***A*nnual *P*hosphorus *L*oss *E*stimator**

**User’s Manual**

**Version 3.0**

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**Model Description**

**APLE** is a Microsoft Excel spreadsheet model that runs on an annual time step. The model simulates dissolved and sediment bound phosphorus (P) loss in surface runoff only. It does not consider subsurface loss of P through leaching or artificial drainage. It is intended to estimate edge-of-field P loss for uniform fields of several hectares in size, or smaller. **APLE**does not simulate P loss through grassed waterways or buffers that may occur beyond the field edge. The model will consider all kinds of animal manure (beef, dairy, poultry, swine), applied either by machine or by grazing beef or dairy cattle, but consider only highly soluble commercial fertilizers such as superphosphate, triple superphosphate, or mono- and di-ammonium phosphate.

**APLE** is intended to be user-friendly and does not require extensive input data to operate. All data are input into directly into the first worksheet labeled ***Data Entry and Results***. User-input data include:

* Soil property data, including depth of the top two soil layers, soil bulk density, Mehlich-3 soil test P, soil clay content, and soil organic matter content
* The area of the field (ha)
* The annual rain, runoff, and erosion amounts
* APLE 3.0 gives users the option to input daily rainfall and calculate runoff using the SCS Curve Number Method.
* The total annual crop P export removed in harvested material.
* When grazing animals are present, the total number of animal days in the field, including beef cattle and calves, dairy lactating and dry cows, and dairy heifers and calves.
* For manure applications, the manure amount applied, manure % solids, manure total P205 content, % of manure total P that is water extractable P, the % of manure that is incorporated, and the depth of incorporation.
* For fertilizer applications, the mass of fertilizer P applied, the % of fertilizer that is incorporated, and the depth of incorporation.
* APLE 3.0 gives users the option to enter uncertainties in model inputs which are then used to estimate uncertainties in model predictions using Monte Carlo simulations.

**Data Input and Description**

The model runs in a Microsoft Excel spreadsheet. All data required for the model to operate are input directly into the spreadsheet on the ***Data Entry and Results*** page. The following describes the input variables needed.

**Variable Name Definition**

***Soil Properties***

Depth of Soil layers The model is intended to simulate processes in only the topsoil, but can simulate two layers in the topsoil. This is intended to estimate P stratification (i.e., significantly different P concentrations in different soil layers) in soils with no or limited tillage. This would be important for pastures or no-till soils where more P might accumulate in the top 1 inch of soil than deeper in the topsoil. The depth in inches to the bottom of each of the two layers in the topsoil should be entered. The first layer could be a depth such as 1 or 2 inches, while the second layer depth could be 6 or 8 inches. APLE will return error messages if the top layer is less than 1 inch or the bottom layer is not deeper than the top layer.

 If only one topsoil layer is to be simulated, the depth of the first layer should be set to the entire thickness of the layer desired (e.g., 0-6 inches). The bottom layer should be set to a similar thickness (e.g., 6-12 inches.

Soil Bulk Density Soil bulk density can be assigned to both soil layers. The bulk density is used to calculate total P in each layer and thus the P concentrations. This modification is in response to findings by Bolster et al. (2022) that predictions of soil test P (STP) were relatively sensitive to bulk density values, particularly for stratified soils. Bulk density is used in APLE for calculating the total amount of P within each soil layer. For simulations with no P additions, this means that increasing bulk density results in greater predicted P loss in runoff and lower rates of soil P drawdown (i.e., higher STP concentrations) for the same initial Mehlich-3 equivalent STP concentration. Conversely, for simulations where P is added to the soil, increasing bulk density results in lower predicted runoff P loss and lower buildup rate of STP concentrations.

Mehlich 3 Soil P This is the soil test P content in ppm for the two simulated soil layers. The model is currently designed based on Mehlich 3 soil extraction data. Other soil test data should be converted to a Mehlich 3 equivalent. For these modeling purposes, it can be assumed that Mehlich 3 P is equal to Bray-1 P, and twice as much as Mehlich-1 P, Olsen P, Fe-oxide strip extractable P, and anion exchange resin extractable P.

Soil Clay This is the clay content in % of the two soil layers. These data are used to estimate the PSP value that controls soil P transformations. It is therefore important to have accurate soil clay data. However, testing of the model has shown some inaccurate soil P predictions for low clay soils (<10%) that still have significant P sorption capacity, such as sandy soils with significant amounts of iron or aluminum. In these cases, soil clay should be set at about 10% to make sure the model still accounts for adequate P sorption.

Soil OM This is the organic matter content in % of the two soil layers. These data are used to estimate the PSP value that controls soil P transformations. It is therefore important to have accurate soil organic matter data.

Field Area This is the area in acres of the field being simulated. Field area is only used when calculating manure application from grazing animals. If no grazing animals are present, the value entered is not critical. However, the cell should not be left blank or set to 0 because that will cause errors in calculations.

***Transport***

Rain Two options exist for inputting annual rain. If runoff is entered manually, input annual precipitation (rain, snow, and irrigation) in inches. If runoff is calculated using the Curve Number method, daily or event rainfall are entered in the worksheet “Precip Data’. Be sure to delete previously entered data.

Runoff Two options exist for inputting annual runoff. The first option is to select ‘Entry’ from the drop-down menu in cell **D26**. If this is selected, annual runoff is entered in inches for each year the model is run. The second option is to estimate runoff from recorded daily or event precipitation data using the SCS Curve Number (CN) method by selecting ‘CN’ from the dropdown menu in cell **D26**. If using the CN method, a curve number must be entered for each year. The CN is assumed to be a function of soil group, land cover, and antecedent moisture condition. Published tables of CNs are available for a wide range of soil types and land uses/covers ([neh630ch9cov (usda.gov)](https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1043088.pdf)).

Sediment Loss Enter the total annual erosion rate in ton/acre. The user has to estimate this value. Well established pastures may lose only 0.1 ton/acre of soil, while highly erosive soils may lose 7-8 tons/acre of soil per year.

***Annual Crop P***

Crop P Export Enter the total annual crop P export in lb/acre. This is P that is actually removed from the field in harvested products. For typical row crops with high yields, this value may be 25 lb/acre. For double crops, the value may be greater, while for poorly yielding crops or pastures, the value may be only 5-10 lb/acre.

Grazing Animals Enter the total number of grazing animal days in each category. For example, if 50 lactating cows grazed for 20 days, the value entered should be 1000 (50x20).

***Manure Applications***

The following information is for both solid manure applications and liquid manure applications. Manure application information should be entered in the appropriate season. This is important because applications in the fall affect P loss estimates in the following year. ***For this model, solid manures are defined as manures with 15% solids or greater. Liquid manure applications with less than 15% solids should not be entered into the solid manure category because the model calculates P loss in runoff differently for the two manure forms***.

Manure Applied Enter the application rate in wet ton/acre for solid manures and gallons/acre for liquid manures. For liquid manures, the rate of application will determine how much of the manure P infiltrates into soil at application. This will reduce the amount of manure P that will be lost in runoff, so it is important to enter an accurate value.

Manure Solids Enter the solids content of the manure. This value is used only to determine if the manure has enough liquid that will cause significant immediate infiltration of manure P into the soil. For values less than 15% solids, the model assumes that a portion of the manure P applied immediately infiltrates into the soil. This will reduce the amount of manure P that will be lost in runoff, so it is important to enter an accurate value.

Manure P2O5 Enter the total P2O5 content of the manure applied in either lbs/wet ton for solid manures or lbs/1000 gallons for liquid manures. Be sure to enter P2O5 content and not P content. Total P is typically measured by digestion of a manure sample, such as Kjeldahl digestion. If measured data are not available, typical manure total P contents can be taken from literature sources such as Kleinman et al. (2005).

Manure WEP/TP This is the % of manure total P that is in a water-extractable form (WEP). For this model, manure WEP can be measured by shaking fresh manure with de-ionized water at a dry weight equivalent, water to manure solids ratio of 250:1 for 1 h, filtering extracts through 0.45-um filters, and measuring P in filtrates colorimetrically. Manure water extraction data are becoming more common (Bundy et al., 2004; (Kleinman et al., 2005; Vadas and Kleinman, 2006), but most extractions will not use the procedure required for our model, particularly the 250:1 extraction ratio. However, data from any extraction ratio can be extrapolated to estimate manure P at a 250:1 ratio using regression figures relating extraction ratio to extractable P in Vadas et al. (2005). Default values can be used, including 50%, for dairy and beef manure, 20% for poultry manure, 35% for swine manure, and 10% for manures amended to reduce soluble P (such as poultry litter amended with alum).

Manure Injection Enter either 1 or 2 to indicate if liquid manure is injected without tillage. APLE determines how much of the manure P actually enters the soil based on application rate, with the idea that liquid manures cannot be effectively injected at high rates (e.g., 25000 gallons per acre) and the manure P essentially remains on the soil surface.

Manure Incorporated Enter the % of total manure applied that is incorporated into the soil by tillage. Table 1 at the end of the document lists values for common tillage equipment.

Depth of Incorporation Enter the depth in inches to which manure is directly injected or tilled into the soil. Enter the deeper depth if injection and tillage both occur, although this is unlikely.

***Fertilizer Applications***

Fertilizer P2O5 Applied Enter the total amount of commercial fertilizer P2O5 applied in lb/acre. Be careful to enter the amount of P2O5 applied and not the amount of P applied (P is 44% of P2O5) or the amount of fertilizer mass applied.

Fertilizer Incorporated Enter the % of fertilizer incorporated into the soil either by injection or by tillage. Table 1 at the end of the document lists values for common tillage equipment.

Depth of Incorporation Enter the depth in inches to which fertilizer is directly injected or tilled into the soil.

Degree of Soil Mixing This variable determines how much the two soil layers are mixed together each year, either by tillage or by natural processes, and also how much P added in fertilizer or manure gets mixed into the second soil layer. For pastures or no-till soils, there is still soil mixing even though no tillage occurs. A value such as 10-15% should be entered for such soils. For tilled soils, Table 1 lists values for common tillage equipment. If multiple tillage implements are used in a year, a value should be entered for the tillage operation that causes the most mixing. If the deepest depth of tillage is less than the depth of the first soil layer, than a value that is appropriate for no-till soils should be entered. Practically, this value should never be 0.

***Error Range in Model Inputs***

APLE 3.0 allows users to enter an error range (± % of the value of the model input) using a drop-down menu. Specifically, the user now has the option of assigning an error range of ± 0, 5, 10, 15, 20, 25, 30, 35, or 40% for each model input from a drop-down menu (Fig. 1). While these pre-defined error ranges are subjective, they provide users reasonable options for model input errors. The error ranges can be determined from variability in measured values or reported in the literature when available; otherwise, best-professional judgement can serve as a guide to estimate reasonable error ranges in the model inputs.

***Running the Model***

 To limit the number of times that the Monte Carlo simulations are performed, the model only runs after pressing the **F9** key. Thus, when any model input, either value or error range, is changed, the **F9** key must be pressed to update the model predictions.

**Model Output**

Model predictions and lower and upper confidence intervals are displayed in a table on the ***Model Predictions*** worksheet. The average value and confidence intervals are determined from 1000 Monte Carlo Simulations using the user supplied error range, and an assumed beta distribution of the model input value. The table displays annual predictions in kg P/ha for eroded sediment P loss; soil, manure, and fertilizer dissolved P loss; and total dissolved and total P loss. Values are given for each of the ten years simulated. Predictions are also given for soil test P (Mehlich-3) at the end of the year for both topsoil layers and the entire topsoil with both layers combined. There is also a table that allows the user to enter observed P loss or STP data (and assumed error range in these measured values) that will be included on the output graphs on the ***Output Graphs*** worksheet.

**References**

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Table 1. Incorporation and mixing efficiencies of common tillage implements.

|  |  |  |
| --- | --- | --- |
| Implement | Incorporation Efficiency | Mixing Efficiency |
| Anhydrous ammonia applicator | 0.05 | 0.05 |
| Bedder-lister | 0.95 | 0.05 |
| Burn | 0.00 | 0.00 |
| Chisel | 0.10 | 0.05 |
| Cultivator-field (Hoeme) | 0.10 | 0.10 |
| Cultivator--row | 0.10 | 0.10 |
| Digger--peanut | 0.05 | 0.05 |
| Digger--potato | 0.15 | 0.05 |
| Disk harrow-offset | 0.85 | 0.60 |
| Disk harrow--tandem | 0.75 | 0.50 |
| Disk hiller | 0.30 | 0.05 |
| Disk plow | 0.80 | 0.40 |
| Disk plow -- one way | 0.50 | 0.50 |
| Do-all | 0.10 | 0.25 |
| Drill--deep furrow (dempster) | 0.30 | 0.05 |
| Drill--small grain | 0.05 | 0.05 |
| Harrow--spike tooth | 0.05 | 0.05 |
| Harrow--spring tooth | 0.05 | 0.05 |
| Moldboard plow | 1.00 | 0.25 |
| Paraplow | 0.05 | 0.05 |
| Planter--in-row chisel | 0.05 | 0.05 |
| Planter--knife, disk, sweep | 0.05 | 0.00 |