***TECHNICAL DOCUMENTATION***

*Web-Based Model Version*

*ANNUAL*

*PHOSPHORUS*

*LOSS*

*ESTIMATOR*

*FOR WISCONSIN ANIMAL LOTS-WI*

*Model Developers*

*Peter Vadas, USDA-ARS, Formerly U.S. Dairy Forage Research Center, Currently National ARS Research Leader*

*Laura Good and Jim Beaudoin, UW-Madison, Department of Soil Science*

*John Panuska, UW Extension, Biological Systems Engineering*

*March 2021*

Acknowledgements

The model developers would like to express their thanks to the APLE-Lots Advisory Committee that provided valuable insight, feedback and guidance during the model development process.

Matt Woodrow, WI Department of Agriculture and Consumer Protection

Drew Zelle, WI Department of Agriculture and Consumer Protection

Paul Sebo, Washington County Land Conservation Department

Chris Arnold, Columbia County Land Conservation Department

Scott Mueller, USDA - Natural Resources Conservation Service

Alexis Straka, USDA - Natural Resources Conservation Service

Bernie Michaud, WI Department of Natural Resources

The APLE-Lots website and this technical guidance development was supported by the U.S. Department of Agriculture, Agricultural Research Service, under agreement No. 58-5090-5-053.

Any opinions, findings, conclusion, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture

**Introduction**

Pollution of surface waters by phosphorus (P) and the associated accelerated eutrophication of receiving waters 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 sources should be estimated to effectively identify the major P sources to 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 of manure deposition and P accumulation relative to pastures and cropland. Second, cattle holding areas can be partially or completely devoid of vegetation and have compacted soil or an impermeable (e.g., concrete) surface, which can lead to high rates of runoff. 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 developed this implementation of the APLE-Lots model described by Vadas et al. (2015) to estimate P and sediment loss in runoff from cattle lots in Wisconsin.

**APLE-Lots Description**

The goal of the model is to estimate average annual P and sediment loss from lots.

APLE-Lots is intended to be user-friendly and does not require extensive input data to operate. All data are input directly into the user interface (See APLE-LotsUser Notes/Quick Guide). Lot information is entered into a GIS-system where lot boundaries and contributing areas can be drawn over aerial photos and soil maps. The model also supports tabular input via a no-map feature. User-input data include:

* The area of the lot (sq ft).
* Location of the lot (county is required).
* The number and type of cattle on the lot, including beef cattle and calves, dairy lactating and dry cows, and dairy heifers and calves and hours per day they are on the lot (animals on the lot can vary by month).
* The number of days between lot cleanouts (scraping) for paved lots.
* The surface type (paved or earthen) and the % vegetative cover for earthen lots.
* Area and surface type (or curve number) of areas contributing flow to the lot.
* The volume of a functional sedimentation basin (if present).
* The existence of any run-on flow diversions and percent of flow diverted.
* Soil test P (Bray P) and organic matter (%) for earthen lots (optional).

**Model Algorithms**

The total annual runoff P (TP) at the edge of a paved lot is calculated as dissolved P (DP) released from manure plus the P in manure sediments in lot runoff.

 ` **Paved lot TP= manure DP + sediment P**  (1)

For an earthen lot, the underlying soil is added as a source of dissolved P and sediments in lot runoff P.

**Earth lot TP = manure DP + soil DP + sediment P** (2)

These calculations require estimating the accumulation of manure P on the lot and lot runoff. APLE-Lots calculates solids and P loss for the frozen ground (FG) (Dec. – Mar.) (4 month = 121 day) period and the non-frozen ground (NFG) (Apr. - Nov.) (8 month = 244 day) period.

**Manure Production and Phosphorus Content by Animal Type**

Calculating manure loss from a lot requires first estimating the manure dry matter (DM) and P mass present on the lot. APLE-Lots users enter the number of animals on the lot by animal type (shown in Table 1) and the number of hours per day each type is present. Animal numbers and hours can be constant for the whole year or can vary by season and by month.

 Table 1. Daily feces production and fecal total P content by animal type.

|  |  |  |
| --- | --- | --- |
| Animal Type | Daily Dry Matter (DM) Fecal Production per Head (lb/day) | Daily Fecal Total P(manure P content) (lb/day) |
| Dairy Calf 150 lbs.Dairy Calf 250 lbs.Dairy Young stock 500 lbs.Dairy Heifer 750 lbs.Dairy Heifer 1000 lbs.Dairy Lactating Cows 1000 lbs.Dairy Lactating Cows 1200 lbs.Dairy Lactating Cows 1400 lbs.Dairy Lactating Cows 1600 lbs.Dairy Dry Cows 1000 lbs.Dairy Dry Cows 1200 lbs.Dairy Dry Cows 1400 lbs.Dairy Dry Cows 1600 lbs.Beef Calf 450 lbs.(confinement)Beef Calf 650 lbs.(confinement)Beef Finishing 750 lbs.Beef Finishing 1100 lbs.Beef Cow 1200 lbs.Beef Bulls 1600 lbs.Goat 170 lbs.Sheep 100 lbs.Horse 1100 lbs. | 1.32.44.66.48.414.317.220.122.99.09.710.410.84.26.04.05.714.610.82.21.18.4 | 0.0070.0130.0250.0350.0450.1260.1510.1770.2020.0550.0590.0630.0660.0390.0550.0370.0530.0970.0720.0080.0090.028 |

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Sources: Vadas et al. (2015); ASAE, (2005); Lorimor et al. (2004); Johnson and Eckert (1995), USDA-NRCS (2008).

Daily animal numbers and the daily dry matter and total P excretion values in Table 1 are used to calculate separate values for the average daily DM and TP excreted on the lot during the FG and NFG seasons.

**DailyDMtotal = Sum for all animal types of (AvDailyHead x DailyDMperHead)** (3)

Where the *DailyDMtotal* (lb) is average daily manure dry matter mass deposited for the season, AvDailyHead is the average number of animals per day over the season, and *DailyDMperHead* (lb/day) is the daily dry matter fecal production per head from Table 1.

 **DailyTP = Sum for all animal types of (AvDailyHead x DailyPperHead**) (4)

Where *DailyTP* (lb) is the average daily total P deposited in manure per season; AvDailyHead is as previously calculated and DailyPperHead (lb/day) is the daily fecal total P per head from Table 1.

**Runoff Volume Calculation**

Runoff volume is a major driver of both dissolved and sediment P losses from lots. The model calculates event lot FG and NFG runoff volumes using the NRCS Curve Number (CN) Method (USDA-SCS, 1972) for both paved and earthen lots with modifications for FG as explained below.

**Q = (Precip - 0.2S)2 / (Precip + 0.8S), where Precip is > 0.2S** (5)

Where *Q* (in) is the event runoff; **Precip**(in) is the event precipitation (or snow water release during the winter), and S = (1000/CN) – 10 from the NRCS CN runoff equation.

Frozen ground runoff on earth lots is calculated with the following modified equation to account for less initial infiltration when the ground is frozen. Variables are as defined above.

**FG Q = (P - 0.1S)2/(Precip + 0.9S), where Precip is > 0.1S**  (6)

Event runoff Q is calculated for each Precip event size increment and then multiplied by the average number of Precip Events of that size to get the average annual Q for the event size class. Frozen ground and NFG runoff totals are calculated as the sum of Q for all runoff event size increments in each season, while **Annual runoff** is the sum of FG runoff and NFG runoff.

**Precipitation Histograms**

Non frozen ground event precipitation:

APLE-Lots includes a dataset for each Wisconsin county of the average annual number of NFG precipitation events for all event sizes in 0.05-inch increments. These histograms were assembled from 24-hour precipitations records maintained by the Midwest Regional Climate Center (MRCC, 2020) for April through November 1996 -2006 from the daily observation station closest to the centroid of the county in the database. Any missing data was supplied by the next closest available observation station. Daily precipitation observations for these stations were also used to calculate average total annual precipitation for each county (**AnnPrecip**).

Frozen ground event precipitation and snowmelt:

As with NFG, APLE-Lots includes histograms of the average number of FG snowmelt melt + precipitation events in 0.05-inch increments. These were constructed with data from the same MRCC observation stations using December through March Daily Mean Temperature (DMT°F), Precipitation (Precip, water equivalent, inches), Snow Fall (SF, in), and Snow Depth (SD, in).

Water available for runoff from snowmelt plus precipitation not adsorbed in snow for each day was calculated as **Available Water for Runoff (AWR)** in inches.

* **If DMT is 32° F or below, AWR is 0.**
* **If DMT is > 32° F (Melt rate >0), and if today's ASWC is > than Precip + Melt rate, then AWR is 0.**
* **If DMT is > 32° F and SD = 0, then AWR = Precip**
* **If DMT is > 32° F and SD > 0 and ASWC < Precip + Melt rate and Melt rate is > AFP, then AWR = Precip + AFP.**
* **If DMT is > 32° F and SD > 0 and ASWC < Precip + Melt rate and Melt rate is < AFP, AWR = (Precip + Melt rate - AWSC).**

Where:

**Melt rate** in inches per day is the Degree day coefficient for melt (DDC) x Degree Days (DD)

DDC = 0.13 in/degree day F. This is only calculated when both DD and SD are greater than 0.

DD is DMT - 32° F.

**AFP** is Accumulated Frozen Precipitation, the water equivalent of the snowpack at start of the day. If no snow (SD=0), AFP is 0. If SD > 0, AFP is Prior day’s AFP + Prior day’s Precip minus Prior day’s AWR (defined below).

**ASWC is Available snow water capacity.** This calculation assumesthat if the prior day’s AWR is greater than 0, then the prior day’s ASWC was over-filled by Precip or melt water and the only additional source of storage is new SF. If there was no water release the day before (Prior day’s AWR = 0), then the storage in inches is the minimum of either (Prior day's ASWC + (Prior day’s SF x 0.7) – Prior day’s AWR) or today's OSWC (defined below). Keeping ASWC at or below the OSWC maintains realistic capacity when standing snow depth is lowered through consolidation, evaporation, etc. and storage capacity is reduced.

**OSWC is Original snow water capacity**, the water holding capacity in inches of the prior day’s accumulated snow and equals prior day’s SD + SF in inches times 0.07 in water holding capacity per inch.

**Curve Numbers**

Curve numbers (CN) for paved and earthen lots are calculated using empirical relationships between annual precipitation and lot CN described by Vadas et al. (2015).

Paved Lot CN:

Manure on a paved lot surface can hold water and reduce runoff. The formula used to calculate the CN for a paved lot accounts for manure accumulation and is as follows.

 **CNpaved = Min. of 99 or ((66.156 x AnnPrecip0.1108) + ((1- (Minimum of**

**(ManBtwnClns/DMfull) or 1)) x (99 - (66.156 x AnnPrecip0.1108)))**  (7)

Where:

**ManBtwnClns** (lb) is the manure dry matter accumulating on the lot over the number of days between lot cleaning (entered by the user) and is calculated using the annual average daily dry matter (DailyDMTotal). If the lot is not cleaned, the model uses a maximum accumulation of 120 days.

**DMfull** (lb) is the amount of manure dry matter that would completely cover the lot assuming 250 g (0.55 lb) of manure (dry weight) covers an area of 659 cm2 (102 in2) (James et al., 2007).

**DMfull = Lot area ft2 x 0.777 lb/ft2**  (8)

**AnnPrecip (**in)is the average annual precipitation for the county derived from the daily precipitation records described in the Precipitation section.

Earthen Lot CN:

Runoff from an earthen lot decreases with increasing vegetive cover. This is accounted for using the following equation.

**CNdirt = CNbase x (AnnPrecip)0.1069** (9)

Where CNbase adjusts the curve number for the vegetated percent cover.

 **CNbase = - 0.1225 x % Lot Vegetated Cover (user entered) + 64.6** (10)

**Contributing Area Run-on Calculations**

When a contributing area is identified in APLE-Lots, the user specifies the type of land use for the area. The software uses this cover type and the Hydrologic soil group for the predominant soil map unit in the designated area to select a CN based on the TR-55 tables (USDA-NRCS, 1986). This CN is used to calculate runoff with the equations and precipitation-event depth distributions used for lots. The calculated contributing area runoff volume for each precipitation event is then multiplied by the ratio of contributing area size to lot size to get the depth of the contributing area run-on assuming it flows over the whole lot area. The resulting contributing area run-on depth is added to the precipitation depth for each precipitation event prior to calculating lot runoff.

**Run-on Flow Diversions**

A flow diversion decreases the volume of water entering the lot from contributing areas therefore decreasing the loss of sediment and total P loss from a lot. The percent diversion volume is a user input variable ranging from 0 to 100%.

**Annual Dissolved Phosphorus Loss**

For paved lots in APLE-Lots, manure is assumed to be the sole source of dissolved P in runoff. Manure and soil are both dissolved P sources for earth lots.

**Manure Dissolved P**

ManureDP (lb) is the annual manure DP loss from the lot area and is calculated as the sum of RainfallMDP, all NFG event manure DP losses, and WinterMDP, all FG event manure DP losses. Each season’s DP load is calculated using the appropriate county precipitation event distribution and equations 11 or 12.

**RainfallMDP = Sum for all NFG event size increments: (MDP Event x Avg No Events) x**

 **lot area ft2 / 43,560** (11)

**WinterMDP = Sum for all FG event size increments: (MDP Event x Avg No Events ) x**

 **lot area ft2 / 43,560** (12)

Where **MDP Event** (lb/a) is the manure DP loss for each rainfall or snowmelt event*;* **Avg No Events** is the average annual number of events for the specified season.

 **MDP Event = MWEPAv x Kw x RoC x PD**  (13)

Where **MDP event** (lb/a)is the manure DP loss for each precipitation event; **MWEPAv** (lb/a) is the manure water extractable P (WEP) available for each event; **Kw** is proportion of available manure WEP released to runoff (no units); **RoC** is the Runoff Coefficient (Runoff/Precipitation, no units) and **PD** is a phosphorus distribution factor (no units) where PD= 1 (paved a lot) and PD =(RoC)0.225 for an earthen lot (Vadas et al., 2015).

 **MWEPAv = ManureWEP + (Manure NonWEP \* 0.2)**  (14)

Where **ManureWEP** (lb/a) is the amount of water-soluble P in the manure as it is excreted; **ManureNonWEP (**lb/a) is the amount of manure P that is not immediately water soluble.

**ManureWEP = ManureTPrate x 0.55** (15)

**ManureNo.WEP = ManureTPrate x 0.45**  (16)

Where **ManureTPrate**(lb/a) is the total animal-deposited P on the lot surface and is calculated as follows.

**ManureTPrate = ManureTPEffect / (Lot area ft2/43650)**  (17)

Where **ManureTPEffect** (lb) is the manure total P accumulated on the lot surface between cleans or rains and is calculated as follows.

**Manure TPEffect = DailyTP x Lesser of: Days between clean outs or DaysBtwnRunoff** (18)

Where **DailyTP** is from Eq. 4**; DaysBtwnRunoff** is the average number of days between runoff events (> 0.5 in) over the season, calculated by dividing the number of days in the season by the average number of runoff events with Q > 0.5 in.

**Kw** (no units) is the proportion of available manure water extractable P that is released to runoff and is calculated as follows.

 **Kw = minimum of 1 or (1.2 x (W / (W + 73.1)))** (19)

Where **W** = precipitation to dry matter ratio (cm3 / gram) and is calculated using the equation below:

 **W = Precip Event x 2.54 x Mcover x (100)4 / (Mmass DP x 1000)**  (20)

Where **Mcover (ha)** is the surface area covered by the deposited manure and **Mmass DP**(lb) is the manure mass used in the dissolved P calculations; **Precp Event** (in) is the precipitation event depth.

 **Mcover = Lesser of (lot area / 107,639) or (Mmass DP/ 0.25 x 659/(100)4)** (21)

and

 **Mmass DP = Lesser of (ManApEffect or DMfull)**  (22)

Where **DMfull** is defined in Eq 8.

 **ManApEffect** (lb) is the manure dry matter applied between cleans or rains and is calculated as

**Manure ApEffect = DailyDMTotal x Lesser of: Days between clean outs or DaysBtwnRunoff** (23)

Where Days between clean outs is entered by the user (for paved lots only) and DaysBtwnRunoff is as defined for Eq 18.

**Soil Dissolved P**

The dissolved P released from the soil (lb/yr) in an earthen lot is calculated using the following equation from the Wisconsin P Index (Good et al., 2012).

 **Soil DP = Soil test P (Bray P1) x 0.006 x AnnRunoff x 0.2265 x Lot area/43,560**  (24)

Where **Soil test P** (mg/kg) is a user input with a default value of 250 mg/kg, AnnRunoff is the lot’s annual runoff volume is in inches and the lot area is in square feet. Bray P1 is the routine soil test used in Wisconsin.

**Total Annual Solids and Total Particulate Phosphorus Loss**

**Paved Lots Solids and Particulate P Loads**

The model estimates annual solids loss from the estimated annual runoff using relationships identified in Vadas et al., (2015). For a paved lot, the solids loss is calculated using the equation below:

**SedLossPv = (0.28 x AnnRunoff 1.62) x (Lesser of ManBtwnClns or DMfull)/(DMfull) x Area/43560** (25)

Where **SedLossPv** (ton/yr) is the annual sediment loss from a paved lot; **AnnRunoff** (in) is the estimated annual runoff; **ManBtwnClns** (lb) is the manure remaining on the lot between cleanings (defined for Eq.8); **DMful**l (lb) is the amount of manure dry matter that would completely cover the lot (Eq. 8); and Area is the lot area in ft2. Note that lot cleaning is only applied to paved surfaces (ex. paved lots and the paved portion of lots with both earthen and paved surfaces).

All sediment in runoff from a paved lot is assumed to be manure solids and have the same P concentration as the manure. Sediment-bound P in lot runoff (lb/yr) is calculated as

**Paved SedP = ManPconc x SedLossPv x 2000** (26)

Where **ManPconc** is the annual average manure P concentration calculated as the annual (FG + NFG) average DailyTP (Eq 4) divided by the annual average DailyDM (Eq 3).

**Earth Lot Solids and Particulate P Loads**

Sediment loss from earthen lots decreases with increasing vegetative cover. The model allows total solids loss for earthen lots to fluctuate based on percent cover on the lot, down to a minimal amount (<0.1 ton/acre at 39 in annual precipitation as per Vadas et al., 2015).

**SedLossE = (-0.0027 x % Vegetated cover + 0.28) x (AnnRunoff)1.62 x Lot Area/43560** (27)

Where **SedLossE** is the total ton/yr. sediment loss from the earthen lot, AnnRunoff (in) is the annual runoff volume, and lot area is in ft2 .

For an unvegetated earth lot that is fully covered by manure, 30% of the total solids in the lot runoff is expected to be from manure with the remaining 70% from soil. The equation for calculating the P in runoff solids from a lot assumes the percentage of manure solids is proportionality reduced when the lot surface has less than full coverage.

 **Earth SedP = ((0.3 x (ManEr/DMfull) x ManPconc) + ((1 - (0.3 x ManEr/DMfull)) x SoilTP))**

**x SedLossE /2000** (28)

Where **Earth SedP** is the sediment-bound P in lot runoff in lb/yr. **ManEr** (lb) is the minimum of DMfull or the total amount of manure DM deposited over 120 days; SoilTP (ppm) is the P concentration of soil and is calculated using an equation relating routine Wisconsin soil test P (Bray P1) and OM% to soil total P (Good et al., 2012.)

 **SoilTP = (13 + (2.7 x OM %) + (0.03 x BrayP))2**  (29)

Where **OM%** is the percent organic matter (user input, default = 6 %) and **BrayP** (ppm, user input, default = 250 ppm)

**Sedimentation Basins**

The model includes the ability to calculate the effectiveness of sedimentation basins in removing annual sediment and sediment-bound P. The predictive equations were developed from literature studies of basins used to treat lot runoff (Woodbury et al. , 2002; Sutton et al., 1986; Edwards et al., 1986; Edwards et al., 1983; Gilbertson et al., 1979).

The primary equations describing the decrease in sediment and P loss from the lot as it passes through a sedimentation basin follow.

 **SedSB = SedLoss x (1-(-0.0176 x AnnRO / Design volume +0.945))**  (30)

 **SedPSB = SedPLoss x (1-(-0.02014 x AnnRO / Design volume +0.819))**  (31)

Where **SedSB** (tons) is the annual sediment loss from sediment basin; **SedPSB** (lb) is the annual sediment-bound P loss from sediment basin and **AnnRO**(ft3) is the annual runoff converted to cubic feet (*Annrunoff*/12 x Lot area ft2).

REFERENCE LIST

American Society of Agricultural Engineers. 2005. ASABE Standard ASAE D 384.2, Manure production and characteristics, March 2005.

Edwards, W.M., L.B. Owens, R.K. White. 1983. Managing runoff from a small, paved beef feedlot. J. Environ. Qual. 12 (2), 281-286.

Edwards, W.M., L.B. Owens, R.K. White, N. R. Fausey. 1986. Managing feedlot runoff with a settling basin plus tiled infiltration bed. Trans. ASAE, 29 (1), 24.

Gilbertson, C.B., N J.A. Nienabar, J.L. Gartung,, J.R. Ellis and W.E. Splinter. 1979. Runoff Control Comparisons for Commercial Beef Cattle Feedlots. Trans. ASAE 22, 842-849.

Good, L.W., P. Vadas, J.C. Panuska, C.A. Bonilla, and W. E. Jokela. 2012. Testing the Wisconsin Phosphorus Index with year-round, field-scale runoff monitoring. J. Environ. Qual. 41:1730-1740.

James, E., P. Kleinman, T. Veith, R. Stedman, and A. Sharpley. 2007. Phosphorus contributions from pastured dairy cattle to streams of the Cannonsvlle watershed, New York. J.Soil Water Cons. 62(1) 42-47.

Johnson, J. D. Eckert. 1995. Best management practices: Land application of animal manure. The Ohio State University Extension Agronomy Facts. AGF-208-95. Columbus Ohio.

Lorimor, J. C., W. J. Powers, and A. L. Sutton. 2004. Manure Characteristics, Manure Management System Series MWPS Sect. 1. Second Edition, Midwest Plan Service.

Midwest Regional Climate Center (MRCC). 2020. Cli-MATE database. [cli-MATE: MRCC Application Tools Environment (illinois.edu)](https://mrcc.illinois.edu/CLIMATE/).

Sutton, A.L., D.D. Jones, D. T. Kelly, and D.H. Bache. 1986. Two types of runoff control systems for open concrete swine feedlots. Applied Engineering in Agriculture 2 (2) 193-198.

USDA-Natural Resource Conservation Service. 2008. Agricultural Waste Characteristics. Chap. 4. Part 651- Agricultural Waste Management Field Handbook. 210–VI–AWMFH, March 2008.

USDA-Natural Resource Conservation Service. 1986. Urban Hydrology for Small Watersheds Technical Release 55 . 210–VI–TR-55, Second ed. June 1986.

USDA-SCS. 1972. Estimation of direct runoff from storm rainfall. In: *National Engineering Handbook Section 4: Hydrology*. Washington, D.C.: USDA Soil Conservation Service.

Vadas, P. A., L.W. Good, J. C. Panuska**,** D. L. Busch and R.A. Larson. 2015. A new model for predicting phosphorus export in runoff from outdoor cattle lots. *Trans. ASABE*, Vol. 58(4), 1035-1045.

Woodbury, B.L., J.A. Nienaber, and R.A. Eigenberg.2002. Performance of a passive feedlot runoff control and treatment system. Trans. ASAE 46(6) 1525-1530.