when the computed P-Index value is near the threshold between the high and very high level of impact to surface water was calculated for each of the three regions assuming that the computed value is at the mean of the distribution (Table 3.19). A greater probability of being in a different P management category was seen in this threshold compared to the medium to high threshold value. The Ridge and Valley and Piedmont regions had similar distributions and thus the probabilities for being in a different P management category were similar. Since the variance or range of the distribution was less for the Eastern Shore region, there is less of a chance of being in a different P management category than in the other regions.

Table 3.18: Probability of being in each P management category near the threshold between the medium and high level of impact to surface water for all regions

		P Management Category			
P-Index Value	Region	Low (0-30)	Medium (31-60)	High (61-100)	Very High (>100)
50	Ridge and Valley	0	1	0	0
	Piedmont	0	1	0	0
	Eastern Shore	0	1	0	0
55	Ridge and Valley	0	0.84	0.16	0
	Piedmont	0	0.9	0.1	0
	Eastern Shore	0	1	0	0
60	Ridge and Valley	0	0.49	0.51	0
	Piedmont	0	0.47	0.53	0
	Eastern Shore	0	0.47	0.53	0
65	Ridge and Valley	0	0.14	0.86	0
	Piedmont	0	0.06	0.94	0
	Eastern Shore	0	0	1	0
70	Ridge and Valley	0	0	1	0
	Piedmont	0	0	1	0
	Eastern Shore	0	0	1	0

Table 3.19: Probability of being in each P management category near the threshold between the high and very high level of impact to surface water for all regions

		P Management Category			
P-Index Value	Region	Low (0-30)	Medium (31-60)	High (61-100)	Very High (>100)
90	Ridge and Valley	0	0	0.79	0.21
	Piedmont	0	0	0.82	0.18
	Eastern Shore	0	0	1	0
95	Ridge and Valley	0	0	0.66	0.34
	Piedmont	0	0	0.7	0.3
	Eastern Shore	0	0	0.86	0.14
100	Ridge and Valley	0	0	0.48	0.52
	Piedmont	0	0	0.5	0.5
	Eastern Shore	0	0	0.52	0.48
105	Ridge and Valley	0	0	0.36	0.64
	Piedmont	0	0	0.31	0.69
	Eastern Shore	0	0	0.12	0.88
110	Ridge and Valley	0	0	0.21	0.79
	Piedmont	0	0	0.16	0.84
	Eastern Shore	0	0	0	1

This analysis is useful in a broader scope in determining differences in P management recommendations based on user and parameter estimation error. This analysis showed that near the threshold between the medium and high impact of P delivery to surface water if a value is between 0 and 5 of the threshold value there is up to 0.16 chance of being in a different P management category. The probability increased for the high to very high impact of P delivery to surface water and even within 10 from the threshold value there is up to a 0.21 chance of being in a different P management category. This analysis showed that variability of the inputs could affect the management recommendations, especially in higher risk of P delivery scenarios. The variability of calculating soil loss using RUSLE is the greatest source of variability since this factor could vary considerably from person to person and ultimately affect the management recommendations. Consistency among users in calculating RUSLE is important and could reduce the variability of the P-Index and thus have less of a chance of a misdiagnosis into a different management recommendation. Since the greatest variability occurs at the high risk end, different management recommendations for P application are more likely between 1.5 times P crop removal and P crop removal than from N-based nutrient needs to P-based on crop removal.

3.3.4 Output Distribution

The P management guidelines associated with the Virginia P-Index are based on low, medium, high, or very high risk of potential water quality impact. Results of each run completed for the sensitivity analysis were analyzed for each scenario evaluating the frequency distribution of the overall output within the management categories. When parameters were varied by percentages, the P-Index output also changed a percentage from the baseline. Those ranges of values were calculated to evaluate changes in management guidelines and to determine if there was any overlap of values between the P risk of delivery scenarios. For instance, did any of the output generated in the low risk of P delivery scenarios overlap with output from the medium risk of P delivery scenario?

Since the baseline output was located near the middle of the management recommendations in most of the scenarios, there was not much change between management categories. The frequency distribution of the P-Index output for +/- 15% and +/- one category for all regions baseline scenarios is shown in Figure 3.17. The frequency distributions are also provided in Tables 3.20 through 3.22.

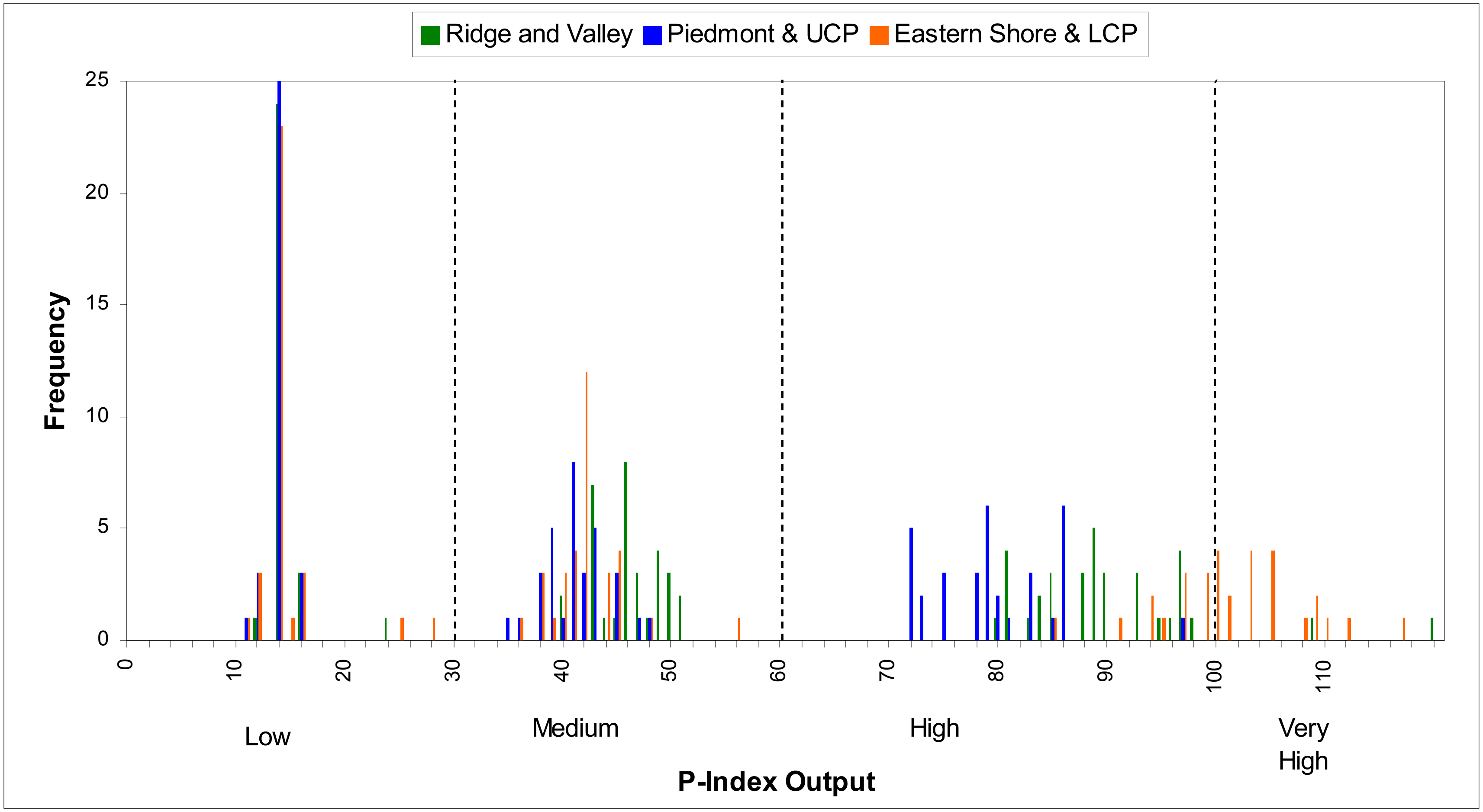

Figure 3.17: Frequency distribution of P-Index Output for +/- 15% and +/- 1 category for all of the regions baseline scenarios

Table 3.20: Frequency distribution for the low P risk of delivery scenarios when parameters were varied +/- 15% and within +/- 1 category

Ridge and Valley		Piedmont		Eastern Shore	
Output Value	*Frequency*	*Output Value*	*Frequency*	*Output Value*	*Frequency*
12	1	11	1	11	1
14	24	12	3	12	3
16	3	14	25	14	23
24	1	16	3	15	1
				16	3
				25	1
Base Value Output	14	Base Value Output	14	Base Value Output	14

Table 3.21: Frequency distribution for the medium P risk of delivery scenarios when parameters were varied +/- 15% and within +/- 1 category

Ridge and Valley		Piedmont		Eastern Shore	
Output Value	*Frequency*	*Output Value*	*Frequency*	*Output Value*	*Frequency*
40	2	35	1	28	1
43	7	36	1	36	1
44	1	38	3	38	3
45	1	39	5	39	1
46	8	40	1	40	3
47	3	41	8	41	4
48	1	42	3	42	12
49	4	43	5	44	3
50	3	45	3	45	4
52	2	47	1	48	1
80	1	48	1	56	1
		86	1		
Base Value Output	46	Base Value Output	41	Base Value Output	42

Only P-Index values generated by varying all parameters +/- 15% and +/- one category for calculating relative sensitivity were used to generate the distribution. Output from the P-Index for relative sensitivity when parameters were varied +/- 35% and +/- two categories were not used to generate the distribution since these values were less likely to occur as a result of user variability or parameter estimation error.

In the Ridge and Valley region, the only subfactors when varied +/- 15% or +/- 1 category that resulted in a management category change were curve number in the high baseline scenario and soil texture/drainage class factor in the medium and high baseline scenarios. In the Piedmont region, the only change into another management category was due to the soil texture/drainage class factor for the medium and high baseline scenarios. For the Eastern Shore region, only the high baseline scenario had changes between management categories from varying subfactors +/- 15% and +/- 1 category. For the high baseline scenario, the P-Index value was 101, which is at the low end of the very high management category. Therefore, within the Eastern Shore high risk of P delivery region, most of the parameters changed management categories. Since there were very few changes between management categories within the baseline scenarios, there was also very little overlap for regions between their low, medium, and high risk of P delivery baseline scenarios.

Table 3.22: Frequency distribution for the high P risk of delivery scenarios when parameters were varied +/- 15% and within +/- 1 category

Ridge and Valley		Piedmont		Eastern Shore	
Output Value	*Frequency*	*Output Value*	*Frequency*	*Output Value*	*Frequency*
81	4	72	5	85	1
83	1	73	2	91	1
84	2	75	3	94	2
85	3	78	3	95	1
88	3	79	6	97	3
89	5	80	2	99	3
90	3	81	1	100	4
93	3	83	3	101	2
95	1	85	1	103	4
96	1	86	5	104	3
97	4	97	1	105	3
98	1	186	1	108	1
109	1			109	2
160	1			110	1
				112	1
				117	1
Base Value Output	89	Base Value Output	79	Base Value Output	101

The significance of this analysis is that unless the output lies within 5-10 units from a different management category, it is unlikely that variability would have a different management recommendation. However, it is possible to switch into a higher or lower management category if a parameter is different than its actual value by 10% as shown in the probability distribution analysis (Section 3.3.2). In the low risk categories, the output did not vary much from the baseline when varied +/- 15 and 35%. Therefore, there is not much concern of error in parameter estimation that would switch the result into a different management category. However, for the medium and high risk scenarios, there is a larger span of output values and it is more likely that an error in parameter estimation could move the result into a different management category.

3.3.5 Summary

In summary, the sensitivity analysis indicated that the level of sensitivity was dependent on baseline scenarios. For the low baseline scenarios, the P-Index output was most sensitive to the P management factors. For the medium baseline scenarios for the Ridge and Valley and Piedmont regions, the P-Index was most sensitive to the P management factors and curve number. For the high scenarios in the Ridge and Valley and Piedmont regions, the P-Index output was most sensitive to the erosion subfactors and curve number. The P-Index output was most sensitive to the P management subfactors in the Eastern Shore region low and medium risk of P delivery scenarios. In the Eastern Shore region, Mehlich I P was the most sensitive parameter in the high risk of P delivery scenarios. The sensitivity analysis of the P-Index can be useful in identifying areas of concern and to identify if for any of the scenarios it appears that the P-Index is too sensitive to a factor. Further, time and effort could be focused on the factors to which the P-Index was sensitive.

The results of the sensitivity analysis can be used to identify scenarios and situations where careful parameter estimations are needed because the P-Index was sensitive. In low P risk of delivery scenarios, it is important that the correct P application rate, method of application, and source of fertilizer P be used since the P-Index was most sensitive to those parameters. In the medium P risk of delivery scenarios with soils that are moderately to well drained, it is important that the correct P application rate, method of application, source of fertilizer P, and curve number are chosen. In the high risk of P delivery scenarios with soils that are moderately to well drained, estimation of soil loss using RUSLE, sediment delivery factor, and curve number should be carefully determined. In the Eastern Shore region with soils that are somewhat poorly drained and poorly drained, careful estimation of Mehlich I and the soil texture/drainage factor is needed since the P-Index was most sensitive to those factors.

The sensitivity analysis was useful in identifying when the sensitivity of the P-Index does not appear to correspond to expected conditions based on knowledge of the processes. The P-Index was sensitive to P application rate, the method of P application factor, and the source availability factor. Although the output should be sensitive to the P management factors, when there is low runoff this factor should not contribute to the overall runoff P risk as much as in cases of high P runoff. The sensitivity of these P management factors is therefore a concern at the low to medium category when P application recommendation switches from N-based to 1.5 times P crop removal. Although P in runoff may be very low, the amount of P application may be N-based as defined by the low risk of P delivery. Since the P-Index is sensitive to P application rate, the N-based rate could change the category to a higher more stringent P management category, although there is very little to no P loss in runoff. Therefore, additional investigation of the P management factor is needed to ensure the representative level of sensitivity and risk of P delivery to surface water is achieved.

Variability of the input parameters as represented by probability distributions increased as P risk increased and, therefore, there is a larger concern of being in a different P management category at the higher risk of P delivery scenarios. Since, in most of the scenarios, the baseline P-Index value was located near the middle of the management recommendations, there was not much change between management categories with the only non-zero probability of being in a different P management category at the high risk of P delivery level. In the medium to high impact of P delivery to surface water threshold baseline, if a value is between 0 and 5 of the threshold value there is up to a 0.16 chance of being in a different P management category. The probability increased for the high to very high impact of P delivery to surface water and even within 10 from the threshold value, there is up to a 0.21 chance of being in a different P management category. The probability of being in a different management category based on the P-Index value could be provided to users to allow them to assess the strength of the corresponding P management recommendation.

4.0 Expert Opinion Survey

4.1 Introduction

An expert opinion survey was developed and administered to obtain the opinion of experts on the appropriateness of parameter estimation methods used in the Virginia P-Index. The survey was completed as a means of assessing if each method or process of representing the factors was most appropriate for the management tool, in the opinion of experts. The following tasks were completed to assess the appropriateness of the parameter estimation methods for the Virginia P-Index:

1) Developed expert opinion survey;
2) Determined who to send the survey to and sent the survey out to willing participants;
3) Evaluated survey results and overall appropriateness of the parameter methods based on the results of the expert opinion survey and sensitivity analysis; and
4) Facilitated a discussion with the P-Index development team to evaluate comments and results of the survey.

4.2 Methodology

A procedure was developed to determine the appropriateness of the parameter estimation methods in the Virginia P-Index. The procedure included developing and conducting an expert opinion survey. The survey was designed and distributed to survey participants that have expert or advanced knowledge on the P cycle or P management. A written survey was developed as this appeared to be the easiest way to gather opinions from others within a large geographical area. The survey format was chosen to best meet the objective of evaluating the appropriateness of the parameter estimation methods used in the Virginia P-Index. In order for the survey to provide valuable or useful information, it was important that the survey questions be worded appropriately. The P-Index development team was consulted to discuss format, content, and wording of survey questions.

The first step of survey development was to determine the overall goals or objectives of the survey. Once the goals and objectives were defined, survey questions were developed that matched the objectives. The overall goal of the survey was to determine expert opinion on appropriateness of the parameter estimation methods in the P-Index. Also of interest was what experts thought of the values chosen for some of the parameters and whether values were judged to be realistic. In addition, it was of interest to obtain the opinion of experts as to other parameter estimation methods that could be used instead of those currently used.

Since not all survey participants were familiar with the Virginia P-Index, an introduction or overview was included at the beginning of the survey. The overview included background on the Virginia P-Index, a description of the P-Index format, how to calculate the P-Index, and an interpretation of the results that correspond to P management recommendations. Detail was kept to a minimum to avoid a lengthy survey. To provide additional information and detail on the Virginia P-Index and factors that comprise the index, a technical guide was included with the survey. Since all factors were important in the calculation of the Virginia P-Index it was determined to create a question for each of the factors.

The survey was organized so that questions were presented in a logical order. The P-Index is divided into three site-specific risk factors: erosion, runoff, and subsurface. Within these factors, there are subfactors. Initially, the survey was divided into the three different categories of factors: source, transport, and management. However, skipping between erosion, runoff, and subsurface factors was thought to be confusing to people not familiar with the Virginia P-Index. Therefore, the survey format was changed so that questions were grouped into the three factors (erosion, runoff, and subsurface) as outlined in Figure 2.4, along with a fourth category of general. A brief definition and explanation of the sub-factors was provided with each set of survey questions. All questions were formatted with the same scale and general wording to maintain consistency. A five-point scale was chosen for use in the survey modeled after a nine-point scale used by the RAND Corporation (Fitch et al., 2001). In the nine point scale, 1-3 assessed the degree of inappropriateness, 3-6 the degree of uncertainty, and 7-9 the degree of appropriateness. The RAND model was developed as an instrument to enable the measurement of the overuse and underuse of medical and surgical procedures (Fitch et al., 2001). The appropriateness scale used in the P-Index survey instrument is outlined in Figure 4.1.

Scale	Inappropriate	1	2	3	4	5	Appropriate

Where:
5 = appropriate: this is your method of choice
4 = fairly appropriate: this method is preferred over others
3 = equivocal: there are other methods that could be used with equal appropriateness
2 = fairly inappropriate: this method does not represent the factor effectively
1 = inappropriate: this method does not at all represent the factor correctly and should not be used

Figure 4.1: Appropriateness scale for expert opinion survey on the Virginia P-Index

The overall question for each factor was formatted into a multiple part question as follows:

1) A definition of the factor;
2) A general question as to whether the method was inappropriate to appropriate;
3) A question that solicited what other methods, if any, would the survey participant suggest using to estimate the parameter in question;
4) A question to assess if the values were reasonable or realistic. For this question, the factor values were included and experts were to indicate by checking in the table whether the given values of the factor seem low, reasonable, or high as shown in Table 4.1 for the sediment delivery factor; and
5) A place for comments for each of the sub-factors.

Please indicate by checks in the table below whether the given values of the sediment delivery factor seem low, reasonable, or high.

Flow Distance from Edge of Field to an Intermittent or Perennial Stream, or a Stream Buffer Width	**Sediment Delivery Factor**	**Values**		
		Low	**Reasonable**	**High**
> 500 ft OR stream buffer width > 100 ft	0.3			
300-500 ft OR stream buffer width of 75-100 ft	0.5			
200-300 ft OR stream buffer width of 50-75 ft	0.7			
100-200 ft OR stream buffer width of 25-50 ft	0.8			
25-100 ft AND stream buffer width < 25 ft	0.9			
< 25 ft	1.0			

Figure 4.2: Example of the question and table in the Virginia P-Index expert opinion survey for assessing if values of the sediment delivery factor were reasonable

A question was also included to determine what experts thought of the equal weighting of the erosion, runoff, and subsurface factors. The erosion, runoff, and subsurface factors are summed together and multiplied by a scaling factor to obtain the output value. This question arises since in the original P-Index developed by NRCS, weighting factors were used to place importance on the most significant factors directly. Although these factors are summed without a weighting factor, results of the sensitivity analysis indicated that factors contributed to the overall output differently and varied based on scenario. The survey participants were also asked to rate their overall expertise on risk of P loss on a scale similar to the appropriateness scale, as shown in Figure 4.3. Space was also provided for survey participants to provide any additional comments on the Virginia P-Index. The survey instrument is included in Appendix C.

Not knowledgeable 1 2 3 4 5 very knowledgeable

5 = very knowledgeable, I am considered an expert on the subject
4 = knowledgeable, I am very familiar and knowledgeable with this subject
3 = somewhat knowledgeable, I work with this subject some, but not on a regular basis
2 = slightly knowledgeable, I have some knowledge on this subject, but do not work with it very often
1 = not very knowledgeable, I have little to no knowledge on this subject

Figure 4.3: Scale for survey participants' rating of their overall expertise on risk of P loss

Prior to administration of the survey, some members of the P-Index development team and other people familiar with P management were consulted as to the format and wording of the survey questions. Their comments were taken into consideration and some of the wording and format of the survey was modified. For example, in a previous draft there was some confusion between the erosion, runoff, and subsurface factors and the factors that comprise each of these three factors. Therefore, the wording of sub-factors was used to clarify the format of the Virginia P-Index.

A cover letter was developed to provide additional information for the survey participants. Since the topic is specific and could be new to some of the survey participants, the introduction for the survey had to be concise, but informative. Since it was assumed that all survey participants had knowledge of P management, detailed background was not necessary. A form was also included at the end of the survey that respondents could submit to receive results of the survey. They could send the form in separately, if they chose to remain anonymous.

The survey participants were determined based on various criteria including: 1) should include participants with extensive education, training, and experience in non-point source pollution, nutrient management, and other agricultural management practices, and/or developed a P-Index for their state; 2) should include participants from the State of Virginia and other surrounding states; and 3) should comprise professionals employed within federal, state, and academic areas. The survey was first distributed at a technical session on state P-indexes at the American Society of Agricultural Engineers (ASAE) International Conference in Chicago, IL in July 2002 since a number of experts in the field were present. Additional survey participants were selected based on the above criteria. Members of the P-Index survey development team helped provide names of possible survey participants that met the above criteria. An e-mail message was sent to the potential participants to ask them to complete the survey. A cover letter, survey, and technical guide were then mailed to those who agreed to participate. The survey participants were given from four to six weeks to complete the survey and were given pre-paid envelopes to return the surveys.

4.3 Results and Discussion

4.3.1 Appropriateness of Parameter Methods

Sixty-three surveys were sent to experts with thirty-eight surveys returned. The surveys were sent out from July 29 to September 22, 2002. Survey respondents were comprised of professionals from various states within academia, state, and federal positions (Table 4.1).

Table 4.1: Description of survey respondents

Description of Respondents	#
From Virginia	17
From other states	21
Other States included:	AR, KY, IL, TN, PA, NH, OH, GA, FL, TX, MD, IA
Total from Academic	7
Total from NRCS/ARS (not in VA)	14
Total from local NRCS & DCR (VA)	15
Total from private	2

Survey participants were asked to rate the appropriateness of each of the P-Index parameter methods based on the scale given in Figure 4.1. The means, minimum and maximum values, standard deviations, and modes for each of the methods are given in Table 4.2. All comments and individual answers to the questions are provided in Appendix D.

Table 4.2: Appropriateness on a scale of 1 (not appropriate) to 5 (appropriate) of parameter estimation methods for all survey participants

Question	Mean	Standard Deviation	Min	Max	Mode	# answered (out of 38)
Question 1(a) - RUSLE to estimate edge of field soil loss	4.35	1.10	1	5	5	37
Question 2(a) - sediment delivery factor to estimate the amount of sediment transported to a stream	4.11	0.88	1	5	5	37
Question 3(a) - sediment total P factor to estimate P available in eroded sediment	4.40	0.74	3	5	5	37
Question 4(a) - curve number method to estimate average annual runoff	4.38	0.78	3	5	5	37
Question 5(a) - runoff delivery factor to estimate the amount of runoff transported to a stream	4.17	1.14	1	5	5	36
Question 6(a) - runoff DRP factor to estimate amount of dissolved soil P potentially available to runoff	4.32	0.97	1	5	5	37
Question 7B (a) - source availability factor to estimate P available for runoff in applied fertilizer	4.69	0.62	2	5	5	35
Question 7C (a) - method of application factor to estimate P potentially available for runoff based on method of application	4.61	0.65	2	5	5	36
Question 7D (a) - Adding the applied fertilizer factor to the other runoff factors to account for the amount of DRP in runoff due to P applications	4.11	1.20	1	5	5	35
Question 8(a) –a water balance method to estimate average annual percolation	4.31	0.98	1	5	5	35
Question 9(a) – a soil texture/drainage class factor to evaluate the effects of soil texture and drainage on the potential of P movement through subsurface leaching	4.21	0.96	1	5	5	36
Question 10(a) –subsurface DRP factor to estimate dissolved P potentially available for subsurface loss	4.17	1.07	1	5	5	35

The overall means ranged from 4.11 to 4.69 on a scale out of 5. For all methods, the mode, or most often chosen value, was 5 indicating that the majority of the experts thought the estimation methods were appropriate. For the appropriateness of the methods question, the sediment delivery factor had the lowest mean and the source availability factor had the highest mean. No participants thought that the estimation methods for the source availability factor, method of application factor, sediment total P factor, and runoff from the field were inappropriate. For all other factors, at least one survey respondent thought the method used for parameter estimation was inappropriate. The factors with the lowest averages were sediment delivery, runoff delivery, and subsurface DRP. The concept of adding the applied fertilizer factor to the runoff factor also had a lower average (4.11/5).

Results of additional questions are included in Table 4.3 including respondents' expertise ratings. Overall, most thought that application rate should be included in the P-Index. The question about equal weighting received mixed results and this could be due to confusion over what was being asked. Most of the respondents rated themselves as being somewhat knowledgeable to very knowledgeable on risk of P loss.

Table 4.3: Survey results for additional questions

Question	Mean	Standard Deviation	Min	Max	Mode	# answered (out of 38)
Question 7A (a) –application rate be included	33-Yes, 2-No, 2-Undecided					37
Question 11(a) - Equal weighting of the erosion, runoff, and subsurface risk factors	3.73	1.24	1	5	5	37
Question 12 - rating of overall expertise on risk of P loss	3.58	0.83	2	5	4	38

Results were also analyzed based on the different groups that completed the survey to see if there were any major differences between groups. Table 4.4 includes the means, standard deviations, and modes separated into participant groups based on common variables including expertise rating $\geq$ 4 versus expertise rating < 4, and all but local NRCS conservationists versus local NRCS conservationists. A t-test ($\alpha = 0.05$) was also completed to determine if means were significantly different (Table 4.5). The Statistical Analysis System (SAS) (SAS Institute, 1993) was used for the analysis. The SAS code is included in Appendix E.

Table 4.4: Appropriateness means, standard deviations, and modes for separate groups of survey participants

Question	ALL Participants			Knowledge Rating ≥ 4			Knowledge Rating <4			All but local NRCS			Local NRCS		
	Mean	S.D.	Mode	Mean	S.D.	Mode	Mean	S.D.	Mode	Mean	S.D.	Mode	Mean	S.D.	Mode
Question 1(a) – Soil Loss	4.35	1.10	5	4.55	1.05	5	4.12	1.05	5	4.41	1.19	5	4.09	0.70	4
Question 2(a) - Sediment Delivery	4.11	0.88	5	4.16	0.90	5	3.94	1.21	4	4.04	0.92	4	4.17	1.34	5
Question 3(a) - Sediment P	4.40	0.74	5	4.25	0.85	5	4.63	0.50	5	4.33	0.78	5	4.70	0.48	5
Question 4(a) - Runoff from field	4.38	0.78	5	4.35	0.88	5	4.41	0.62	4	4.33	0.83	5	4.55	0.52	5
Question 5(a) - Runoff Delivery	4.17	1.14	5	3.95	1.35	5	4.41	0.71	5	3.92	1.20	5	4.82	0.40	5
Question 6(a) - Runoff DRP	4.32	0.97	5	4.35	0.88	5	4.29	1.05	5	4.19	1.04	5	4.73	0.47	5
Question 7B (a) – Source Availability	4.69	0.62	5	4.95	0.23	5	4.38	0.81	5	4.76	0.66	5	4.55	0.52	5
Question 7C (a) - Method of Application	4.61	0.65	5	4.84	0.37	5	4.35	0.79	5	4.65	0.69	5	4.55	0.52	5
Question 7D (a) - Applied Fertilizer	4.11	1.20	5	4.21	1.08	5	4.00	1.26	4	3.92	1.29	5	4.64	0.50	5
Question 8(a) – Percolation	4.31	0.98	5	4.11	1.15	5	4.53	0.62	5	4.15	1.05	5	4.73	0.47	5
Question 9(a) - Soil texture/drainage class	4.21	0.96	5	4.36	1.03	5	3.82	1.33	4	4.15	1.04	5	4.08	1.51	5
Question 10(a) – Subsurface DRP	4.17	1.07	5	4.44	0.92	5	3.88	1.11	4	4.12	1.17	5	4.36	0.67	5
Question 11(a) - Equal weighting	3.73	1.24	5	3.85	1.14	5	3.59	1.50	5	3.81	1.23	5	3.67	1.50	4
Question 12 - Expertise on P loss	3.58	0.83	4	4.28	0.41	4	2.81	0.55	3	3.85	0.81	4	2.83	0.72	3
Total Participants in category		38			20			18			26			12	

Differences were identified between participants based on their expertise on risk of P loss ratings. Means were significantly different ($\alpha = 0.05$) for soil loss, source availability factor, and subsurface DRP factor. Appropriateness means were higher for the estimation methods for participants that rated their expertise as ≥ 4 on a five-point scale for the following parameters: soil loss, sediment delivery, runoff DRP, source availability, method of application, applied fertilizer, and soil texture. Appropriateness means were lower for estimation methods for participants that rated their expertise as ≥ 4 on a five-point scale for the following parameters: sediment total P, runoff, runoff delivery, percolation, and subsurface DRP. In general, means were higher for those that rated themselves as having a higher expertise on risk of P loss. Factors that the experts with a ≥ 4 rating in risk of P loss had a lower rating in appropriateness than other respondents were sediment P, runoff delivery, and percolation based on differences between means (Table 4.5). Sediment P had an overall high appropriateness mean and the overall mean for percolation was in the middle. However, for runoff delivery appropriateness mean was overall low. Based on this interpretation, it appears that experts were not as confident in the method used to estimate the runoff delivery factor.

Table 4.5: Differences in means between groups

Question	Difference in means between expertise ratings [*]	Means are significantly different ($\alpha = 0.05$)	Difference in means between all but local and local NRCS [†]	Means are significantly different ($\alpha = 0.05$)
Question 1(a) - Soil Loss	0.43	X	0.32	X
Question 2(a) - Sediment Delivery	0.21		-0.13	
Question 3(a) - Sediment P	-0.38		-0.37	
Question 4(a) - Runoff from field	-0.06		-0.21	
Question 5(a) - Runoff Delivery	-0.46		-0.90	
Question 6(a) - Runoff DRP	0.06		-0.54	
Question 7B (a) - Source Availability	0.57	X	0.21	
Question 7C (a) – Method of Application	0.49		0.11	
Question 7D (a) – Applied Fertilizer	0.21		-0.72	X
Question 8(a) – Percolation	-0.42		-0.57	X
Question 9(a) - Soil texture/drainage class	0.54		0.06	
Question 10(a) - Subsurface DRP	0.56	X	-0.24	
Question 11(a) - Equal weighting	0.26		0.14	
Question 12 - Expertise on P loss	1.47	X	1.02	X

[*] Positive value means for group with ≥ 4 expertise rating is higher.
[†] Positive value means for all but local NRCS group is higher.

The local NRCS survey participants do not work with P risk of delivery on a daily basis, and thus many have lower expertise on the P-Index as indicated by their overall rating of themselves. These participants were asked to complete the survey since they are going to be one of the main users of the P-Index. Looking at differences between local NRCS and other participants in Table 4.4 and Table 4.5, local NRCS participants had generally higher overall means than the other participants and, therefore, generally thought the methods used in the Virginia P-Index were appropriate. The means were significantly different (α =0.05) for soil loss, adding of the applied fertilizer factor to the runoff factor, and percolation.

4.3.2 Values of Parameter Estimation Methods

For some of the parameters, survey participants were asked to evaluate whether the given values for selected methods seemed low, reasonable, or high. In Table 4.6 are results from respondents on values for the sediment delivery factor.

Table 4.6: Survey respondents' opinions on values of the sediment delivery factor

Flow Distance from Edge of Field to an Intermittent or Perennial Stream, or a Stream Buffer Width	Sediment Delivery Factor	Values			
		Low	Reasonable	High	Did not answer
> 500 ft OR stream buffer width > 100 ft	0.3	3	18	10	7
300-500 ft OR stream buffer width of 75-100 ft	0.5	2	19	10	7
200-300 ft OR stream buffer width of 50-75 ft	0.7	2	21	8	7
100-200 ft OR stream buffer width of 25-50 ft	0.8	2	22	9	5
25-100 ft AND stream buffer width < 25 ft	0.9	3	25	5	5
< 25 ft	1	2	26	4	6

Although most survey respondents thought sediment delivery factor values were reasonable, some thought the values for distance to stream and large buffer widths were too high and thus could be underestimating the reduction of sediment P to a stream. Therefore, in those cases, respondents felt P delivery risk was overestimated.

Survey respondents' opinion on values of the runoff delivery factor are given in Table 4.7. Although most survey respondents thought the runoff delivery values were reasonable, some thought the values for distance to stream and large buffer widths were too high and thus could be underestimating the reduction of dissolved P transported to surface water.

Table 4.7: Survey respondents' opinions on values of the runoff delivery factor

Flow Distance from Field to an Intermittent or Perennial Stream, or a Stream Buffer Width	Runoff Delivery Factor	Values			
		Low	Reasonable	High	Did not answer
> 500 ft OR stream buffer width > 100 ft	0.4	3	14	11	9
300-500 ft OR stream buffer width of 75-100 ft	0.6	3	15	9	10
200-300 ft OR stream buffer width of 50-75 ft	0.8	3	18	5	10
100-200 ft OR stream buffer width of 25-50 ft	0.9	3	21	3	9
0-100 ft AND stream buffer width < 25 ft	1	0	22	3	8

Over one-half of the respondents thought that the source availability factor values were reasonable (Table 4.8). One-third of the respondents did not answer the question. Some possible reasons why the respondents did not answer the question include that they were not comfortable answering the question or did not have the expertise within this area, as indicated by four of the survey participants. Five survey participants indicated that the manure/litter source availability values were low and/or should be broken into different categories for different availability of manure types. Inorganic fertilizer values were thought to be low by some of the experts and availability could vary in different types of inorganic fertilizers. Eight participants thought values of source availability for biosolids were either too high or too low since availability varies based on the treatment processes involved.

Table 4.8: Survey respondents' opinions on values of the source availability factor

Fertilizer Type	Source Availability Factor	Values				
		Low	Reasonable	High	Did not answer	Unsure
Manure/Litter	0.2	5	22	1	11	1
Litter with phytase	0.25	2	18	5	12	1
Alum-treated Litter						
0.7 < Al:P ratio < 1.0	0.1	1	24	0	12	1
0.4 < Al:P ratio < 0.7	0.15	1	24	0	12	1
Inorganic	0.25	6	18	1	12	1
Biosolids	0.2	4	22	4	11	1

Participants' opinions on values of the method of application factor are summarized in Table 4.9. Generally, participants thought values were reasonable, with some participants suggesting that values are low and do not place enough emphasis on the effect of application method, especially for surface applied with no incorporation. Less than one-fourth of the participants did not answer the survey question.

Table 4.9: Survey respondents' opinions on values of the method of application factor

Method of Application	Method of Application Factor	Values				
		Low	Reasonable	High	Did not answer	Unsure
Surface applied, no incorporation	0.2	8	22	0	7	1
Injected or incorporated immediately	0.05	2	27	1	7	1
Incorporated within 3-5 days of application	0.1	5	25	0	7	1

Most participants thought the values of the soil texture/drainage class factor were reasonable (Table 4.10). However, one-fourth of the respondents did not answer the question. Some participants thought values for the coarser than loamy fine sand for somewhat poorly drained and moderately-well drained were low, while others thought values for somewhat poorly drained finer than sandy clay loam texture were low. For these cases, respondents thought that either subsurface P loss could occur or that the risk of subsurface P delivery should be higher in those instances.

Table 4.10: Survey respondents' opinions on values of the soil texture/drainage class factor

Soil drainage class	Soil texture to depth of 18"												
	Coarser than loamy fine sand				Between loamy fine sand and sandy clay loam				Finer than sandy clay loam				
		L	R	H		L	R	H		L	R	H	Did not answer
Very poorly and poorly drained	**1.0**	0	23	3	**0.75**	0	23	3	**0.5**	2	22	2	11
Somewhat poorly drained	**0.25**	8	19	0	**0.25**	3	23	1	**0**	7	20	0	11
Moderately-well and well-drained	**0**	6	20	0	**0**	5	20	1	**0**	3	23	0	11

L-low, R-reasonable, H-high

Some possible explanations why respondents did not answer the questions were that they did not understand the question or were not comfortable with answering the question since they did not feel they had adequate expertise in that area to comment on values, as indicated by some of the respondents. It seemed that many participants did leave questions blank as suggested in the cover letter if they did not feel comfortable answering the question (some participants commented on the survey when they left a section blank that they did not have enough expertise in the subject to answer the question). One participant indicated that she did not feel comfortable commenting on the actual value but completed the questions relative to the other values given. Regardless of the amount of thought given to evaluate the values, there was consistency relating to many of the values. Further evaluation of the values that one-fourth of the participants thought were either too high or two low could be beneficial in improving the P-Index.

4.3.3 Other Methods Suggested

Overall, there were very few alternative methods suggested for estimating values of the parameters in the Virginia P-Index. Outlined in Table 4.11 are other methods suggested by survey participants to be considered for each of the factors of the P-Index.

Table 4.11: Other parameter estimation methods for the P-Index factors

P-Index Factor	Other Methods Suggested
Soil loss	❖ RUSLE2, an improved version of RUSLE (6*) ❖ Historical or measured data ❖ USLE ❖ Choose a storm based on local intensity duration frequency curve and determine soil loss based on that event.
Sediment delivery factor	❖ using only distance to stream and not buffer width for the sediment delivery factor ❖ factoring in a length of slope weighted average to the sediment delivery factor
Sediment total P Factor	❖ iron-oxide strip method to provide an estimate of bio-availability ❖ water extractant values, modify or refine factor to account for true physiographic regions since Piedmont and Upper Coastal soil surfaces are probably different enough to require this modification over time ❖ within each region look at major soil types to determine if P sorption capacities are similar. P sorption Index or % P saturation could be used to estimate these properties

Runoff from field	❖ NRCS hydrologic soil groups and soil series classification ❖ runoff class or risk factor assessment (3) ❖ WEPP ❖ If data available, use more detailed, process orientated models that use Green-Ampt equations such as RZWQM ❖ Regional rainfall/runoff relationships
Runoff delivery factor	❖ Approach this one from the what is entering the field; the contributing area and contribution area shape contribute to this factor
Runoff DRP factor	❖ water extractant ❖ modifications on this factor based on source timing and management system ❖ develop relationship between Mehlich I soil test P and DRP in runoff for a variety of soils that fall into the three physiographic regions
Applied fertilizer DRP factor	❖ bringing management factor (type of tillage) into the P-Index would alter this factor ❖ including timing effects unless the likelihood of runoff is constant throughout the year (2)
Percolation	❖ NRCS leaching index ❖ regional data ❖ maybe just use drainage
Soil texture/drainage class factor	❖ consider depth to water table as well ❖ P sorption Index; (soil's ability to fix P) ❖ Include distance. ❖ Differences between drained and undrained fields
Subsurface DRP factor	❖ water extractant ❖ soil variability within each physiographic region; also look at how well connected the field is to surface water, especially if it is drained and where the outlet is.
Equal weighting	❖ a heavier weighting on whatever source is greater (2)

* Numbers in parentheses indicate the number of participants that suggested the alternative method; if not indicated, only one person gave the suggestion.

4.4 Analysis of sensitivity and appropriateness

Relating appropriateness to sensitivity of the P-Index is important in evaluating the results. The parameters were grouped based on appropriateness survey results (Table 4.12). Since all parameter methods were considered appropriate by the respondents, two categories were considered: appropriate (mean ≥ 4.30) and less appropriate (mean < 4.30). A rating of 5 corresponds to appropriate and the method of choice and a rating of 4 corresponds to fairly appropriate and the method is preferred over others.

Table 4.12: Grouping of appropriateness of factor methods based on overall means

Factor	Mean
Appropriate	
Application rate	
Source Availability	4.69
Method of Application	4.61
Sediment total P	4.40
Runoff from field	4.38
Soil Loss	4.35
Runoff DRP	4.32
Percolation	4.31
Less Appropriate	
Soil texture/drainage class	4.21
Subsurface DRP	4.17
Runoff Delivery	4.17
Adding Applied Fertilizer	4.11
Sediment Delivery	4.11

Parameters were then organized into three distinct categories of relative sensitivity within the baseline scenarios as follows: insensitive to slightly sensitive (|0-0.1|), moderately sensitive (|0.1 – 0.6|), and sensitive ($|\geq 0.6|$). Due to similarities, the Ridge and Valley and Piedmont Regions low risk of P delivery scenarios and medium risk of P delivery scenarios were grouped together. Rating of appropriateness and sensitivity were then combined (Table 4.13). Three variables, Mehlich I P, distance to stream, and applied fertilizer, were not assessed with respect to appropriateness of estimation method.

Evaluation within the groupings identifies the strengths and weaknesses of the factor estimation methods used in the P-Index. Factors of most concern are those whose methods were considered less appropriate by respondents and sensitive. The P-Index output is sensitive to the soil texture/drainage class factor and the method to estimate the factor was also considered less appropriate. The factor methods that were considered appropriate by the respondents and that the P-Index was determined to be moderately sensitive are thought to be the best represented within the P-Index. If the P-Index is moderately sensitive to a parameter, an expected change in the output is observed based on the knowledge of the process when the parameter is varied from the baseline.

Table 4.13: Parameter method appropriateness versus P-Index sensitivity for all baseline scenarios

Appropriate Grouping*	Insensitive to slightly sensitive | 0 - 0.1|	Moderately sensitive | 0.1 – 0.6 |	Sensitive | ≥ 0.6 |
Ridge & Valley and Piedmont Regions: low risk of P delivery			
A	soil loss, sediment total P, CN, runoff, STDRP in runoff, percolation		annual application rate, method of application, source availability
LA	sediment delivery, runoff delivery, subsurface DRP		soil texture/drainage class
N	Mehlich I P, distance to stream		applied fertilizer
Ridge & Valley and Piedmont Regions: medium risk of P delivery			
A	runoff, STDRP in runoff, percolation	soil loss, sediment total P, annual application rate, method of application, source availability	CN
LA	runoff delivery, subsurface DRP	sediment delivery	soil texture/drainage class
N		Mehlich I P, applied fertilizer	
Ridge & Valley Region: high risk of P delivery			
A	runoff, STDRP in runoff, percolation	annual application rate, method of application, source availability	soil loss, sediment total P, CN
LA	runoff delivery, subsurface DRP		sediment delivery, soil texture/drainage class
N		Mehlich I P, Applied Fertilizer	
Piedmont Region: high risk of P delivery			
A	percolation	soil loss, sediment total P, runoff, STDRP in runoff, annual application rate, method of application, source availability	CN
LA	subsurface DRP	sediment delivery, runoff delivery	soil texture/drainage class
N		Mehlich I P, applied fertilizer	
Eastern Shore Region: low risk of P delivery			
A	soil loss, sediment total P, runoff, STDRP in runoff, percolation	CN	annual application rate, method of application, source availability
LA	sediment delivery, runoff delivery, subsurface DRP		soil texture/drainage class
N	Mehlich I P, distance to stream		applied fertilizer
Eastern Shore Region: medium risk of P delivery			
A	soil loss, sediment total P, runoff, STDRP in runoff	CN, percolation	annual application rate, method of application, source availability
LA	sediment delivery, runoff delivery	subsurface DRP, soil texture/drainage class	
N		Mehlich I P	applied fertilizer

* A-appropriate
LA-less appropriate
N-appropriateness not assessed

Table 4.13(cont.)

Appropriate Grouping*	Insensitive to slightly sensitive | 0 – 0.1|	Moderately sensitive | 0.1 - 0.6 |	Sensitive | ≥ 0.6 |
Eastern Shore Region: high risk of P delivery			
A		soil loss, sediment total P, runoff, STDRP in runoff, annual application rate, method of application, source availability, percolation	CN
LA		sediment delivery, runoff Delivery, subsurface DRP, soil texture/drainage class	
N		applied fertilizer	Mehlich I P

* A-appropriate
LA-less appropriate
N-appropriateness not assessed

4.5 Comments on Factors and Responses

Specific comments for each of the factors were provided by many survey participants and are included in Appendix D. The overall results of the sensitivity analysis and survey were presented to the Virginia P-Index development team and specific comments for each factor were identified and discussed to evaluate concerns relating to the P-Index. In the following sections, for each factor, the respondents' comments are presented followed by responses from the Virginia P-Index development team, an evaluation and interpretation of the comments, and analysis based on the findings of the sensitivity analysis and survey.

4.5.1 Soil Loss Factor

Comments from survey respondents:

For the edge of field soil loss factor, most participants agreed that RUSLE was the best available tool to use to estimate soil loss. However, six participants suggested using RUSLE2 and improved versions of RUSLE as well as new technologies when available. The edge of field soil loss factor includes a vegetated filter strip adjustment factor to account for a filter strip located at the edge of the field. One participant was concerned about double crediting a downslope filter with the vegetated filter strip adjustment factor and the sediment delivery factor. Another concern from a respondent was use of RUSLE in that RUSLE is typically calculated for a rotation, whereas use in the P-Index is based on the average annual soil loss. In addition, four participants noted that soil loss from concentrated flows such as waterways and gullies should be included.

P-Index development team response:

Comments on using RUSLE for soil loss were evaluated by the P-Index development team including if it is considered a "plug-in" module and if methods should be included to account for gully erosion. The team clarified that the P-Index requires an estimate of soil loss. Their current recommendation is to use RUSLE to calculate that estimate because that is what NRCS in Virginia is using. When RUSLE2 is implemented in Virginia, it should be used in the P-Index as well. The development team did not consider accounting for gully erosion since in those cases soil erosion would exceed the soil loss tolerance to participate in government programs and erosion controls would have already been implemented to reduce soil loss.

Evaluation of response and analysis:

RUSLE is the best available "plug-in" module currently available since it is currently being used by many of the future users of the Virginia P-Index. Not accounting for gully erosion limits accuracy of the model when gully erosion accounts for most of the site erosion. The P-Index development team justifies not accounting for gully erosion since in the P-Index's current use in conjunction with NRCS funded projects, soil loss must be below two times the threshold loss of the soil. At this level, it is unlikely that gully erosion would occur. Although under current uses for the P-Index gully erosion is not found, if the P-Index was implemented and used for other cases, gully erosion could not be accounted for. If the P-Index is implemented for sites where gully erosion is present, then gully erosion should be considered within the P-Index. The sensitivity analysis determined that soil loss was a moderately sensitive parameter and using RUSLE was considered appropriate from the survey. Based on these conclusions, the method should be left unchanged until further technologies such as RUSLE2 become available. In the probability distribution analysis to evaluate parameter variability, soil loss results impacted the variability of the P-Index output the most (except in the Eastern Shore medium risk of P delivery scenario). Therefore, consistency of parameter estimation among users is the largest concern for this parameter and steps should be taken to ensure user consistency.

4.5.2 Sediment Delivery Factor

Comments from survey respondents:

Experts provided their opinions on estimation methods for the sediment delivery factor. Two participants suggested there needed to be additional information provided to justify the values from either published literature or field data and validation. Two participants suggested further clarification of the definition of “stream”. For example, one respondent wanted to know if gullies and ditches are considered streams. One participant pointed out that application of manure would occur most likely when intermittent streams were dry or had very little to no flow. Nine comments were provided related to buffer characteristics. Of those, six were concerned that the buffer width did not account for the condition of the buffer, type of vegetation present, or slope of the buffer. There was also concern about the effectiveness of the buffer between sheet flow and channelized flow since a buffer is less effective under channelized flow. Another participant thought other best management practices (BMPS) should be considered beyond buffer strips. Other professionals wanted additional guidance on which factor values to choose. For instance, if the field is located 200-300 ft from a stream with a 40 ft buffer, should he/she choose 0.7 or 0.8 as the factor value? Another suggestion was to include an additional category of <10 feet and shift the factors adding 0.1 to the > 500 feet category. One respondent was concerned that a field with a contour/strip rotation at 7-15 % slope within 25-100 feet of a stream will have the same sediment delivery factor as a 0-2% continuous cropped floodplain field within 25-100 feet of a stream. The participant stated that both fields will have the same sediment delivery factor value, but under the same storm event, sediment delivery from the 7-15% slope field will be higher than the 0-2% slope field. Further, the participant stated that sediment/nutrient loading is more related to storm events in relation to time of application.

P-Index development team response:

For the sediment delivery factor, the development team agreed that wording in the technical guide should be revised relating to stream definition and buffers. However, they did not agree with some of the survey respondents in adding further buffer characteristics. This would be too complicated for a P-Index.

Evaluation of response and analysis:

Including buffer characteristics would make the index more complicated, however, if characteristics accounted for a better maintained and thus better functioning buffer it may give the producer more incentive for continuing to maintain the buffer. For the sediment delivery factor, the most concerns were over the buffer strip. Further clarification or improvements could improve the accuracy of the P-Index. Wording within the technical guide could state that the buffer strip must be maintained. However, there are not enough data available to make significant improvement regarding the accuracy or method for this factor. A study in the mid-Atlantic states to measure the amount of sediment leaving the field and then entering the stream for a small watershed along with modeling of the results is needed, however, this does not appear to be a feasible project in conjunction with the development of the Virginia P-Index. Further, a modeling study could be used to evaluate sediment delivery to a stream and evaluate differences in delivery due to soil properties, slope, and land cover.

4.5.3 Sediment Total P Factor

Comments from survey respondents:

There were mostly positive comments from survey respondents on the sediment total P factor. One participant stated that the sediment total P factor should be tied to soil texture as well as geographic region. Another participant thought this was an innovative means of addressing sediment enrichment ratios for P and suggested publishing the results on the relationship of soil test P to total P. One participant stated that not all sediment P is available to cause water quality problems and this should be accounted for. There was also a comment on the discrepancy of estimating P loss in sediment based on a typical soil test P that is taken to a depth of 5 to 7 inches whereas soil loss occurs in the top layer, which may only be the thickness of a dime.

P-Index development team response:

Relating to the sediment P factor, one respondent asked if a sediment "enrichment" factor was considered. While the development team explained they had considered including an enrichment factor, they concluded that there were not enough data available to estimate values of such a factor.

Evaluation of response and analysis:

Different data including additional soil parameters would be needed to include an enrichment factor. The method for sediment total P factor is considered appropriate. The sensitivity of the P-Index to the sediment total P factor varies with different levels of soil loss and source conditions, as expected. The P-Index is less sensitive to sediment total P under low soil loss and source conditions. Improvements within this factor could include further separation into more categories to account for variability in soil texture and regions when more data are provided during further testing and validation of the P-Index. This would improve the accuracy of the P-Index, since the input to this factor, Mehlich I P, could also vary within a field. It is also suggested to develop these relationships based on results of the Mehlich III P (1984) test, if the Virginia Tech Soil Testing Laboratory switches to this extraction method.

4.5.4 Runoff Factor

Comments from survey respondents:

Most of the participants agreed curve number is the best method to use for estimating runoff from the field. However, one participant believed that Virginia's use is stretching curve number capabilities but agrees this is okay for risk assessment. One respondent questioned if the results look "real" and wanted to know how developers went from a storm-base to annual calculation and if developers took into account smaller rains that do not produce surface runoff. Another professional did not agree with altering the curve number look-up tables as outlined in Tables 6 and 7 in the technical guide. This participant felt that the NRCS document or table is designed to be used in its entirety and altering or condensing magnifies the level of accuracy. The respondent felt that slope should be included in this factor as well since slope affects the transport capacity of runoff.

P-Index development team response:

The development team stated that they accounted for smaller storms that do not produce runoff within the precipitation data. They also stated that there were not enough data to include slope. The development team also stated that the NRCS curve number table was not altered except for representing two crops within one year in which the average of the two curve numbers was used.

Evaluation of response and analysis:

Using curve number to estimate runoff was considered less appropriate (mean < 4.3) and runoff was considered only slightly sensitive within the medium risk of P delivery scenarios as well as the Ridge and Valley high risk of P delivery scenario. Curve number was considered a sensitive parameter, however, the actual runoff is more important than the impact of curve number since curve number will not vary as much as runoff. For example in the central mountain region, a 15% change in curve number from 72 to 83 changes runoff from 1.06 inches to 3.71 inches, whereas a 15% change in runoff would only increase runoff 0.2 inches. Based on the overall analysis, it appears that using curve number to estimate runoff is the best method available, however, the experts were aware of the faults or inaccuracies this method can produce. Although the P-Index should be more sensitive to sediment P parameters than the runoff parameters since P in most cases is attached to sediment at a higher concentration than in runoff, it seems that the risk of runoff within different risk potentials was not adequately represented based on the much lower relative sensitivity results for the runoff risk factors compared to the other factors.

4.5.5 Runoff Delivery Factor

Comments from survey respondents:

Some concern relating to the method for estimating values of the runoff delivery factor was brought up by many of the survey participants. Six survey participants brought up concern again over the buffer as in the sediment delivery factor. One participant thought the characteristics of the buffer should be addressed in the factor and another participant suggested a category to credit buffer strips that improve infiltration. Two survey respondents agreed that a buffer strip may reduce P in runoff but did not understand the basis for the distances to the stream. One participant who stated that runoff delivery must be somewhat dependent on the field size or drainage area had no reason to believe runoff would be reduced by 60% from flowing over 500 feet of some unknown landuse and definitely thought this would change between a 5 acre and 500 acre field. Another argument was that there are too many things happening in the landscape to assume similar delivery rates comparing any two fields based on distance to the stream alone. A couple of respondents' reactions were that the values were too high. One participant was concerned with over-prediction of reduction in runoff volume as the field gets further from the stream. Another participant stated that this factor should be based on a study to justify the values.

P-Index development team response:

In response to comments on the runoff delivery factor, the development team thought further wording could be added to the technical guide to clarify stream definition and buffers. Again due to limited data relating to the factor, no changes can be currently made to improve the factor.

Evaluation of response and analysis:

As indicated in the sediment delivery factor section, a push for additional studies within this area would be beneficial. The survey participants considered the method for runoff delivery factor less appropriate than many of the other factors. The P-Index was considered only slightly sensitive to the runoff delivery factor within the medium risk of P delivery scenarios as well as the Ridge and Valley high risk of P delivery scenario, which may not be representative of the potential runoff P risk. Since not enough data are available to further validate the values of the P-Index and the factor is not considered very sensitive overall, values of this factor should be re-evaluated by the Virginia P-Index development team. One modification would be to have fewer categories for this factor to place less emphasis on the distances since there are not a lot of data to support the difference in delivery.

4.5.6 Runoff DRP Factor

Comments from survey respondents:

Most of the survey respondents agreed the method for the runoff DRP factor was appropriate. One participant commented that runoff DRP might have little connection with soil test P if there was a recent application to the field.

P-Index development team response:

In comments relating to the runoff DRP, the development team agreed with one of the respondents that they would like to develop further relationships for different soil types and physiographic regions, since only limited data have been collected to date. In some instances, studies have shown cases where high extractable P levels correlate to low runoff where there is a high pH, however, this is a rare exception so was not considered within this factor. The P-index team thus suggested adding further guidance within the technical guide for situations with high pH.

Evaluation of response and analysis:

Collection of additional soil samples within other physiographic and textures could improve this factor. The method for the runoff DRP factor was considered appropriate. Improvements to this factor could be made as more data are available such as separation into more categories based on soil texture and more detailed regional characteristics.

4.5.7 Application Rate

Comments from survey respondents:

Most of the survey respondents agreed that application rate should be included in the P-Index. One participant stated that the management factor is critical in understanding the impact of management on potential/risk for P loss and is often more important than soil P. One respondent did not agree with including application rate in the P-Index because it was not logical to him to input the amount of P applied so that the P-Index can then tell how much P should be applied since soil test P accounts for the impact of application rate.

Analysis:

Since most of the survey participants agreed that application rate should be included in the P-Index, this should remain within the P-Index. However, since the P-Index was sensitive to this parameter further evaluation across scenarios should be evaluated to ensure the level of risk for this factor represents expected conditions based on the knowledge of the processes.

4.5.8 Source Availability Factor

Comments from survey respondents:

For the source availability factor, most survey respondents agreed the approach seems appropriate but provided suggestions to improve the subfactor. Four participants thought that biosolids source availability depends on the wastewater treatment process and may have a lower availability than manure. Further, respondents did not like that there is only one category for manures and suggested further differentiation among types since they may have different availabilities. There was some disagreement on the litter w/phytase source availability value. Two respondents did not think there should be any difference in availability while another agreed that phytase does increase P solubility.

P-Index development team response:

The P-Index development team agreed that further source availability factors relating to manures and biosolids should be included upon availability of the data. However, there have not been enough studies to date to make major modification to the source availability factor. One respondent suggested differentiating between dry and liquid suspension chemical fertilizers. The P-Index team does not agree with this comment since dry fertilizers are 100% water soluble.

Evaluation of response and analysis:

Future studies in other states may be used for comparison to Virginia's source availability factor. The source availability factor approach was determined appropriate by most survey participants and had the highest overall mean for appropriateness. The output was moderately sensitive to the source availability factor under most conditions. A study is needed to evaluate the measured losses of dissolved and sediment P for different manure sources under various climates and soil textures typical in Virginia.

4.5.9 Method of Application Factor

Comments from survey respondents:

Most survey participants agreed the method of application factor is appropriate and provided suggestions to improve the factor. One respondent was concerned over which category to choose if, for instance, manure was incorporated immediately, but commercial P was surface applied. Three of the survey participants would like to see more categories. Another concern was with injected and immediately incorporated being in the same category because if immediately incorporated is 1-2 days, there is a potential for loss not present with injection. There was further concern from a participant over the differences between conventional tillage and a no-till system. Two participants were concerned about the timing of application and surface cover at the time of application, which may reduce runoff P. A respondent from the NRCS in Virginia who will be using the Virginia P-Index felt this information needs to be based on a study before it will be accepted in the field.

P-Index development team response:

For the method of application factor, the development team thought considering timing and tillage would overcomplicate the P-Index.

Evaluation of response and analysis:

Adding timing effects would overcomplicate the P-Index as a simple tool. The index is based on an average annual result and thus there is not a feasible way to account for the occurrence of storms after application. Including more effects relating to tillage should be considered since more and more farmers are switching to no-till systems. However, it is unclear how to add additional effects of tillage than are already embedded in runoff curve number values. The survey participants thought that the method of application subfactor is appropriate. The output was considered moderately sensitive to method of application under applicable conditions.

4.5.10 Applied Fertilizer Factor

Comments from survey respondents on adding the applied fertilizer factor to the runoff factor:

Overall comments on the applied fertilizer factor were also solicited from the experts. Two participants thought applied fertilizer losses should be dependent on runoff. One respondent suggested including timing effects.

P-Index development team response for adding the applied fertilizer factor to the runoff factor:

The applied fertilizer factor is added to the runoff factor and thus the amount of runoff is not considered within this factor. According to the development team, that was okay since this is a conservative approach and even without runoff there is still some risk. The development team does not have enough data to develop a regression equation to account for the amount of fertilizer associated with the amount of runoff.

Evaluation of response and analysis:

It appears that there were not enough data available to account for runoff of applied P, however, since the applied fertilizer factor is considered a sensitive parameter, the amount of runoff should be tied into application rate when data become available either by developing a regression equation or by some other method. However, this is difficult since many factors including timing, source, method, and rate of application contribute to how much of the applied fertilizer P is transported in runoff. Dissolved P in runoff would need to be measured related to manure type and application rate to develop this relationship.

4.5.11 Percolation Factor

Comments from survey respondents:

Some concerns were identified by various survey participants about the method for estimating percolation. One participant wanted to know how this method accounted for the water absorbed and held by the crop. Another participant indicated that percolation is also influenced by ground disturbance levels and soil condition. One respondent did not agree with the categories for percolation based on curve number and crop. The respondent thought it was a bit of a stretch for percolation to be the same for all row crops since evapotranspiration will vary with growing season (winter vs. summer crop) and crop type (biomass difference). This participant also thought hay crops should have higher percolation rates relative to pasture and row crops given difference in average annual biomass and evapotransipiration and runoff rates.

Analysis:

The method for percolation was determined appropriate, however, was at the lower end of this rating with an overall mean of 4.31. When subsurface loss was applicable, the output was considered moderately sensitive to percolation. The survey respondents raised some good points on the drawbacks of this method, however, including ground disturbance and cover would overcomplicate this method. Although some participants saw drawbacks to this method, this was considered the best method available.

4.5.12 Soil Texture/Drainage Class Factor

Comments from survey respondents:

Comments about the soil texture/drainage class factor varied among survey participants. Two survey participants commented that it should not be assumed that all poorly drained soils have artificial drainage. One participant stated that NRCS spent years delineating “farmed wetlands” for the 1985 farm bill and found thousands of sites where very poorly, poorly, and somewhat poorly drained soils do not have artificial drainage. To overcome this issue, a suggestion was to include a subfactor to consider drained versus undrained soils. Another participant suggested looking at literature on P leaching relating to tile drainage and French drains, since in fine-textured soils leaching can be worse than leaching through sandy soils. Another respondent wanted more information on the assumption of artificial drainage to clarify differences between tile drains and drainage ditches. This same respondent suggested the following improvements: the source of hydrology to be considered for drainage classes; time of application be considered in the rating factor; type of water table may be needed (perched vs. permanent); and including permeability. This participant also suggested recommending to not apply any P to artificially drained soil in the Ridge and Valley region, especially in limestone geology in spring or late fall. According to the participant this is because if the soil is drained by open ditches the field would be very vulnerable to subsurface risk.

P-Index development team response:

As for the soil texture/drainage class factor, further revising of the technical guide may clear up some of the comments. For example, a more detailed explanation of what conditions include drained soils could be included. Further, looking at separating the factor into drained and not drained will also be evaluated based on comments by the respondents.

Evaluation of response and analysis:

Separating the factor into drained and not drained could indirectly account for connectivity to surface water and thus improve the accuracy of this parameter. The method for the soil texture/drainage class factor was considered less appropriate. Additional clarification associated with artificial drainage and further review of the values could improve implementation of this factor. The science behind this factor is complex, so it is important not to oversimplify results. Developing a relationship based on distance to a stream would be ideal, however, subsurface transport is too complex to include this as part of the Virginia P-Index.

4.5.13 Subsurface DRP Factor

Comments from survey respondents:

The respondents provided specific comments with respect to the method of estimating the subsurface DRP factor. One respondent wanted to know at what depth the samples were taken since results could vary due to variability in textures at various depths. Another respondent wanted to know if there were sufficient data to develop the equations since he finds DRP can move vertically through soil at a much higher concentration than what eventually comes out of tile drains with lateral movement through P-deficient subsoils. One participant looked at the slopes of the equations between the subsurface and runoff DRP and determined that a greater concentration of DRP would be located in subsurface flow than in surface runoff and questioned this result. Another participant stated that this factor was pushing the science of P transport.

P-Index development team response:

According to the P-Index development team, the subsurface DRP relationship is based on current data and seems reasonable.

Evaluation of response and analysis:

As further data become available from testing and validation of the P-Index, this factor could be improved. However, further studies and advances in the science of subsurface leaching of P are needed to bridge the gap. The method for subsurface DRP was determined to be less appropriate and was considered moderately sensitive under applicable conditions (when there is a risk of P subsurface loss). Since this factor is of most concern for sites that have a shallow water table, accounting for soil sample collection depth is not necessary. Further, subsurface P transport is somewhat complicated and transport could vary between tile drains, ditch drainage, and no drainage.

4.5.14 Equal Weighting of the Erosion, Runoff, and Subsurface Factors

Comments from respondents:

Comments on the appropriateness of equal weighting of the erosion, runoff, and subsurface risk factors were similar for many of the survey participants. One participant suggested that a heavier weighting should be on whatever source is greater. Generally participants agreed that subsurface risk should be lower weight relative to erosion and runoff. One participant felt the "weighting" is done in the way the three components are independently computed and using a weighting factor is just redundant.

Analysis:

More explanation for this question would have made this question more useful. The approach of the Virginia P-Index is that the erosion, runoff, and subsurface factors are equally added together to obtain an overall value of risk. Although this approach is considered "equal weighting", in actuality, the factors have different overall risks as shown in the sensitivity analysis and under different scenarios. Since this is a mass-based approach, any weighting would have to represent the error associated with estimation of the factors. However, if the risk is determined not to be representative of expected conditions, the factors and values themselves should be modified.

4.5.15 Factor Values

P-Index development team response to values of specific factors:

The sediment delivery and runoff delivery factors values for greater distance and buffer widths seemed high to approximately one-fourth of the respondents. Although these results are noteworthy, according to the P-Index development team, data are not available for Virginia to modify the values at this time.

Evaluation of response and analysis:

Based on all comments from respondents, these factors methods were determined to be less appropriate than many of the other factors. If data are not available then research including future studies should be proposed. A better understanding of these scientific processes is also important for targeting fields for reducing nutrient and sediment losses from a field to nearby surface waters. Approximately one-fourth of the participants thought the values of the sediment and runoff delivery factors for longer distances and wider buffers were too high. These factors should be reevaluated as more data become available. Both the sediment delivery and runoff delivery factors were in the less appropriate category and runoff delivery was considered not sensitive to moderately sensitive for all baseline scenarios. The source availability factor method had the highest mean on appropriateness and was within the moderately sensitive range for all but the low Ridge and Valley and Piedmont regions baseline scenarios. For the values for the source availability factor, some participants thought the manure/litter values were too low and should be broken into multiple categories for manure type. Since only five participants thought the manure/litter value was too low, this value appears reasonable based on limited data that was used to develop the initial factor value. However, as data become available, the values of this factor could be improved and/or separated into different manure types since this parameter was determined to be moderately sensitive to sensitive. The biosolids source availability factor should be evaluated to assess if differences exist based on different treatment processes based upon comments from various participants. Some participants thought values for the coarser than loamy fine sand for somewhat poorly drained and moderately-well drained were low, while others thought values for somewhat poorly drained finer than sandy clay loam texture were low. Since the estimation method for soil texture/drainage class factor was determined less appropriate and was determined to be a sensitive parameter when there is subsurface risk of P loss, improvement within this factor would be beneficial.

4.5.16 General Comments on the Virginia P-Index

The survey asked participants to provide general comments on the Virginia P-Index. Generally, positive comments were given about the P-Index in this section along with some helpful comments for improvements. Most thought the P-Index was well thought out and a very collaborative effort. A concern with the overall accuracy of the P-Index was identified since some factors are subject to user interpretation or field measurements while others are based on charts, curves, and data sets that have been condensed or consolidated for simplicity.

One respondent was concerned as to whether the P-Index as a whole is accurate enough for use when producers may have to alter their management based on the output of the P-Index. One respondent suggested that emphasis be given that the P-Index is not only a tool to improve P management but management in general (cropping, tillage, erosion control). A concern brought up by two respondents was that the Virginia P-Index is pretty complicated and time consuming to quantify an inexact science of P movement and transport. Two survey participants wanted to know where the 6.3 factor came from. One respondent questioned the interpretation of the medium risk (31-40), which allows P application not exceeding 1.5 times crop uptake. This may or may not be a reduction in P application and in many states the switch from N management is at the high risk level. The participant felt the approach is appropriate at the high end of the (>50) medium risk but not at the low end (<40).

It was also suggested that the percent accuracy of the Virginia P-Index should be communicated to the planner and land-user. The respondent questioned whether the P-Index is a "bottom-line" tool or an estimate in which the users need to be made aware of any shortcomings in determining strict conclusions.

4.5.17 Comparison of Comments of Other State Respondents

An evaluation of comments by respondents outside Virginia in relation to their background and format of their state's P-Index was also conducted to gain insight on some of the comments and evaluate their usefulness. The Iowa P-Index is the most similar index to Virginia. Both indexes are based on long-term average conditions in lb P/acre/yr, with the exception that Iowa does not scale the output. A suggestion from a respondent from Iowa was to include other erosion control practices such as terraces and to account for ephemeral and classical gully erosion. This is in fact what Iowa uses in their P-Index. Gross erosion is calculated using RUSLE, ephemeral gullies, and classical gully erosion procedures. Iowa uses a sediment trap factor to account for the sediment captured by certain conservation practices such as terraces, a sediment delivery ratio derived from distance from the center of the field to the nearest stream downslope for four major landform regions within Iowa, and a buffer factor based on buffer width. It appears that Iowa's method may result in a more accurate estimate of loss of sediment from the field and the only additional time would be for calculating to account for gully erosion.

Iowa's runoff component includes a runoff factor, precipitation, a soil test P runoff factor, and a P application factor. The first two factors are multiplied together and added to the multiplication of the third and fourth factors to yield the runoff component. The runoff factor assumes that 50% of the total rainfall will not produce runoff. This approach is somewhat different than that of Virginia and there is no runoff delivery factor. Based on this method one respondent wanted to know how the developers went from a storm-basis to an annual calculation and whether smaller storms that do not produce runoff were accounted for. Further, the respondent from Iowa thought the runoff delivery effect is being overemphasized. The respondent agreed that the approach is appropriate and can see how the filter strip has some effect, but does not agree with distance to stream having that large of an effect.

One respondent from Maryland suggested that more management factors be included to account for differences in, for example, tillage. The Maryland P-Index does take into account different management factors and intends to separate out a few characteristics such as manure type and biosolids treatment. However, their approach is more of an index risk approach with classes of risks for each factor (0, 2, 4, 6) and is not based as much on overall values to assess the risk. Maryland uses a unique approach that places a greater risk on fields that are located in regions with greater surface water impairment.

A respondent from Ohio thought the Virginia P-Index was too complicated and time-consuming. The majority of time to complete the Virginia P-Index is within RUSLE since a user-friendly spreadsheet interface has been developed. The Ohio P-Index also used RUSLE to calculate soil loss, therefore, their index is just as time consuming to use for large farms.

4.6 Survey Format

A few problems in wording and formatting became evident upon reviewing the returned survey. In the effort to keep the survey a reasonable length, the level of included detail may not have been adequate for all factors. For example, development of the source factors (sediment total P, runoff DRP factor, and subsurface DRP) was not explained adequately. Most of the survey participants understood the factors, however, it appeared that some did not understand they were based on site-specific soil test P levels, as opposed to general regional characteristics. Further explanation would have eliminated this misunderstanding. For rating of the values for each of the questions on whether values were low, reasonable, or high, it was unclear to some participants whether to rate based on values overall or relative to the other values in the table. The equal weighting question was not as useful as expected based on different user interpretation of the question. More explicit directions and changed wording for some of the questions would have been helpful in clearing up some confusion.

4.7 Recommendations on factors to improve

Analysis of the results of the sensitivity analysis and expert opinion survey identified strengths and weaknesses of the Virginia P-Index. The following are recommendations to improve the Virginia P-Index based on the analysis completed:

- Further evaluation of the sediment delivery factor during the validation phase of the P-Index through comparison of field sites to assess if distances and buffer width values appear to represent reduction of risk. Further studies and data are needed within Virginia to further modify values. A study in the mid-Atlantic states that measures the amount of sediment leaving the field and then entering the stream for a small watershed along with modeling of the results is needed, however, this does not appear to be a feasible project in conjunction with the development of the Virginia P-Index. Another approach may be to look at existing data and modify for conditions in Virginia through modeling. A modeling study could evaluate differences in sediment delivery to a stream due to soil properties, slope, and land cover.

- Further evaluation of the runoff delivery factor during the validation phase of the P-Index through comparison of field sites to assess if distances and buffer width values appear to represent reduction of risk. The P-Index is not sensitive to this parameter; therefore, inclusion within the P-Index does not affect the overall output. Although data may not be available to improve this factor, further literature and studies in the future may be beneficial in improving this factor. Since the P-Index output was considered insensitive to slightly sensitive to this factor, this factor should be re-evaluated by the Virginia P-Index development team. One modification would be to have fewer categories for this factor to place less emphasis on the distances since there are not a lot of data to justify the difference in delivery.

- Runoff determined by the curve number approach was considered less appropriate than some of the other subfactors. A comparison is needed with measured field data at sites where annual losses of dissolved P were measured (very limited studies have been completed to date) to P-Index runoff losses to ensure an appropriate level of risk is represented within the runoff risk factor.

- Further evaluate various scenarios between conventional and conservation (no-till) tillage. This could be conducted by comparing literature and data available with testing of the P-Index on sites in Virginia that use conventional and conservation tillage.

- Some language within the technical guide should be revised to address questions and comments by respondents. For instance, further clarification of runoff values and that small storms that do not produce runoff were excluded from precipitation should be included in the technical guide. Further clarification about the soil texture/drainage class factor and artificial drainage should also be included in the technical guide. More guidance for calculating soil loss using RUSLE could be included so that user consistency is maintained such as clarification on determining slope steepness and slope length.

- Soil texture/drainage class factor was given less appropriate rating and the output was determined to be very sensitive to this parameter when there is subsurface risk of P losses. A modification could be to have different values based on if the soil is drained or undrained. This could indirectly account for the connectivity to surface water since in many cases drained sites are located closer to surface water (ditches).
- Further evaluate the applied fertilizer factor since this factor was sensitive in many of the scenarios. Since the amount of runoff P was not included within this factor and respondents thought that adding of the applied fertilizer factor to the runoff risk factors was less appropriate, further evaluation of this factor should be conducted to ensure risk potential is represented. The amount of runoff should be tied into application rate when data become available either by developing a regression equation or by some other method. It is important that the appropriate level of risk be represented for the applied fertilizer factor as overestimation could alter the P management recommendation, especially at the low to medium level from N-based to 1.5 times P crop removal.
- Include additional regression equations, if applicable, for the source factors under more soil textures and physiographic regions when more data become available.

5.0 Summary and Conclusions

5.1 Summary

The overall goal of the research was to contribute to the continued development of the Virginia P-Index as an effective P management tool. The research focused on determining which parameters require additional analysis and evaluation. The sensitivity of the Virginia P-Index to input parameters, including an assessment of output variability across a range of climate, soil, and management conditions, was determined. The sensitivity analysis identified which parameters the P-Index was most sensitive to and under what conditions. In low erosion and runoff conditions, the P-Index was most sensitive to the P management factors including application rate. As erosion and runoff potential increased, the P-Index was most sensitive to the erosion risk factors including soil loss. Under conditions with subsurface leaching, the P-Index was most sensitive to the subsurface leaching factors and Mehlich I soil test P. An analysis of variability of some subfactors was conducted. Probability distributions for distance to stream, Mehlich I P, and soil loss were defined for each of the baseline scenarios and the output distribution was generated using a Latin hypercube random generator sampling technique. The variance of the output distributions was larger as the risk of P delivery increased. The probability distribution analysis showed that for the medium to high risk of P delivery to surface water if a value is between 0 and 5 of the threshold value there is up to a 0.16 chance of being in a different P management category. The probability increased for the high to very high impact of P delivery to surface water and, even within 10 from the threshold value, there is up to a 0.21 chance of being in a different P management category. Thus, input variability could affect management recommendations.

An expert opinion survey was completed to aid in the evaluation of the appropriateness of the parameter estimation methods used in the Virginia P-Index. The expert opinion survey was formatted as follows: 1) a general definition of the sub-factor; 2) a general question as to whether the method was inappropriate to appropriate; 3) a question that solicited what other methods, if any, the survey participant would suggest using to estimate the parameter in question; 4) a question to assess if the values were reasonable or realistic; and 5) a place for comments for each of the subfactors. Thirty-eight surveys were returned representing a diverse range of participants within and outside of Virginia, all with some background on susceptibility of P delivery or a related field. Comments from the respondents were determined to be useful by the P-Index development team when results were presented to the team. In synthesizing results from the sensitivity analysis and survey, it became evident which factor estimation methods were most appropriate and which factors and methods could be improved. All estimation methods were determined appropriate based on the overall means for appropriateness (>4 out of 5). Estimation methods for the following factors were determined to be less appropriate than the other subfactors by the survey respondents: soil texture/drainage class, subsurface DRP, runoff delivery, and sediment delivery. In addition, adding the applied fertilizer factor to the runoff factors was also less appropriate.

5.2 Conclusions

The following conclusions were determined based on the completion of objective 1: to determine the sensitivity of the Virginia P-Index to input parameters including assessment of output variability across a range of climate, soil, and management conditions.

- The level of sensitivity was dependent on baseline scenarios. In low erosion and runoff conditions, the P-Index was most sensitive to the P management factors including application rate. As erosion and runoff potential increased, the P-Index was most sensitive to the erosion risk factors including soil loss. Under conditions with subsurface leaching, the P-Index was most sensitive to the subsurface leaching factors and Mehlich I soil test P.
- The P-Index was sensitive to P application rate, the method of P application factor, and the source availability factor. Although the output should be sensitive to these parameters, when there is low runoff these factors should not contribute to the overall runoff P risk as much as in cases of high P runoff. The sensitivity of these P management factors is therefore a concern at the low to medium category when P application recommendation switches from N-based to 1.5 times P crop removal. Although P in runoff may be very low, the amount of P application may be N-based as defined by the low risk of P delivery. Since the P-Index is sensitive to P application rate, the N-based

rate could change the category to a higher P management category, although there is very little to no P loss in runoff.

- Variability of the input parameters from user and parameter estimation error could impact the results and affect the overall management recommendations. The variance of the output distributions was larger as the risk of P delivery increased. The probability of being in a different management category based on the P-Index value could be provided to users to allow them to assess the robustness of the corresponding P management recommendation.
- Soil loss using RUSLE was determined to contribute to the largest variability of the P-Index output. Therefore, consistency of parameter estimation among users is needed.

The following conclusions were determined based on the completion of objective 2: to determine the appropriateness of the parameter estimation methods used in the Virginia P-Index.

- All estimation methods are appropriate based on the overall means for appropriateness (>4 out of 5). Estimation methods for the following factors were determined to be less appropriate than the other subfactors by the survey respondents: soil texture/drainage class, subsurface DRP, runoff delivery, sediment delivery. In addition, adding the applied fertilizer factor to the runoff factors was also less appropriate.
- Testing of the P-Index is needed to ensure values represent conditions throughout Virginia and to improve some of the values including the source factors.
- While the analysis identified areas where improvements could be made, the lack of existing studies within Virginia relating to sediment and runoff delivery, source availability of P, and method of application limits the improvements that could be made currently. Additional studies within these areas would be beneficial to improving the Virginia P-Index.

The Virginia P-Index was determined to be a well thought out management tool. Generally, the format of the P-Index produces results that identify sites with a low to very high risk of P delivery to surface water. This index, although based on a mass-balance approach, is a simple tool to identify fields that have a high risk of delivery of P to surface water. Therefore, some uncertainty is expected, inherent in any risk procedure. This tool should be considered a work in progress with improvements continually being made as data become available.

5.3 Recommendations

This analysis identified strengths and weaknesses of the factors and estimation methods within the Virginia P-Index. The following recommendations for improving the Virginia P-Index were identified and are considered to have the highest priority for focusing time and efforts:

- Testing under various field conditions is needed to validate the P-Index. Further evaluation of the sediment delivery factor and runoff delivery factor is needed through comparison of field sites to assess if distances and buffer width values appear to represent reduction of risk.
- Some language within the technical guide should be revised to address questions and comments by respondents. More guidance for calculating soil loss using RUSLE could be included so that user consistency is maintained such as clarification on determining slope steepness and slope length.
- Separate the soil texture/drainage factor into drained versus undrained.
- The amount of runoff should be tied into application rate when data become available by either developing a regression equation or by some other method.

The following recommendations for improving the Virginia P-Index were identified and are considered to have less priority than the other recommendations:

- Include additional regression equations, if applicable, for the source factors under more soil textures and physiographic regions when more data become available;
- Compare measured annual losses of dissolved P (very limited studies have been completed to date) to P-Index runoff losses is needed to ensure the adequate level of risk is represented within the runoff risk factor; and
- Update the P source availability factor as more data and research become available.

References

@Risk Version 4. 2000. Newfield, NY: Palisade Corp.

Anderson Cook, C. M., M. M. Alley, R. Noble and R. Khosla. 1999. Phosphorus and potassium fertilizer recommendation variability for two mid-Atlantic Coastal Plain fields. *Soil Sci Soc Am J.* 63(6): 1740-1747.

Artherton, R.W., R.B. Schainker, and E.R. Ducot. 1975. On the Statistical Sensitivity Analysis of Models for Chemical Kinetics. *AIChE.* 21: 441-448.

Ayyub, B.M. 2001. *Elicitation of Expert Opinions for Uncertainty and Risks.* Boca Raton, Florida: CRC Press.

Beegle, D., A. Sharpley, and D. Graetz. 1998. Chapter 4: Interpreting soil test phosphorus for environmental purposes. In: *Soil Testing for Phosphorus: Environmental Uses and Impacts.* Southern Cooperative Series Bulletin No. 389. USDA.

Bray, R.H. and L.T. Kurtz. 1945. Determination of total, organic and available forms of phosphorus in soils. *Soils Science* 59(1): 39-45.

Breeuwsmaa, A. and S. Silva. 1992. Phosphorus fertilization and environmental effects in the Netherlands and the Po region (Italy). Agri. Res. Dep. Rep. 57. Winand Staring Centre for Integrated Land, Soil and Water Res., Wageningen, the Netherlands.

Breeuwsma, A., J.G.A. Reijerink, and O.F. Schoumans. 1995. Impact of manure on accumulation and leaching of phosphate in areas of intensive livestock farming. In *Animal waste and the land-water interface*. 239-249. New York: Lewis Publ.-CRC Press.

Coale, F. 2001. The Maryland Phosphorus Site Index Technical Users Guide. University of Maryland, College Park, MD. Available at http://www.agnr.umd.edu/MCE/Publications/Publication.cfm?ID=538 Accessed on October 1, 2002.

Cooke, R.M. 1991. Experts in uncertainty – opinion and subjective probability in science. Oxford, UK: Oxford University Press.

Czymmek, K., L. Geohring, and Q. Ketterings. 2001. New York P Runoff Index. *What's Cropping Up?* 11(4):1-3.

Dickinson, R.P. and R.J. Gelinas. 1976. Sensitivity analysis of ordinary differential equation systems - a direct method. *J. Computational Phys.* 21: 123-143.

Fitch, K., S.J. Bernstein, M.D. Aguilar, B. Burnand, J.R. LaCalle, P. Lazaro, M. van het Loo, J. McDonnell, J.P. Vader, and J.P. Kahan. 2001. *The RAND/UCLA Appropriateness Method User's Manual*. Santa Monica, CA: RAND.

Florida Phosphorus Work Group. 2000. The Florida Phosphorus Index. Available at http://www.fl.nrcs.usda.gov/flgeneral/pifinal.pdf. Accessed on October 1, 2002

Freid, J.S. and J.K. Gilless. 1989. Expert opinion estimation of fireline production rates. *For. Sci.* 35(3): 870-877.

Gartley, K.L. and J.T. Sims. 1994. Phosphorus soil testing: Environmental uses and implications. *Commun. Soil Sci. Plant Anal.* 25(9/10): 1565-1582.

Gaynor, J.D. and W.I. Findlay. 1995. Soil and phosphorus loss from conservation and conventional tillage in corn production. *J. Environ. Qual.* 24(4): 734-741.

Grant, R., A. Laubel, B. Kronvang, H.E. Anderson, L.M. Svendsen, and A. Fugelsang. 1996. Loss of dissolved and particulate phosphorus from arable catchments by subsurface drainage. *Water Res.* 30(11):2633-2642.

Gburek, W. J., A. N. Sharpley, and H.B. Pionke. 1996. Identification of critical source areas for phosphorus export form agricultural catchments. In *Advances in Hillslope Processes*, eds. M.G. Anderson and S. Brookes. 263-282. Chichester, U.K.: John Wiley & Sons.

Gburek, W. J., A. N. Sharpley, L. Heathwaite, and G. J. Folmar. 2000. Phosphorus management at the watershed scale: a modification of the phosphorus index. *J Environ. Qual.* 29(1): 130-144.

Havlin, J.L., J.D. Beaton, S.L. Tisdale, W.L. Nelson. 1999. *Soil Fertility and Fertilizers: An Introduction to Nutrient Management.* Upper Saddle River, NJ: Prentice Hall

Hamby, D. M. 1994. A review of techniques for parameter sensitivity analysis of environmental models. *Environ. Mont. & Assess.* 32(2): 135-154.

Haygarth, P.M., P.J. Chapman, S.C. Jarvis, and R.V. Smith. 1998. Phosphorus budgets for two contrasting grassland farming systems in the UK. *Soil Use Manage.* 14:160-167.

Heckrath, G., P. C. Brookes, P. R. Poulton, and K. W. T. Goulding. 1995. Phosphorus leaching from soils containing different phosphorus concentrations in the Broadbalk Experiment. *J. Environ. Qual.* 24(5): 904-910.

Heinen, J.T. and J.G. Lyon. 1989. The effects of changing weighting factors on wildlife habitat index values: a sensitivity analysis. *Photogrammetric Engineering and Remote Sensing*. 55(10):1445-1447.

Helton, J.C., R.L. Iman, and J.B. Brown. 1985. Sensitivity analysis of the asymptotic behavior of a model for the environmental movement of radionuclides. *Ecol. Modelling.* 28(3): 243-278.

Hoffman, F.O. and R.H. Gardner. 1983. Evaluation of uncertainties in environmental radiological assessment models. In *Radiological assessments: a textbook on environmental dose assessment.,* eds. Till, J.E. and H.R. Meyer, Washington, DC: US Nuclear Regulatory Commission. Report No. NUREG/CR-3332.

Iman, R.L., J.C. Helton, and J.E. Campbell. 1981. An approach to sensitivity analysis of computer models: Part I –Introduction, input variable selection, and preliminary assessment. *J. Environ. Qual.* 13(1): 174-183.

James, L. D. and S. J. Burges. 1982. Selection Calibration and Testing of Hydrologic Models. In *Hydrologic Modeling of Small Watersheds*. Ch 11,437-470. St. Joseph, MI: ASAE.

Jokela, B. 2001. The Phosphorus Index: a tool for management of agricultural phosphorus in Vermont. Draft 5. University of Vermont, Burlington, VT.

Kingery, W.L., C.W. Wood, D.P. Delaney, J.C. Williams, and G.L. Mullins 1994. Impact of long-term land application of broiler litter on environmentally related soil properties. *J. Environ. Qual.* 23(1):139-147.

Kleinman, P. J. A., R. B. Bryant, W. S. Reid, A. N. Sharpley, and D. Pimentel. 2000. Using soil phosphorus behavior to identify environmental thresholds. *Soil Sci.* 165(12): 943-950.

Lane, L. J. and V. A. Ferreira. 1980. Sensitivity analysis. *In* CREAMS a field scale model for chemical, runoff, and erosion from agricultural management systems. USDA Cons. Res. Rpt. No. 26: USDA

Lawrence, P.A., J.J. Stone, P. Heilman, and L.H. Lane. 1997. Using measured data and expert opinion in a multiple objective decision support system for semiarid rangelands. *Trans. ASAE.* 40(6):1589-1597.

Lemunyon, J.L., and R.G. Gilbert. 1993. Concept and need for a phosphorus assessment tool. *J. Production Agric.* 6(4): 483-486.

Linstone, H.A. and M. Turoff. 1975. *The Delphi Method, techniques and applications.* Reading, MA: Addison Wesley.

McDowell, R., A. Sharpley, P. Brookes, and P. Poulton. 2001. Relationship between soil test phosphorus and phosphorus release to solution. *Soil Sci.* 166(2): 137-149.

Mehlich, A. 1984. Mehlich 3 soil test extractant: a modification of Mehlich 2 extractant. *Commun. Soil Sci. Plant Anal.* 15: 1409-1416.

Meier, W.L., A.O. Weiss, C.D. Puentes, and J.C. Moseley. 1971. Sensitivity analysis: a necessity in water planning. *Water Resour. Bull.* 7: 529-542.

Morisawa, S. and Y. Inoue. *1974.* On the selection of a ground disposal site by sensitivity analysis. *Health Phys. 26: 251-261.*

Mullins, G., M.L.Wolfe, L. Daniels, L. Zelazny, M. Beck, and J. Pease. 2002a. The Virginia Phosphorus Index: A Planning Tool for Phosphorus Management. Virginia Tech, Blacksburg, VA.

Mullins, G., M.L. Wolfe, J. Pease, L. Zelanzy, L. Daniels, M. Beck, M. Brosius, A. Vincent, and D. Johns. 2002b. Virginia Phosphorus Index: Version 1 Technical Guide. Virginia Tech, Blacksburg, VA.

Mullins, G., M.L. Wolfe, J. Pease, L. Zelanzy, L. Daniels, M. Beck, M. Brosius, A. Vincent, and D. Johns. 2002c. Virginia Phosphorus Index: Version 1.1 Spreadsheet. Available at http://p-index.agecon.vt.edu/. Accessed on January 3, 2003.

Natural Resources Conservation Service-Virginia. 2001. Virginia Conservation Practice Standard: Nutrient Management. Technical Guide Section IV. Code 590. State of Virginia.

Natural Resources Conservation Service-Iowa. 2001. Iowa Phosphorus Index. Iowa Technical Note no. 25., State of Iowa.

Nutrient Management Information for North Carolina. 2002. http://www.soil.ncsu.edu/nmp Updated April 4 2002. Accessed on October 1, 2002.

Olsen, S.R., C.V. Cole, F.S. Watanabe, and L.A. Dean. 1954. Estimation of available phosphorus is soils by extraction with sodium bicarbonate. US Department of Agruculture Circular No. 939. Washington, DC.

P-Index development team, Virginia Tech. 2000. Phosphorus Mobility on Agricultural Lands in Virginia, Quarterly Process Report, April 1, 2000-June 30, 2000. Virginia Tech, Blacksburg, VA.

Palisade Corporation. 2000. *Guide to using @Risk*. NewField, NY: Palisade Corporation

Pautler M.C. and J.T. Sims. 2000. Relationships between soil test phosphorus, soluble phosphorus, and phosphorus saturation in Delaware soils. *Soil Sci. Soc. Am. J.* 64(2): 765-773.

Pennsylvania Phosphorus Index. 2001. Available at http://pswmru.arsup.psu.edu/phosphorus/PIndices/PennsylvaniaPI.pdf . Accessed on October 1, 2002.

Peters, R.H. 1981. Phosphorus availability in Lake Memphremagog and its tributaries. *Limnol. Oceanogr.* 26: 1150-1161.

Pote, D. H., T. C. Daniel, A.N. Shapley, P.A. Moore, Jr., D.R. Edwards, and D.J. Nichols. 1996. Relating extractable soil phosphorus to phosphorus losses in runoff. *Soil Sci Soc Am J.* 60(3): 855-859.

Pote, D.H., T.C. Daniel, D.J. Nichols, A.N. Shapley, P.A. Moore, Jr., D.M. Miller, and D.R. Edwards. 1999. Relationship between phosphorus levels in three ultisols and phosphorus concentrations in runoff. *J. Environ. Qual.* 28(1): 170-175.

Prins, H.T., and J. Wind. 1993. Research for nature conservation in south-east Asia. *Biological Conserv.* 63(1): 43-46.

Raines, David. 2002. Personal communication with David Raines from Augusta Co-op. Riverbend and Scottland farm grid sampling results. Augusta and Goochland County, Virginia.

Renard, K. G. and V. A. Ferreira. 1993. RUSLE model description and database sensitivity. *J Environ. Qual.* 22(3): 458-466.

Richey, J.S., B.W. Mar, and R.R. Horner. 1985. The Delphi Technique in environmental assessment. I. Implementation and effectiveness. *J. Environ. Manag.* 21(2):135-146.

SAS Institute. 1993. SAS user's guide: Statistics. SAS Institute. Cary, NC.

Schmidt, J.P., R.K. Taylor, and G.A. Milliken. 2002. Evaluating the potential for site-specific phosphorus applications without high-density soil sampling. *Soil Sci. Soc. Am. J.* 66(1): 276-283.

Sharpley, A. N., S. J. Smith, O. R. Jones, W. A. Berg and G. A. Coleman. 1992. The transport of bioavailable phosphorus in agricultural runoff. *J Environ Qual.* 21(1): 30-35.

Sharpley, A.N. 1993. Assessing phosphorus bioavailability in agricultural soils and runoff. *Fertilizer Research.* 36(3): 259-272.

Sharpley, A., Chapra, S.C. Wedepohl, R., Sims, J.T., Daniel, T.C., and K.R. Reddy, 1994. Managing agricultural phosphorus for the protection of surface waters: Issues and options. *J. Environ. Qual.* 21(1): 30-35.

Sharpley, A.N. 1995a. Dependence of runoff phosphorus on extractable soil phosphorus. *J. Environ. Qual.* 24(5): 920-926.

Sharpley, A.N. 1995b. Identifying sites vulnerable to phosphorus loss in agricultural runoff. *J. Environ. Qual.* 24(5): 947-951.

Sharpley, A., T. C. Daniel, J. T. Sims, and D. H. Pote. 1996. Determining environmentally sound soil phosphorus levels. *J. Soil Water Conserv.* 51(2): 160-166.

Sharpley, A.N. and S. Rekolainen. 1997. Phosphorus in agriculture and its environmental implications. In *Phosphorus loss from soil to water.* Eds. Tunney, H., O.T. Carton, P.C. Brookes, and A.E. Johnston. Ch.1, 1-54 . Cambridge, U.K.: CAB Int. Press.

Sims, J.T. 1993. Environmental soil testing for phosphorus. *J. Prod. Agric.* 6(4): 501-507.

Sims, J. T., A. C. Edwards, O. F. Schoumans, and R. R. Simard. 2000. Integrating soil phosphorus testing into environmentally based agricultural management practices. *J. Environ. Qual.* 29(1): 60-71.

Stark, K.D.C., R.S. Morris, H.J. Benard , and M.W. Stern. 1998a. EpiMAN-SF: a decision-support system for managing swine fever epidemics. *Rev. Sci. Tech.* 17(3): 682-690.

Stark, K.D.C., M Nielen, and R.S. Morris. 1998b. Setting priorities for investigating movement traces during a classical swine fever epidemic. In *Proc. 15th International Pig Veterinary Society Congress,* 167. Nottingham, U.K.: Nottingham University Press.

Storm, D. E., T. A. Dillaha, and S. Mostaghimi. 1986. Modeling phosphorus transport in surface runoff. *Trans ASAE.* 31(1): 117-127.

Tennessee, University of Biosystems Engineering &Environmental Science Department, USDA-ARS, the National Sedimentation Laboratory, USDA-NRCS, and Bureau of Land Management. 2002. RUSLE2. Available at http://bioengr.ag.utk.edu/rusle2/. Accessed on December 31, 2002.

Tiscareno-Lopez, M. 1991. Sensitivity analysis of the WEPP watershed model. M.S. Thesis. Tucson, AZ: Univ. of Arizona. #E9791 1991 718.

U.S. Environmental Protection Agency. 1994. Water quality standards handbook. 2nd Ed. EPA 823-B-94-005a. USEPA Office of Water, Washington, DC.

USDA-NRCS-VA. 1997. Revised Universal Soil Loss Equation (RUSLE), Technical Guide Erosion Prediction. Natural Resources Conservation Service, Virginia Implementation.

USDA-SCS. 1994. The Phosphorus Index – A Phosphorus Assessment Tool, Water Resources/Water Quality Technical Note. No. 1901. Soil Conservation Service South National Technical Center.

Van der Fels-Klerz, H.J., H.S. Horst, and A.A. Dijkhuizen. 2000. Risk factors for bovine respiratory disease in dairy youngstock in the Netherlands: the perception of experts. *Livestock Prod. Sci.* 66(1):35-46.

Virginia Department of Conservation & Recreation. 1995. Virginia Nutrient Management Standards and Criteria. Department of Conservation & Recreation, Richmond, VA.

Walton, C.P. and G.F. Lee. 1972. A biological evaluation of the molybdenum blue method for orthophosphate analysis. *Tech. Int. Ver. Limnol.* 18: 676-684.

Appendix A – RUSLE Calculations

RUSLE was calculated based on guidelines outlined in the Virginia RUSLE technical guide (USDA-NRCS-VA, 1997). Soil loss is calculated by multiplying the following factors:

$$A = R\ \text{Factor} * K\ \text{Factor} * LS\ \text{Factor} * C\ \text{Factor} * P\ \text{Factor} \quad [A.1]$$

where, R = the factor for climatic erosivity
K = the factor for soil erodibility
LS = the factor for slope length/slope steepness
C = the factor for cover management
P = the factor for support practices
A = average annual soil loss (tons/acre/yr)

Factors were determined from look-up tables in the technical guide based on field characteristics including crop and rotation, tillage, soil texture/drainage, slope steepness, slope length, and location.

Table A.1: Site characteristics and input parameters for RUSLE calculations for all baseline scenarios

Field	crop	tillage	fertilizer	Soil	Acres	R Factor
Low Rock	Hay		inorganic	silt loam WD*	10	130
Med Rock	corn/sm grain	no-till	p.litter	silt loam WD	10	130
High Rock	corn	conv	dairy slurry	silt loam	10	130
Low Amelia	Hay		inorganic	silt loam WD	10	195
Med Amelia	corn/sm grain	no-till	p.litter	silt loam WD	10	195
High Amelia	corn/sm grain	conv	dairy slurry	silt loam	10	195
Low Accom	corn/beans/cover	no-till	inorganic	Bojac sandy loam, WD	10	215
Med Accom	corn/sm grain	no-till	p.litter	Dragston fine sandy loam, Somewhat PD†	10	215
High Accom	corn/cover	conv	p.litter	Nimmo sandy loam PD	10	215

Field	R adjusted for ponding	K factor	K adjusted climatic	hydrologic code	% Slope	Slope Length
Low Rock	130	0.24	0.22	B	4	150
Med Rock	130	0.24	0.22	B	5	150
High Rock	130	0.28	0.26	B	5	150
Low Amelia	195	0.24	0.2	B	4	175
Med Amelia	195	0.24	0.2	B	6	175
High Amelia	195	0.28	0.22	B	6	175
Low Accom	146.2	0.17	0.15	B	0.5	250
Med Accom	165.55	0.2	0.17	C	1	300
High Accom	187.05	0.2	0.17	D	2	300

- WD - well drained soil based on soil survey description

† PD - Poorly drained soil based on soil survey description

Field	LS Chart #	LS Factor	C Factor	Cover Mgt. Condition	final P factor	Annual soil loss tons/acre/yr
Low Rock	4-1	0.54	0.008	hay	1	0.12
Med Rock	4-2	0.6	0.136	cs2ntcch*	1	2.33
High Rock	4-2	0.76	0.177	cg2csmhd	1	4.55
Low Amelia	4-1	0.565	0.008	hay	1	0.18
Med Amelia	4-2	0.99	0.062	cg4cntcc	1	2.39
High Amelia	4-2	0.99	0.101	cg4cwsm	1	4.29
Low Accom	4-2	0.09	0.049	cg1csbtn	1	0.10
Med Accom	4-2	0.17	0.036	cg1ncmw	1	0.17
High Accom	4-2	0.35	0.13	cg1tdscc	1	1.45

- From Virginia RUSLE guide (USDA-NRCA-VA, 1997)
  cs2ntcch - no-till corn silage and conv. till small grain in Mountain and Valley area
  cg2csmhd - conv. till corn grain, spring plow in Mountain and Valley area
  cg4cntcc – no-till corn grain and conv. till small grain in Southern Piedmont area
  cg4cwsm – conv. till corn grain, spring plow in Southern Piedmont area
  cg1csbtn – no-till corn, no-till soybeans w/mulch till cover in Coastal Plain area
  cg1ncmw – no-till corn grain and conv till small grain in Coastal Plain area
  cg1tdscc – conv. till corn grains, spring plow in Coastal Plain area

Table A.2: Summary of RUSLE factors and soil loss for all of the baseline scenarios

Field	R Factor	K Factor	LS Factor	C Factor	P factor	Annual soil loss tons/acre/yr
Low Rock	130	0.22	0.54	0.008	1	0.12
Med Rock	130	0.22	0.6	0.136	1	2.33
High Rock	130	0.26	0.76	0.177	1	4.55
Low Amelia	195	0.2	0.565	0.008	1	0.18
Med Amelia	195	0.2	0.99	0.062	1	2.39
High Amelia	195	0.22	0.99	0.101	1	4.29
Low Accom	146.2	0.15	0.09	0.049	1	0.10
Med Accom	165.55	0.17	0.17	0.036	1	0.17
High Accom	187.05	0.17	0.35	0.13	1	1.45

Appendix B – Sensitivity Analysis Results

Table B.1: Sensitivity analysis results for the Ridge and Valley low P risk delivery region scenario

Parameter	Base Value	Base P-Index Output	P-Index Output 15%	-15%	35%	-35%	Direct Method Relative Sensitivity
Ridge and Valley- Low P Risk Delivery Scenario							
Mehlich P (ppm)	30	14.16	14.17	14.15	14.19	14.14	0.005
Edge of field soil loss (RUSLE) (million lbs/ac)	0.000248	14.16	14.24	14.10	14.35	13.97	0.039
Vegetated Filter Strip Adjustment Factor	1	14.16	14.24	14.08	14.35	13.97	0.039
Sediment Delivery Factor	0.5	14.16	14.24	14.08	14.35	13.97	0.039
Sediment Total P (ppm P in soil)	698.7	14.16	14.24	14.08	14.35	13.97	0.039
CN	58	14.16	14.38	14.10	15.16	14.09	na
Distance to Stream (ft)	400	14.16	14.16	14.16	13.92	14.40	na
Runoff from field (million lbs water/ac)	0.004	14.16	14.18	14.16	14.20	14.14	0.005
Runoff Delivery Factor	0.6	14.16	14.17	14.15	14.19	14.14	0.005
Runoff DRP (ppm)	0.52	14.16	14.17	14.15	14.19	14.14	0.005
Annual Application Rate (lbs P/ac)	43	14.16	16.19	12.13	18.90	9.42	1.00
Method of Fertilizer Application Factor	0.2	14.16	16.19	12.13	18.90	9.42	0.96
Applied Fertilizer DRP Factor	2.15	14.16	16.19	12.13	18.90	9.42	0.96
Percolation (million lbs/ac)	6.55	14.16	14.16	14.16	na	na	0
Subsurface DRP Factor (ppm P in solution)	4.02	14.16	14.16	14.16	14.16	14.16	0

Parameter	Base Value	Base P-Index Output	P-Index Output +1 cat	-1 cat	+2 cat	-2 cat	Direct Method Relative Sensitivity
Ridge and Valley- Low P Risk Delivery Scenario							
Sediment Delivery Factor	0.5	14.16	14.38	13.94	14.49	na	0.039
Runoff Delivery Factor	0.6	14.16	14.19	14.14	14.20	na	0.005
Source Availability Factor	0.25	14.16	na	11.45	na	8.74	0.96
Method of Fertilizer Application Factor	0.2	14.16	na	7.39	na	4.00	0.96
Soil Texture/Drainage Class Factor	0	14.16	24.16	na	34.16	na	0

na=not applicable

Table B.2: Sensitivity analysis results for the Ridge and Valley medium P risk delivery region scenario

Parameter	Base Value	Base P-Index Output	P-Index Output				Direct Method Relative Sensitivity
			15%	-15%	35%	-35%	
Ridge and Valley- Medium P Risk Delivery Scenario							
Mehlich P (ppm)	175	46.29	47.59	44.99	49.31	43.26	0.19
Edge of field soil loss (RUSLE) (million lbs/ac)	0.0046	46.29	49.25	43.33	53.19	39.38	0.43
Vegetated Filter Strip Adjustment Factor	1	46.29	49.25	43.33	53.19	39.38	0.43
Sediment Delivery Factor	0.7	46.29	49.25	43.33	53.19	39.38	0.43
Sediment Total P (ppm P in soil)	972.75	46.29	49.25	43.33	53.19	39.38	0.43
CN	75	46.29	52.47	44.32	65.61·	43.70	na
Distance to Stream (ft)	275	46.29	40.00	46.29	40.00	49.43	na
Runoff from field (million lbs water/ac)	0.39	46.29	46.72	45.92	47.25	45.39	0.056
Runoff Delivery Factor	0.8	46.29	46.68	45.90	47.20	45.37	0.056
Runoff DRP (ppm)	1.35	46.29	46.69	45.90	47.21	45.38	0.056
Annual Application Rate (lbs P/ac)	95	46.29	49.88	42.70	54.67	37.91	0.52
Method of Fertilizer Application Factor	0.2	46.29	49.88	42.70	54.67	37.91	0.52
Applied Fertilizer DRP Factor	3.8	46.29	49.88	42.70	54.67	37.91	0.52
Percolation (million lbs/ac)	5.27	46.29	46.29	46.29	na	na	0
Subsurface DRP Factor (ppm P in solution)	4.02	46.29	46.29	46.29	46.29	46.29	0
Parameter	**Base Value**	**Base P-Index Output**	**P-Index Output**				**Direct Method Relative Sensitivity**
			+1 cat	**-1 cat**	**+2 cat**	**-2 cat**	
Ridge and Valley- Medium P Risk Delivery Scenario							
Sediment Delivery Factor	0.7	46.29	49.11	40.65	51.93	35.01	0.43
Runoff Delivery Factor	0.8	46.29	46.62	45.63	46.94	44.98	0.056
Source Availability Factor	0.2	46.29	52.27	40.30	na	34.32	0.52
Method of Fertilizer Application Factor	0.2	46.29	na	34.32	na	28.33	0.52
Soil Texture/Drainage Class Factor	0.0	46.29	79.65	na	113.01	na	0

·results for curve number when varied 25%
na-not applicable

Table B.3: Sensitivity analysis results for the Ridge and Valley high P risk delivery region scenario

Parameter	Base Value	Base P-Index Output	P-Index Output 15%	-15%	35%	-35%	Direct Method Relative Sensitivity
Ridge and Valley- High P Risk Delivery Scenario							
Mehlich P (ppm)	400	89.12	94.56	83.69	101.80	76.44	0.41
Edge of field soil loss (RUSLE) (million lbs/ac)	4.5	89.12	97.45	80.80	108.54	69.70	0.62
Vegetated Filter Strip Adjustment Factor	1	89.12	97.45	80.80	108.54	69.70	0.62
Sediment Delivery Factor	0.7	89.12	97.45	80.80	108.54	69.70	0.62
Sediment Total P (ppm P in soil)	1398	89.12	97.45	80.80	108.54	69.70	0.62
CN	78	89.12	108.67	83.63		82.07	na
Distance to Stream (ft)	225	89.12	89.12	97.95	71.48	97.95	na
Runoff from field (million lbs water/ac)	0.54	89.12	90.18	88.03	91.61	86.60	0.081
Runoff Delivery Factor	0.8	89.12	90.20	88.05	91.63	86.61	0.081
Runoff DRP (ppm)	2.63	89.12	90.20	88.05	91.63	86.61	0.081
Annual Application Rate (lbs P/ac)	105	89.12	93.09	85.15	98.38	79.86	0.30
Method of Fertilizer Application Factor	0.2	89.12	93.09	85.15	98.38	79.86	0.30
Applied Fertilizer DRP Factor	4.2	89.12	93.09	85.15	98.38	79.86	0.30
Percolation (million lbs/ac)	5.12	89.12	89.12	89.12	na	na	0
Subsurface DRP Factor (ppm P in solution)	8.74	89.12	89.12	89.12	89.12	89.12	0

Parameter	Base Value	Base P-Index Output	P-Index Output +1 cat	-1 cat	+2 cat	-2 cat	Direct Method Relative Sensitivity
Ridge and Valley- High P Risk Delivery Scenario							
Sediment Delivery Factor	0.7	89.12	97.05	73.27	104.98	57.42	0.62
Runoff Delivery Factor	0.8	89.12	90.02	87.33	90.92	85.53	0.081
Source Availability Factor	0.2	89.12	95.74	82.51	na	75.89	0.30
Method of Fertilizer Application Factor	0.2	89.12	na	75.89	na	69.28	0.30
Soil Texture/Drainage Class Factor	0	89.12	159.59	na	230.06	na	0

Table B.4: Sensitivity analysis results for the Piedmont and Middle/Upper Coastal Plain low risk of P delivery region scenario

Parameter	Base Value	Base P-Index Output	P-Index Output				Direct Method Relative Sensitivity
			15%	-15%	35%	-35%	
Piedmont/Upper Coastal Plain- Low P Risk Delivery Scenario							
Mehlich P (ppm)	30	14.01	14.02	13.99	14.04	13.98	0.009
Edge of field soil loss (RUSLE) (million lbs/ac)	0.0004	14.01	14.08	13.94	14.17	13.84	0.033
Vegetated Filter Strip Adjustment Factor	1	14.01	14.08	13.94	14.17	13.84	0.033
Sediment Delivery Factor	0.5	14.01	14.08	13.94	14.17	13.84	0.033
Sediment Total P (ppm P in soil)	366.2	14.01	14.08	13.94	14.17	13.84	0.033
CN	58	14.01	14.01	14.01	14.01	14.01	na
Distance to Stream (ft)	400	14.01	14.01	14.01	13.82	14.19	na
Runoff from field (million lbs water/ac)	0.05	14.01	14.01	14.01	14.01	14.01	0
Runoff Delivery Factor	0.6	14.01	14.01	14.01	14.01	14.01	0
Runoff DRP (ppm)	0	14.01	14.01	14.01	14.01	14.01	0
Annual Application Rate (lbs P/ac)	43	14.01	16.04	11.97	18.75	9.27	0.97
Method of Fertilizer Application Factor	0.2	14.01	16.04	11.97	18.75	9.27	0.97
Applied Fertilizer DRP Factor	2.15	14.01	16.04	11.97	18.75	9.27	0.97
Percolation (million lbs/ac)	6.55	14.01	14.01	14.01	na	na	0
Subsurface DRP Factor (ppm P in solution)	0.97	14.01	14.01	14.01	14.01	14.01	0

Parameter	Base Value	Base P-Index Output	P-Index Output				Direct Method Relative Sensitivity
			+1 cat	-1 cat	+2 cat	-2 cat	
Piedmont/Upper Coastal Plain- Low P Risk Delivery Scenario							
Sediment Delivery Factor	0.5	14.01	14.19	13.82	14.28	na	0.033
Runoff Delivery Factor	0.6	14.01	14.01	14.01	14.01	na	0
Source Availability Factor	0.25	14.01	na	11.30	na	8.59	0.97
Method of Fertilizer Application Factor	0.2	14.01	na	7.23	na	3.85	0.97
Soil Texture/Drainage Class Factor	0	14.01	14.01	na	14.01	na	0

Table B.5: Sensitivity analysis results for the Piedmont and Middle/Upper Coastal Plain medium risk of P delivery region

Parameter	Base Value	Base P-Index Output	P-Index Output				Direct Method Relative Sensitivity
			15%	-15%	35%	-35%	
Piedmont/Upper Coastal Plain- Medium P Risk Delivery Scenario							
Mehlich P (ppm)	175	41.28	43.04	39.53	45.38	37.19	0.28
Edge of field soil loss (RUSLE) (million lbs/ac)	0.0048	41.28	43.38	39.18	46.19	36.38	0.34
Vegetated Filter Strip Adjustment Factor	1	41.28	43.38	39.18	46.19	36.38	0.34
Sediment Delivery Factor	0.7	41.28	43.38	39.18	46.19	36.38	0.34
Sediment Total P (ppm P in soil)	662	41.28	43.38	39.18	46.19	36.38	0.34
CN	75	41.28	48.46	38.82	na	38.00	na
Distance to Stream (ft)	290	41.28	36.45	41.28	36.45	43.70	na
Runoff from field (million lbs water/ac)	0.51	41.28	41.78	40.78	42.45	40.12	0.081
Runoff Delivery Factor	0.8	41.28	41.78	40.78	42.45	40.12	0.081
Runoff DRP (ppm)	1.31	41.28	41.79	40.79	42.46	40.12	0.081
Annual Application Rate (lbs P/ac)	95	41.28	44.87	37.69	49.66	32.90	0.58
Method of Fertilizer Application Factor	0.2	41.28	44.87	37.69	49.66	32.90	0.58
Applied Fertilizer DRP Factor	3.8	41.28	44.87	37.69	49.66	32.90	0.58
Percolation (million lbs/ac)	5.28	41.28	41.28	41.28	na	na	0
Subsurface DRP Factor (ppm P in solution)	4.02	41.28	41.28	41.28	41.28	41.28	0

Parameter	Base Value	Base P-Index Output	P-Index Output				Direct Method Relative Sensitivity
			+1 cat	-1 cat	+2 cat	-2 cat	
Piedmont/Upper Coastal Plain- Medium P Risk Delivery Scenario							
Sediment Delivery Factor	0.7	41.28	43.28	37.28	45.29	33.27	0.34
Runoff Delivery Factor	0.8	41.28	41.70	40.45	42.11	39.62	0.081
Source Availability Factor	0.2	41.28	47.27	35.30	na	29.31	0.58
Method of Fertilizer Application Factor	0.2	41.28	na	29.31	na	23.33	0.58
Soil Texture/Drainage Class Factor	0	41.28	85.71	na	130.14	na	na

Table B.6: Sensitivity analysis results for the Piedmont and Middle/Upper Coastal Plain high risk of P delivery region scenario

Parameter	Base Value	Base P-Index Output	P-Index Output				Direct Method Relative Sensitivity
			15%	-15%	35%	-35%	
Piedmont/Upper Coastal Plain- High P Risk Delivery Scenario							
Mehlich P (ppm)	350	79.03	85.07	72.99	93.13	64.94	0.51
Edge of field soil loss (RUSLE) (million lbs/ac)	0.0086	79.03	85.66	72.41	94.49	63.57	0.56
Vegetated Filter Strip Adjustment Factor	1	79.03	85.66	72.41	94.49	63.57	0.56
Sediment Delivery Factor	0.8	79.03	85.66	72.41	94.49	63.57	0.56
Sediment Total P (ppm P in soil)	1019	79.03	85.66	72.41	94.49	63.57	0.56
CN	75	79.03	97.16	72.81	na	70.74	na
Distance to Stream (ft)	150	79.03	79.03	79.03	72.58	85.49	na
Runoff from field (million lbs water/ac)	0.51	79.03	80.60	78.00	82.33	76.26	0.11
Runoff Delivery Factor	0.9	79.03	80.29	77.77	81.98	76.09	0.11
Runoff DRP (ppm)	2.94	79.03	80.29	77.77	81.98	76.09	0.11
Annual Application Rate (lbs P/ac)	105	79.03	83.00	75.06	88.29	69.77	0.33
Method of Fertilizer Application Factor	0.2	79.03	83.00	75.06	88.29	69.77	0.33
Applied Fertilizer DRP Factor	4.2	79.03	83.00	75.06	88.29	69.77	0.33
Percolation (million lbs/ac)	5.12	79.03	79.03	79.03	na	na	0
Subsurface DRP Factor (ppm P in solution)	8.74	79.03	79.03	79.03	79.03	79.03	0
Parameter	**Base Value**	**Base P-Index Output**	**P-Index Output**				**Direct Method Relative Sensitivity**
			+1 cat	**-1 cat**	**+2 cat**	**-2 cat**	
Piedmont/Upper Coastal Plain- High P Risk Delivery Scenario							
Sediment Delivery Factor	0.8	79.03	84.55	73.51	90.08	62.47	0.56
Runoff Delivery Factor	0.9	79.03	79.97	78.10	na	76.23	0.11
Source Availability Factor	0.2	79.03	85.65	72.42	na	65.80	0.33
Method of Fertilizer Application Factor	0.2	79.03	na	65.80	na	59.19	0.33
Soil Texture/Drainage Class Factor	0	79.03	185.95	na	292.87	na	na

na=not applicable

Table B.7: Sensitivity analysis results for the Eastern Shore and Lower Coastal Plain low risk of P delivery region scenario

Parameter	Base Value	Base P-Index Output	P-Index Output				Direct Method Relative Sensitivity
			15%	-15%	35%	-35%	
Eastern Shore/Lower Coastal Plain- Low P Risk Delivery Scenario							
Mehlich P (ppm)	30	14.07	14.13	14.01	14.22	13.92	0.030
Edge of field soil loss (RUSLE) (million lbs/ac)	0.00014	14.07	14.09	14.05	14.12	14.02	0.010
Vegetated Filter Strip Adjustment Factor	1	14.07	14.09	14.05	14.12	14.02	0.010
Sediment Delivery Factor	0.5	14.07	14.09	14.05	14.12	14.02	0.010
Sediment Total P (ppm P in soil)	314.3	14.07	14.09	14.05	14.12	14.02	0.010
CN	72	14.07	14.93	13.77	na	14.07	na
Distance to Stream (ft)	400	14.07	14.07	14.07	13.89	14.25	na
Runoff from field (million lbs water/ac)	0.39	14.07	14.13	14.01	14.21	13.93	0.027
Runoff Delivery Factor	0.6	14.07	14.13	14.01	14.21	13.93	0.027
Runoff DRP(ppm)	0.26	14.07	14.13	14.01	14.21	13.93	0.027
Annual Application Rate (lbs P/ac)	43	14.07	16.10	12.04	18.81	9.33	0.96
Method of Fertilizer Application Factor	0.2	14.07	16.10	12.04	18.81	9.33	0.96
Applied Fertilizer DRP Factor	2.15	14.07	16.10	12.04	18.81	9.33	0.96
Percolation (million lbs/ac)	7.08	14.07	14.07	14.07	na	na	0
Subsurface DRP Factor (ppm P in solution)	0	14.07	14.07	14.07	14.07	14.07	0

Parameter	Base Value	Base P-Index Output	P-Index Output				Direct Method Relative Sensitivity
			+1 cat	-1 cat	+2 cat	-2 cat	
Eastern Shore/Lower Coastal Plain- Low P Risk Delivery Scenario							
Sediment Delivery Factor	0.5	14.07	14.13	14.01	14.15	na	0.010
Runoff Delivery Factor	0.6	14.07	14.20	13.94	14.26	na	0.027
Source Availability Factor	0.25	14.07	na	11.36	na	8.65	0.96
Method of Fertilizer Application Factor	0.2	14.07	na	7.30	na	3.91	0.96
Soil Texture/Drainage Class Factor	0	14.07	24.69	na	35.31	na	0

Table B.8: Sensitivity analysis results for the Eastern Shore and Lower Coastal Plain medium risk of P delivery region scenario

Parameter	Base Value	Base P-Index Output	P-Index Output 15%	-15%	35%	-35%	Direct Method Relative Sensitivity
Eastern Shore/Lower Coastal Plain- Medium P Risk Delivery Scenario							
Mehlich P (ppm)	75	41.79	44.29	39.29	47.63	35.95	15.83
Edge of field soil loss (RUSLE) (million lbs/ac)	0.0004	41.79	41.94	41.64	42.13	41.45	0.023
Vegetated Filter Strip Adjustment Factor	1	41.79	41.94	41.64	42.13	41.45	0.023
Sediment Delivery Factor	0.9	41.79	41.94	41.64	42.13	41.45	0.023
Sediment Total P (ppm P in soil)	427.25	41.79	41.94	41.64	42.13	41.45	0.023
CN	78	41.79	44.85	39.70	na	40.55	na
Distance to Stream (ft)	100	41.79	41.37	41.79	41.37	41.79	na
Runoff from field (million lbs water/ac)	0.75	41.79	42.26	41.33	42.89	40.71	0.074
Runoff Delivery Factor	1	41.79	42.26	41.32	42.88	40.70	0.074
Runoff DRP (ppm)	0.66	41.79	42.26	41.32	42.88	40.70	0.074
Annual Application Rate (lbs P/ac)	95	41.79	45.38	38.20	50.17	33.41	0.57
Method of Fertilizer Application Factor	0.2	41.79	45.38	38.20	50.17	33.41	0.57
Applied Fertilizer DRP Factor	3.8	41.79	45.38	38.20	50.17	33.41	0.57
Percolation (million lbs/ac)	24.59	41.79	43.86	39.72	46.61	36.97	0.33
Subsurface DRP Factor (ppm P in solution)	1.57	41.79	43.86	39.72	46.61	36.97	0.33

Parameter	Base Value	Base P-Index Output	P-Index Output +1 cat	-1 cat	+2 cat	-2 cat	Direct Method Relative Sensitivity
Eastern Shore/Lower Coastal Plain- Medium P Risk Delivery Scenario							
Sediment Delivery Factor	0.9	41.79	41.90	41.68	na	41.47	0.023
Runoff Delivery Factor	1	41.79	na	41.48	na	41.17	0.074
Source Availability Factor	0.2	41.79	47.77	35.80	na	29.82	0.57
Method of Fertilizer Application Factor	0.2	41.79	na	29.82	na	23.83	0.57
Soil Texture/Drainage Class Factor	0.25	41.79	55.56	28.02	69.34	na	0.33

na-not applicable

Table B.9: Sensitivity analysis results for the Eastern Shore and Lower Coastal Plain high risk of P delivery region scenario

Parameter	Base Value	Base P-Index Output	P-Index Output 15%	-15%	35%	-35%	Direct Method Relative Sensitivity
Eastern Shore/Lower Coastal Plain- High P Risk Delivery Scenario							
Mehlich P (ppm)	125	101.24	111.60	90.88	125.42	77.06	23.60
Edge of field soil loss (RUSLE) (million lbs/ac)	0.0029	101.24	102.75	99.72	104.77	97.70	0.10
Vegetated Filter Strip Adjustment Factor	1	101.24	102.75	99.72	104.77	97.70	0.10
Sediment Delivery Factor	1	101.24	102.75	99.72	104.77	97.70	0.10
Sediment Total P (ppm P in soil)	552.75	101.24	102.75	99.72	104.77	97.70	0.10
CN	89	101.24	na	110.13	na	112.99	na
Distance to Stream (ft)	12	101.24	101.24	101.24	101.24	101.24	na
Runoff from field (million lbs water/ac)	2.31	101.24	103.65	98.85	106.85	95.65	0.16
Runoff Delivery Factor	1	101.24	103.65	98.85	106.85	95.65	0.16
Runoff DRP(ppm)	1.1	101.24	103.65	98.85	106.85	95.65	0.16
Annual Application Rate (lbs P/ac)	105	101.24	105.21	97.27	110.50	91.98	0.26
Method of Fertilizer Application Factor	0.2	101.24	105.21	97.27	110.50	91.98	0.26
Applied Fertilizer DRP Factor	4.2	101.24	105.21	97.27	110.50	91.98	0.26
Percolation (million lbs/ac)	4.009	101.24	108.54	93.94	118.28	84.20	0.48
Subsurface DRP Factor (ppm P in solution)	2.57	101.24	108.54	93.94	118.28	84.20	0.48
Parameter	**Base Value**	**Base P-Index Output**	**P-Index Output +1 cat**	**-1 cat**	**+2 cat**	**-2 cat**	**Direct Method Relative Sensitivity**
Eastern Shore/Lower Coastal Plain- High P Risk Delivery Scenario							
Sediment Delivery Factor	1	101.24	na	100.23	na	99.22	0.10
Runoff Delivery Factor	1	101.24	na	99.64	na	98.04	0.16
Source Availability Factor	0.2	101.24	107.85	94.62	na	88.01	0.26
Method of Fertilizer Application Factor	0.2	101.24	na	88.01	na	81.39	0.26
Soil Texture/Drainage Class Factor	0.75	101.24	117.47	85.01	na	68.78	0.48

Table B.10: Relative sensitivity for curve number and distance to stream from varying +/- 15% and +/-35% from baseline value for all regions

Parameter	Base Value	Base P-Index Output	Relative Sensitivity			
			RS	RS	RS	RS
			15%	-15%	35%	-35%
Ridge and Valley- Low P Risk Delivery Scenario						
CN	58	14.16	0.097	0.028	0.20	0.014
Distance to Stream (ft)	400	14.16	0	0	-0.049	-0.049
Ridge and Valley- Medium P Risk Delivery Scenario						
CN	75	46.29	0.91	0.29	1.65·	0.16
Distance to Stream (ft)	275	46.29	-0.91	0	-0.39	-0.19
Ridge and Valley- High P Risk Delivery Scenario						
CN	78	89.12	1.43	0.40	na	0.23
Distance to Stream (ft)	225	89.12	0.000	-0.66	-0.57	-0.28
Piedmont/Upper Coastal Plain- Low P Risk Delivery Scenario						
CN	58	14.01	0	0	0.000	0.000
Distance to Stream (ft)	400	14.01	0	0	-0.038	-0.038
Piedmont/Upper Coastal Plain- Medium P Risk Delivery Scenario						
CN	75	41.28	1.19	0.41	na	0.23
Distance to Stream (ft)	290	41.28	-0.78	0	-0.33	-0.17
Piedmont/Upper Coastal Plain- High P Risk Delivery Scenario						
CN	75	79.03	1.56	0.54	na	0.30
Distance to Stream (ft)	150	79.03	0	0	-0.23	-0.23
Eastern Shore/Lower Coastal Plain- Low P Risk Delivery Scenario						
CN	72	14.07	0.402	0.14	na	0
Distance to Stream (ft)	400	14.07	0.000	0.000	-0.037	-0.037
Eastern Shore/Lower Coastal Plain- Medium P Risk Delivery Scenario						
CN	78	41.79	0.48	0.32	na	0.085
Distance to Stream (ft)	100	41.79	-0.067	0.000	-0.029	0.000
Eastern Shore/Lower Coastal Plain- High P Risk Delivery Scenario						
CN	89	101.24	na	-0.60	na	-0.33
Distance to Stream (ft)	12	101.24	0	0	0	0

·results for curve number when varied 25%
na-not applicable

Appendix C– Virginia P-Index Expert Opinion Survey

OVERVIEW OF THE VIRGINIA PHOSPHORUS INDEX

The Virginia P-Index is a field level assessment tool that determines the relative risk of P losses through surface runoff and subsurface transport to surface water bodies. The Virginia P-Index was created as a tool to improve phosphorus management in Virginia. The Virginia P-Index includes site-specific erosion, runoff, and subsurface risk factors that are used to categorize the overall site vulnerability to P loss under a given management system. Each risk factor is determined from source, transport, and/or management sub-factors, as illustrated on the next page.

The erosion risk factor is calculated by multiplying the edge of field loss by a sediment delivery factor by the sediment total P factor.

The runoff risk factor includes the following sub-factors: 1) runoff from field; 2) runoff delivery factor; 3) runoff dissolved reactive orthophosphate (DRP) factor; and 4) applied fertilizer DRP factor. The first three sub-factors are multiplied together to estimate risk of loss of soluble soil P based on the level of residual soil P and then added to the fourth sub-factor (loss of soluble P from any recent addition of P fertilizer) to yield the runoff risk factor.

The subsurface risk factor is calculated by multiplying average annual percolation by a soil texture/drainage factor by the subsurface DRP factor.

The P-Index is calculated by summing the erosion, runoff, and subsurface risk factors and then multiplying by a scaling factor. Thus, there is equal weighting for each of the three factors. The scaling factor shifts the values to the management scale shown on the next page ("Summary Interpretation of Phosphorus Index"). Computed P-Index values range from 0 to greater than 100. Management guidelines for P application are a function of P-Index values and are related to potential water quality impact.

Each of the source, transport, and management sub-factors are defined in the survey. Additional information is provided in the enclosed Technical Guide.

Virginia P-Index

Phosphorus Risk = Erosion Risk Factor + Runoff Risk Factor + Subsurface Risk Factor

P Index = 6.3 * Phosphorus Risk

Erosion Risk Factor	=	1* Edge of field soil loss (million lbs/ac)	X	2 Sediment P delivery factor (dimensionless)	X	3 Sediment total P factor (ppm)		
Runoff Risk Factor	=	4 Runoff from field (million lbs/ac)	X	5 Runoff P delivery factor (dimensionless)	X	6 Runoff DRP** factor (ppm)	+	7 Applied fertilizer DRP** factor (lb/ac)
Subsurface Risk Factor	=	8 Percolation (million lbs/ac)	X	9 Soil texture/drainage factor (dimensionless)	X	10 Subsurface DRP** factor (ppm)		

* The number corresponds to the survey question.
**DRP is dissolved reactive orthophosphate.

Summary Interpretation of Phosphorus Index

P Index Value	Potential Water Quality Impact	Phosphorus Management Guidance Based on Proposed Management Practices
0 – 30	Low	Phosphorus application according to N-based nutrient management is acceptable.
31 – 60	Medium	Phosphorus applications for this site should not be more than 1.5 times crop removal.
61 – 100	High	Phosphorus applications should not be greater than crop removal.
> 100	Very High	No phosphorus should be applied.

EXPERT OPINION SURVEY – VIRGINIA PHOSPHORUS INDEX

The overall objective of this survey is to assess expert opinion of the factor estimation methods used in the Virginia P-Index.

Please answer each question in terms of the following scale:

Scale	Inappropriate	1	2	3	4	5	Appropriate

Where:
5 = appropriate: this is your method of choice
4 = fairly appropriate: this method is preferred over others
3 = equivocal: there are other methods that could be used with equal appropriateness
2 = fairly inappropriate: this method does not represent the factor effectively
1 = inappropriate: this method does not at all represent the factor correctly and should not be used

Questions are given in the boxes below. Please circle your response and include any additional comments. This survey is divided into four sections: erosion risk sub-factors, runoff risk sub-factors, subsurface risk sub-factors, and general.

EROSION RISK FACTORS

1

Edge of field soil loss factor: soil transported to the edge of the field by erosion. The Revised Universal Soil Loss Equation (RUSLE) is used to estimate average annual soil loss from a field. If there is a vegetated filter strip at the downslope edge of the field, RUSLE-estimated soil loss is multiplied by an adjustment factor based on the width of the filter strip. The adjustment factor is included since the version of RUSLE used in Virginia does not include a filter strip adjustment.

a) Using RUSLE to estimate edge of field soil loss is:

Inappropriate 1 2 3 4 5 Appropriate

b) Considering that the P-Index is a field scale, annual risk assessment tool, what other methods, if any, would you suggest using to estimate edge of field soil loss?

Comments:

2

Sediment P delivery factor: proportion of sediment transported from the edge of field to an intermittent or perennial stream. The factor value is based on the stream buffer width (buffer immediately adjacent to the stream) and/or distance to the nearest stream from the edge of the field as shown in the following table.

Sediment delivery factor for the Virginia P Index

Flow Distance from Edge of Field to an Intermittent or Perennial Stream, or a Stream Buffer Width	**Sediment Delivery Factor**	**Values**		
		Low	**Reasonable**	**High**
> 500 ft OR stream buffer width > 100 ft	0.3			
300-500 ft OR stream buffer width of 75-100 ft	0.5			
200-300 ft OR stream buffer width of 50-75 ft	0.7			
100-200 ft OR stream buffer width of 25-50 ft	0.8			
25-100 ft AND stream buffer width < 25 ft	0.9			
< 25 ft	1.0			

a) Using a sediment delivery factor to estimate the amount of sediment transported to a stream is:

Inappropriate 1 2 3 4 5 Appropriate

b) Please indicate by checks in the above table whether the given values of the sediment delivery factor seem low, reasonable, or high.

c) Considering that the P-Index is a field scale, annual risk assessment tool, what other methods, if any, would you suggest to estimate sediment delivery from the field to a stream?

Comments:

Sediment total P is a source sub-factors developed based on results from soil samples collected within three different physiographic regions in Virginia. Regressions equations were generated based on analyses of the soil samples.

3

Sediment total P factor : total P content of the eroded sediment (ppm). The factor was developed based on soil samples collected from fields in three different physiographic regions in Virginia. A linear equation for each of the three regions estimates the sediment total P as a function of Mehlich I extract soil test P.

a) Using a sediment total P factor to estimate P available in eroded sediment is:

Inappropriate 1 2 3 4 5 Appropriate

b) Considering that the P-Index is a field scale, annual risk assessment tool, what other methods, if any, would you suggest to estimate P adsorbed to sediment?

Comments:

RUNOFF RISK FACTOR

4

Runoff from field factor: amount of water (million lbs/acre) that is lost through surface runoff annually. Average annual runoff is calculated using the NRCS curve number approach based on six different climatic divisions in Virginia. The curve number represents the effect of crop and soil hydrologic group on runoff.

a) Using the curve number method to estimate average annual runoff is:

Inappropriate 1 2 3 4 5 Appropriate

b) Considering that the P-Index is a field scale, annual risk assessment tool, what other methods, if any, would you suggest to estimate runoff?

Comments:

5 **Runoff delivery factor:** proportion of runoff water delivered to an intermittent or perennial stream. This factor is determined based on stream buffer width and/or flow distance from the edge of field to intermittent or perennial stream.

Runoff delivery factor for the Virginia P Index

Flow Distance from Field to an Intermittent or Perennial Stream, or a Stream Buffer Width	Runoff Delivery Factor	Values Low	 Reasonable	 High
> 500 ft OR stream buffer width > 100 ft	0.4			
300-500 ft OR stream buffer width of 75-100 ft	0.6			
200-300 ft OR stream buffer width of 50-75 ft	0.8			
100-200 ft OR stream buffer width of 25-50 ft	0.9			
0-100 ft AND stream buffer width < 25 ft	1.0			

a) Using a runoff delivery factor to estimate the amount of runoff transported to a stream is:

Inappropriate 1 2 3 4 5 Appropriate

b) Please indicate by checks in the above table whether the given values of the runoff delivery factor seem low, reasonable, or high.

c) Considering that the P-Index is a field scale, annual risk assessment tool, what other methods, if any, would you suggest to estimate runoff delivery from the field to a stream?

Comments:

Runoff dissolved reactive orthophosphate (DRP) is a source sub-factors developed based on results from soil samples collected within three different physiographic regions in Virginia. Regressions equations were generated based on analyses of the soil samples.

6

Runoff dissolved reactive orthophosphate (DRP) factor: amount of soil P released in dissolved forms to surface runoff (ppm). A linear equation for each of the three regions describes the runoff DRP based on results of a Mehlich I extract soil test P.

a) Using a runoff DRP factor to estimate amount of dissolved soil P potentially available to runoff is:

Inappropriate 1 2 3 4 5 Appropriate

b) Considering that the P-Index is a field scale, annual risk assessment tool, what other methods, if any, would you suggest to estimate dissolved P in runoff?

Comments:

7

Applied fertilizer DRP factor: is a management sub-factor and represents the amount of DRP in runoff due to phosphorus applications. The factor is calculated by multiplying annual application rate by a source availability factor by a method of application factor.

7a

Annual Application Rate: (lbs P/acre) : elemental P applied annually

a) Should application rate be included in the P-Index? Yes undecided No

Comments:

7b **Source Availability factor:** amount of P available for runoff based on applied fertilizer type.

Source availability factor for the Virginia P Index

Fertilizer Type	Source Availability Factor	Values		
		Low	Reasonable	High
Manure/Litter	0.20			
Litter with phytase	0.25			
Alum-treated Litter 0.7 < Al:P ratio < 1.0 0.4 < Al:P ratio < 0.7	 0.10 0.15			
Inorganic	0.25			
Biosolids	0.20			

a) Using a source availability factor to estimate P available for runoff in applied fertilizer is:

Inappropriate 1 2 3 4 5 Appropriate

b) Please indicate in the above table if the given values seem low, reasonable, or high.

Comments:

7c **Method of application factor:** amount of P available for runoff based on method of application.

Method of application factor for the Virginia P Index

Method of Application	Method of Application Factor	Values		
		Low	Reasonable	High
Surface applied, no incorporation	0.20			
Injected or incorporated immediately	0.05			
Incorporated within 3-5 days of application	0.10			

a) Using a method of application factor to estimate P potentially available for runoff based on method of application is:

Inappropriate 1 2 3 4 5 Appropriate

b) Please indicate in the above table if given values seem low, reasonable, or high.

Comments:

7d The **applied fertilizer factor** (application rate * source availability factor * method of application factor) is added to the other runoff risk factors, thus its impact is independent of the amount of runoff.

a) Adding the applied fertilizer factor to the other runoff factors to account for the amount of DRP in runoff due to P applications is:

Inappropriate 1 2 3 4 5 Appropriate

b) Considering that the P-Index is a field scale, annual risk assessment tool, what other methods, if any, would you suggest to represent the amount of DRP in runoff due to P applications?

Comments:

SUBSURFACE RISK FACTOR

8

Percolation factor: potential amount of water that percolates through the root zone (million lbs/acre). Percolation is determined by subtracting annual runoff (function of curve number) and evapotranspiration from annual rainfall. Lookup tables for percolation are in the technical guide based on curve number and crop.

a) Using a water balance method to estimate average annual percolation is:

Inappropriate 1 2 3 4 5 Appropriate

b) Considering that the P-Index is a field scale, annual risk assessment tool, what other methods, if any, would you suggest to estimate percolation?

Comments:

9

Soil texture/drainage class factor: effects of soil texture and drainage on the potential for P movement through subsurface transport with recharge to surface water. The factor is based on soil drainage class (NRCS) and soil texture to a soil depth of 18 inches from soil surveys. It is assumed that very poorly, poorly, and somewhat poorly drained soils will have artificial drainage if they are being farmed.

Soil texture/drainage class factor

Soil drainage class[1]	**Soil texture to depth of 18"**											
	Coarser than loamy fine sand				**Between loamy fine sand and sandy clay loam**				**Finer than sandy clay loam**			
		L	**R**	**H**		**L**	**R**	**H**		**L**	**R**	H
Very poorly and poorly drained	1.0				0.75				0.5			
Somewhat poorly drained	0.25				0.25				0.0			
Moderately-well and well-drained	0.0				0.0				0.0			

a) Using a soil texture/drainage class factor to evaluate the effects of soil texture and drainage on the potential of P movement through subsurface leaching is:

Inappropriate 1 2 3 4 5 Appropriate

b) Please indicate by checks in the above table if the given values seem low (L), reasonable (R), or high (H).

c) Considering that the P-Index is a field scale, annual risk assessment tool, what other methods, if any, would you suggest to represent subsurface leaching with recharge to surface water?

Comments:

Subsurface DRP is a source sub-factors developed based on results from soil samples collected within three different physiographic regions in Virginia. Regressions equations were generated based on analyses of the soil samples.

10

Subsurface DRP factor: amount of soil P released in dissolved forms to percolating water. A linear equation for each of the three regions describes the subsurface DRP based on results of a Mehlich I extract soil test P.

a) Using a subsurface DRP factor to estimate dissolved P potentially available for subsurface loss is:

Inappropriate 1 2 3 4 5 Appropriate

b) Considering that the P-Index is a field scale, annual risk assessment tool, what other methods, if any, would you suggest to estimate dissolved P in percolating water?

Comments:

GENERAL

The Virginia P-Index is determined by summing the erosion, runoff, and subsurface risk factors.

11

a) Equal weighting of the erosion, runoff, and subsurface risk factors is:

Inappropriate 1 2 3 4 5 Appropriate

b) Considering that the P-Index is a field scale, annual risk assessment tool, what other weighting methods, if any, would you suggest?

Comments:

12

a) Please rate your overall expertise on risk of P loss:

Not knowledgeable 1 2 3 4 5 very knowledgeable

5 = very knowledgeable, I am considered an expert on the subject
4 = knowledgeable, I am very familiar and knowledgeable with this subject
3 = somewhat knowledgeable, I work with this subject some, but not on a regular basis
2 = slightly knowledgeable, I have some knowledge on this subject, but do not work with it very often
1 = not very knowledgeable, I have little to no knowledge on this subject

Additional comments on the Virginia P-Index:

Demographic Data:

Work in VA or ________________ (Please indicate state or country)

____________________________ Occupation (or job title)

____________________________ Employer (i.e. private, state, federal, academic)

Name (optional): ____

Thank you for very much for your time and input in completing this survey!

Please return survey by October 15 2002 to: Julie Jesiek, Biological Systems Engineering Dept. (0303) Virginia Tech, Blacksburg, VA 24061. Please fill out your name and address below if you would like to receive the results of this survey. If you would like to remain anonymous, please send in this sheet separately.

Name: ____

Address: ____

____

____

____

E-mail: ____

Mail to:
Julie Jesiek
Biological Systems Engineering Dept. (0303)
Virginia Tech
Blacksburg, VA 24061

Appendix D - Expert Survey Opinion Results

Table D.1: Individual results for all questions that assess appropriate ratings, factors, and expertise ratings questions

Respondent #	Range	# 1	# 2	# 3	# 4	# 5	# 6	# 7	# 8
Category of survey participant: State, Federal, Private, Academic.		State-DCR	Private	Federal-NRCS	Federal-NRCS	Academic	Federal-NRCS	Fed-ARS/Acad	Federal
Occupation		Nutrient management	Fertilizer dealer/ NMP Writer	Agronomist	State agronomist	Professor	State resource cons.	Research soil scientist	Soil scientist
State of employment		VA	VA	IA	FL	MD	MD	PA	PA
Question 1(a) - Soil Loss	1-5	1	5	5	5	5	5	5	5
Question 2(a) - Sediment Delivery	1-5	4	5	3	4	5	4	5	3
Question 3(a) - Sediment P	1-5	4	5	5	3	3	5	5	3
Question 4(a) - Runoff from field	1-5	4	5	5	3	4	5	3	5
Question 5(a) - Runoff Delivery	1-5	4	5	5		5	4	5	5
Question 6(a) - Runoff DRP	1-5	4	1	3	5	3	4	5	5
Question 7A (a) - Application rate	yes or no	no	yes	yes	yes	yes	Yes	yes	yes
Question 7B (a) - Source Availability	1-5	2	5	5	5	5	5	5	5
Question 7C (a) - Method of Application	1-5	2	5	5	5	5	4	5	5
Question 7D (a) - Applied Fertilizer	1-5	1	1	3	5	5	3	5	5
Question 8(a) - Percolation	1-5	3	5	5	5	4	4	1	5
Question 9(a) - Soil texture/drainage class	1-5	2	3	5	4	5	3	5	5
Question 10(a) - Subsurface DRP	1-5	2	1	5		4	4	5	5
Question 11(a) - Equal weighting	1-5	5	5	5	4	4	3	5	5
Question 12 - Expertise on P loss	1-5	3	3.5	4	4	5	4	5	4

Respondent #	Range	# 9	# 10	# 11	# 12	# 13	# 14	# 15	# 16	# 17
Category of survey participant: State, Federal, Private, Academic.		Fed-NRCS	Academic	Fed-ARS	Fed-ARS	State-DCR	Fed-ARS	Fed-NRCS	Private	Fed-NRCS
Occupation		Soil cons.	Professor	Soil phys.	Ag eng.	Nutrient manag. specialist	Research soil scientist	Soil scientist	Asst. commodity director	District cons.
State of employment		VA	IA	MD	TX	VA	PA	GA	VA	VA
Question 1(a) - Soil Loss	1-5	3	5	4	5	5	5	3	5	3
Question 2(a) - Sediment Delivery	1-5	5	5	2	4	5	5	4	4	5
Question 3(a) - Sediment P	1-5	5	5	5	4	5	4	4	4	5
Question 4(a) - Runoff from field	1-5	5	5	4	4	5	5	5	4	5
Question 5(a) - Runoff Delivery	1-5	5	5	4	3	5	5	3	4	5
Question 6(a) - Runoff DRP	1-5	5	5	5	4	5	5	3	4	5
Question 7A (a) - Application rate	yes or no	undecided	yes	yes	yes	yes	yes	yes	yes	Yes
Question 7B (a) - Source Availability	1-5	5	5	5	4	5	5	5	5	5
Question 7C (a) - Method of Application	1-5	5	5	4	4	5	5	5	5	5
Question 7D (a) - Applied Fertilizer	1-5	5	2	4	4	5	5	5	4	5
Question 8(a) - Percolation	1-5	5	5	5	4	5	5	3	4	5
Question 9(a) - Soil texture/drainage class	1-5	5	5	4	4	5	5	4	4	5
Question 10(a) - Subsurface DRP	1-5	5	5	4	4	5	5	3	4	5
Question 11(a) - Equal weighting	1-5	5	2	1	3	3	5	3	3	5
Question 12 - Expertise on P loss	1-5	2	4.5	3	3	4	5	4.5	3.5	4

Respondent #	Range	# 18	# 19	# 20	# 21	# 22	# 23	# 24	# 25	# 26
Category of survey participant: State, Federal, Private, Academic.		Academic	Academic	Academic	Fed-NRCS	State-DCR	State-NRCS	Acad/state	FED-ARS	FED-NRCS
Occupation		Professor	Professor	Professor /exten. specialist	Agron.	Nutrient Manag.	District conserv.	Extension educator	Hydrologist	District Conserv.
State of employment		FL	PA	GA	OH	VA	VA	NH	PA	VA
Question 1(a) - Soil Loss	1-5	5	5	5	1	4	4	5	5	4
Question 2(a) - Sediment Delivery	1-5	5	4	4	2	5	5	4	3	4
Question 3(a) - Sediment P	1-5	5	5	5	4	5	5	3	3	4
Question 4(a) - Runoff from field	1-5	5	3	5	4	5	4	5	5	4
Question 5(a) - Runoff Delivery	1-5	2	4	2	2	3	5	5	3	5
Question 6(a) - Runoff DRP	1-5	5	5	5	4	5	5	5	4	4
Question 7A (a) - Application rate	yes or no	yes	yes	yes	yes	undecided	yes	yes	Yes	yes
Question 7B (a) - Source Availability	1-5	5	5	5	4		5	5		4
Question 7C (a) - Method of Application	1-5	5	5	5	4	5	5	5		4
Question 7D (a) - Applied Fertilizer	1-5	4	2	5	4		5	5		4
Question 8(a) - Percolation	1-5	5	2		3	5	5	4	4	4
Question 9(a) - Soil texture/drainage class	1-5	5	2	4	2		5	4.5		5
Question 10(a) - Subsurface DRP	1-5	5	5	3	2	5	5	5		4
Question 11(a) - Equal weighting	1-5	5	2	5	3		4	4	2	4
Question 12 - Expertise on P loss	1-5	4	4	4	4	2	4	4	4.5	3

Respondent #	Range	# 27	# 28	# 29	# 30	# 31	# 32	# 33	# 34
Category of survey participant: State, Federal, Private, Academic.		Fed-NRCS	Academic	FED-ARS	FED-NRCS	FED-NRCS	FED-NRCS	NRCS	NRCS
Occupation		WQ specialist	Professor	Soil scientist	District Cons.	District Cons.	State agronomist	District Cons.	District Cons.
State of employment		TN	IL	AR	VA	VA	KY	VA	VA
Question 1(a) - Soil Loss	1-5	3	5	5	5	4	5	5	4
Question 2(a) - Sediment Delivery	1-5	4	3		5	5	4	4	5
Question 3(a) - Sediment P	1-5	5	5	4	5	5	4	4	5
Question 4(a) - Runoff from field	1-5	5	3	3	5	5	3	5	4
Question 5(a) - Runoff Delivery	1-5	4	5	1	5	5	4	5	4
Question 6(a) - Runoff DRP	1-5	3	5	3	5	5	3	4	5
Question 7A (a) - Application rate	yes or no	yes	yes	yes	yes	yes	no	yes	yes
Question 7B (a) - Source Availability	1-5	4	5	5	5	5	5	4	5
Question 7C (a) - Method of Application	1-5	4	5	5	5	5	4	4	5
Question 7D (a) - Applied Fertilizer	1-5	5	4	4	5	5	3	4	5
Question 8(a) - Percolation	1-5	4	5	4	5	5	4	4	5
Question 9(a) - Soil texture/drainage class	1-5	4	5		5	5	5	4	4
Question 10(a) - Subsurface DRP	1-5	3	5	4	5	5	5	4	4
Question 11(a) - Equal weighting	1-5	5	4	5	5	1	3	4	4
Question 12 - Expertise on P loss	1-5	3.5	3	5	3	3	4	2	3

Respondent #	Range	# 35	# 36	# 37	# 38	Mean	Std. dev.	Mode
Category of survey participant: State, Federal, Private, Academic.		NRCS	NRCS	NRCS	NRCS			
Occupation		Cons.	Cons.	District Cons.	Cons.			
State of employment		VA	VA	VA	VA			
Question 1(a) - Soil Loss	1-5	4	5	4		4.35	1.10	5
Question 2(a) - Sediment Delivery	1-5	5	4	2	1	4.11	0.88	5
Question 3(a) - Sediment P	1-5	4		5		4.40	0.74	5
Question 4(a) - Runoff from field	1-5	4	4	5		4.38	0.78	5
Question 5(a) - Runoff Delivery	1-5	5	5	4		4.17	1.14	5
Question 6(a) - Runoff DRP	1-5	5	4	5		4.32	0.97	5
Question 7A (a) - Application rate	yes or no	Yes	yes	yes				
Question 7B (a) - Source Availability	1-5	4	4	4		4.69	0.62	5
Question 7C (a) - Method of Application	1-5	4	4	4		4.61	0.65	5
Question 7D (a) - Applied Fertilizer	1-5	4	5	4		4.11	1.20	5
Question 8(a) - Percolation	1-5	5	5	4		4.31	0.98	5
Question 9(a) - Soil texture/drainage class	1-5	4	5	1	1	4.21	0.96	5
Question 10(a) - Subsurface DRP	1-5	4	3	4		4.17	1.07	5
Question 11(a) - Equal weighting	1-5	4	5	1	2	3.73	1.24	5
Question 12 - Expertise on P loss	1-5	2	3	3	2	3.58	0.83	4

Table D.2: Soil Loss Survey Results

#	Question 1 - Soil Loss
	Other Methods Suggested:
2	RUSLE 2
3	RUSLE 2 and other new technology when available
11	RUSLE 2
12	Historical data if available
20	I think you need to make P Index into something a producer can use without assistance. This means no computer models. My suggestion would be to sacrifice accuracy and develop tables of estimated erosion for various crops, locations, and management practices. Another option is to use USLE which is a little easier (they didn't listen to me in Georgia either)
22	RUSLE 2
24	none at the time, you may want to look at identifying (or try to identify) areas of concentrated flow within a field with the idea of increasing buffer width
27	RUSLE 2 may provide a better assessment
28	Most soil loss occurs in a few intense storms. One could chose a storm based on local intensity duration frequency curve and determine soil loss based on that event
	Comments:
1	RUSLE is the best tool to use to estimate the rate that erosion is moving from critical parts of the landscape. The soil loss computed by RUSLE is not the amount of sediment leaving a field or watershed. I do not know what should be used to estimate edge of field soil loss but according to the RUSLE manual, RUSLE is not intended for this use. RUSLE is also subject to user interpretation which can extremely diminish its accuracy
3	Should incorporate new technology such as RUSLE2 when available. Should also include other sediment trap conservation practices such as terraces, buffer strips in field etc. Since RUSLE only addresses sheet and rill erosion need to address other erosion occurring in field such as ephermerial gully erosion. NRCS has a method listed in national agronomy manual.
6	Thought should be given regarding how future release of RUSLE will impact this model. Development (improvement) of RUSLE is quickly advancing. Suggest making this a 'plug-in --plug-out' module for easier modification
7	I am concerned about the possibility of 'double crediting' a downslope filter strip. Conceptually, this seems to be something that should be accounted for in the "sediment P delivery factor" as it represents a management practice beyond the field boundary.
8	RUSLE seems most appropriate. The only concern is that RUSLE is typically calculated for a rotation and as indicated above the Virginia Phosphorus Index is an annual assessment. This issue is raised in most P indices that use RUSLE
9	RUSLE would become the "method of choice" if we did not assume a slope that is uniform. As we advance in the use of RUSLE it is my desire to see that we calculate soil loss using complex slopes. This would give us a more accurate edge of field soil loss
12	a "how-to" reference or web page for RUSLE would be helpful to users. I noticed that Michigan has a web-based RUSLE version suited for use in Michigan
14	At the moment there are no other methods more suitable. Although, we have found RUSLE calculations to be very time consuming (up to 75% of a site PI assessment), few alternatives are available. Several States (e.g. PA, MD) are calculating RUSLE values at a county soils map level. In PA, this is being done by NRCS. The ultimate goal to have a state map from which one can obtain essential RUSLE parameters (except crop management, which is site specific), would streamline the process. Eventually, this will be digitized and parameters obtained by simply entering a soil name

	Additional Comments: Soil loss
16	If the P Index uses RUSLE to determine appropriate P applications as a general guide for fields assuming no conservation treatments are in place, then procedures should be allowed, or consideration should be given, on a case by case basis for producers to improve the fields P-Index by accounting for post-conservation implementation treatments whether the BMPs already exist at each site or are installed for the purpose of decreasing erosion potential and thus improve the site's actual P-Index
19	Consider annual soil loss rather than average soil loss over the rotation
21	RUSLE only measures erosion on the soil, slope, & length represented. It does not predict edge of field sediment delivery. The critical area to measure soil loss is within 250 feet of concentrated flow that carries runoff.
22	RUSLE 2 should provide a better value for soil loss from the field. I'm concerned about the long term P buildup in the filter strip. At some point in time the filter strip will be a P contributor if it isn't already. Research done in MD shows this happening within certain landscapes.
23	Is there also an adjustment factor based on type of vegetation and condition of filter strip?
24	We (UNHCE) are looking at identifying areas of concentrated flow where most of the water & sediment leaves a field. In our case, we do not have even movement over the width of the field.
26	Concentrated flows (waterways, gullies) need to be accounted for.
31	Based on my knowledge of RUSLE, it is an estimate of total soil movement (loss) in a field. It does not suggest that all the soil is lost out of the field or moves through the edge of the field. However, this may be the only tool available for the loss of soil to the field edge.
32	The RUSLE soil loss calculation estimates soils displacement on a given slope. Note that all soil being displaced on the slope may not actually make it to the filter strip in the first place! The calculation has some shore comings but it is the best for this use. One other concept: In reality the conservation plan on the field should include provisions that soil loss be controlled to within tolerable levels before any manure application is made.
35	This would probably be the best accepted method in the field because it takes into consideration various environmental factor based on studies
36	Use RUSLE where sheet and rill erosion is main type of erosion present at edge of field. If gully or other erosion is predominate erosion (where there is concentrated flow), RUSLE could not be used accurately
37	RUSLE probably best method

Table D.3: Sediment Delivery Survey Results

#	Question 2 - Sediment Delivery
	Other Methods Suggested:
8	Using only a distance from the edge of field to an intermittent/perennial stream
34	Factors could be included to account for slope across filters and areas between the field and streams
38	Suggest factoring in a length of slope weighted average to your sediment delivery factor.
	Comments:
2	1) Is there ever a point when sediment delivery is 0? For example: distance to stream=1,000 feet, buffer width=600 feet of hay field & woods below the corn field we are working on 2) The Factors on the low end need more steps, how much will this alter the end results? Is there enough difference to warrant this up to 150-200 feet? Example 0-25 feet 1.0, 25-50 0.95, 50-75 0.9, 75-100 0.87
3	Sediment delivery factor is good to use but need more information on how it was developed. What is the research supporting this factor. Did you use land farm regions to adjust sediment delivery etc. Dr. Jim Baker has shown that much of the sediment is trapped in the first 10-20 feet.
7	Definition of the water course is very important. Does this definition (stream) exclude channelized flow such as gullies & ditches? On the Delmarava Pennin. Ditches serve as streams but would be possibly emitted from consideration
8	It seems as if buffers are being double accounted. A credit is being given for the soil transported to the edge of field and another credit being given for how much will be delivered to a stream. Perhaps the filter strip should be in one the of two factors, but not both
10	were different landscapes considered (particularly or related to slopes and drainage patterns)?
11	By just the width of buffer, we can not assign a factor. A 100 ft buffer that is not maintained at proper condition (height, density, etc.) may not be effective at all. Also, the micro relief within the buffer sometimes can result in concentrated flow within the buffer and flow does not go through the buffer matrix. So somehow other factors should be included
12	Give Guidance on which factor to choose. For instance, if 200-300 feet with 40 ft buffer, do I choose 0.7 or 0.8?
14	This method seems appropriate as long as some field data or validation be obtained. Some field evaluation or survey of the literature could justify the relative values for the various buffer widths.
15	I like the above method. Literature shows that even a filter strip of 10 to 25 ft is helpful. Add an additional category <10 feet and shift factors adding 0.1 to >500 ft. I am assuming it is clear that this buffer is a no apply zone and certain amount of cover is necessary
16	This Factor should differentiate between intermittent or perennial stream. If a producer is following a nutrient management plan, which many are required to do so, P-application would likely occur when intermittent stream flow is subsiding
20	NRCS in Georgia felt that the P Index was a tool to estimate edge of field risks (it is defined this way nationally) They also argue that the land between the field and stream might be controlled by a different landowner so you should not depend on it being in the given condition. I don't agree and like your approach.
21	Very few fields deliver "sheet flow" to streams. The key question is how does runoff reach the stream (Inlet, concentrated flow via w/w, drainage way). Buffer adjacent to streams are ineffective, unless they capture most of the field runoff as "sheet flow"
22	Buffers do slow down water velocity and settle sand, silt, and some clay. Runoff events in SW VA will have a significant amount of clay in the water that cannot be filtered out. What percentage of P in the soil is attached to the clay? If water is running off the field and through the buffer to the stream P is going with it.
25	Distances are arbitrary, further, what about such conditions as diversion/terrace at bottom of field going into drop inlet & piped directly to stream? Considering 'buffers" is fine, but there are other "bmps" not included

	Additional Comments: Sediment Delivery
27	I do like the comparison of buffer width to flow distance. A buffer should be defined. A setback zone area or area of non-application with vegetation capable of filtering runoff. Considering NRCS standards (minimum width of 35') I would expect to see a lower value for 25-50, <25. Publish literature support high filtering capabilities of 35 feet width (esp. sediment)
28	I think the factor should include some coefficient to account for differences in slope. Buffer strips of the same width would not perform comparably if they were on different slopes
29	Are you assuming sheet flow? In our situation, most runoff is channelized by the time it leaves the field
31	Overall the sediment delivery estimates are too high based on some of the factors we have used for watershed plans in the past
32	you may want to consider vegetation in area adjacent to the application field. Lets say what if you are 200 feet away from the stream but the buffer is in trees or grass.
34	Steep slopes across filters and areas acting as filters effect the sediment trapping ability
35	This seems very appropriate and proportional but remember streams are not straight lines and buffer widths vary
36	Buffer quality (makeup, characteristics) need to be better defined
37	Just a best guess (values); However, the slope of the buffer should be a factor also the shape to predict sheet flow vs concentrated flow
38	Should the widths correspond to a slope class also? Or to a landscape position, I.e. flood plain, sideslope. On an unrelated non-technical issue: This rating scale will be hard to define within the confines of NRCS's standards and specification of environmentally enhancing programs like CREP & EQUIP & the state's BMP program. Other Methods: Suggest factoring in a length of slope weighted average to your sediment delivery factor. I could foresee for Example: With a this rating system a field on a contour/strip rotation @ 7-15 % slopes within 25-100 feet to a stream will have the same sediment delivery factor given as a 0-2% continuous cropped flood plain field 25-100 feet to a stream. Both theoretically will have the same T value also but under the same storm event-sediment delivery from the 7-15% slope field will be higher than the 0-2% slope field. Generally stated, erosion calculations under RUSLE is an estimation over time. Sediment/nutrient loading is more related to storm events in relation to time of application

Table D.4: Sediment total P survey results

	Question 3 - Sediment P
	Other Methods Suggested:
4	In FL we consider flow through a wetland, buffer strip, or overland flow treatment area, the potential to affect a water body would be low. If there is a ditch drainage or direct discharge to a class 3 water body, then the potential would be medium. When there is direct discharge to a lake, sinkhole, class 1 or 2 water body, or outstanding FL water body, then it is high
8	Another possible method would be an iron-oxide strip method to provide an estimate of bio-availability
12	water extractant values
15	with time this factor should be modified or refine to account for true physiographic regions. Piedmont and Upper Coastal soil surfaces are probably different enough to require this modification over time
24	1)within each region look at major soil types to determine if P sorption capacities are similar. 2)P sorption Index or % P saturation could be used to estimate these properties
	Comments:
1	Should the sediment total P subfactor be tied to surface soil texture as well as geographic region of the state?
5	[misinterpreted question] soil test P variability with a geographic region will be very large
7	I think this is an innovative means of addressing sediment enrichment ratios for P. Bravo. Have you published the study that supports these equations? If not, please do so soon.
10	In effect, that's what we have done in IA, however, did you consider a sediment "enrichment" factor? (where nutrient concentrations in sediment are greater than those for in-place soil because of selective erosion processes)
14	The conversion factor for Mehlich-1 soil P to total P has been obtained from field data, which makes it defensible. However, I would have thought total soil P to be the controlling parameter, but I realize this value is rarely available. It looks as though the intercept and slope values for the three selected regions reflect soil P saturation (more P in coastal plain soils than ridge and valley) and some degree of enrichment (flatter coastal plain soils more likely to be clay and P enriched than steeper ridge and valley soils)?
20	Haven't seen VA data but looks OK
21	Varies some by percent clay in sediment
24	Soils with varying P sorption capacities can act as a source of P or a sink for P once the sediment reaches surface water.
25	Does Sediment P delivery factor also address some of this component?
32	This method is good, however soil loss is measured in tons/acre/year and reflects only the top of the soil profile. The thickness of a dime over an acre may be a ton. However, soil samples that yield residual P data are taken from cores that may be 5-7 inches deep in the soil profile
33	Any thought given to quantifying type of buffer, I.e. thick grass, forested, alfalfa, etc.?
35	This seems to be the best method available

Table D.5: Runoff from field survey results

#	Question 4 - Runoff from field
	Other Methods Suggested:
4	In Florida we are just using the NRCS hydrologic soil groups and soil series classification
8	The only other method is runoff class or risk factor assessment seen in P indices in the use of soil permeability and slope. However, with this method (permeability and slope) the impact of management (crops) is not assessed.
10	WEPP
11	If data available, use a more detailed, process orientated, models that use Green-Ampt equations such as RZWQM
12	regional rainfall/runoff relationships
19	runoff class
24	Selecting the runoff class or grouping from NRCS info (slope, etc.) is also used. Using the runoff curve number is more appropriate (if you have the data to support it).
	Comments:
1	My main concern regards the difference in tables 6 and 7 of the P Index and the NRCS document they are derived from. I feel sure the NRCS document or table is designed to be used in its entirety. If altered or condensed, its accuracy declines. This NRCS document, like most scientifically derived data sets, assumes a certain level of accuracy less than 100%. Altering or condensing such a document only magnifies the level of its accuracy.
7	It is unclear how effective the CN is in shallow upland systems where variable source area hydrology dominates runoff generation processes. However, as w/ RUSLE, as NRCS is a target user-group, and that agency is familiar w/ the CAN, then from a practical stand point, the CN is as good a tool as is out there.
10	Do Results look "real?" and how did you go from a storm-base to an annual calculation (did you take into account smaller rains that do not produce surface runoff?)?
11	The notion is that we should replace CN method with something that can take advantage of our GIS & Landuse/cover information that are much more easily available now. However, this technology is not easily available, but it appears that GeoWEPP is going to this direction when its ready is the question
12	stretching curve # capabilities but OK for risk assessment
14	As for soil erosion, there is little better alternative at the moment, even though theoretically curve number is inappropriate. However, what works - leave alone ! We are evaluating whether some factors in RUSLE that describe runoff and soil properties may better describe variable runoff response across a landscape not captured by curve number. In our area, the presence of even vague plow pans or impermeable layers can greatly influence surface runoff from soils that would have the same curve number.
15	We must further test the CN with real field data. To date it is the best we have but with GIS, perhaps in the next 10 years, we can refine the CN.
20	could hide all of this using computer program and inputting soil type, management, and crop
25	So long as this is understood to be "edge-of-field" runoff
28	Again, slope should be included here, as slope affects the transport capacity of runoff
32	The runoff from the field may not include all the area from where manure applications are made!
35	Consistency is important here
37	There are other methods to estimate runoff, but the NRCS curve number, is the method used for many years. There could be a better method developed in recent times
38	I do not understand why the climatic zone map does not correspond more closely to the VA annual precipitation map: therefore, I do not agree with the rankings

Table D.6: Runoff delivery survey results

	Question 5 - Runoff Delivery
	Other Methods Suggested:
15	I would approach this one from the what is coming in direction
34	Runoff delivery factors may need to be a range based on the slope across the buffer and condition of vegetation in the buffer
	Comments:
1	Again, as in question 2, is there ever a point where runoff delivery is essentially 0? Ie.: A corn field is 1,200 feet from a stream all of which is tall grass hay field and trees. How much impact does expanding this chart have?
4	Why is the runoff water calculated separate from the sediment P delivery factor? Both factors are using a flow distance from field to an intermittent or perennial stream or a stream buffer width.
7	I would obtain a category to credit buffer strips that many improve infiltration. Also, please refer to my concern over the definition of "stream". If this excludes ditches, than this factor is not satisfactory.
8	Inclusion of buffer width seems appropriate for the runoff delivery factor. Concern may be raised if buffer width was accounted for in the curve number determination.
10	I think this effect is being over-empathized; (especially the 0.4 value); some reduction does take place, but with concentrated flow next to a stream, not much additional infiltration can take place (with a VFS, the number would be a little better). * approach is appropriate, but see above (I can see a VFS having some effect, but little for "distance from stream".
11	Again, other buffer characteristics should come into play in order to derive RDF values. If buffer is in a good shape, I think these factors are high
12	This factor is difficult to evaluate. For edge of field losses I would consider runoff and infiltration, and not consider transmission losses of runoff.
14	Again, as for sediment delivery ration, it would be good to have some supporting field data eventually. I was impressed by the fact that the buffers affected dissolved P or runoff delivery ratio less than for sediment.
15	Don't feel comfortable indicating low or high on this one. Slope length, contributing area, and contributing area shape tangle me up on this one.
16	See comment from question 2, "This Factor should differentiate between intermittent or perennial stream. If a producer is following a nutrient management plan, which many are required to do so, P-application would likely occur when intermittent stream flow is subsiding"
18	It seems like this should be a P delivered in runoff factor instead of a runoff delivery factor. The runoff will likely get to the stream, but the P may be partially removed by buffer. It seems to me that this removal would be small.
20	I think the runoff delivery must be somewhat dependent on the field size or drainage area. I have no reason to believe that runoff would be reduced by 60% flowing over 500 feet of some unknown landuse and definitely think this would change between a 5 acre and 500 acre field. I don't have any suggestions but thought that curve numbers were for watershed outlet estimations and maybe no delivery factor is needed.
21	same as question 2 "Very few fields deliver "sheet flow" to streams. The key question is how does runoff reach the stream (Inlet, concentrated flow via w/w, drainage way). Buffer adjacent to streams are ineffective, unless they capture most of the field runoff as "sheet flow""
22	These factors seem appropriate for buffers but not for distance to stream. There are too many things happening in the landscape to assume similar delivery rates comparing any two fields based on distance to the creek alone.

	Additional Comments: Runoff Delivery
25	No basis for distances! Can't see them being uniform across the state!! Further, how do you equate the straight distance to a stream buffer width distance? As a farmer being impacted by your PI, I'd certainly question the "rationale" for these distances. Maybe the Gburek et al. paper in J. Soil & Water conserve. in the near future would help?
29	What makes you think the distance from field affects delivery?
31	All runoff delivery factors may be too high
33	Why not use six categories as with the sediment delivery factor?
35	Needs to be based on study. Again, streams are not straight lines and buffers vary
37	Just a reaction to examples - feels a little high

Table D.7: Runoff DRP survey results

	Question 6 - Runoff DRP
	Other Methods Suggested:
12	water extractant
15	modifications on this factor based on source timing and management system
24	Develop relationship between Mehlich I soil test P and DRP in runoff for a variety of soils that fall into your 3 physiographic regions
	Comments:
2	Dissolved P seems to be a factor of soil type, not geographic location
5	Runoff DRP may have little connection with soil test P if recent P application to field
7	The use of various equations to represent different regions is highly appropriate
10	same approach as Iowa
14	excellent use of field data obtained from very well focused trials
24	soils with varying P sorption capacities can act as a source of P or a sink for P once the sediment reaches surface water
27	In the past the correlation with soil test P and loss has proven to result in error in certain situations . Variables play a role in availability and loss. If this is questionable, could a coefficient be used to represent error?
37	Is pH a factor?

Table D.8: Application rate survey results

#	Question 7A - application rate
	Comments:
4	In Florida we take a Mehlich I soil test in ppm of P X 2 X 0.025 to determine our fertility index value
5	Definitely include P application rate
7	Absolutely include application rate. DRP concentration is strongly related to rate of P application
8	Including the rate of P application is important/critical in understanding the impact of management on potential/risk for P loss. Also, if management changes need to be made having the rate as a component of the index that can be changed provides clear options to the planner and or producer
12	Definitely
16	The application rate is necessary for using the P-Index as a site specific management tool on an annual basis
19	Application rate is often more important than soil P
21	Should break application on: 1. Type of manure/biosolid, 2. Inorganic fertilizer * surface applied inorganic is likely to produce more DRP than manure
22	I don't know of the P already in eh soil, how much is going to be in solution during a runoff event compared t the amount of P going into solution from annual application of fertilizer P applied.
25	a little out of my area of expertise
32	Not sure that applications of commercial fertilizer in the current year are impacted by P-Index. Commercial fertilizer applications contribute to P building but the applied rate should be calculated based on soil test recommendations.
34	Managing nutrients includes using nutrients. Not considering what is applied makes calculating nutrients needs impossible.
35	It is vary important as a management tool for applicators and nutrient mgt. Specialists

Table D.9: Source availability survey results

#	Question 7B - Source Availability
	Comments:
1	I apply 30 lbsP205 in dairy manure and 20 lbs P205 with commercial P. What do I do now?
4	We also have an additional factor for lbs/ac of P205 for wastewater, which would take into account Phosphorus in lagoon water
5	Comment of biosolids value: depends on wastewater treatment process
6	Litter w phytase become a diet issue. If rate of P application has already been factored in (7A), I suspect that presence of phytase will have little if any influence on availability
7	This factor and the values assigned represent the best available estimated of source availability. However, considerable recent work has shown large variability in manure & biosolid P solubility. I recommend you incorporate these findings as they are published
8	It is difficult to rate the availability factors as I do not know the maximum value. Therefore, I rated them relative to each other. Also, it is not clear how these assessments were made or factors assigned. It would seem that biosolids, depending on treatment, would have a lower availability than manure.
10	Great if you have adequate date to justify differences between sources in "availability" based on what could be lost in the 1st year after application, 1st even, ….?
12	Seem to be low, especially when coupled with method of application factor
14	I assume these factors are obtained from experimental data. Several states (PA, MD, DE) have a similar factor for source availability by a simple water extraction, which is now routinely run of samples sent to the state analytical lab at Penn State. A book value or actual measure availability can then be used.
15	Manure/litter is too big or broad a category, manure application depends on manure source dairy: slurry, compost, solids, Poultry: broiler Inorganic, soluble P is at least 3 times as much as some manures
16	Inorganic sources should differentiate between dry & liquid suspension of fertilizers (chemical). Unless the phytase increased P solubility in litter, litter with phytase should be the same as manure/litter.
19	What about differences between manure types. Depending on treatment biosolids may be significantly lower than manures, it is difficult to evaluate these numbers on an absolute scale but they seem reasonable on a relative scale.
20	seems like inorganic should be higher
23	How do you account for slower release and carbon loading/buffering associated with organic sources?
24	If you deal with only one type of manure or only one type of treated biosolids then one factor for each is appropriate. We have various manure and several different types of treatment for biosolids and the P availability is different.
25	Ditto, Others more in tune w/ "source" factors can address this better
28	This is outside my area of expertise
29	You are the first group that recognizes phytase increases P solubility. Good Job!
33	I have no basis on which to judge this I assume the research from which these factors came is solid.

Table D.10: Method of application survey results

#	Question 7C - Method of Application
	Comments:
1	my manure was incorporated immediately. My commercial P was surface applied. What do I do now?
6	My gut estimates are that 5-10 days would be a better category than 3-5 days. I would not suggest changing the factor (0.10)
8	Again, factors were ranked relative to each other since I did not know the maximum value. Combining injection and immediate incorporation into one factor may be a concern. If immediate incorporation is 1-2 days, there is a potential for loss of the manure P that is not present with injection\
10	Relative #s look good; how do these relate to the #'s in 11; do you have enough data to separate the source and method effects
11	I think, again, this would also depend on the type of tillage system. If you surface applied to a no-till/less tillage field, then the 0.2 seems to be high, but if you apply to a conventional -till field this value may be even low
12	values seem too low
14	Relative values vary from other states but this is probably due to other differences in related parameter inputs.
15	Factors seem proportionate
16	Surface applied should read "Surface applied, incorporated after 5 days or no incorporation." Injected inorganic fertilizer should have a lower value than 0.05 since the injection furrow is typically packed or compressed. The factor 0.05 is probably appropriate for other P sources applied/incorporated under this method type
17	3-5 days factor OK provided there are no heavy rains
19	seem OK on a relative scale, what about time of year?
21	Need to address surface cover at the time of application-under high residue situations (75%) or vegetative cover (hay or pasture) runoff "P" is reduced
24	Your "methods of application" can reflect either current or encourage management. A lower factor for more environmental approaches. (since we have seasons that vary dramatically from one another, the timing of application is also important). With the method of application, breaking it into more categories, an incorporation of within 24 hours and 1-2 days would round out the choices.
35	This information needs to be based on a study before it will be accepted in the field

Table D.11: Applied fertilizer survey results

#	**Question 7D - Applied Fertilizer**
	Other Methods Suggested:
7	This is the most logical approach
11	If you consider bringing management factor (type of tillage) into the P-Index, then this esq. would also need to be modified?
20	might consider including timing effects unless your likelihood of runoff is constant throughout the year.
	Comments:
1	I thought the P-Index was supposed to help us figure out how much P we could apply. Why are we inputting how much P we want to apply so we can have the index tell us how much P we can or cannot apply? If this is to tell us where we have been with P applications, we have already done that because several previous calcs are based on P soil test level.
2	If there is no runoff, there should be no applied P leaving the field. Except in very coarse soils, any P leaching downward through the soil profile is very likely to be tied up. Applied fertilizer losses should be a product of runoff.
10	Shouldn't the "applied fertilizer factor" (maybe it should be the applied P factor) be dependent on volume of runoff to?
12	Source availability and method of application factors seem too low, especially in multiplicative relationship
15	Where is the timing factor?
19	Why is this handled different from the runoff DRP?
28	I would have multiplied the other risk factors by the applied fertilizer factor, after scaling it to between 0 and 1. This would be a better way, in my opinion, to demonstrate that it is orthogonal t the amount of runoff.

Table D.12: Percolation survey results

#	**Question 8 - Percolation**
	Other Methods Suggested:
5	NRCS leaching index
12	again regional data will be helpful as well
19	maybe just use drainage
27	soil characteristics are appropriate fro determining percolation rate. I realize you have captured this in #9 (good)
	Comments:
1	How does this method account for the water absorbed and held by the crop?
4	Here in Florida we used a leaching potential, which takes into account where loamy/clayey layers in the soil profile, coated sands are also evaluated and the depth that they occur at
6	Not a big fan for these kinds of mass balancing but I agree some estimation is needed
7	Subsurface P transport is dominated by preferential flow through macropores. Large concentrations of [P] can be transported in leachated w/compacting tilth infiltration. I'm not sure this factor (8) is necessary
14	This is a simple assessment of subsurface risk factor, which is a very complex process. However, it is good to help if simple as it represents subsurface flow potential.
16	Row crops-it seems to be a bit of a stretch for percolation to be same for all row crops since evapotranspiration will vary with growing season (winter crop vs summer crop) and crop type (biomass difference). Hay crops should have higher percolation rates relative to pasture & row crops given difference in average annual biomass and evaptranspiration & runoff rates. Fallow crops-I was surprised to see fallow has the highest percolation rates unless it significantly reduces runoff throughout the year-it would seem that evapotranspiration would be less than hay since the fallow should ? sooner during the year
19	seems very complicated for an index
21	appropriate if tile drained
25	Considering Percolation is OK, but my question is: Does what is percolated get to the stream? There is little or no evidence that P in just plain percolation anywhere impact streamflow, unless there is some type of artificial drainage to move it laterally. Getting it below the root zone is only part of the picture, just like the "edge of field" part of the surface runoff transport. A "link" to the stream must be included!
32	Percolation can be influenced also by ground disturbance levels and soil condition
33	Does tillage vs no-till need to be considered here since no-till allows more infiltration and hence less runoff? Of course tillage type is considered in RUSLE, but should it be considered here too? And if you no-till, then you don't incorporate the P unless you inject(7c)
35	This would be the best method, and could be adapted locally

Table D.13: Soil texture/drainage survey results

#	Question 9 - Soil texture/drainage class
	Other Methods Suggested:
20	could consider depth to water table as well. This may be better depending on soil mapping.
24	P sorption Index; (soil's ability to fix P) % P out
25	Distance? Actual question of whether there is or not drainage on the field? Don't make the assumption! See previous page for comments
	Comments:
2	Should not assume that all poorly drained soils are tiled. If tiled, then change classification perhaps, but there is a lot of ground "poorly drained" that is farmed with no tile- or with non-functioning tile.
6	These factors appear reasonable. However, I'd suggest a sub-factor be considered for "drained" vs. "undrained". A lot of "somewhat poorly drained" soils may be in crop production, but w/out drainage. Also, pasture may not be in drainage
7	Need to look @ existing literature on P leaching. Tile drainage & French drains in fine textured soils can be worse than leaching though sandy soils (contact HaroldVanEs@ Cornell Univ. for good example)
10	Are the factors based on both hydrology and the potential for P removal from solution by adsorption/precipitation, etc.? Does the geology affect the "fate" of water percolating through well-drained soil (I.e. fact that water does not reach the stream quickly in some cases?)?
11	I'm just wondering if there is a way that we can include tillage practice in here? For example macropore flow/prefential flow are more common phenomenon in conservation tillage/no-tillage systems. Than conventional tillage
15	I do not agree with assumption on artificial drainage
16	The assumption that very poorly , poorly and somewhat poorly drained soils will have artificial drainage is grossly inaccurate. NRCS spent years delineating "farmed wetlands" and "prior converted wetlands" for the 85 farm bill. There are thousands of sites where very poorly, poorly, and somewhat poorly drained soils do not have artificial drainage
19	seems very complicated for a Index
21	Unless the field is underlaid by a sand/gravel layer & adjacent to a stream this factor really stretches science
22	All soil textures should be listed in the table or maybe ranges of clay content to make table easier to use. Clay content has the most impact on subsurface transport. For example, loams and silt loams can have less clay than some sandy loams.
24	Since you are assuming that very poorly drained and somewhat poorly drained soils are drained, should the factors for these two drainage classes be that different?
37	Texture and Drainage can have major impact
38	detail artificial drainage (drain tile vs field ditches??)
38	For chart: 1) source of hydrology would need to be considered for classes 2)should time of application be considered in the rating factor 3) Type of water table may be needed here (perched vs. permanent) 4)permeability may also be needed here
38	This is confusing to me. But, by simply stating altered drainage it will be more clear. Recommend not applying any P to artificially drained soil in the ridge and valley. Especially in limestone geology in spring or late fall. If it is drained by open ditches the field would be very vulnerable to subsurface risk

Table D.14: Subsurface DRP survey results

#	Question 10 - Subsurface DRP
	Other Methods Suggested:
12	water extractant
13	Again, Consider the soil variability within each physiographic region; also look at how well connected the field is to surface water, especially if it is drained and where the outlet is.
	Comments:
4	I would like to know the depth at which the samples were taken. On a field scale the test results could vary depending on the soil types and textures at various depths
10	Do you have data sufficient to develop these equations (we find DRP can move vertically through soil at much higher concentrations than what eventually comes out tile drains with lateral movement through P-deficient sub-soils)?
9	Please refer to "Do you have data sufficient to develop these equations (we find DRP can move vertically through soil at much higher concentrations than what eventually comes out tile drains with lateral movement through P-deficient sub-soils)? I'm just wondering if there is a way that we can include tillage practice in here? For example macropore flow/prefential flow are more common phenomenon in conservation tillage/no-tillage systems than conventional tillage"
14	I assume these equations come from source field or laboratory study. Looking at the slopes w/ surface runoff/DRP (table 9) it would appear that a greater concentration of DRP would be supported in subsurface flow than in surface runoff. Is this right?
15	Potential of direct delivery to groundwater or surface water or subsurface percolation? Subsurface percolation would need a depth of sub soil factor in eh equation. IS there one? Or distance to H20). Macroporosity or potential for high likelihood of macroporosity is important as well.
20	I'm not sure where the equations come from but it seems that if you are looking at DRP in subsurface it would be related to more than just P in surface soil.
21	This is really pushing the science of P transport
25	How does this "below-the-root-zone" DRP relate to what might be delivered to the stream by natural subsurface flow, or that influenced by artificial drainage?

Table D.15: Equal weighting survey results

#	Question 11 - Equal weighting
	Other Methods Suggested:
24	A heavier weighting on whatever source is greater. In New Hampshire the erosion contribution is greater so reducing the erosion (pp) can have a greater impact on the total.
31	I would suggest a heavier weighting be given to erosion and runoff risk factors; maybe 40/40/20 weighting
	Comments:
1	I feel the "weighting" is done in the way these three components are independently computed. For instance, the subsurface P loss is generally thought to be minimal. If this is the case, the calculation for subsurface loss should usually generate a relatively small number. To take this number and multiply it by a 0.X weighting factor is just redundant.
5	Subsurface risk should be lower weight relative to erosion & runoff. Also, erosion may possibly need to be weighted heavier than surface runoff
6	I trust that science is on our side but I still believe that erosion & surface runoff will carry an inherently higher risk than subsurface.
10	In Iowa, we considered that 30% of P with sediment would not be available in a reasonable length of time (years?) before burial would remove it from having any effect.
11	It really depends on the receiving end? Based on that the weighting risk factor should be changed. I'm for a more flexible "weighting factor" approach
12	Tilled - Erosion>Runoff>subsurface weighting
	Pasture - Runoff >Erosion=subsurface weighting
13	P-Index should be evaluated through the process as research data becomes available, which I know it will be.
14	Within each erosion, runoff, and subsurface factors, multiplication is used. Thus, addition of these at the end seems appropriate
15	weight of these factors would be dependent on management and the water source being protected
16	subsurface risk should be de-empathized relative to erosion & runoff
19	I'm not sure subsurface should be equal to erosion and runoff
25	Have much problem w/considering subsurface loss equal to in importance to erosion & runoff losses, can't suggest specifics as to how to weight them though
31	Just my gut feeling that the risk for P-loss from subsurface risk factors is less than the other 2 categories
37	Site evaluation is important, no all field are the same (I.e. soil, slope, drainage etc.)
38	Perhaps landscape position should be noted in the field then a weighted risk factor could be calculated. I think this would be conditional based on soil & landscape position. For example 1)For altered hydrology or artificially drained soils, the subsurface risk should be weighted far more 2) on well drained soils on flood plains vs side slopes, subsurface may need to be weighted more on the flood plain. 3) On gentle residuals landscape positions ratings should be equal. 4)on very steep > 15% maybe erosion and runoff should be ranked higher than subsurface risk

Table D.16: General comments on P-Index survey results

#	**General Comments on Index:**
1	Several factors go into the P Index. Some factors are subject to user interpretation or field measurements. Other factors are based on charts, curves, data sets, etc. that have been condensed or consolidated for simplicity. Considering RUSLE is said to be +/- 50% accurate and assuming all other factors are +/- 10% accurate, the P Index as a whole is probably only +/- 35% accurate. Is this close enough for government work? I don't think our clients will agree that it is close enough when they have to alter management because of it. I do not disagree with the process or most of the factors used to generate this index. My concern is that each step be as accurate as it can be. We cannot give up accuracy or confidence for simplicity and speed at this point. Once the index has been used a while, we may see some components are extremely predictable or calculated values are extremely consistent, then we may be able to accept simplification of that step. We may also reach a point when we can look back and say all fields with a 6 +/- slope, straight row crops, H or greater P test, hyd grp B well drained fsl soils, P index will be X.
3	The Virginia P-Index is very similar to the Iowa P-Index. In order to make the Index more user friendlier you may want to consider incorporating the index into a spreadsheet. Iowa has an example on the NRCS webpage www.nrcs.usda.gov
6	Appears to have been a very collaborative effort and a reasonably well thought out process!
7	A very nice P Index that is relatively easy to follow & for the most part, highly defensible
8	Many states have automated their P-Index. Many states have also developed a screening tool to identify fields that pose a high risk for P transport based on a few of the P Index factors. This might be an option in Virginia
10	-should emphasis be given that it is a tool to not only improve phosphorus management, but management in general (e.g. cropping, tillage, erosion control practices)? - should emphasis be given that this is based on long-term averages of weather, erosion, etc.? -why was the 6.3 factor used; it seems to complicate things considerably?-were other states approaches considered (e.g. Iowa)? -have your calculated some examples? -are there plans for further testing, possible revisions? -my biggest concern would be over-prediction of reduction in runoff volume or the field gets further from the stream, and that all the sed-P is available to cause water quality problems
11	Overall, I think the work has been done very carefully and have incorporated many of the critical parameters into the overall calculation of the P-Index. I'm just wondering if this can be improved by adding a few more management type factors into the procedure?
12	Seems like a lot of good work has been done !! Thank you for this opportunity.
14	Extremely well thought out and comprehensively documented. There are a few additional steps compared to other states PI's but these are well justified
19	Technically it seems ok. My one concern is that is it pretty complicated for an Index.
21	Please take this as constructive comments: This index is a very complicated and time consuming method to measure an inexact science of "P" movement & transport. Consider working on a large farm 300-3000 acres. The time to work with this method does not seem feasible. Attached is a simple method we use in Ohio and seems to work well.
24	In your interpretation, the medium risk level (31-40) allows 1.5 times crop uptake. This may or may not be a reduction in P application but in many states the switch from N management to P management is at the high risk level. Your approach may be appropriate at he high end of the (>50)"medium risk" but may not be at the low end(<40). Where did the 6.3 factor come from?

	Additional Comments on the P-Index
27	I helped develop TN's P-Index. My position is water quality specialist. 2000-2001 I was highly involved and up to date with literature research pertaining to nutrient management . But this year my activities and responsibility haven't been centered around nutrient management. I feel that many of the developed P-Indexes have been oversimplified and significant variables are not considered. I feel that you have done a good job @ including these variables. At first glance, I felt that is may be a little difficult for field practioners to use, but after reviewing it I feel that a competent field practioner can easily assess factors and calculate the P-Index. I like Table 1 & Table 2.
29	Great Job! Do you think that you can use it to estimate P runoff? (lbs P/acre/year) If so, try that rather than a relative rating.
33	Will probably work OK. Need something that is straight forward when in the field.
35	Thanks for using existing methodology as much as possible. A basic understanding will help field personnel and users adapt and adopt the VA P-Index more readily
36	Every effort should be made to simplify and streamline the use of the P-Index by the planner, especially where accuracy of the outcome would not be sacrificed. The % accuracy of Virginia P-Index should be communicated to the planner and land-user. Is this a "bottom-line" tool or an estimate in which we need to be made aware of any shortcomings in determining strict conclusions?

Appendix E – SAS CODE

```
title 'Expert opinion survey differences in means';
title2 'Julie Jesiek';
data survey;
input trt Q1 Q2 Q3 Q4 Q5 Q6 Q7B Q7C Q7D Q8 Q9 Q10 Q11 Q12;
datalines;
1      1      4      4      4      4      4      2      2      1      3      2      2
       5      3
1      5      5      5      5      5      1      5      5      1      5      3      1
       5      3.5
1      5      3      5      5      5      3      5      5      3      5      5      5
       5      4
more input data………………
5      5      4      4      5      5      4      4      4      4      4      4      4
       4      2
5      4      5      5      4      4      5      5      5      5      5      4      4
       4      3
5      4      5      4      4      5      5      4      4      4      5      4      4
       4      2
5      5      4             4      5      4      4      4      5      5      5      3
       5      3
5      4      2      5      5      4      5      4      4      4      4      1      4
       1      3
;
run;
title;
title2;
proc glm data=survey;
class trt;
model Q1 = trt;
means trt / lsd;
run;
quit;
```

Vita

Julie B. Jesiek was born on July 13th, 1975 in Elk Grove Village, Illinois. She attended Michigan Tech and obtained Bachelor of Science degrees in Biology and Environmental Engineering. After completing her degree in May 1998, she worked in the environmental consulting field for two and a half years. In January 2001, she continued her studies and ventured to Virginia Tech to pursue a Master of Science degree in Biological Systems Engineering. She married Brent Jesiek on August 3, 2002 and they continue to reside in Blacksburg, VA.