APLE-Lots

Annual **P**hosphorus **L**oss **E**stimator for Outdoor Cattle Lots

Theoretical Documentation
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Introduction

Pollution of surface waters by phosphorus (P) and associated accelerated eutrophication continue to pose significant environmental quality challenges. Phosphorus loss from farms via surface runoff is as a major non-point pollution source. For dairy and beef farms, P loss originates from cropland, grazed pastures, and open-air cattle lots, such as feedlots, barnyards, exercise lots, or over-wintering lots. From a whole-farm perspective, P loss from all of these sources should be estimated to effectively identify the major P sources and then target remediation practices. Research shows cattle lots can be significant sources of P loss for two reasons. First, the high concentration of cattle leads to high rates manure deposition and P accumulation relative to pastures and cropland. Second, cattle holding areas can be partially or completely devoid of vegetation and have a compacted or impermeable (e.g., concrete) surface, which can lead to high rates of runoff and erosion. This combination of a concentrated P source and transport pathways creates the potential for high rates of P loss.

In areas with both non-point source P pollution issues and a high prevalence of cattle farms with outdoor lots, there is a need to assess the P loss impact of lots relative to other land uses on farms to see if alternative lot management is needed and cost-effective. Computer models can be cost- and time-effective tools to help quantify P loss from farms and identify alternative management practices that reduce the impact of agriculture on water. We have developed the APLE-Lots model as a user-friendly, annual time-step model to estimate P loss in runoff from cattle lots.

APLE-Lots Description

A flow chart of **APLE-Lots** operations is shown in Fig. 1. The goal of the model is to estimate annual dissolved and solids-bound P loss from lots. To achieve this, some calculations are made on an annual basis, while others are the sum of calculations made for a series of individual precipitation events.

APLE-Lots is intended to be user-friendly and does not require extensive input data to operate. All data are input directly into the spreadsheet (See **APLE-Lots** User's Manual). User-input data include:

- Soil Mehlich-3 P for earthen lots
- The area of the lot
- The annual precipitation for the lot location
- The number and type of cattle in the lot, including beef cattle and calves, dairy lactating and dry cows, and dairy heifers and calves.
- The number of days between lot cleanouts.
- The surface type (paved or earthen), and the % vegetative cover for earthen lots.

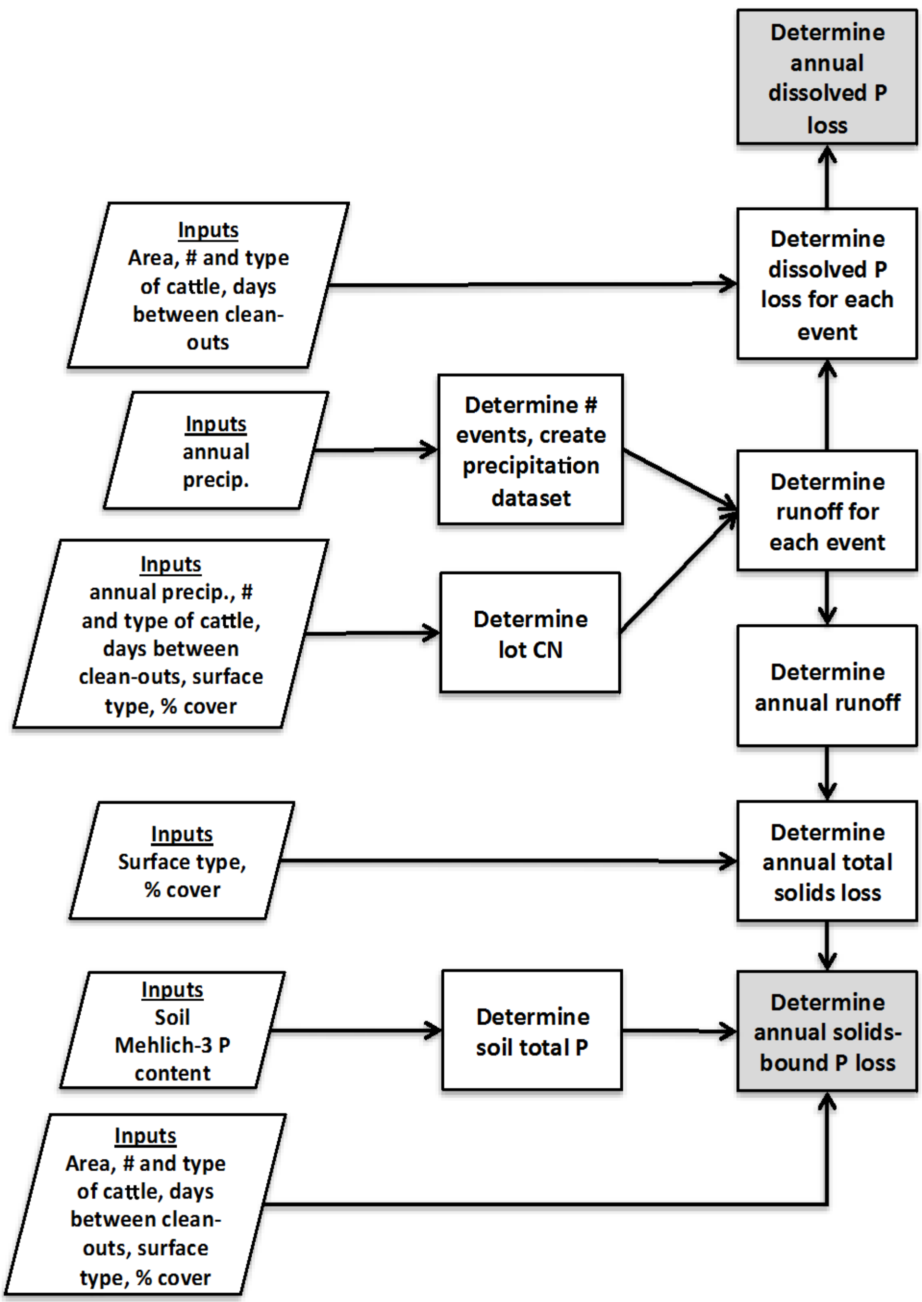

Figure 1. Flow chart of the **APLE-Lots** model.

Annual Runoff Estimation

APLE-Lots first estimate annual runoff from lots using the NRCS Curve Number (CN) approach. The CN was developed from an empirical analysis of runoff from small catchments and hillslope plots, and is widely used to approximate runoff from a rainfall event given the event is larger than a model-determined threshold value. The method requires a dataset of annual precipitation events, for which runoff is estimated for each event and summed for annual runoff. For an empirical precipitation dataset for a given location, the model first estimates an appropriate number of events during a year as:

$$\text{Number of events} = 0.578\ (\text{annual precipitation})^{0.693} \qquad [1]$$

To determine the amount of precipitation (mm) for each event, the model assumes event amounts follow a lognormal distribution with a minimum of 1.0 and a maximum of 50.0 mm. Precipitation (mm) for a given event is determined as:

$$\text{Event Precipitation} = \text{C1 x ln(Event Sequence Number)} + 50.0 \qquad [2]$$

The variable C1 varies with the total number of annual events as:

$$\text{C1} = 3.525 \text{ x ln(Number of annual events)} – 26.351 \qquad [3]$$

In Equations [1]-[3], as the annual precipitation increases, both the number of annual events and the precipitation per event increase. This empirical approach generates an annual precipitation amount that differs slightly from the user-specified amount. Therefore for all events, estimated precipitation is changed proportionally so total annual precipitation equals the user-defined value. Through this adjustment, the maximum event value also differs from 50.0 in an appropriate way for different regions. For example, drier regions are less likely to have large events compared to wetter regions. In the model, a location with 100 cm of annual precipitation would have a maximum event size of 6.0 cm, whereas a location with 25 cm of annual precipitation would have a maximum event size of 3.3 cm.

With a precipitation dataset calculated, the model then determines a CN value to use to calculate runoff for each event. The model uses different relationships for different lot surfaces, to estimate Cn from annual precipitation as:

$$\text{Paved Lots: CN} = 46.2\ (\text{mm Annual Precipitation})^{0.11} \qquad [4]$$

$$\text{Earthen Lots: CN} = 46.3\ (\text{mm Annual Precipitation})^{0.10} \qquad [5]$$

The model allows the CN for only paved lots to increase up to a maximum of 99 based on the percentage of the lot covered by manure. For example, if the paved lot is completely covered, Eq. [4] is used to calculate CN. As lot coverage decreases due to low cattle density or frequent cleaning, CN can increase up to a maximum of 99. The increase is in direct proportion the percent of the total lot area covered. The logic is that paved lots with more manure have a more uneven surface with greater depressional water storage and thus less runoff. Finally, research has shown that increasing vegetative cover can decrease runoff amounts. Accordingly for earthen lots, the regression coefficient in Eq. [5] varies linearly between 46.3 for no vegetation and 38.9 for full vegetation. The value estimated between these two extremes is determined in direct proportion to the percent of vegetative cover. The 38.9 is taken from some of our previous lot runoff data from.

Annual Total Solids Loss Estimation

The model estimates annual eroded solids loss from a cattle lot as a function of how much runoff water moves across the surface as:

$$\text{Annual Solids Loss (Mg ha}^{-}1) = 0.0033\ (\text{mm Annual Runoff})^{1.62} \qquad [6]$$

For earthen lots, the model also allows total solids loss to fluctuate down to a minimal amount (~0.15 Mg ha^{-1} at 100 cm of annual precipitation) based on user-defined % vegetative cover of the lot. This minimal amount is taken from field plot research of Vadas and Powell (2013) for well-vegetated cattle lots. Equation [6] shows a non-linear relationship between runoff and total solids loss, which is logical conceptually. Greater runoff volumes are likely due to a greater occurrence of larger storms, which may generate proportionately more and related sediment transport.

Equation [6] will over-predict solids loss for paved cattle lots that have manure consistently removed by cleaning. Assumedly this is true because such lots have less manure on the surface and therefore less manure solids loss in runoff. To account for lot cleaning, the model first estimates how much lot area is covered by manure from cattle in between cleanings, with time between cleanings specified by the model user. The model takes user-defined cattle information and manure production information in Table 1 and assumes that each 250 g of manure (dry weight) covers an area of 659 cm^2. The model then estimates how much of the lot area is covered between cleanings. If less than the full lot area is covered between cleanings, the model reduces the estimated annual solids loss in proportion to how much of the lot is covered with manure between cleanings. For example, if a lot is cleaned once per week, and only 23% of the total lot area is covered in a week, annual solids loss is reduced by multiplying by 0.23.

Table 1. Daily feces production and fecal total P content for grazing dairy and beef cattle.

Animal Type	Daily Fecal Production (kg)	Fecal Total P content (kg/kg)
Lactating Dairy Cow	8.9	0.0088
Dairy Heifer	3.7	0.0054
Dairy Dry Cow	4.9	0.0061
Dairy Calf	1.4	0.0054
Beef Cow	6.6	0.0067
Beef Calf	2.7	0.0092

Annual Solids-bound and Dissolved P Loss Estimation

In the model, annual solid P loss (kg ha^{-1}) is determined by multiplying annual solids loss by solids P content (mg kg^{-1}). For paved or concrete lots, the dominant source of eroded solids is cattle manure; and the eroded solids P content is the same as manure P content. The model estimates manure P content based on user-provided information about the type and number of cattle on the lot and information in Table 1 for cattle type, daily manure production, and manure

P content. On earthen lots, both manure and soil are sources of solids P loss, and the P content of eroded solids is generally less than the P content of manure. Thus for earthen lots, the model assumes eroded solids is 30% from manure and 70% from soil. The model estimates soil total P content based on the approach in the APLE soil P model (http://ars.usda.gov/Services/docs.htm?docid=21763), which requires Mehlich-3 P content of the lot soil as an input. The model then calculates eroded solids P content based on manure P content, soil total P content, and the 30/70 ratio. The model also allows this 30/70 ratio to fluctuate between 30/70 and 0/100 in direct proportion to percent of the lot area covered by manure. For example, if manure covers 50% of the lot area, the ratio is 15/85. At 75% manure coverage, the ratio is 25.5/74.5.

For dissolved P loss estimation, the model first estimates how much P is released from manure during a precipitation event using an empirical relationship that relates P release to the ratio of manure mass to rainfall volume. Then, an estimate is made of how much of that released P infiltrates into soil and how much is lost in runoff. This is done using an empirical relationship that relates P movement to the ratio of runoff volume to precipitation volume. For each event in the precipitation dataset, dissolved P released (kg ha^{-1}) from manure on the lot surface is estimated based on the precipitation to manure dry matter ratio (W, $cm^3\ g^{-1}$) as:

$$\text{Dissolved P Released} = [1.2\ (W / (W + 73.1)]\ (\text{Manure WEP}) \qquad [7]$$

Where WEP = manure water-extractable P (kg ha^{-1}). The W is calculated as:

$$W = \text{Precipitation} / \text{Manure Mass} \times \text{Manure Cover Area} \times 100{,}000 \qquad [8]$$

where precipitation is in cm, manure mass is in kg, manure cover area is in ha, and 100,000 ensures $cm^3\ g^{-1}$ units. If runoff occurs, some released manure P is transferred to runoff, with the amount of dissolved P in runoff (kg ha^{-1}) calculated as:

$$\text{Runoff Dissolved P} = \text{Dissolved P Released} \times (\text{Runoff} / \text{Precipitation}) \times \text{PDfactor} \qquad [9]$$

where PDfactor is a P Distribution Factor that varies between 0.0 and 1.0, as:

$$\text{PDfactor} = (\text{Runoff} / \text{Precipitation})^{0.225} \qquad [10]$$

The model then sums the estimates of runoff dissolved P for all runoff events in the precipitation dataset to estimate annual loss of dissolved P from manure on the lot surface.

Three important variables for calculations in equations [7]-[10] are manure WEP, manure mass, and manure cover area. All of these variables are in reality very dynamic, depending on animal diet, lot management, cattle density, and climate, but the model uses representative values for the sake of simplicity and compatibility with an annual timestep approach. To estimate these variables, the model first determines how much manure cattle deposit during the lesser number of days either between lot cleanings or between runoff events. The model user specifies time between cleanings. Time between runoff events is determined as 365 divided by the number of runoff events as determined during runoff estimation. While this is a necessary simplification given how the model generates a precipitation dataset, it obviously does not represent reality. The model then takes the user-defined cattle information and manure production information in

Table 1 to estimate the manure applied, manure total P applied, and lot area covered by the manure applied during the specified time period. Maximum values are set for the amount of manure that covers the total lot area. The model assumes that 64% of total manure applied is manure WEP. This 64% represents initial manure WEP and manure P that becomes WEP through mineralization processes.