Vermont Phosphorus Index User Guide

version 6.3 – November 2021

The Phosphorus Index is a tool developed to assess the potential for phosphorus runoff from individual fields based on soil and field characteristics and on management practices. The P Index is much more comprehensive than relying only on a soil test value because it considers the likelihood that phosphorus present on the field will actually reach a surface water body. The P Index provides a relative rating of the risk of P runoff from individual fields, which can be used to prioritize fields for nutrient and soil management practices.

This version of the Vermont Phosphorus Index traces phosphorus losses from field to water body along surface and subsurface pathways, accounting for both particulate and dissolved forms. While it is not a complete quantitative model, we have attempted to estimate relative P losses from several distinct sources (soil, fertilizer, and manure) as well as the effects of soil type, topography, and management practices. In each pathway, an estimate of the amount of phosphorus mobilized from a variety of sources (e.g., applied manure or fertilizer, erosion) is modified by one or more multipliers for soil, crop, or management factors that reduce or increase P loss relative to a base amount. P losses from all sources are then added, and multiplied by a scaling factor to produce a P Index. Interpretations and management recommendations are given in the chart below.

Pathway 1: Surface Particulate P loss = (Eroded soil P + Manure P) x Scaling Factor
Pathway 2: Surface Dissolved P loss = (Soil P + Manure P + Fertilizer P) x Scaling Factor
Pathway 3: Subsurface Particulate and Dissolved P loss = (Eroded Soil P + Particulate Manure P + Soil P + Manure P + Fertilizer P) x Scaling Factor

Phosphorus Index = $PI_{\text{Surface Particulate}} + PI_{\text{Surface Dissolved}} + PI_{\text{Subsurface Particulate and Dissolved}}$

P Index Interpretation and Recommendations

P Index Value	Category	Management Interpretation
0-50	**Low**	**Low** potential for P movement from site. If farming practices are maintained at the current level there is a low probability of an adverse impact to surface waters from P loss. **N-based nutrient management is acceptable.**
51-80	**Medium**	**Medium** potential for P movement from site. Chance for an adverse impact to surface water exists. **P applications at rates not to exceed crop P removal rate or the soil test P recommended rate for the planned crops in rotation.**
81-100	**High**	**High** potential for P movement from site and for an adverse impact on surface waters to occur unless remedial action is taken. P applications at rates not to exceed crop P removal rate or the soil test P recommended rate if the following requirements are met: -A soil P drawdown strategy has been developed, documented, and implemented for the crop rotation. The drawdown strategy should include eliminating or reducing manure applications. In addition, on cropland fields with "pattern tile drainage" (subsurface tile drainage systematically installed in a repeating pattern), apply nutrients at less than the UVM phosphorus crop nutrient removal rates. -Implementation of all mitigation practices determined to be needed by site-specific assessments for nutrients and soil loss to protect water quality. -Any deviation from these high-risk requirements that would increase the risk of P runoff requires the approval of the Chief of the NRCS.
101 or Higher	**Very High**	**Very High** potential for P movement from site and for an adverse impact on surface waters. **No manure, P containing fertilizers or P applications shall be be made.** Active remediation techniques shall be implemented to reduce P loss potential from this site. 1. A soil P drawdown strategy (e.g., set a number of years to be drawn down to optimum nutrient levels under normal cropping conditions before additional nutrients can be added) has been developed, documented, and implemented for the crop rotation. 2. Implementation of all mitigation practices determined to be needed by site-specific assessments for nutrients and soil loss to protect water quality.

The remainder of this document discusses some of the terms and factors used in the P Index, then describes in general how phosphorus losses in the three pathways are estimated.

P Index features

Soil texture

At several points in the P Index, different calculations are made for clay and non-clay soil types. All soil series with one of the following textures in the surface horizon are considered in the clay group: clay, silty clay, silty clay loam, and clay loam. All other soils are placed in the non-clay group.

Sediment and Runoff Delivery Ratios

Several components of the P Index use a delivery ratio to account for particulate or dissolved P mobilized on the field but deposited in a buffer (or manure setback) before it reaches a surface water body. There are two forms of the factor, shown below:

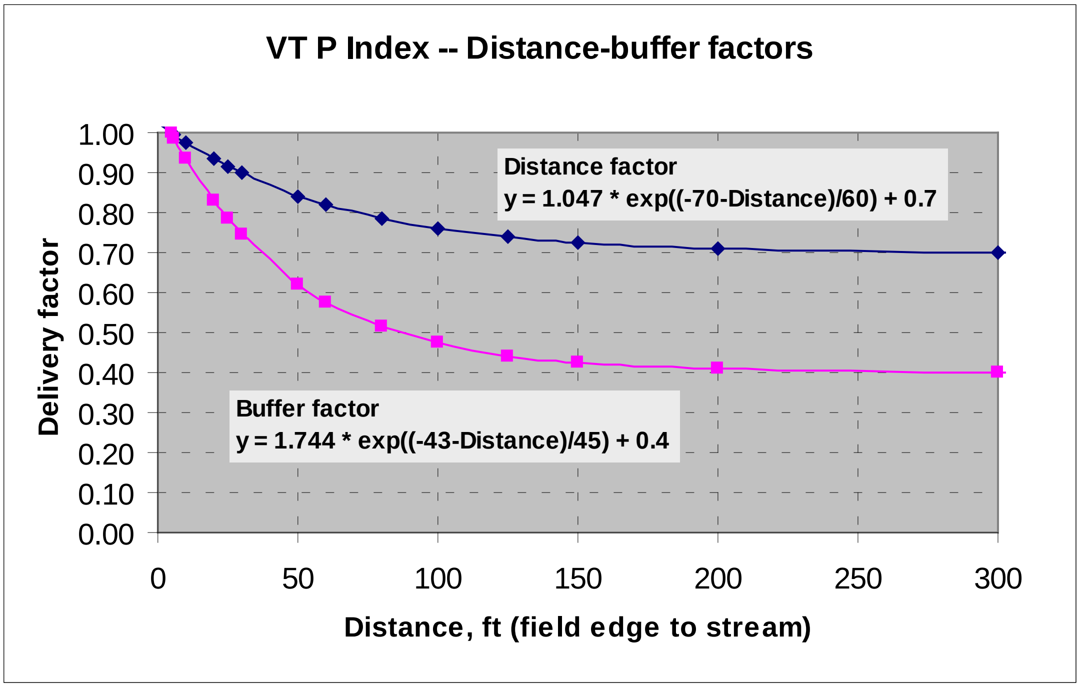


Figure 1. Vermont P Index Distance-Buffer Factors.

The **Buffer Factor** was derived by examining data from several published studies on the effectiveness of buffer strips in reducing sediment load. For distance (buffer width) less than 5 feet, the factor is defined as 1; it reaches its minimum value of 0.4 at about 300 feet. In other words, 60% of the original load has been deposited by 300 feet, and no further deposition is expected. In the Vermont P Index, the Buffer Factor is applied to particulate P in sediment (eroded soil) from fields with non-clay surface soil textures passing through permanent vegetation in non-concentrated flow pathways.

The **Distance Factor** was designed to be about halfway between the value calculated from the Buffer Factor at a given distance, and 1.0 (in other words, the process that the Distance Factor describes is half as effective at removing P loads as the process described by Buffer Factor). It is used for those situations where we judged that runoff crossing a certain distance between field and surface water would be likely to lose some P but less than in the case of sediment loss in a vegetated buffer. These include: sediment (eroded soil) from a clay surface soil (vegetated buffer only); sediment from any soil texture crossing a non-vegetated distance; particulate manure P (vegetated buffer only, including manure setback distance); and dissolved P from any source (manure, fertilizer, or soil test; vegetated buffer only, including manure setback distance for dissolved P derived from manure).

Both equations apply only to sheet (rather than concentrated or channelized) flow.

Manure Factor

The weighting given to applied manure rates is adjusted using a factor that estimates the proportion of applied P that is lost to surface runoff. This Manure Factor (MF) combines effects of season and method of manure application with time to incorporation. It has its **Minimum** value if incorporated immediately (ranging from 0 for injection to 0.4 if disking, implying that only 40% of the applied manure is still exposed to surface runoff; see MF = Minimum + (Maximum - Minimum) * Relative Risk.

= Method factor + (Seasonal factor - Method factor) * Relative Risk.

Table 1). The factor is at a **Maximum** value for unincorporated manure left on the surface, which varies from 0.5 to 1.3, depending on the time of year (see Table 2). If manure is incorporated after some intermediate time (ranging from 2 to 14 days), the factor takes on an intermediate value. The relative risk that surface applied manure not immediately incorporated will be subject to loss via runoff is assigned a multiplier that increases as time to incorporation increases. This risk multiplier (see Table 3) is derived from the probability that runoff will occur in a given time interval (probabilities calculated from NRCS Runoff Curve Number model applied to 30 years of local precipitation data) and the relative solubility of manure (which decreases with time of exposure). Thus, the total influence of incorporated manure application on the P Index is as follows:

MF = Minimum + (Maximum - Minimum) * Relative Risk.
= Method factor + (Seasonal factor - Method factor) * Relative Risk.

Table 1. Factors for method of manure incorporation.

Manure application method	Factor
Inject / subsurface band	0
Moldboard	0.05
Chisel	0.25
Disk	0.4
Not incorporated	1.0
None applied	0

Table 2. Factors for time of manure application.

Manure application timing	Factor
May – September	0.5
October – December 15	1.0
December 15 – March	1.3
April – bare	0.8
April – vegetated	0.6
None applied	0

Table 3. Relative risk of P loss before manure incorporation.

Time to incorporation	Risk
Immediate	≈ 0
< 1 day	0.07
1 – 2 days	0.13
2 – 4 days	0.24
5 – 7 days	0.38
8 – 21 days	0.74
> 21 days, or not incorporated	1.00
None applied	0

Fertilizer Factor

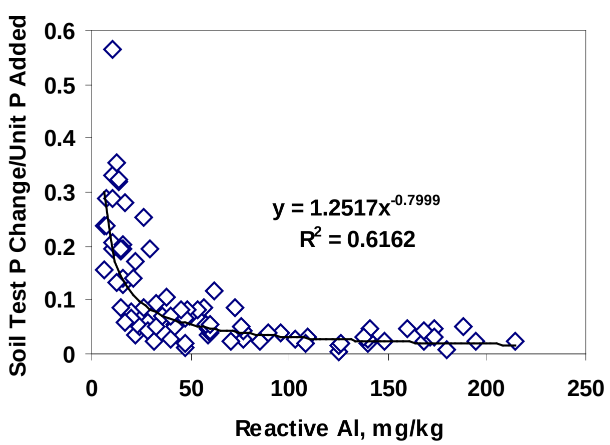
Applied fertilizer rates are adjusted using a factor that estimates the proportion of applied P released to surface runoff. Factors are given in Table 4 for different methods and times of application.

Table 4. Factors for risk of P loss from fertilizer application.

Fertilizer application method/timing	Factor
Surface applied May-September	0.5
Surface applied October-December 15	1.0
Surface applied December 15-March	1.3
Surface applied April	0.8
Surface applied April	0.6
Incorporated / moldboard	0.05
Incorporated / chisel	0.25
Incorporated / disk	0.40
Injected or subsurface banded	0
None applied	0

Aluminum factor

Soil "reactive aluminum" binds a fraction of added P, making it less available to plants, and also less extractable by buffer solutions used in soil testing laboratories to determine "soil test P" (STP), such as the Modified Morgan test in Vermont. The relation between reactive Al and the change in STP per unit of added fertilizer P is described in Jokela (1998) by a power curve, **ΔSTP per 1-ppm added P = 1.277 * $Al^{-0.7639}$** (see diagram). This equation is used in the P Index to estimate the increases in soil test P and total P with added fertilizer and manure.



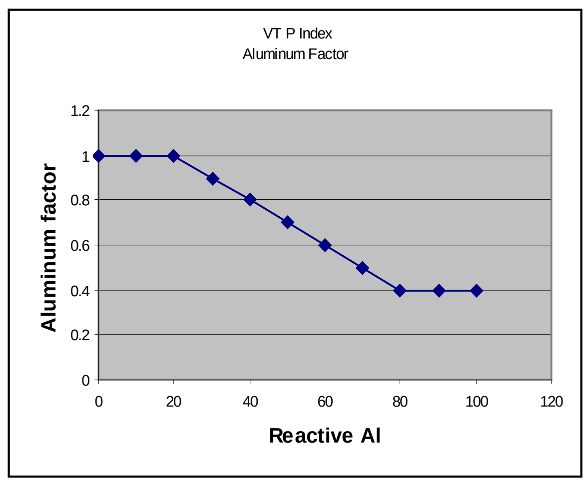


Figure 2. Effect of soil reactive aluminum on the change in STP with added P, and a simplified Aluminum Factor.

A simplified form of this relationship is used for an Aluminum Factor, such that manure and fertilizer P added to soils high in aluminum contributes less P to runoff than does the same amount of P added to low-Al soils. The factor, F_{Al}, has a value of 1 for reactive Al < 20 ppm (i.e., added P has its maximum effect on runoff) and a minimum value of 0.4 for Al > 80 ppm; Al concentrations beyond this point have little additional effect on the change in STP with added P. The aluminum factor changes linearly between 20 and 80 ppm Al: $F_{Al} = 1.2 – 0.01*Al$. If the added P is not incorporated, the Al factor is increased by one-half its difference from 1.0 (for example, a calculated value of 0.8 is increased to 0.9) to account for the fact that it is interacting with less soil depth, hence less affected by soil Al.

Pathway 1: Surface Particulate P loss = Eroded soil + Particulate manure

In the Vermont P Index, particulate P comes from two sources: eroded soil and manure.

1. Sediment (eroded soil) P loss = E * TP * TP Availability * SDR

The four terms are:

a. **E = Annual soil loss**. The RUSLE (ver. 1 or 2) or WEPP edge-of-field erosion rate in tons/ac is divided by 500 to convert it to million lb/ac. Annual rather than rotation erosion value should be used.

b. **TP = Soil Total Phosphorus** concentration (parts per million). TP is estimated from soil test P (STP, Modified Morgans extract) by a regression equation. There are separate equations for clay and non-clay soils (Note: the clay and non-clay equations in the graph are switched; for a given STP, clay has lower TP than non-clay {jpt 3/10/09}):

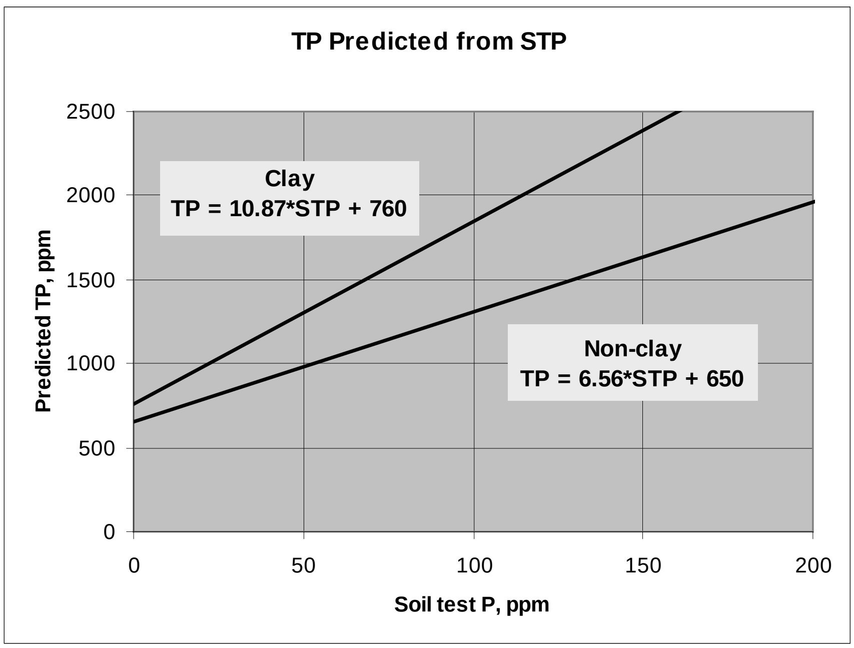


Figure 3. Estimating Total P from Soil Test P.

It is assumed that the soil test was made before any manure or fertilizer applications. Therefore, the added P (after subtracting crop uptake, and dissolved and particulate P losses) is used to adjust soil test P by the equation, **ΔSTP/added P = 1.277 * $Al^{0.7639}$** (see **Aluminum factor** above). This adjusted STP is then plugged into the appropriate regression equation for Total P.

A limit on this TP estimate is made by adding the applied manure and fertilizer P (minus losses, as above), which represents added TP, to the TP calculated by regression from the original soil test P. The estimate cannot be greater than this limiting value.

c. **TP availability factor**. Research suggests that only a fraction of the total P in soils is available for the growth of algae. This factor ranges from 0.2 (i.e., 20% of TP is algal available) at a soil test P of 0 ppm, to a maximum of 0.4 at STP = 100 ppm (based on a chemical extraction of Lake Champlain sediments that approximates algal uptake).

d. **SDR = Sediment Delivery Ratio** (see **Sediment and Runoff Delivery Ratios**, above). For the case of sediment, if a sediment control structure is entered into the P Index, its factor (with a range of 0 to 0.2) is used instead of the SDR (range 0.4 to 1.0). In addition, if the total distance to the nearest water body is greater than the buffer width, the additional distance beyond the buffer is considered to have some effect on sediment load. The Distance Factor is calculated for this additional distance, and is multiplied by the Buffer Factor for the final SDR.

2. Manure particulate P loss = Manure rate (lb P_2O_5 / ac) * MPLF * Manure Factor * SDR_M * 0.44.

The applied manure P rate is multiplied by three factors:

a. **MPLF = manure particulate loss fraction,** a constant fraction (0.5%) of surface-applied manure P lost in particulate form.
b. **Manure Factor** accounts for the timing and method of application (described above).
c. **SDR_M = Sediment Delivery Ratio** for manure, a factor between 0.7 and 1.0, to account for particulate manure mobilized on the field but deposited in a buffer (or manure setback) before it reaches a surface water body (see **Sediment and Runoff Delivery Ratios**, above). The Distance Factor (rather than the Buffer Factor) is used.

The adjusted rate is then multiplied by 0.44 to convert P_2O_5 to P.
Two separate manure applications can be entered into the P Index.

Pathway 2: Surface Dissolved P loss = Soil P + Manure P + Fertilizer P

In the P Index, surface dissolved P comes from three sources: soil test P, and applied manure and fertilizer P. The three risk factors are calculated separately, then added together.

1. Dissolved soil P loss = DRP * Base RO * RO Adjustment Factor * RDR

The first calculated source of dissolved phosphorus in runoff is related to soil P concentration. Its contribution is estimated in the P Index from the following factors:

a. **Dissolved reactive P (DRP)** concentration in runoff, expressed in parts per million. Research involving simulated rainfall applied to field plots on a wide variety of Vermont agricultural soils has provided a good relationship between soil test P (STP) and DRP concentration in runoff: **DRP = 0.1275 + 0.0104 * STP** (see Figure 4). Soil test P is first adjusted for any increment due to manure or fertilizer P added since the soil test was made.

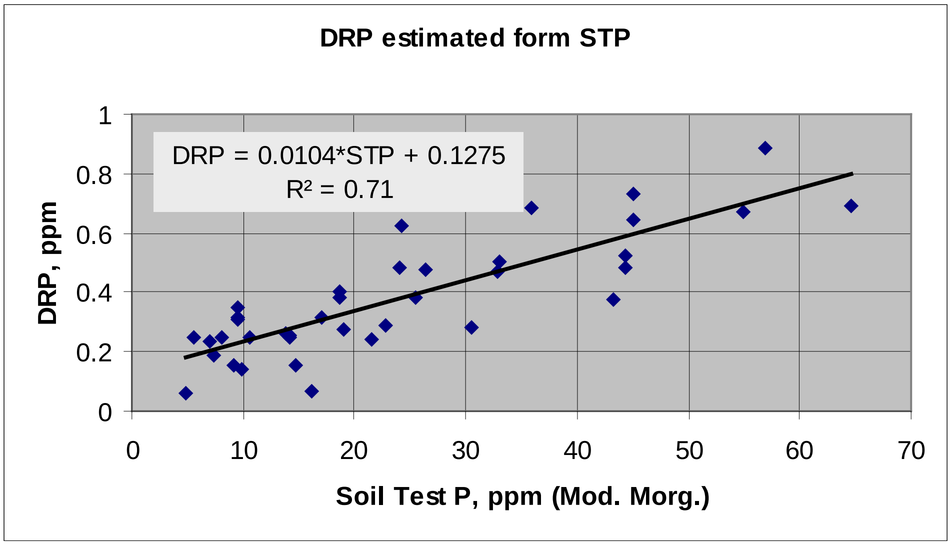


Figure 4. Estimating Dissolved Reactive Phosphorus concentration from Soil Test P.

b. **Base runoff volume**. The NRCS Curve Number model was applied to 30 years of precipitation data from 15 Vermont locations to estimate growing-season runoff for a base situation (Hydrologic Soil Group B, row crops, 5-20% cover). The state was divided into 5 regions and 3 elevation zones. Precipitation and runoff are at a minimum in the NE and NW regions, and a maximum in the SE, and generally increase with elevation. Snowmelt runoff was estimated by taking half the average snow water equivalent at the end of March. Runoff values are given in Table 6. The sum of growing season and snowmelt runoff is multiplied by 0.22651 to convert inches to million lb of water per acre.

Table 5. Growing season and snowmelt runoff values used in the VT P Index.

Region (VT counties)	Runoff, inches (by elevation zone)					
	Growing season			Snowmelt		
	< 600 ft	600-1000 ft	> 1000 ft	< 600 ft	600-1000 ft	> 1000 ft
SW (Bennington, Rutland)	1.70	1.54	1.66	0.75	1.00	1.81
SE (Windham, Windsor)	1.53	1.62	1.78	0.94	1.25	1.94
NW (Addison, Chittenden, Franklin, Grand Isle)	1.54	1.49	1.75	0.81	1.13	1.81
NCent (Washington, Lamoille)	1.52	1.55	1.58	0.88	1.19	1.75
NE (Orange, Orleans, Essex, Caledonia)	1.47	1.45	1.84	0.94	1.31	2.06

c. **Runoff adjustment factor.** For soils and crops other than the base situation, the base runoff amount is multiplied by this factor (obtained from Table 4 of the Minnesota P Index Users Guide; see Table 7). The crop/cover factors were further simplified by eliminating the <5% cover category and expanding the 5-20% category to 0-20%. We felt that, in Vermont at least, there are not many cases where <5% cover is present for very long, and the large increase in the runoff multiplier for a very small change in cover is unjustified.

Table 6. Runoff adjustment factors for different soil Hydrologic groups and amount and types of vegetative cover (USDA-NRCS, 1990. Engineering Field Manual. Taken from Table 4 of the Minnesota P Index Users Guide (Moncrief et al., 2004) and adapted to include additional vegetation types).

	Soil Hydrologic Group							
	A		B		C		D	
	0-20 %	> 20 %	0-20 %	> 20 %	0-20 %	> 20 %	0-20 %	> 20 %
Veg. Type	**Runoff Adjustment Factor**							
Row crops	0.42	0.25	1.00	0.75	1.96	1.48	2.65	1.98
Row crops + successful cover crop	0.22	0.15	0.67	0.55	1.48	1.23	2.17	1.82
Vegetables: clean cultivated	0.42	0.25	1.00	0.75	1.96	1.48	2.65	1.98
Vegetables: mulched, living row cover	0.22	0.15	0.67	0.55	1.48	1.23	2.17	1.82
Vegetables: vining or high-canopy	0.22	0.15	0.67	0.55	1.48	1.23	2.17	1.82
Small grains	0.22	0.15	0.67	0.55	1.48	1.23	2.17	1.82
Alfalfa, other forages	----	0.12	----	0.55	----	1.37	----	1.98
Pasture	----	0.02	----	0.30	----	1.08	----	1.82
CRP, other ungrazed, perm. veg.	----	0.01	----	0.12	----	0.50	----	1.00
Woodland	----	0.01	----	0.15	----	0.62	----	1.10

d. **Runoff Delivery Ratio (RDR)—**see **Distance Factor** above; applies to vegetated buffer distance only.

2. **Dissolved manure P loss = Application rate (lb P_2O_5 / ac) * Manure Runoff Factor * Al Factor * Manure Factor * Hydrologic Factor * Manure Availability Coefficient * 0.44 * RDR**

The Vermont P Index uses a **Manure Runoff Factor** of 0.02 (in other words, a maximum of 2% of applied P is lost in the dissolved form).
The **Aluminum** and **Manure Factors** are explained above.
The **Hydrologic Factor** accounts for the varying runoff amounts from soils of different Hydrologic Group. Because the risk of runoff P from manure (and fertilizer) application is greatest for a relatively short time after application, we used this simplified factor rather than the Runoff Adjustment Factor (see above), which adjusts the base runoff amount over the entire growing season for soil and crop/cover type, and has a much wider range (from 0.12 to 2.65).

Hydrologic Soil Group	Factor
A	0.5
B	1.0
C	1.6
D	2.0

Currently, the **Manure Availability Coefficient** is fixed at 1.0 for all organic P sources except for stabilized biosolids, which have a coefficient of 0.4 (BPR biosolids excluded). This version of the P Index is based on research using dairy manure, which shows that manure and fertilizer applied at the same rates yield similar runoff P concentrations. Research on P loss from stablilized biosolids was also reviewed and considered, and the coefficient was reduced accordingly due to decreased solubility. Future versions may incorporate further research involving manure from other animals, composted manure, and other organic P sources, which may have different availabilities.
The factor 0.44 converts lb P_2O_5 to lb P.
The edge-of-field P loss is multiplied by the **Runoff Delivery Ratio** (see above) to give a dissolved manure P risk factor. The Distance Factor is used, and applies only to vegetated buffer and manure setback distances.

3. **Dissolved fertilizer P loss = Application rate (lb P_2O_5 / ac) * Fertilizer Runoff Factor * Al Factor * Fertilizer Factor * Hydrologic Factor * 0.44 * RDR**

Dissolved P loss from applied fertilizer is calculated similarly to that from manure.
The **Fertilizer Runoff Factor** is the same as the Manure Runoff Factor, 0.02 or 2%. Availability is assumed to be 1.0 for fertilizer P.
The **Aluminum** and **Fertilizer Factors** are explained above.
The **Runoff Delivery Ratio** uses vegetated buffer distance only.

Pathway 3: Subsurface Particulate and Dissolved P loss = Eroded Soil P + Manure Particulate P + Soil P + Manure P + Fertilizer P

In the Vermont P Index, subsurface P comes is in both the dissolved and particulate forms, and is therefore derived from the same five P sources utilized in Pathway 1 and Pathway 2, but total loss is calculated differently to account for different transport mechanisms. Pathway 3 is calculated and added to the P-Index total only if the majority of the field being evaluated has a pattern tile drainage system.

1. **Subsurface Particulate P loss = PF_6 * (Sediment P loss + Manure Particulate P loss)**

The **PF_6** coefficient is based on the assumption that the soil surface in a narrow strip over a tile line is hydrologically connected to that underlying tile line via preferential flow paths (i.e., soil cracks and macropores). Surface water, and sediment and manure particulates, can be transported through those flow paths. The Vermont P-Index assumes that all P loss through tiles lines occurs due to preferential flow during storm events, and that base flow (i.e., through soil matrix) is negligible in comparison. The **PF_6** coefficient used is **0.2**, based upon a commonly-installed spacing of 30 feet between laterals in a modern tile drainage system and a six foot wide zone of influence for preferential flow above each tile lateral. This coefficient can be adjusted in the future as more research is performed and the partitioning of matrix and preferential flow in subsurface P transport is better understood.

The **Sediment P loss** and **Manure Particulate P loss** values are taken from calculations performed during the determination of Pathway 1, after changing **SDR** and **RDR** values to '1.0' for subsurface calculations. Particulate P is assumed to bypass any vegetative buffers, and accompanying reduction, if traveling through tile flow. Soil loss values (i.e, t/acre) should be reduced during prerequisite RUSLE2 or WEPP calculations if a field contains tile drainage due to a reduction in surface runoff.

2. **Subsurface Dissolved P loss = PF_6 * (Dissolved Soil P loss + Dissolved Manure P loss + Dissolved Fertilizer P loss)**

As in the above Subsurface Particulate P loss determination, the **PF_6** coefficient is set to **0.2** to account for the preferential flow of dissolved P and its assumed dominance in loading from Vermont tile drainage systems. To account for a reduction in surface runoff from artificially drained soils, the Hydrologic Soil Group of the field being evaluated is reduced by one letter if pattern tile drainage is present (e.g., HSG D soil is reduced to a HSG C soil). This reduced HSG is then used for calculations within Pathway 2.

The **Dissolved Soil P loss, Dissolved Manure P loss,** and **Dissolved Fertilizer P Loss** values are taken from calculations performed during the determination of Pathway 2 using the modified Hydrologic Soil Group, and after changing **SDR** and **RDR** values to '1.0' for subsurface calculations. As in the above Subsurface Particulate P loss calculations, water and dissolved P will bypass any vegetative buffers when traveling through artificial subsurface drainage.

References

Jokela, W., F. R. Magdoff and R. P. Durieux. 1998. Improved phosphorus recommendations using modified Morgan phosphorus and aluminum tests. Comm. Soil Sci. Plant Anal. 29:1739-1749.

Moncrief, J., P. Bloom, D. Mulla, N. Hansen, G. Randall, C. Rosen, E. Dorsey and A. Lewandowski. 2004. Minnesota Phosphorus Site Risk Index. Users Guide. p. University of Minnesota, St. Paul, MN. http://www.mnpi.umn.edu/downloadfiles/MNPIndexUserGuideNov2004.pdf

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