Estimating Field and Watershed Parameters Used in USEPA's Office of Pesticide Programs Aquatic Exposure Models – The Pesticide Water Calculator (PWC)/Pesticide Root Zone Model (PRZM) and Spatial Aquatic Model (SAM)

U.S. Environmental Protection Agency
Office of Pesticide Programs

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Supporting Spreadsheets and Data Tables

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Crop Dates.xlsx	Milestone cropping dates – planting, emergence, full canopy cover, harvest/canopy removal – for major crops and crop groups in support of Section 2.3.1 and Appendix E.
Crop Input Data.xlsx	Miscellaneous crop inputs – rooting depth, USLE C Factor – in support of Section 2.3.2.
Irrigation Input Data by Crop and State.xlsx	Irrigation inputs in support of Section 2.3.3.

Acronyms and Abbreviations

Abbreviation	Description
CDL	Cropland Data Layer, provided by USDA NASS
EFED	Environmental Fate and Effects Division, Office of Pesticide Programs
ESRL	NOAA Earth System Research Laboratory
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
HUC/HUC2	Hydrologic Unit Code
MUSS/MUSLE	Modified Universal Soil Loss Equation
NASS	USDA National Agricultural Statistics Service
NCEP/NCAR	National Centers for Environmental Prediction and Atmospheric Research
NOAA	National Oceanic and Atmospheric Administration
NRCS	USDA Natural Resources Conservation Service
OPP	USEPA Office of Pesticide Programs
ORD	USEPA Office of Research and Development
PRZM / PRZM5	Pesticide Root Zone Model / version 5 (the current version)
PWC	Pesticide Water Calculator, the interface that combines PRZM5 and VVWM
SAM	Spatial Aquatic Model
SSURGO	Soil Survey Geographic database, the geospatial soil dataset developed by the USDA Natural Resources Conservation Service
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USLE	Universal Soil Loss Equation
VVWM	Variable Volume Water Model

NOTE: Appendix A lists the individual field scenario input parameter acronyms and names, along with definitions.

1. Field Scenario Inputs for PWC and SAM

1.1 Background

As a part of the requirements for pesticide registration and periodic review of existing registrations, the U.S. Environmental Protection Agency's Office of Pesticide Programs (OPP) conducts aquatic exposure assessments to determine whether pesticides that are applied according to label directions can result in concentrations in water that have the potential to adversely impact human health or aquatic organisms. To do this for the hundreds of registration and registration review actions each year, OPP estimates pesticide concentrations in water using models that account for a combination of soil, weather, hydrology, and management/use conditions that are expected to influence the potential for pesticides to move into water.

These models include the Pesticide in Water Calculator (PWC) (Young, 2019) and the Spatial Aquatic Model (SAM) (USEPA OPP, 2015). SAM is pending further development. PWC uses field, watershed, and waterbody properties to simulate environmental conditions. Underlying the PWC, the Pesticide Root Zone Model, PRZM5 (Young and Fry, 2016), simulates pesticide fate and transport in the field for defined pesticide applications, estimating pesticide loads to both surface water and ground water. Both field and waterbody parameters define the *environmental scenario* simulated in PWC. The term *field scenario* refers to the set of parameters that describe the field/environmental conditions used in PRZM5 (Figure 1).

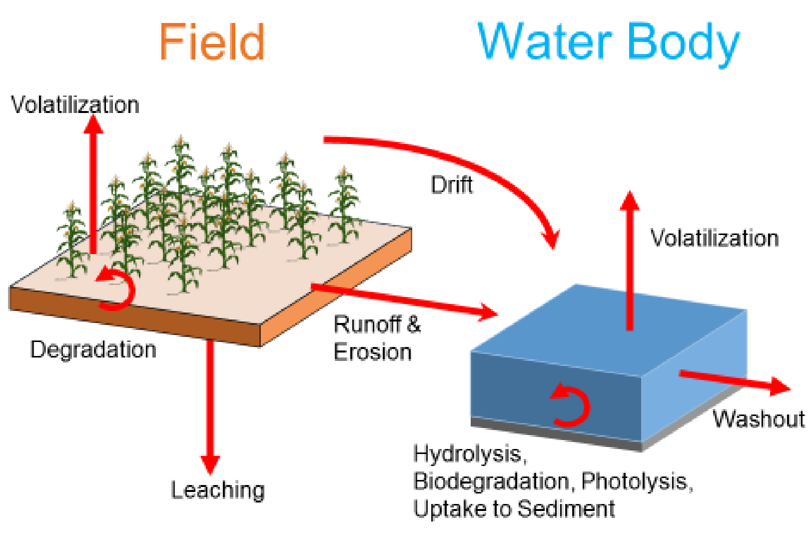

Figure 1. Conceptualization of an environmental scenario for surface water assessments in the PWC. The scenario includes both a field and a waterbody. The *field scenario* refers only to the field inputs.

PWC uses a single field scenario to represent an entire contributing area (watershed) for the crop/use for which the pesticide active ingredient is registered. In PWC, PRZM5 simulates pesticide fate and transport in the field, delivering pesticide loads to both surface water bodies and ground water aquifers. The model simulates the fate/transport of the mass of pesticide from this single pesticide use area into a fixed water body. In contrast to PWC, SAM accounts for the contributions of multiple soil-land cover-weather combinations as they occur together in the watershed and can directly account for multiple pesticide uses in watersheds throughout the use area. Thus, runoff, erosion, and pesticide transport loading reflect the aggregated contributions of multiple fields in the watershed. SAM incorporates contributions of pesticide loadings for a range of water bodies (rivers, streams, ponds, lakes, and reservoirs) and accounts for the time of travel differences in larger watersheds.

1.2 Creating Soil-Land Cover-Weather Field Scenarios from Spatial Datasets

Field scenarios represent a combination of soil, land cover, and weather conditions. OPP identified all possible soil-land cover-weather combinations for the conterminous 48 U.S. states by overlaying spatial data layers for soils from USDA's Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database (USDA NRCS SSS, 2018), crops/land cover from the latest five years of USDA National Agricultural Statistics Service's (NASS) Cropland Data Layer (CDL) (USDA NASS, 2014-2018), and meteorological files/weather station grids generated from NOAA data (Fry et al, 2016). Section 2 provides more detail on these datasets. USEPA OPP (2019) describes the code used to create the overlays, extract field scenario inputs, and create the input data matrix for each soil-land cover-weather grid combination.

The three spatial data sets (SSURGO, CDL, Weather Grids) are overlaid in GIS to generate a spatial index. The input datasets are joined to the spatial index and subsequently collated into field scenarios (Figure 2).

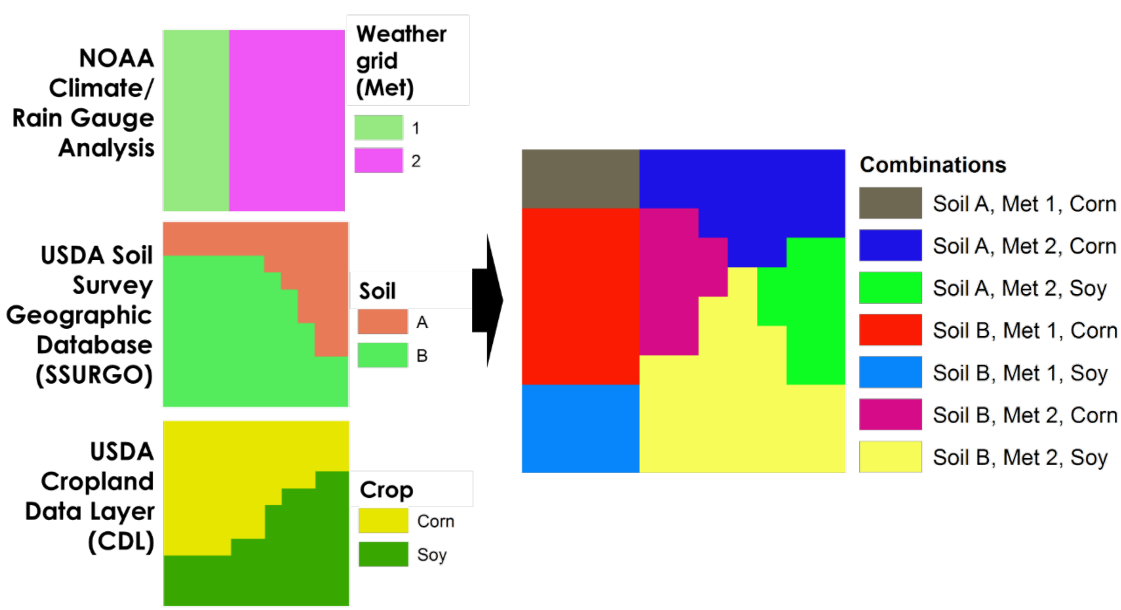

Figure 2: Scenario combinations are built from the overlap of primary spatial data layers - weather grids (NOAA), soils (SSURGO), and land cover (CDL).

1.3 Document Organization

This guidance document updates the Parameter Estimation chapter from the PRZM5 manual (Young and Fry, 2016) and the Data Inputs chapter and associated appendices from the Scientific Advisory Panel (SAP) materials on SAM (USEPA OPP, 2015). Updates include

- Specifying up-to-date input data sources to be used in developing field scenarios
- Updating runoff curve number and soil loss cropping practice factors to reflect current common agriculture practices
- Identifying primary data sources for crop-related inputs described in Section 2.3
- Identifying general crop groupings used for developing field scenarios (Appendix C)

Section 2 describes the field input parameters used in OPP's aquatic models, along with any calculations used to derive the inputs. The inputs are organized by the primary data sources used to generate the field scenario input parameters. Appendices provide additional information on the input parameters and sources (A and B), land cover classes (C), and details for deriving runoff curve numbers (D), crop milestone dates (E), and aggregating soil horizons and map units for SAM scenarios (F).

2. Scenario Input Parameters

The field scenario input parameters used in PWC and in SAM are organized by primary data source. The descriptions and parameter estimation guidance are adapted from documentation for PRZM 5 (Young and Fry, 2016) and SAM (USEPA OPP, 2015). Appendix A summarizes the parameter names, data sources, extraction and derivation methods, and relationships with other input parameters.

Field scenarios are identified by a unique scenario identification (*scenario_id*), which is a combination of the 2-letter state name, SSURGO soil map unit key (*soil_id*), the weather grid designation (*weather_grid*), and the cropland data layer category (*cdl*) (USEPA OPP, 2019). For instance, the field scenario identifier ILS208621W20916LC24 consists of the state IL, the SSURGO map unit key 208621 (which can be used to search for the map unit in SSURGO), the weather grid 20916, and the CDL value 24 (for winter wheat, see Table 8 in Appendix C).

The inputs are organized by primary data sources: soil and landscape inputs from SSURGO, crop-related inputs from a variety of crop data sources, and weather inputs from NOAA.

2.1 Soil and Landscape Inputs Derived from the Soil Map Unit Data

USDA's Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database (USDA NRCS SSS, 2018) is the primary source for soil-related inputs. The SSURGO database contains a wealth of information about soils on the landscape, stored and presented in spatial and tabular formats. Soils are grouped into map units based on similarities in properties (such as hydrologic soil group and slope class). Each map unit has unique properties and interpretations for use. Map units may contain one or more components (individual soil series or non-soil features such as rock outcrops) that are likely to occur together in a landscape (Figure 3). Within each component, soil properties vary with depth. Soil horizons reflect differences in properties with depth (Figure 3). USDA NRCS's resources on soil surveys and SSURGO (USDA NRCS SSS, 2018) has more information related to soil properties, data organization, and map scale.

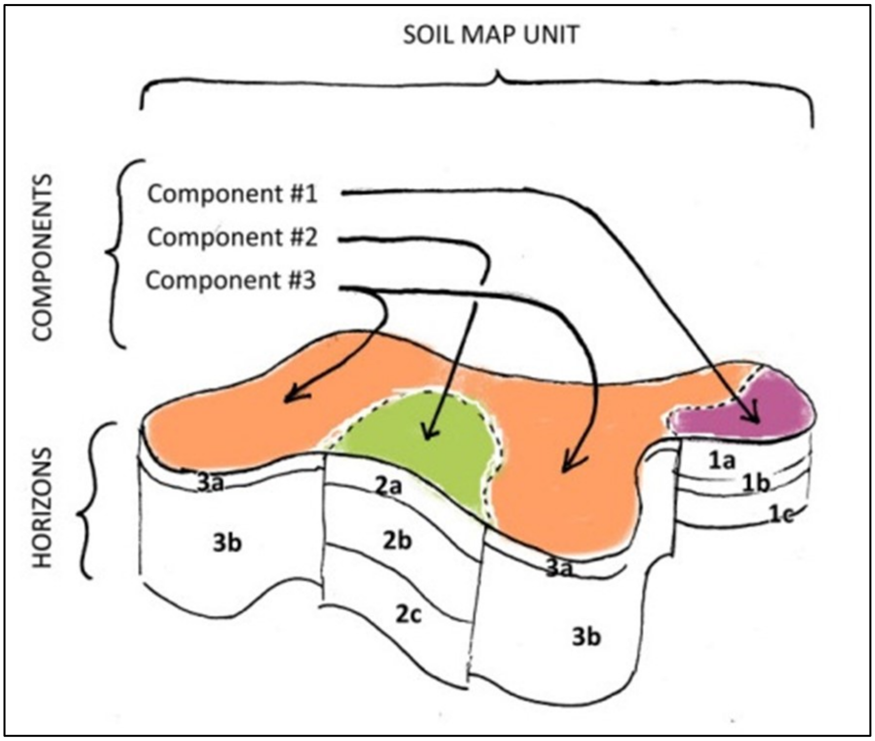

Figure 3: Illustration of a single soil map unit composed of 3 individual soil components. Each component has multiple soil horizons. The USDA NRCS SSURGO dataset contains data for the soil map unit, individual components within the map unit, and horizons for each component.

Soil data are stored in unique data tables in SSURGO. Pertinent to field scenario inputs, data specific to the map unit are stored in the *muaggatt* table; data for individual components within the map unit are stored in the *component* table; and data for individual horizons within each component are stored in the *chorizon* table. Appendix B cross-references the soil inputs used in PWC and SAM with the SSURGO table in which these data are stored.

Soil inputs for each map unit represent the major component comprising the greatest percentage of the map unit. However, if that component is missing data required for model inputs, then the highest-percentage component with soil data is selected. When one or more major components make up an equal percentage of the map unit, the more runoff-prone component is used, according to hydrologic soil group designation in order: D > C > B > A.

The SSURGO database includes non-soil map units, such as quarries, landfills, rock outcrops, and unspecified developed land, that do not contain data. These non-soil map units are not used in PWC field scenarios. For SAM, a default runoff curve number of 99 is used for these map units to account for runoff contributions within the watershed. Neither model simulates pesticide transport from non-soil map units.

Soil and landscape inputs derived from SSURGO use a representative value of the reported range in soil properties. While a single representative number doesn't capture the range in properties, it is expected to be value-neutral in terms of impact on concentration estimates.

The *runoff curve number* is the major soil/landscape input affecting runoff (Jones and Russell, 2001; Jones and Mangels, 2002). It is dependent upon the hydrologic soil group associated with the major soil map unit, general land cover types, crop production system, predominant agricultural practice, and hydrologic condition (Table 1).

Soil erodibility (*usle_k*) and slope steepness/length (*usel_ls*) describe landscape factors that affect the amount or erosion/sediment that can occur. These factors may be important for chemicals that have a high affinity to sorb to soil.

2.1.1 Hydrologic Soil Group (*hydro_group*)

Although not a direct input into PWC or SAM, the hydrologic soil group and land cover are used to determine the runoff curve number (Table 1). The hydrological soil group reflects the general runoff characteristics of the soil based on its hydraulic conductivity and depth to drainage-restrictive layers. Designations range from A (lowest runoff potential) through D (highest runoff potential). The runoff curve number is based on the dominant hydrologic soil group (HYDGRPDCD in the SSURGO *muaggatt* table) for the map unit. If that designation is not available, the hydrologic soil group of the major map unit component with data is used.

Some wet soils have dual hydrologic groups (e.g., A/D, B/D, C/D). In their natural (undrained) state, these soils behave as hydrologic group D because they are saturated at or near the surface and have little capacity to accommodate additional water from precipitation. If drained, the soil's capacity to hold rainfall increases and the less runoff-prone hydrologic group designation is used (USDA NRCS, 2007). For dual hydrologic groups associated with cultivated cropland, the better-drained soil group is used while the D designation is used for non-agricultural land classes.

2.1.2 Runoff curve numbers (*cn_cov, cn_fal*)

Runoff curve numbers represent runoff conditions under full crop canopy (*cn_cov*) and post-harvest/canopy removal (*cn_fal*) conditions. The default condition for *cn_fal* assumes fair to good hydrologic condition and contour cropping with crop residue left on the surface after harvest. The treatment/practice and cover condition can be updated to reflect regional differences as such information becomes available. The cover types used for curve number determination (USDA NRCS 2004a, 2008) are more general than either the individual CDL cover classes or the general cover classes (Appendix C). Table 1 shows the curve numbers used for scenario development. Appendix D describes how curve numbers are determined from the original USDA NRCS (2004a, 2008) tables.

Table 1 - Curve Numbers for Cover Type-Hydrologic Soil Group (HSG) Combinations from USDA NRCS (2004a, 2008).

Cover Type	Treatment or Practice[1]	Hydrologic Condition	Cover	HSG A	HSG B	HSG C	HSG D
Fallow	Bare Soil	---		77	86	91	94
	Residue left	Good		74	83	88	90
Row crops	C + CR	Good	Crop	64	74	81	85
			Residue	74	83	88	90
Small grain	C + CR	Good	Crop	60	72	80	83
			Residue	74	83	88	90
Close-seeded legumes/rotation meadow	C	Good	Crop	55	69	78	83
			Residue	74	83	88	90
Pasture, grassland, range		Fair		49	69	79	84
Meadow - continuous grass, protected from grazing		---		30	58	71	78
Brush - brush-weed-grass		Fair		35	56	70	77
Woods - grass combination (orchards)		Fair		43	65	76	82
Woods		Fair		36	60	73	79
Developed Open Space	>75% grass cover	Good		39	61	74	80
Residential (developed-low)	1/3 ac lots	30% impervious		57	72	81	86
Residential (developed-medium)	1/8 ac lots or less	65% impervious		77	85	90	92
Urban (developed high)	Commercial, business	85% impervious		89	92	94	95

1 – Cropping practice: C = contour cultivation; CR = crop residue left on the surface.

2.1.3 Soil Erodibility (K) Factor (*usle_k*)

The K factor (*usle_k*), an indicator of the inherent susceptibility of the soil to water erosion, is used in the universal soil loss equation (USLE) to estimate erosion loss. Each soil horizon in SSURGO has a K factor (KWFACT in the *chorizon* table in SSURGO). Because the topmost layer is most exposed to runoff, the K factor for the surface layer is used. In cases where SSURGO doesn’t include a K factor for the surface layer, the K factor for the next layer is used.

2.1.4 Slope, Slope length, and USLE Slope Length/Steepness (LS) Factor (*usle_ls*)

Slope represents the area-weighted average gradient for the soil map unit in SSURGO (SLOPEGRADWTA in the *muaggatt* table). Slope length is the average slope length for the major component in the map unit (SLOPLENUSLE_R in the *component* table). If no value is available for the slope length, a default length of 300 feet, the maximum representative slope length value in SSURGO, is used.

Slope and slope length determine the USLE Slope Length/Steepness (LS) Factor (*usle_ls*), using equation [1], from Wischmeier and Smith (1978):

[1] $LS = (\lambda/72.6)^M * \{65.41 \sin^2\Theta + 4.56 \sin \Theta + 0.065)$

where

λ = slope length, feet

Θ = angle of slope (converted from % slope)

M = adjustment factor (0.5 if slope is >5%; 0.4 for slopes of 3.5-4.5%; 0.3 on slopes of 1-3%, and 0.2 for slopes <1%)

2.2 Soil Inputs Derived from Horizon Data

SSURGO reports organic matter content, bulk density, field capacity, wilting point, sand and clay contents for each soil horizon. The impact of these soil properties on pesticide fate and transport vary with pesticide properties but are less than the impact of rainfall and curve number (Sinnathamby et al, 2019; D'Andrea et al, 2020). Properties of the surface soil layer, which includes the zone from which runoff extracts chemicals, have the largest impact. Organic carbon content impacts sorption for high K_{oc} pesticides; field capacity, wilting point, and bulk density impact water storage capacity.

Soil components in SSURGO may have data for up to 14 different horizons. The current version of PRZM in PWC can accommodate up to 8 horizons. Because SAM is focused on surface water runoff rather than leaching to groundwater, properties for the surface horizon are the most critical for estimating pesticide transport and properties for the subsurface horizons have been aggregated in depth-weighted layers (Appendix F). The # symbol in the input parameter names below refer to the horizon, numbered consecutively from surface to subsurface.

SSURGO reports a high, low, and representative value for each input. Soil inputs in the field scenario are based on the representative value.

2.2.1 Number of horizons (n_horizon)

PWC/PRZM uses the number of SSURGO horizons to set the number of soil layers with inputs in the model. This parameter refers to the number of horizons with complete inputs for bulk density, soil organic content, and water capacity (minimum and maximum). Those horizons with missing data, usually lower-most horizons that describe weathered rock or thin leaf-litter surface horizons, are not included in the model routines.

2.2.2 Horizon thickness (thickness_#)

Horizon thickness (*thickness_#*) is the representative value for the total thickness of the individual horizon (HZTHK_R in the SSURGO *chorizon* table) in centimeters (cm). Thickness defines the extent through which water and any associated chemical moves downward through the soil by leaching.

2.2.3 Bulk density (*bd_#*)

Soil bulk density (mass per unit volume of soil) is used in chemical transport equations to estimate total soil porosity and soil moisture content. The bulk density for each layer (*bd_#*) is the representative value for soil bulk density at one-third bar moisture content (DBTHIRDBAR_R in the *chorizon* table).

2.2.4 Soil organic carbon content (*orgC_#*)

SSURGO reports soil organic matter (OM_R in the *chorizon* table) as a percent for each layer. This conversion from organic matter to soil organic carbon (*orgC_#*) assumes soil organic matter contains approximately 58% carbon (USDA NRCS, 2009):

[2] Soil orgC = OM / 1.724

2.2.5 Water capacity (water_max_#, water_min_#)

PRZM uses a tipping bucket concept for vertical water movement and this requires a maximum and minimum level for the "bucket." Because such values are not directly available from SSURGO, OPP uses the water content of the soil at 1/3-bar pressure (WTHIRDBAR_R in the *chorizon* table) to represent *water_max_#* and the water content of the soil at 15 bars pressure (WFIFTEENBAR_R in the *chorizon* table) to represent *water_min_#*. The 1/3-bar value is often used to approximate the amount of water remaining after free drainage (i.e., field capacity) and is a first approximation for the maximum value of the bucket. The 15-bar value is frequently used as the wilting point or the least amount of water accessible to transpiration.

2.2.6 Sand (*sand_#*) and Clay (*clay_#*) content

The percent of sand (SANDTOTAL_R in the *chorizon* table) and clay (CLAYTOTAL_R) determine the texture class of the soil. Sand is used as an input for the soil temperature routine in PWC. Sand and clay are included as criteria in the soil grouping classes for SAM (Appendix F).

2.3 Crop-Related Inputs

USDA National Agricultural Statistics Service's (NASS) Cropland Data Layer (CDL) provides spatial distributions of numerous crops using satellite imagery, remote sensing, and data training with independent crop data (USDA NASS, 2014-2018). The CDL provides the land cover footprint for collecting crop-related data and determining the general crop cover class (Appendix C) used for field scenarios. OPP uses the most recent five years of CDL to capture representative cropping patterns and to take advantage of improvements in land cover estimation methods.

The CDL provides the most detailed spatial resolution for various crops and crop groups at the national level. Key areas of uncertainty include (a) the relative accuracy of the CDL in identifying actual crops, which is covered in detail in the CDL accuracy assessments, (b) generic land cover classes used for crops that, individually, have poor accuracy in CDL, and (c) year-to-year variation in crop cover. Appendix C lists the current generic agricultural cover classes OPP will use to develop field scenarios – corn, cotton, soybeans, wheat, vegetables and ground fruit, grapes, citrus, other orchards, other grains, other row crops, other cultivated crops, and pasture/hay/forage. These general crop groups provide viable distinctions among inputs that impact the use of pesticides and subsequent fate/transport from the field, such as land cover class as it impacts runoff (curve number) or erosion (crop practice factor) and time of plant or harvest as it relates to potential timing of pesticide application.

No single national dataset exists to supply all the crop/management-related inputs. Sections 2.3.1 and 2.3.2 identify available defaults for initial development. These will be updated as state and/or regional crop data are developed.

Crop planting and harvesting dates are used to estimate crop emergence and the timing and duration of canopy growth and to provide a framework that can be used to estimate the timing and duration of pesticide applications. The crop stages have a greater impact on model outputs when used for estimating timing of pesticide applications than for estimating canopy growth and resulting crop intercept of rainfall and pesticide applications.

OPP used USDA reports on usual planting and harvest dates (USDA NASS, 2006, 2007, and 2010) to estimate crop growth dates by state. These reports provide the usual range in planting and harvest dates by state for many field, vegetable, and fruit/nut tree crops. These dates are used to estimate the key plant growth stages needed for modeling.

OPP compiled crop-related inputs for the current generic agricultural cover classes it plans to use to develop field scenarios – corn, cotton, soybeans, wheat, vegetables and ground fruit, grapes, citrus, other orchards, other grains, other row crops, other cultivated crops, and pasture/hay/forage (Appendix C). Additional crops or crop groups may be added if differences in specific management practices or environmental factors would impact the management and transport of pesticides.

2.3.1 Crop Milestone Dates

Appendix E provides more detail on the methods used to derive the crop milestone dates, including steps for estimating missing dates or for estimating dates for crops not included in the USDA publications. The file *Crop Dates.*xlsx contains the detailed methods, crop dates, and documentation for the dates.

2.3.1.1 Planting dates (plant_begin, plant_end, plant_date)

The beginning plant date (*plant_begin*) is either the first date in the “Most active” planting dates in USDA NASS (2006, 2007, and 2010) or, if the most active range is not provided, the “Begin” date for planting. The ending plant date (*plant_end*) is either the last date in the “Most active” planting dates in USDA NASS (2006, 2007, and 2010) or, if the most active range is not provided, the “End” date for planting. These dates, reported as month-day in the USDA publications, are converted to Julian days (1 to 365). For PWC, a single plant date (*plant_date*) is derived from the midpoint of *plant_begin* and *plant_end*. In SAM, the full range is used. Plant date is not a direct input in PWC but is used to estimate the emergence date for modeling. In

SAM, the plant date range provides a framework for linking pesticide applications to crop milestones.

2.3.1.2 Harvest dates (harvest_begin, harvest_end, harvest_date)

"Harvest" for modeling purposes refers to the time when the crop canopy is removed, and root depth returns to zero (effectively zeroing transpiration). For many annual crops, this coincides with the agricultural harvest of the crop when the crop and canopy are actually removed. For these crops, the beginning harvest date (*harvest_begin*) is either the first date in the "Most active" harvesting dates in USDA NASS (2006, 2007, and 2010) or, if the most active range is not provided, the "Begin" date for harvesting. The ending harvesting date (harvest_*end*) is either the last date in the "Most active" harvesting dates in USDA NASS (2006, 2007, and 2010) or, if the most active range is not provided, the "End" date for harvesting. These dates, reported as month-day in the USDA publications, are converted to Julian days (1 to 365). For PWC, a single harvest date (harvest_*date*) is derived from the midpoint of *harvest_begin* and *harvest_end*. In SAM, the full range is used.

For perennial field crops, such as alfalfa, the cutting dates best approximate canopy removal. For perennial deciduous tree crops, leaf drop, which may occur well after the fruit/nut is harvested, best approximates canopy removal. For these orchard crops, leaf drop dates will be approximated from the first frost/freeze date in the fall.

2.3.1.3 Blooming dates (bloom_begin, bloom_end)

USDA includes the usual blooming dates (the period of time in which most orchards come into full bloom) for fruit and nut trees (USDA NASS, 2006). For pesticides that may be applied during bloom, the reported beginning date for bloom sets the start of the pesticide application window in SAM and the range in blooming dates defines the length of the pesticide application window in SAM. In some instances, bloom will be used to estimate other milestone dates, such as beginning of leafing (for emergence) or full canopy cover, for fruit and nut crops.

2.3.1.4 Emergence dates (emergence_begin, emergence_end, emergence_date)

The emergence date for modeling purposes refers to the beginning of canopy cover for a crop. Beginning and ending emergence dates are estimated by adding 7 days to the corresponding planting dates for the crop in the state. For many annual crops, planting dates are available in USDA NASS (2006, 2007, and 2010). In PWC, a single emergence date (*emergence_date*) is derived from the midpoint of *emergence_begin* and *emergence_end*. In SAM, the full range is used.

For perennial field crops, such as alfalfa, the beginning of growth either in the spring or immediately after a cutting approximates emergence dates. For perennial deciduous tree crops, the beginning of canopy development or leaf bud approximates emergence. For these orchard crops, the midpoint between beginning and ending bloom dates approximates the beginning of canopy development.

2.3.1.5 Maximum canopy cover dates (maxcover_begin, maxcover_end, maxcover_date)

In the absence of data, the timing to maximum canopy cover is estimated as the midpoint between emergence and harvest. This represents the maximum capacity of the crop to intercept rainfall and pesticide applied above canopy. Crop growth in PWC and SAM assume the canopy coverage and root depth increase proportionally with time from emergence date to full canopy coverage. In PWC, a single date (*maxcover_date*) is derived from the midpoint of *maxcover_begin* and *maxcover_end*. In SAM, the full range is used.

For perennial field crops, such as alfalfa, the maximum canopy is estimated as the midpoint between cuttings/harvest dates. For perennial deciduous tree crops, maximum canopy cover is estimated as the midpoint between canopy development and canopy removal/leaf drop.

2.3.1.6 Annual crops with missing milestone dates

In some instances, a crop occurs in a state, but not in sufficient acreage for inclusion in the usual planting/harvest date publications (USDA NASS, 2006, 2007, and 2010). In these instances, OPP used surrogates to fill-in data gaps. Surrogate dates are assigned in order of:

1. Same crop with dates from an adjacent state, with preference to states with similar latitude
2. Another crop in the same state that is in the same General CDL Class (Appendix C)

Appendix E and the CropDates.xlsx spreadsheet describe the methods used to estimate missing dates.

2.3.1.7 Milestone dates for perennial crops

Non-annual/perennial crops do not have reported planting dates in USDA NASS (2006, 2007, 2010), such as alfalfa and grass hay, pasture, orchards, and some berries/fruits. Emergence (beginning of active growth), maximum canopy cover, and harvest (loss of foliage cover) are still needed to set canopy and root growth model routines (for rain/pesticide interception and evapotranspiration) and to define the times of crop cover and crop removal for runoff curve numbers.

One approach for perennial crops is to tie canopy and root growth to the beginning and end of the growing season based on the timing of the last and first killing frost, respectively. Canopy cover differences can be linked to reported harvest dates – in the case of hay crops, multiple harvests may occur – or, for deciduous orchards, the timing of leaf bud to leaf fall. Proposed approaches to define significant crop milestone dates for use in modeling are described in this section.

2.3.1.8 Crops with multiple growing seasons in a year

Some crops, such as vegetables, may have multiple growing seasons in a year in some states. These show up in the USDA planting/harvesting reports with multiple planting and harvest dates (USDA NASS, 2007). Although rare, some vegetable crops have up to four seasons in a year. The current approach, outlined in Appendix E, is to develop a generic vegetable scenario with options for up to four growing seasons in a year (spring, summer, fall, winter). In states in which only a single growing season occurs, only the first growing season will be active. In states with more than one growing season in a year, the additional seasons would be activated.

2.3.2 Other Crop-Specific Inputs

Many of the crop-related factors described below are based on guidance in PRZM 3 (Carousel et al, 2005) or PRZM 5 (Young and Fry, 2016) manuals. These crop inputs, along with the supporting data used to derive the inputs, can be found in the file *Crop Input Data.xlsx*.

2.3.2.1 Crop intercept (*crop_intercept*)

Crop intercept is the maximum rainfall interception storage of the crop (cm). This parameter estimates the amount of rainfall that is intercepted by a fully developed plant canopy and retained on the plant surface. The PRZM3 manual (Carousel et al, 2005) provided a range of 0.1 to 0.3 cm for a dense crop canopy. USDA NRCS (2016) noted up to 0.1 inch (0.25 cm) can be temporarily intercepted and stored on plant foliage.

2.3.2.2 Maximum canopy cover (*max_cover*)

The maximum areal crop coverage (or ground cover), as a percentage of the surface, sets the maximum cover value. As a crop grows, its ground cover increases and captures proportionally more pesticide from above canopy applications. Similarly, rainfall intercept and storage capacity increases. For most crops, the maximum coverage is on the order of 80% to 100% (Carousel et al, 2005; Young and Fry, 2016).

2.3.2.3 Maximum active rooting depth (*root_depth*)

The maximum active rooting depth is the depth to which plant roots draw water from the soil. This is used in estimating irrigation needs and soil moisture content over time. The USDA National Engineering Handbook (NEH) provides ranges in depth to which roots of mature crops will extract water from deep, well-drained soils (USDA NRCS, 1997 and 2016). The *root_depth* input for the crop is the average of the depths reported in Table 3-4 of NEH 652 Irrigation Guide (USDA NRCS, 1997) and Table 11-3 of NEH 632 Sprinkler Irrigation Guide (USDA NRCS, 2016).

The SSURGO database reports maximum rooting depths (ROOTZNEMC in the valu_fy2018.gdb in SSURGO) for soils that have a root- or drainage-restrictive layer in the soil. If the maximum active rooting depth for the crop is greater than the depth of the maximum soil root zone depth, the rooting depth for the crop is truncated at the soil depth for that crop-soil map unit.

In PWC/PRZM, the maximum active rooting depth must be less than the total soil depth. If the maximum rooting depth for the crop equals the total soil depth, subtract 0.5 cm from the plant root depth.

2.3.2.4 USLE practice (P) factor (*usle_p*)

The P factor in the Universal Soil Loss Equation estimates the impact of agricultural practices on erosion. Values range from 0.10 (extensive practices) to 1.0 (no supporting practices). Specific values in Table 2 are based on Table 5.6 from Carousel et al, 2005, which are based on values in Wischmeier and Smith (1978). The default practice assumes cultivation along contour (C).

Table 2: USLE P Values for Selected Agricultural Practices and Slope Ranges (from Table 5.6, Carousel et al, 2005, adapted from Wischmeier and Smith, 1978)

Practice	Slope, percent				
	1 – 2	2 – 7	7 – 12	12 – 18	18 – 24
Contouring (C), Default for field scenarios	0.60	0.50	0.60	0.80	0.90
No support practice	1.0	1.0	1.0	1.0	1.0
Contour Strip Cropping (CP)	0.30-0.60	0.25-0.50	0.30-0.60	0.40-0.80	0.40-0.90
Contour Listing or Ridge (CL)	0.30	0.25	0.30	0.40	0.45

2.3.2.5 USLE cover management (C) factor (usle_*c_cov, usle_c_fal*)

The C factor in the Universal Soil Loss Equation estimates the impact of crop cover management practices on erosion. Values for USLEC range from 0.001 (well managed) to 1.0 (fallow or tilled condition). Table 5.7 in the PRZM3 manual (Carousel et al, 2005) is based on crop, management, and rotation practices, which can vary greatly with crops. The USLEC factors in the file *Crop Input Data.xlsx* represent the high and low range for the crop, based on data provided to OPP by USDA in 2000.

2.3.3 Irrigation Inputs

The need for including irrigation in model simulations depends on a combination of crop water needs, rainfall amounts and timing, and the capability of the soil to retain water and supply the crop. When the irrigation routine is triggered (based on the irrigation type parameter), the allowable moisture depletion parameter indicates when irrigation occurs based on soil moisture content.

The file *Irrigation Input Data by Crop and State.xlsx* contains irrigation inputs by crop and state, along with the supporting data used to derive the inputs.

2.3.3.1 Irrigation type (*irrigation_type*)

Irrigation type triggers the irrigation routine in PWC/PRZM and SAM. The dominant type of irrigation can be simplified based on how water is applied:

0 = no irrigation

1 = Over canopy is applied above the crop canopy, such as with pivot or spray booms. Over-canopy irrigation triggers crop intercept and hold-up of applied water.

2 = Below canopy is applied below the crop canopy, such as with furrow or flood irrigation. No crop intercept occurs.

OPP used the 2013 Farm and Ranch Irrigation Survey (USDA NASS, 2014) to determine the appropriate irrigation type. Irrigation is triggered in the scenario when more than 40% of the crop acreage in the state is irrigated. Over-canopy irrigation is used when the majority of irrigated crop acreage in the state is irrigated using pressure or sprinkler systems. Below-canopy irrigation is used when the majority of irrigated crop acreage in the state is irrigated with gravity or low-flow irrigation systems. An update to the irrigation and water management survey, based on the 2017 Census of Agriculture, is expected to be released late in 2019. OPP will update the irrigation triggers based on that report.

2.3.3.2 Allowable moisture depletion (*depletion_allowed*)

Allowable moisture depletion, the fraction of the available water capacity that triggers irrigation for the crop, depends upon the soil moisture-holding characteristics, the type of crop planted, and agricultural practices. The fraction generally ranges between 0.0 (irrigation begins when soil moisture is depleted to the wilting point) and 0.6 (irrigation is applied at 60 percent of the available water capacity) (USDA NRCS, 1997, 2016). Table 3-3 in the National Engineering Handbook (NED), Part 652-Irrigation Guide (USDA NRCS, 1997) provides management-allowable depletion (as a percent of available water capacity) for select crops at different growth stages. OPP used the minimum depletion fraction as an irrigation trigger, with a default depletion of 0.5 for crops not included in the irrigation guide.

2.3.3.3 Leaching fraction (*leaching_frac*)

This refers to the fraction of excess water added by irrigation that is allowed to leach below the root zone, usually to reduce salt build-up from evaporation losses. This factor represents a fraction of the amount of water required to meet the soil water deficit. A default value of 0.1 is used, indicating that 10% more water is used than that required to meet the water deficit.

2.3.3.4 Maximum irrigation rate (*irrigation_rate*)

The irrigation rate specifies the maximum daily amount of irrigation water that is applied. This amount, dictated by soil properties (i.e., curve number), is set to minimize losses of irrigation water by runoff. Irrigation rates for crops will vary with the curve number, following the runoff calculation in the USDA NRCS Curve Number (CN) method (USDA NRCS, 2003):

[3] $S = (2540 / CN) - 25.4$

where

S = potential maximum daily water retention in soil (cm), setting the maximum daily irrigation rate

CN = Curve Number value, based on Table 1, using the value for crop cover

2.4 Weather Inputs

Weather data come from publicly-available, gridded meteorological datasets that provide daily values for precipitation, temperature, wind speed, solar radiation, and potential evapotranspiration at uniform spatial resolution across the country. OPP used the Unified Gauge-Based Analysis of Daily Precipitation from the Climate Prediction Center (CPC) (NOAA ESRL, 2014) and Reanalysis Data from the National Centers for Environmental Prediction (NCEP). Fry et al (2016) describe the data processing and quality assurance steps taken to derive the weather data.

The NCEP Reanalysis data are available as points at 2.5° x 2.5° (latitude/longitude) grid resolution; the CPC precipitation data are at 0.25° x 0.25° US grid resolution. OPP combined the data using grids (Theissen polygons) drawn around each datapoint in GIS and resampled at the finer grid resolution of the CPC data (0.25° x 0.25°). Each weather station contains historical daily weather data – precipitation, temperature, wind speed, solar radiation, and potential evapotranspiration – collected from NOAA.

Additional weather-related parameters – rainfall distribution, depth of evapotranspiration, and snowmelt factor – are based on descriptions and maps provided in the PRZM3 (Carousel et al, 2005) and PRZM5 (Young and Fry, 2016) manuals. The maps for these data sources were digitized into GIS and combined with the 0.25° x 0.25° grids using a spatial overlay.

2.4.1 Daily precipitation (*precipitation*)

Daily precipitation, in cm, comes from the NOAA Climate Prediction Center (CPC) Unified Rain Gauge Analysis. Precipitation in the CPC dataset is converted from mm/day to cm/day.

2.4.2 Daily mean air temperature (*temperature*)

The daily mean air temperature at 2 meters above the surface is converted to degrees Celsius by subtracting 273.15 from the original Kelvin values reported in the NOAA NCEP/NCAR Reanalysis dataset.

2.4.3 Daily evapotranspiration (*et*)

Daily evapotranspiration, in cm, is not directly available in the NOAA data. The calculation, described in Fry et al (2016), uses the Hargreaves-Samani method (FAO, 1998; Hargreaves and Samani, 1985; Lu et al., 2005).

2.4.4 Daily wind speed (*windspeed*)

The wind speed as calculated by Fry et al. (2016) represents the speed at 10 m above the surface, in cm/s.

2.4.5 Daily solar radiation flux (*solarradiation*)

The daily downward solar radiation flux, MJ m^{-2} day^{-1}, is used to calculate daily evapotranspiration (Fry et al, 2016).

2.4.6 Rainfall distribution (*ireg*)

The time of concentration calculation of peak flow is based on the USDA NRCS rainfall distribution region (Young and Fry, 2016, adapted from USDA NRCS, 1986) for the time period from May 1 to September 15. Figure 4 shows the approximate geographic range for the four distribution regions. OPP overlaid the weather station grid to a digital version of Figure 4 to derive the rainfall region by weather station grid.

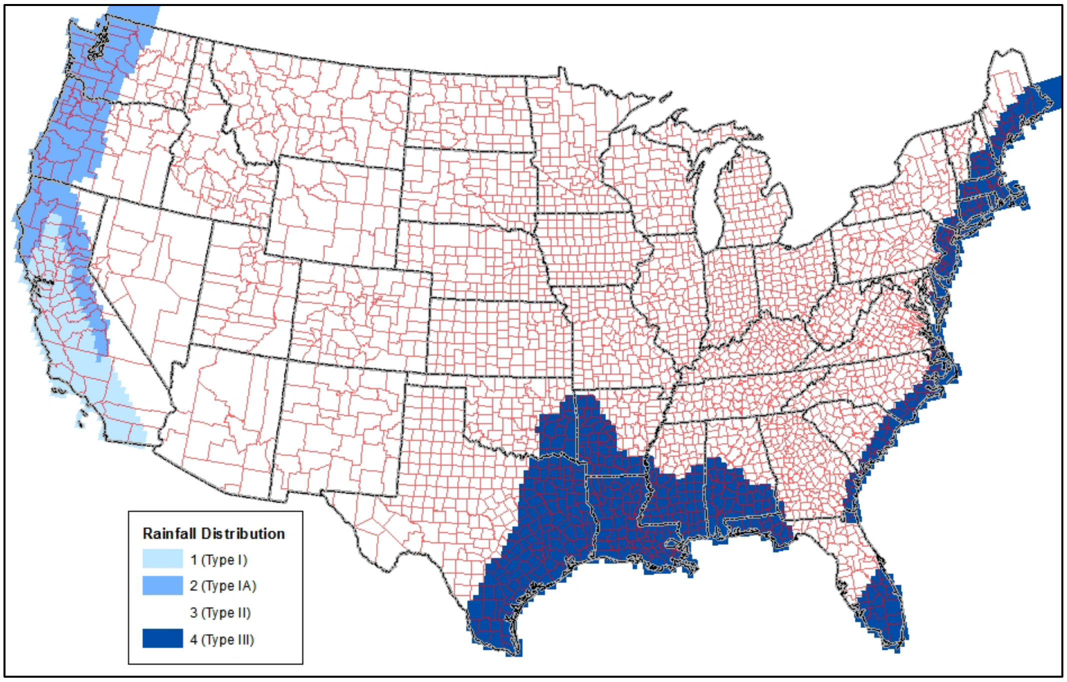

Figure 4: Approximate geographic boundaries for NRCS rainfall distributions, adapted from USDA NRCS (1986) and linked to weather station grids.

2.4.7 Soil evaporation available depth (*anetd*)

This value establishes a minimum depth for which soil water is available for evaporation. Thomson and Troeh (1978) reported usual ranges of 5 to 8 cm. The current default is 8 cm.

2.4.8 Snowmelt factor (*sfac*)

The snowmelt Factor (cm/°C/day) is the amount of accumulated snow that melts per °C above 0°C. USDA NRCS (2004b) recommended a default value of 0.274 when no other information is available.

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Appendix A: Primary Scenario Input Parameters

Tables 3 to 5 summarize the scenario input parameters that are derived for each soil /land cover/weather station combination. Parameters in **bold** are inputs for SAM and PWC; other parameters are used in deriving inputs or providing quality assurance. These tables do not include the scenario identification fields described in Section 2.

Table 3 – Soil and Landscape Inputs used in PWC and SAM. Parameters in bold are direct inputs on both models.

Parameter Name	Parameter Description	Units / Range	Source	Extraction/ Derivation	Notes	Relationships/ correlation
A. Soil and landscape inputs derived from the soil map unit						
hydro_group	**Hydrologic soil group**, used to determine curve number	Numeric, based on alpha designation: 1 (A), 2 (A/D), 3 (B), 4 (B/D), 5 (C), 6 (C/D), 7 (D)	SSURGO for Soil Map Unit: HYDGRPDCD (dominant HSG) from *muaggatt* table; if missing, use HYDGRP from the *component* table for the major component.	Converted to numeric values for processing. Slash groups (A/D, B/D, C/D) provide clues to tile drainage: if cultivated land, use left side; if not cultivated, use D.	Used in combination with land cover to determine runoff curve number	Based on hydraulic conductivity, depth to restrictive layers, which are influenced by soil texture, structure, organic matter content, bulk density, mineralogy
cn_cov **cn_fal**	**Runoff curve numbers** of antecedent moisture condition for crop cover and fallow/residue.	dimensionless whole number, less than 100	Hydrologic soil group from SSURGO, land use from CDL. Curve number guidance from USDA NRCS (2004, 2008).	Follow curve number guidance (Appendix D).	Determines the portion of rainfall that runs off the land, potentially carrying pesticides with it.	Based on hydrologic soil group, land cover type, and management practices
usle_k	**Universal soil loss equation K factor for soil erodibility** factor, whole-soil	dimensionless fraction, range from 0 to 0.64	SSURGO Soil Map Unit, joined to *chorizon* table through *muaggatt*, *component* tables: KWFACT for topmost horizon (hzdept_r = 0)	Extract kwfact (K factor, whole soil) for surface horizon of major component in chorizon table	Sensitivity analysis on soil erosion (RUSLE) model inputs is needed. Expected to have greater impact on high-Koc chemicals, but the extent has not been tested.	Erodibility depends on soil texture, organic matter content, structure (how well soil particles aggregate), permeability

Parameter Name	Parameter Description	Units / Range	Source	Extraction/ Derivation	Notes	Relationships/ correlation
slope	Land slope, the average slope gradient for the soil mapping unit.	% Range from 0 to 100	SSURGO for Soil Map Unit: SLOPEGRADD (wtd. avg. slope) from *muaggatt* table	Weighted average % slope for the soil map unit (SLOPEGRADD) from SSURGO muaggatt table	Used with slope length to estimate USLE LS (slope/length) factor.	Impacts soil erosion potential in combination with the slope length. The combined impact is characterized in the USLE LS factor below.
slope_length	Slope length used in USLE LS factor. Distance from point of origin of overland flow to the point where gradient decreases and deposition begins	feet	SSURGO *component* table: SLOPELENUS_R (linked to mapunit)	SLOPELENUS_R in component table; if no value is available for SLOPELENUS_R, use a default slope length of 300 feet (max. SLOPELENUS_R value in SSURGO)	Used with slope to estimate USLE LS (slope/length) factor.	Correlation with slope gradient is weak. Impacts soil erosion potential in combination with the slope length. The combined impact is characterized in the USLE LS factor below.
usle_ls	Universal soil loss equation (**LS) length-slope topographic factor**	dimensionless fraction	SSURGO for slope, slope_length (above). Equation from Wischmeier and Smith (1978).	Derive using equation from Wischmeier and Smith (1978): LS = (λ/72.6)M * {65.41 sin2Θ + 4.56 sin Θ + 0.065) where λ = slope length, feet Θ = angle of slope M = adjustment factor	Sensitivity analysis on soil erosion (RUSLE) model inputs is needed. Expected to have greater impact on high-Koc chemicals, but the extent has not been tested.	Derived from slope gradient, slope length parameters above.
root_zone_ max	Maximum depth of the root zone (cm) based on soil properties	cm	SSURGO value added data table (valu): rootznemc, available for the major component in each map unit	Serves as maximum depth of active root zone. Adjust maxrootdepth, anetd.	Used to define depth of depletion for irrigation.	Potentially serves as cut-off depth for active root zone depth.

Parameter Name	Parameter Description	Units / Range	Source	Extraction/ Derivation	Notes	Relationships/ correlation
B. Soil inputs derived from horizon data						
n_horizons	**Number of soil horizons** with input data	Count	SSURGO *chorizon* table	Count the number of horizons within each component that have values for bd, orgC, fc, wp	Tracks number of horizon inputs	
thickness_#	**Thickness** of # horizon	cm	SSURGO *chorizon* table (linked to major component, map unit): HZTHK_R for each horizon	No further calculations	Used for accounting for thickness	
orgC_#	Percent **soil organic carbon (orgC)** for # horizon	% Organic soils >35% org. C; mineral soils less	SSURGO *chorizon* table (linked to major component, map unit): OM_R for each layer	Convert from percent organic matter to organic carbon using the equation: orgC=(OM_R)/1.724	With the pesticide sorption coefficient, determines how much pesticide is held (sorbed) to soil and how much is dissolved in water (available for runoff)	Impacts (directly or indirectly) density, water holding capacity, erodibility; with chemical Koc, impacts the amount of pesticide held on soil
bd_#	**Bulk density** for # horizon	g/cm^3 generally >1.00 (except for organic or volcanic soils), <2.00	SSURGO *chorizon* table (linked to major component, map unit): DBTHIRDBAR_R for each horizon	No further calculations	Reflects relative porosity, water capacity. Because of narrow range in bulk density values, the impact of its uncertainty is lessened.	Related to soil texture (sand, silt, clay), structure, organic content. Influences soil permeability/ drainage, which influences hydrologic soil groups

Parameter Name	Parameter Description	Units / Range	Source	Extraction/ Derivation	Notes	Relationships/ correlation
water_max_#	**Maximum water capacity** for # horizon; the amount of water retained after large pores have drained (1/3 bar water content)	cm^3/cm^3 fraction <1.0	SSURGO *chorizon* table (linked to major component, map unit): WTHIRDBAR_R for each horizon	Divide by 100 to convert units from percent to cm^3/cm^3	Combined with water_min, defines water holding capacity of soil, which influences curve number, and the irrigation trigger.	Related to soil texture (sand, silt, clay), structure, bulk density, organic content.
water_min_#	**Minimum water capacity** for # horizon; minimum water content at which plants cannot draw water from the soil (15 bar water content)	cm^3/cm^3 fraction <1.0	SSURGO *chorizon* table (linked to major component, map unit): WFIFTEENBAR_R for each horizon	Divide by 100 to convert units from percent to cm^3/cm^3	Affects irrigation trigger and curve number, but generally less influence than water_max	Similar to field capacity
sand_#	**Percent sand (total)** for # horizon	% Range from >0 to <100	SSURGO *chorizon* table (linked to major component, map unit): SANDTOTAL_R for each horizon	No further calculations	Affects temperature routine for volatility, if used. Indirect impact on water holding capacity of soil. Affects bulk density, total porosity, and movement of water in soil, K factor.	Varies with clay content; influences bulk density, field capacity, wilting point, total porosity, K factor values.
clay_#	Percent clay (total) for # horizon	% Range from >0 to <100	SSURGO *chorizon* table (linked to major component, map unit): CLAYTOTAL_R for each horizon	No further calculations	Affects temperature routine volatility, if used. Indirect impact on water holding capacity of soil. Affects bulk density, total porosity, and movement of water in soil, K factor.	Varies with sand content; influences bulk density, field capacity, wilting point, total porosity, K factor values.

Table 4 – Crop-related inputs used in PWC and SAM. Parameters in bold are direct inputs in PWC.

Parameter name	Parameter Description	Units	Source	Extraction/ Derivation	Notes	Relationships/ correlation
Crop/plant factors that can be used to guide pesticide application window						
plant_begin (SAM)	Julian day for beginning of most active crop planting window	day number (julian)	USDA Usual Planting and Harvesting Dates (2006, 2007, 2010)	Beginning of most active planting date. Convert day/ month to Julian day.	Impact depends on timing of pesticide application; model outputs less sensitive to an application window than a single date.	Vary from year to year based on weather (rain, temperature/ growing degree days), soil moisture content.
plant_end (SAM)	Julian day for last date of most active crop planting window	day number (julian)	USDA Usual Planting and Harvesting Dates (2006, 2007, 2010)	End of most active planting date. Convert day/ month to Julian day.	Impact depends on timing of pesticide application; model outputs less sensitive to an application window than a single date.	Vary from year to year based on weather (rain, temperature/ growing degree days), soil moisture content.
plant_date (SAM)	Julian day for midpoint date of most active crop planting window	day number (julian)	USDA Usual Planting and Harvesting Dates (2006, 2007, 2010)	Midpoint between beginning and end of most active planting date. Convert day/ month to Julian day.	Impact depends on timing of pesticide application; model outputs less sensitive to an application window than a single date.	Vary from year to year based on weather (rain, temperature/ growing degree days), soil moisture content.
harvest_begin (SAM)	Julian day for beginning of most active crop harvest window	day number (julian)	USDA Usual Planting and Harvesting Dates (2006, 2007, 2010)	Beginning of most active harvest date. Convert day/ month to Julian day.	Impact depends on timing of pesticide application.	Dictated by planting date, time to maturity for plant, weather conditions.
harvest_end (SAM)	Julian day for last date of most active crop harvest window	day number (julian)	USDA Usual Planting and Harvesting Dates (2006, 2007, 2010)	End of most active harvest date. Convert day/ month to Julian day.	Impact depends on timing of pesticide application.	Dictated by planting date, time to maturity for plant, weather conditions.

Parameter name	Parameter Description	Units	Source	Extraction/ Derivation	Notes	Relationships/ correlation
harvest_date (PWC)	Julian **day for midpoint date of most active crop harvest window**	day number (julian)	USDA Usual Planting and Harvesting Dates (2006, 2007, 2010)	Midpoint between beginning and end of most active harvest date. Convert day/ month to Julian day.	Impact depends on timing of pesticide application.	Dictated by planting date, time to maturity for plant, weather conditions.
emergence_begin (SAM)	Julian day for beginning of crop emergence window	day number (julian)	Estimated from USDA Usual Planting and Harvesting Dates (2006, 2007, 2010)	Estimated from beginning planting date, in Julian days.	Impact depends on timing of pesticide application.	
emergence_end (SAM)	Julian day for end of crop emergence window	day number (julian)	Estimated from USDA Usual Planting and Harvesting Dates (2006, 2007, 2010)	Estimated from ending planting date, in Julian days.	Impact depends on timing of pesticide application.	
emergence_date (PWC)	Julian **day for midpoint of crop emergence window**	day number (julian)	Estimated from USDA Usual Planting and Harvesting Dates (2006, 2007, 2010)	Estimated from midpoint planting date, in Julian days.	Impact depends on timing of pesticide application.	
bloom_begin (SAM)	**Julian day for beginning of bloom window**, if relevant	day number (julian)	USDA Usual Planting and Harvesting Dates (2006, 2007, 2010) or Crop Profiles	Where available (primarily orchards, vegetables)	Impact depends on timing of pesticide application.	
bloom_end (SAM)	Julian day for end of bloom window, if relevant	day number (julian)	USDA Usual Planting and Harvesting Dates (2006, 2007, 2010) or Crop Profiles	Where available (primarily orchards, vegetables)	Impact depends on timing of pesticide application.	
maxcover_begin (SAM)	Julian day for beginning of maximum canopy cover window	day number (julian)	Estimated from USDA Usual Planting and Harvesting Dates (2006, 2007, 2010)	Estimated from beginning planting date, in Julian days.	Impact depends on timing of pesticide application.	
maxcover_end (SAM)	Julian day for end of maximum canopy cover window	day number (julian)	Estimated from USDA Usual Planting and Harvesting Dates (2006, 2007, 2010)	Estimated from ending planting date, in Julian days.	Impact depends on timing of pesticide application.	

Parameter name	Parameter Description	Units	Source	Extraction/ Derivation	Notes	Relationships/ correlation
maxcover_date (PWC)	Julian **day for midpoint of maximum canopy cover window**	day number (julian)	Estimated from USDA Usual Planting and Harvesting Dates (2006, 2007, 2010)	Estimated from midpiont planting date, in Julian days.	Impact depends on timing of pesticide application.	
Factors Used to Estimate Amount of Rainfall Reaching Ground from Canopy						
crop_intercept	**Maximum rainfall interception** storage of crop (cm)	cm	Table 5.4 in PRZM3 manual (Carousel et al, 2005) for major crops.	Link crop-related data to major crops in CDL general land cover classes	Used to define amount of rainfall intercepted before reaching the soil.	Related to crop type.
max_cover	Maximum areal coverage of **canopy** (%)	%	Carousel et al (2005); Young and Fry (2016)	Link crop-related data to major crops in CDL general land cover classes	Used to define amount of rainfall intercepted before reaching the soil.	Related to crop type. For most crops, 80-100% maximum.
Crop-specific Inputs for Irrigation						
root_depth	Maximum **active rooting depth** of crop (cm)	cm	Table 3-4 of NEH 652 Irrigation Guide (USDA NRCS, 1997) and Table 11-3 of NEH 632 Sprinkler Irrigation Guide (USDA NRCS, 2016)	Average of depths reported in tables; adjust by root_zone_ max (lesser depth); must be at least 0.5 cm less than soil depth	Defines depth for activating irrigation.	Related to crop, soil depth.
irrigation_fraction	Percent of crop area irrigated (area to be designated)	%	2013 Farm and Ranch Irrigation Survey (USDA NASS, 2014)	Table 35, Irrigation Survey (USDA NASS, 2014) – divide irrigated acres by total acres for crop	Determines whether irrigation will be simulated.	Irrigation is triggered when >40% of the crop acres in a state are irrigated.
irrigation_type	**Dominant irrigation type**	blank=none; over=over canopy (e.g., spray, pivot); under=below canopy (e.g., furrow, flood)	2013 Farm and Ranch Irrigation Survey (USDA NASS, 2014)	Table 36, Irrigation Survey (USDA NASS, 2014) – compare over canopy acres (pressure, sprinkler) to under canopy (gravity, low flow)		

Parameter name	Parameter Description	Units	Source	Extraction/ Derivation	Notes	Relationships/ correlation
depletion_allowed	**Fraction of water capacity depletion allowed by crop**	fraction	USDA NRCS National Engineering Handbook (USDA NRCS, 1997, 2016).	Minimum depletion fraction from NEH 652 Table 3-3; default of 0.5.		
leaching_frac	**Extra fraction of water added by irrigation for leaching**	fraction	USDA NRCS National Engineering Handbook (USDA NRCS, 1997, 2016).	Default of 0.1.		
Irrigation_rate	**Maximum daily irrigation rate**	Cm/da	USDA NRCS National Engineering Handbook USDA NRCS, 2003), Chapter 4: Hydrology.	Calculate based on NRCS Curve Number method		
			Crop-specific factors affecting erosion			
usle_p	Universal soil loss **agricultural practices factor** (P value)	dimensionless fraction	Ag Handbook 703; RUSLE data tables; Table 2, Section 2.3.2.4	Derive from slope, practice, using Table 2.	Sensitivity analysis on soil erosion (RUSLE) model inputs is needed. Expected to have greater impact on high-Koc chemicals, but the extent has not been tested.	Derived from slope gradient, agricultural practice.
usle_c_cov, usle_c_fal	Universal soil loss **cover management factors** for fallow and crop cover (C value)	dimensionless fraction	Ag Handbook 703; RUSLE data tables; data provided by USDA in the file *Crop Input Data.xlsx*	Link crop-related data to major crops in CDL general land cover classes.	Sensitivity analysis on soil erosion (RUSLE) model inputs is needed. Expected to have greater impact on high-Koc chemicals, but the extent has not been tested.	Unknown; related to crop type, cultivation practice.

Table 5 – Weather inputs used in PWC and SAM.

Parameter in SAM code	Parameter Name / Description	Units	Source	Extraction/ Derivation	Notes	Relationships/ correlation
Each set of weather data are stored as a separate file identified by the WeatherID number						
month	Calendar month	mm	NOAA CPC Unified Rain Gauge Analysis (US) and NOAA NCEP/NCAR Reanalysis (Global)	See Fry et al, 2016		
day	Calendar day	dd				
year	Calendar year	yyyy				
precipitation	Precipitation, daily total	cm/day			Precipitation in relation to timing of pesticide application is an important driver.	
ET	Evapotranspiration	cm/da				
Temperature	Air temperature at 2m	degrees (°) Celsius				
WindSpeed	wind speed at 10 m	cm/s				
SolarRadiation	Solar radiation flux at surface	La/day (S_L)				
Climate Factors Linked to Weather Station Grids						
sfac	**Snowmelt factor** (cm/C), used to calculate snowmelt rates in relation to temperature.	cm/C	Table 3.6 in PRZM5 manual (Young and Fry, 2014) gives range in SFAC related to forest covers.	Use 0.36 for crops, non-forested land covers; 0.16 for forest covers	Model sensitivity has not been evaluated.	
rainfall	**Rainfall distribution region** used to calculation time of concentration of peak flow	Value 1 to 4	Figure 3.3 in PRZM5 manual (Young and Fry, 2014), based on USDA TR-55.	IREG assigned to weather grids based on rainfall distribution map (Figure 5)	Model sensitivity has not been evaluated. Broad regions across country.	
anted	Min. **depth from which evaporation is extracted** during fallow period (cm)	cm	10 cm for soil w/ limited drainage. Figure 3.1 in PRZM5 manual (Young and Fry, 2014) for free-drainage soils.	Assigned midpoint value from range in Figure 6 for each associated weather grid	Model sensitivity has not been evaluated.	

Appendix B: Soil Input Fields Extracted from SSURGO

Soil data in the gridded version of SSURGO (gSSURGO) are in geodatabases that must be joined to the spatial grids by keys (USDA NRCS SSS, 2018). Table 6 lists the fields and tables for the input parameters extracted from SSURGO.

Table 6 - Soil Input Fields Extracted from SSURGO

SSURGO Field	SSURGO Table	SSURGO Field Name	PWC/SAM Input Name	Application
mukey	muaggatt, component	Mapunit Key	soil_id	Link muaggatt, component tables in SSURGO
muname	muaggatt	Mapunit Name	Used to identify soil for PWC field scenarios	QA to identify type of missing map units, PWC scenario name
slopegradwta	muaggatt	Slope gradient, weighted average for map unit (%)	slope	Slope input
hydgrpdcd	muaggatt	Hydrologic Soil Group, dominant for mukey	hydro_group	Used to derive runoff curve number
cokey	component, chorizon	Component Key	cokey	Link component, chorizon tables; used in QA
comppct_r	component	Component % – Representative Value	not in final scenario inputs	% of component in map unit: sort major components
majcompflag	component	Major Component flag	not in final scenario inputs	Identify major components in the map unit (flag = Yes)
hydgrp	component	Hydrologic Soil Group for the component	hydro_group (alternate)	Alternate hydrologic soil group input if hydgrpdcd is missing
sloplenusle_r	component	Slope Length USLE – Representative Value	slope_length	Soil input to determine USLE LS value (along with slope)
hzdept_r	chorizon	Top Depth – Representative Value	not in final scenario inputs	Sort horizon inputs by depth
hzthk_r	chorizon	Thickness of horizon – Representative Value	thickness_#	Horizon input; depth-weighted calculations for SAM
sandtotal_r	chorizon	Total Sand – Representative Value	sand_#	Horizon input (for volatility), soil grouping parameter
claytotal_r	chorizon	Total Clay – Representative Value	clay_#	Horizon input (for volatility), soil grouping parameter
om_r	chorizon	OM – Representative Value	orgC = om_r/1.724	Derive horizon input for organic C
dbthirdbar_r	chorizon	Db 0.33 bar H2O [bulk density] – Representative Value	bd_#	Horizon input for bulk density (BD)
wthirdbar_r	chorizon	0.33 bar H2O [field capacity] – Representative Value	water_max_#	Horizon input for maximum water capacity
wfifteenbar_r	chorizon	15 bar H2O [wilting point] – Representative Value	water_min_#	Horizon input for minimum water capacity
kwfact	chorizon	K-Factor Whole Soil	usle_k	Soil input (uppermost layer) for soil erodibility
rootznemc	valu_fy2018 .gdb	Maximum depth of the root zone (cm), based on soil properties	not in final scenario inputs	Used, in conjunction with crop rooting depth to define root_depth

Appendix C: Land Cover Classes and General Crop Groups from CDL

USDA NASS (2014-2018) accuracy assessments show that, on a state-by-state basis, the Cropland Data layer (CDL) is relatively accurate (90% or greater) for states that are major producers of major commodity crops, such as corn, soybeans, wheat, and cotton, which are grown over extensive contiguous areas, and for which the USDA has independent data for training and quality assurance analysis[1]. However, a high frequency of error for other crops suggests that CDL may not be suitable for representing non-commodity minor crops. To address this, OPP aggregated minor crops into broader crop groupings to reduce the level of uncertainty in spatial footprints in individual crops.

These general crop groups should provide viable distinctions factors that impact the use of pesticides and subsequent fate/transport from the field, such as land cover class as it impacts runoff (curve number) or erosion (crop practice factor) and time of plant or harvest as it relates to potential timing of pesticide application. Thus, it is more critical to distinguish between vegetable crops and orchards than between apple and peach orchards or between tomatoes and peppers.

OPP evaluated aggregating CDL categories into more general crop groupings similar to those used by the U.S. Geological Survey (Baker and Capel, 2011) and the Generic Endangered Species Task Force (Amos et al, 2010) to improve the accuracy and year-to-year matches.

The full error matrices are available by year on the NAS CDL website[2]. The accuracy assessment looks at two types of accuracy (described in the NASS documentation for Accuracy Assessment): how well the ground truth crop pixels are correctly identified by the CDL (called "Producer's Accuracy") and how well the CDL pixels correctly match the underlying ground truth (called "User's Accuracy"). "Omission error," associated with Producer's Accuracy, refers to the frequency in which the ground truth pixels are missed in the validation data. "Commission error," associated with User's Accuracy, refers to the frequency in which CDL pixels misclassify the underlying ground truth pixels in the validation data.

Commodity crops, such as corn, cotton, and wheat, generally have a relatively high accuracy because of the wealth of training data available, while small/minor crops often have a relatively low accuracy because of insufficient training data. Field size can also have an impact on accuracy, as more identification errors are likely to occur along field boundaries than in the middle of a field with uniform crop coverage.

The CDL error matrices spreadsheets are used to determine whether the accuracy can be improved when the individual crops are aggregated into general class groups. To determine whether the accuracy for the overall general groupings are sufficiently improved to be viable as

[1] Metadata that include error analysis are available for download at https://www.nass.usda.gov/Research_and_Science/Cropland/metadata/meta.php.
[2] Available on the USDA NASS CDL site in the FAQ section at https://www.nass.usda.gov/Research_and_Science/Cropland/sarsfaqs2.php#Section1_11.0

a surrogate for the individual crops in that group, OPP aggregated both the CDL categories and the underlying actual land covers into the respective groups.

OPP then evaluated whether some of the broader general crop groups (vegetables, orchards, grains, ground fruit) could be divided into smaller crop groupings based on the CFR label crop groups (Table 7). In most cases, the smaller label crop groupings are less accurate than the broader general land cover classes. The key here is whether the change in accuracy is sufficiently small to have a small impact on the overall accuracy.

In that analysis, only the orchard and vineyard group was further divided. The accuracies of individual orchard and vineyard crops in CA (2016 CDL) varies from 2 to 90% (producer's accuracy) while the aggregate orchard/vineyard group has a producer's accuracy of 92%. Further analysis indicates that, at least in CA, grapes can be separated with minimal loss in producer's accuracy (89%). Among the CDL Orchard classes, the resulting producer's accuracy was decent for citrus (88%), pome fruit (83%), and tree nuts (90%), but poor for stone fruit (34%). Because the stone fruit categories in CA tended to be mis-identified as tree nuts, a lumped stone fruit/tree nut subgroup might be supported by the accuracy assessment.

Further refinements in the accuracy assessments could be made using NASS CDL confidence layers[3], which provide a confidence value for each pixel based on how well it fit into the decision tree used to classify it, and/or the national cultivated layer, which is based on the most recent five years of data.

The resulting general land cover class groupings (with numeric designation in parentheses) used in scenario development are:

Corn (10): Corn and double-cropped classes with corn in the rotation.

Cotton (20): Cotton and double-cropped classes with cotton in the rotation.

Rice (30): Cultivated rice.

Soybeans (40): Soybeans and double-cropped classes with soybeans in the rotation.

Durum (22), Spring (23), and Winter (24) Wheat: Durum, spring, and winter wheat classes, along with those double-cropped classes with wheat in the rotation.

Vegetables (60) and ground fruit (61): This pulls together the individual vegetable crops, which have low accuracy rates in CDL. It also includes ground fruit which, while using different cultivation patterns, aren't well distinguished from surrounding vegetable (or other) classes.

Grapes (71): Grapes/vineyards, originally grouped as "Orchards and Vineyards", but separated after evaluating the most recent accuracy assessments for grapes and orchards.

Citrus (72): Oranges and other citrus, originally grouped as "Orchards and Vineyards", but separated after evaluating the most recent accuracy assessments for grapes and orchards.

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[3] National confidence layers and national cultivated layers are available for download at https://www.nass.usda.gov/Research_and_Science/Cropland/Release/index.php

Other orchards (70): This includes all nut and fruit trees and other tree orchards that could not be reasonably distinguished due to a relatively high error rate. A number of orchard areas are often misidentified as pasture, grassland or pasture (presumably the grass lanes between tree rows contribute more to the optical signal than do the trees), shrubland, or forest.

Other grains (80): This includes all small grain crops other than wheat.

Other row crops (90): Sunflower, peanuts, tobacco, sugar beets, and hops that could not be reasonably distinguished due to a relatively high error rate.

Other crops (100): CDL classes – other crops, aquaculture, idle cropland – that don't fit in the above groups. These are of minor extent in CDL.

Pasture/hay/forage (110): This includes specific hay crops, such as alfalfa, clover, and vetch, and general pasture, hay, and forage classes. It also includes grassland, which may include pasture land in some parts of the country.

Open (121), Low (122), Medium (123), and High (124) Intensity Developed categories were kept separate because the intensity differences can be used to estimate turf area and relative impervious surface area and curve number determination also depends on intensity of development.

Forest (140): This merges deciduous, evergreen, and mixed forest classes, along with more generic forest classes.

Shrubland (160).

Water (180) includes all water body types identified in CDL.

Woody (190) and herbaceous (195) wetlands were kept as separate groups because of differences in curve number determinations.

Miscellaneous lands (200) include other land classes that don't fit in any of the above groupings. These are of minor extent in CDL.

Table 7 lists the individual CDL class values and names, as reported in the yearly cropland data layer spatial data. The general crop groups are described above. The curve number cover class is used in combination with hydrologic soil groups to determine curve number (Appendix D). The FIFRA label crop group will be used to link pesticide label specifications to the scenarios.

Table 7 - Crosswalk between CDL Classes and General Land Cover Classes.

CDL Value	CDL Category (name)	General CDL Class (number)	Curve Number Cover Class	CFR Label Crop Group (USEPA, 2018)
1	Corn	Corn (10)	Row Crop	Cereal Grains (15B)
2	Cotton	Cotton (20)	Row Crop	Oilseed (20C)
3	Rice	Rice (30)	Small Grain	Cereal Grains (15C)
4	Sorghum	Other grains (80)	Small Grain	Cereal Grains (15B)
5	Soybeans	Soybeans (40)	Row Crop	Legumes (6)
6	Sunflower	Other row crops (90)	Row Crop	Oilseed (20B)
10	Peanuts	Other row crops (90)	Row Crop	not listed

CDL Value	CDL Category (name)	General CDL Class (number)	Curve Number Cover Class	CFR Label Crop Group (USEPA, 2018)
11	Tobacco	Other row crops (90)	Row Crop	not listed
12	Sweet Corn	Vegetables (60)	Row Crop	Cereal Grains (15B)
13	Pop or Orn Corn	Vegetables (60)	Row Crop	Cereal Grains (15B)
14	Mint	Vegetables (60)	Row Crop	Herbs and Spices (25)
21	Barley	Other grains (80)	Small Grain	Cereal Grains (15A)
22	Durum Wheat	Wheat, Durum (22)	Small Grain	Cereal Grains (15A)
23	Spring Wheat	Wheat, Spring (23)	Small Grain	Cereal Grains (15A)
24	Winter Wheat	Wheat, Winter (24)	Small Grain	Cereal Grains (15A)
25	Other Small Grains	Other grains (80)	Small Grain	Cereal Grains (15A)
26	Dbl Crop WinWht/ Soybeans	Wheat (24) / Soybeans (40)	Small Grain / Row Crop	Cereal Grains (15A) / Legumes (6)
27	Rye	Other grains (80)	Small Grain	Cereal Grains (15A)
28	Oats	Other grains (80)	Small Grain	Cereal Grains (15A)
29	Millet	Other grains (80)	Small Grain	Cereal Grains (15B)
30	Speltz	Other grains (80)	Small Grain	Cereal Grains (15A)
31	Canola	Other grains (80)	Small Grain	Oilseed (20A)
32	Flaxseed	Other grains (80)	Small Grain	Oilseed (20A)
33	Safflower	Other grains (80)	Small Grain	Oilseed (20B)
34	Rape Seed	Other grains (80)	Small Grain	Oilseed (20A)
35	Mustard	Vegetables (60)	Row Crop	Vegetables, Brassica Leafy (4-16B)
36	Alfalfa	Pasture/hay/forage (110)	Close-seeded legumes	Nongrass Animal Feeds (18)
37	Other Hay/Non-Alfalfa	Pasture/hay/forage (110)	Pasture, grass, range	Nongrass Animal Feeds (17)
38	Camelina	Other grains (80)	Small Grain	Oilseed (20A)
39	Buckwheat	Other grains (80)	Small Grain	Cereal Grains (15A)
41	Sugarbeets	Other row crops	Row Crop	Vegetables, Root and Tuber (1A)
42	Dry Beans	Vegetables (60)	Row Crop	Vegetables, Legume (6C)
43	Potatoes	Vegetables (60)	Row Crop	Vegetables, Root and Tuber (1C)
44	Other Crops	Other crops (100)	Row Crop	Mixed
45	Sugarcane	Other grains (80)	Small Grain	not listed
46	Sweet Potatoes	Vegetables (60)	Row Crop	Vegetables, Root and Tuber (1D)
47	Misc Vegs & Fruits	Vegetables (60)	Row Crop	Mixed
48	Watermelons	Vegetables (60)	Row Crop	Vegetables, Cucurbit (9A)
49	Onions	Vegetables (60)	Row Crop	Vegetables, Bulb (3-07A)
50	Cucumbers	Vegetables (60)	Row Crop	Vegetables, Cucurbit (9B)
51	Chick Peas	Vegetables (60)	Row Crop	Vegetables, Legume (6C)
52	Lentils	Vegetables (60)	Row Crop	Vegetables, Legume (6C)
53	Peas	Vegetables (60)	Row Crop	Vegetables, Legume (6A, 6B, 6C)
54	Tomatoes	Vegetables (60)	Row Crop	Vegetables, Fruiting (8-10A)
55	Caneberries	Ground fruit (61)	Row Crop	Berries and Small Fruit (13-07A)
56	Hops	Other row crops (90)	Row Crop	not listed

CDL Value	CDL Category (name)	General CDL Class (number)	Curve Number Cover Class	CFR Label Crop Group (USEPA, 2018)
57	Herbs	Vegetables (60)	Row Crop	Herbs and Spices (19)
58	Clover/Wildflowers	Other crops (100)	Close-seeded legumes	Nongrass Animal Feeds (18)
59	Sod/Grass Seed	Other crops (100)	Pasture, grass, range	not listed
60	Switchgrass	Pasture/hay/forage (110)	Pasture, grass, range	Nongrass Animal Feeds (17)
61	Fallow/Idle Cropland	Other crops (100)	Fallow	not listed
62	Pasture/Grass	Pasture/hay/forage (110)	Pasture, grass, range	Nongrass Animal Feeds (17)
63	Forest	Forest (140)	Woods	
64	Shrubland	Shrubland (160)	Brush-weed-grass	
65	Barren	Miscellaneous land (200)	Fallow	
66	Cherries	Other Orchards (70)	Woods-grass	Stone Fruit (12-12A)
67	Peaches	Other Orchards (70)	Woods-grass	Stone Fruit (12-12B)
68	Apples	Other Orchards (70)	Woods-grass	Pome Fruit (11-10')
69	Grapes	Grapes (71)	Woods-grass	Berries and Small Fruit (13-07F)
70	Christmas Trees	Other trees (75)	Woods-grass	
71	Other Tree Crops	Other Orchards (70)	Woods-grass	Mixed
72	Citrus	Citrus (72)	Woods-grass	Citrus Fruits (10-10A)
73	unidentified	Miscellaneous land (200)	Fallow	
74	Pecans	Other Orchards (70)	Woods-grass	Tree Nuts (14-12)
75	Almonds	Other Orchards (70)	Woods-grass	Tree Nuts (14-12)
76	Walnuts	Other Orchards (70)	Woods-grass	Tree Nuts (14-12)
77	Pears	Other Orchards (70)	Woods-grass	Pome Fruit (11-10')
81	Clouds/No Data	Miscellaneous land (200)	Fallow	
82	Developed	Developed-med (123)	Residential-1/8 ac	
83	Water	Water (180)	na	
87	Wetlands	Wetlands -herbaceous (195)	Meadow	
88	Nonag/Undefined	Miscellaneous land (200)	Fallow	
92	Aquaculture	Other crops (100)	na	
111	Open Water	Water (180)	na	
112	Perennial Ice/Snow	Miscellaneous land (200)	Fallow	
121	Developed/Open Space	Developed-open (121)	Developed open space	
122	Developed/Low Intensity	Developed-low (122)	Residential-1/3 ac	
123	Developed/Med Intensity	Developed-med (123)	Residential-1/8 ac	
124	Developed/High Intensity	Developed-high (124)	Urban	
131	Barren	Miscellaneous land (200)	Fallow	

CDL Value	CDL Category (name)	General CDL Class (number)	Curve Number Cover Class	CFR Label Crop Group (USEPA, 2018)
141	Deciduous Forest	Forest (140)	Woods	
142	Evergreen Forest	Forest (140)	Woods	
143	Mixed Forest	Forest (140)	Woods	
152	Shrubland	Shrubland (160)	Brush-weed-grass	
176	Grassland/Pasture	Pasture/hay/forage (110)	Pasture, grass, range	Nongrass Animal Feeds (17)
190	Woody Wetlands	Wetlands-woods (190)	Woods	
195	Herbaceous Wetlands	Wetlands -herbaceous (195)	Meadow	
204	Pistachios	Other Orchards (70)	Woods-grass	Tree Nuts (14-12)
205	Triticale	Other grains (80)	Small Grain	Cereal Grains (15A)
206	Carrots	Vegetables (60)	Row Crop	Vegetables, Root and Tuber (1A)
207	Asparagus	Vegetables (60)	Row Crop	Vegetables, Stem and Stalk (22A)
208	Garlic	Vegetables (60)	Row Crop	Vegetables, Bulb (3-07A)
209	Cantaloupes	Vegetables (60)	Row Crop	Vegetables, Cucurbit (9A)
210	Prunes	Other Orchards (70)	Woods-grass	Stone Fruit (12-12C)
211	Olives	Other Orchards (70)	Woods-grass	Tropical fruit, edible peel (23A)
212	Oranges	Citrus (72)	Woods-grass	Citrus Fruits (10-10A)
213	Honeydew Melons	Vegetables (60)	Row Crop	Vegetables, Cucurbit (9A)
214	Broccoli	Vegetables (60)	Row Crop	Vegetables, Brassica (5-16')
216	Peppers	Vegetables (60)	Row Crop	Vegetables, Fruiting (8-10B, 8-10C)
217	Pomegranates	Other Orchards (70)	Woods-grass	Fruit (24B)
218	Nectarines	Other Orchards (70)	Woods-grass	Stone Fruit (12-12B)
219	Greens	Vegetables (60)	Row Crop	Vegetables, Leafy (4-16A)
220	Plums	Other Orchards (70)	Woods-grass	Stone Fruit (12-12C)
221	Strawberries	Ground fruit (61)	Row Crop	Berries and Small Fruit (13-07G)
222	Squash	Vegetables (60)	Row Crop	Vegetables, Cucurbit (9B)
223	Apricots	Other Orchards (70)	Woods-grass	Stone Fruit (12-12C)
224	Vetch	Pasture/hay/forage (110)	Close-seeded legumes	Nongrass Animal Feeds (18)
225	Dbl Crop WinWht/ Corn	Wheat (24) / Corn (10)	Small Grain/ Row Crop	Cereal Grains (15B / 15A)
226	Dbl Crop Oats/Corn	Other Grains (80) / Corn (10)	Small Grain/ Row Crop	Cereal Grains (15B / 15A)
227	Lettuce	Vegetables (60)	Row Crop	Vegetables, Leafy (4-16A)
229	Pumpkins	Vegetables (60)	Row Crop	Vegetables, Cucurbit (9B)
230	Dbl Crop Lettuce/ Durum Wht	Wheat/Vegetables	Small Grain/ Row Crop	Vegetables, Leafy (4-16A) / Cereal Grains (15A)
231	Dbl Crop Lettuce/ Cantaloupe	Vegetables (60)	Row Crop	Vegetables, Leafy (4-16A) / Vegetables, Cucurbit (9A)
232	Dbl Crop Lettuce/ Cotton	Vegetables (60) / Cotton (20)	Row Crop / Row Crop	Vegetables, Leafy (4-16A) / Oilseed (20C)

CDL Value	CDL Category (name)	General CDL Class (number)	Curve Number Cover Class	CFR Label Crop Group (USEPA, 2018)
233	Dbl Crop Lettuce/ Barley	Vegetables (60)	Row Crop	Vegetables, Leafy (4-16A) / Cereal Grains (15A)
234	Dbl Crop Durum Wht/ Sorghum	Wheat (22) / Other Grains (80)	Small Grain / Small Grain	Cereal Grains (15A/15B)
235	Dbl Crop Barley/ Sorghum	Other grains (80) / Other grains (80)	Small Grain / Small Grain	Cereal Grains (15A/15B)
236	Dbl Crop WinWht/ Sorghum	Wheat (24) / Other Grains (80)	Small Grain / Small Grain	Cereal Grains (15A/15B)
237	Dbl Crop Barley/Corn	Other Grains (80) / Corn (10)	Small Grain/ Row Crop	Cereal Grains (15A/ 15B)
238	Dbl Crop WinWht/ Cotton	Wheat (24) / Cotton (20)	Small Grain/ Row Crop	Cereal Grains (15A) / Oilseed (20C)
239	Dbl Crop Soybeans/ Cotton	Soybeans (40) / Cotton (20)	Row Crop / Row Crop	Legumes (6) / Oilseed (20C)
240	Dbl Crop Soybeans/Oats	Soybeans (40) / Other Grains (80)	Row Crop / Small Grain	Legumes (6) / Cereal Grains (15A)
241	Dbl Crop Corn/ Soybeans	Corn (10) / Soybeans (20)	Row Crop / Row Crop	Cereal Grains (15B) / Legumes (6)
242	Blueberries	Ground fruit (61)	Row Crop	Berries and Small Fruit (13-07B, 13-07G)
243	Cabbage	Vegetables (60)	Row Crop	Vegetables, Brassica (5-16')
244	Cauliflower	Vegetables (60)	Row Crop	Vegetables, Brassica (5-16')
245	Celery	Vegetables (60)	Row Crop	Vegetables, Stem and Stalk (22B)
246	Radishes	Vegetables (60)	Row Crop	Vegetables, Root and Tuber (1A)
247	Turnips	Vegetables (60)	Row Crop	Vegetables, Root and Tuber (1A)
248	Eggplants	Vegetables (60)	Row Crop	Vegetables, Fruiting (8-10B, 8-10C)
249	Gourds	Vegetables (60)	Row Crop	Vegetables, Cucurbit (9B)
250	Cranberries	Ground fruit (61)	Row Crop	Berries and Small Fruit (13-07H)
254	Dbl Crop Barley/Soybeans	Other Grains (80) / Soybeans (40)	Small Grain/ Row Crop	Cereal Grains (15A) / Legumes (6)

Appendix D: Determining the Runoff Curve Number

Runoff curve numbers are based on hydrologic soil group, general land cover class, agricultural/land use practices, and general hydrologic condition (USDA NRCS 2004a, 2008). Use the following steps to assign a curve number for both full canopy cover (*cn_cov*) and post-harvest (*cn_fal*) conditions:

1. Identify the hydrologic soil group (HSG) for the dominant component in the soil mapping unit. If the HSG is a combination (i.e., C/D, B/C), select the most runoff-prone hydrologic value (runoff vulnerability follows the order D > C > B > A).
2. Determine Curve Number Land Cover class from the crosswalk with USDA Cropland Data Layer (CDL) categories (Table 7 in Appendix C).
3. Determine the Curve Number under full canopy cover (*cn_cov*) using Table 9 below.
    a. Unless otherwise specified, assume crops are planted on contour with crop residue left after harvest (C+CR) for treatment practice in Table 9.
    b. Unless otherwise specified, assume good or fair hydrologic conditions.
    c. The curve number cover classes for the developed classes are based on the percent of impervious surface (50-75% grass cover for open; 30% impervious for low; 65% impervious for medium; 85% impervious for high).
4. Determine the curve number for fallow conditions (*cn_fal*)
    a. For the crop/agricultural land cover classes, use the curve numbers for the crop residue cover under fallow in Table 8.
    b. For the woods, meadow, brush, and developed/residential classes, use the same curve number as for the cn_ag

Table 8 - Curve Number Guidance based on NRCS TR-55 Methodology (USDA NRCS, 2008).

Cover Type	Treatment or Practice	Hydrol. Cond.	HSG A	HSG B	HSG C	HSG D
Fallow	Bare Soil	---	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight Row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured and terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T + CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85

Cover Type	Treatment or Practice	Hydrol. Cond.	HSG A	HSG B	HSG C	HSG D
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T + CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80
Pasture, grassland, or range; continuous forage for grazing		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
Meadow - continuous grass, protected from grazing; generally mowed for hay		---	30	58	71	78
Brush - brush-weed-grass mixture w/ brush as the major element		Poor	48	67	77	83
		Fair	35	56	70	77
		Good	30	48	65	73
Woods - grass combination (orchard or tree farm) (based on 50% woods, 50% grass)		Poor	57	73	82	86
		Fair	43	65	76	82
		Good	32	58	72	79
Woods		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	30	55	70	77
Farmsteads - buildings, lanes, driveways, surrounding lots		----	59	74	82	86
Developed Open Space	<50% grass cover	Poor	68	79	86	89
	50 - 75% grass cover	Fair	49	69	79	84
	>75% grass cover	Good	39	61	74	80
Impervious: paved lots, roofs, driveways, etc			98	98	98	98
Streets & Roads	Paved curbs, storm sewers		98	98	98	98
	Paved, open ditches, incl ROW		83	89	92	93
	Gravel, incl ROW		76	85	89	91
	Dirt, incl ROW		72	82	87	89
Urban	Commercial, business	85% imperv	89	92	94	95
	Industrial	72% imperv	81	88	91	93
Residential	1/8 ac lots or less (townhouse)	65% imperv	77	85	90	92
	1/4 ac lots	38% imperv	61	75	83	87
	1/3 ac lots	30% imperv	57	72	81	86
	1/2 ac lots	25% imperv	54	70	80	85
	1 ac lots	20% imperv	51	68	79	84
	2 ac lots	12% imperv	46	65	77	82

Appendix E: Estimating Crop Milestone Dates

Both PWC (PRZM module) and SAM require crop emergence, maturity and harvest dates to characterize crop canopy and root growth. For annual field crops, OPP selected state-level "most active" planting and harvesting dates to parameterize the PRZM crop growth module (USDA NASS, 2010).

In some instances, the crop will occur in a state, but not in sufficient acreage to have a reported date range (USDA NASS, 2006, 2007, and 2010). To address these data gaps, OPP combined the USDA Cropland Data Layer, Census of Agriculture, and Usual Plant and Harvest Dates for Field Crops to estimate missing crop growth dates.

Data Sources

The USDA, NASS Cropland Data Layer (CDL) provides planted acreage estimates for major commodities and digital, crop-specific, 30-meter geo-referenced output products. Data were accessed through the USDA NASS Cropland internet portal (USDA NASS, 2014-2018).

The Census of Agriculture (CoA) is a complete count of U.S. farms and ranches and provides the only source of uniform, comprehensive and impartial agricultural data for every county in the nation. The CoA provides more crop-specific classifications and acreage resolution than CDL. Data were accessed through the USDA NASS Quick Stats internet portal (USDA NASS, 2012).

The USDA Field Crops: Usual Plant and Harvest Dates (UPHD) identifies state-level periods when annual crops are planted and harvested based on 20 years of crop progress data. Beginning dates indicate when planting or harvesting is about 5 percent complete and ending dates when operations are about 95 percent complete. The "most active" range indicates when between 15 and 85 percent of the crop is planted or harvested (USDA NASS, 2010).

For pesticide registration purposes and establishing residue tolerances, USEPA organizes agricultural commodities into crop groups, that are botanically and agronomically related. OPP accounted for the on-going multi-year joint project with NAFTA partners in Canada and Mexico to revise the existing crop groups in 40 CFR 180.41 (USEPA, 2018).

Estimating Surrogate Dates for Annual Field Crops

The CDL provides the spatial footprint for the field scenarios. The area of individual CDL categories and associated general land cover groups and CFR label groups (see Appendix C) are tallied by state to identify the occurrence of the crop/group in the state. This is combined with state-level acreage for each crop from the CoA and state-wide plant and harvest dates from the UPHD.

OPP used both the CDL and the CoA to confirm that the crop was present in the state. If the UPHD listed plant and harvest dates are used for that crop in that state, these dates were used to estimate crop milestone dates. If the UPHD listed no dates for the crop in a state where CDL and CoA confirm that it occurs, OPP estimated surrogate plant and harvest dates.

Where the UPHD were missing for some crops in some states, OPP identified surrogate dates for those states in which the crop occurs but has no reported dates, in the following order of availability:

1. Same crop in an adjacent state
2. Another crop in the same general CDL class in the same state. If more than 1 crop within the general CDL class has dates, select the one that is most similar in terms of agronomic practices

The goal is to ensure that crop milestone dates are available for each of the general scenarios being developed. The dates and estimation methods are documented in the accompanying *Crop Dates.xlsx* file.

Estimating Dates for Double Cropping Categories

The CDL data includes double cropping categories. While USDA NASS focuses largely on summer crops, ground truthing identifies whether a single or double crop was planted in a given year. CDL captures the major crop rotations/patterns, but not winter fruits and vegetables (USDA NASS, 2010-2017). Since published UPHD for double crops were not reported. EFED retained the harvest dates of the second crop but used the harvest dates of the initial crop as the surrogate planting date for the unpublished second crop. The dates and estimation methods are documented in the accompanying *Crop Dates.xlsx* file.

Deriving Emergence, Maturity and Harvest Dates for Annual Field crops

The plant and harvest dates were used to derive the emergence, maturity and harvest dates. The average planting and harvest dates were calculated for each state. The date of emergence was estimated as 7 days after the average planting date for each state. The maturity was calculated as the midpoint between the average planting and harvest dates for each state.

Estimating Dates for Perennial Cropping Categories

Cropping milestone dates for perennial crops – primarily pasture/hay/forage crops, tree orchards, and vineyards – need to be defined in terms of equivalent stages. Emergence for perennials reflects the beginning of active growth, such as new growth in hay/forage crops or the onset of leaf bud in trees. This can be defined based on the last frost/freeze day in the spring, or to the beginning of bloom in orchard trees. Full, or maximum, canopy cover may be tied to timing of growth between cuttings for hay/forage or to full leaf-out in trees. Harvest, which represents the time of foliage/canopy removal, would be tied to times of actual harvest for hay/forage crops but would be better represented by leaf drop, rather than nut/fruit harvest, for orchards. Methods for estimating these equivalent dates for both pasture/hay/forage crops and for fruit/nut orchards and vineyards are documented in the accompanying *Crop Dates.xlsx* file.

Selecting Milestone Dates for General Scenarios

While crop dates are initially developed for individual CDL crops (where available), scenarios will be developed for major crops or general crop classes described in Appendix C. The crop milestone dates will be aggregated by general crop class/group. If more than one crop within the general scenario has dates, OPP evaluated the range in active planting and harvest dates to determine whether distinct differences in timing are evident (i.e., midpoints fall in different seasons).

1. If the active planting and/or harvest date ranges largely overlap, select the crop with the greatest acreage in the state to represent the general group.
2. If distinct differences occur in planting and harvest dates, determine whether a separate scenario should be developed.

Appendix F. Aggregating Soil Horizons and Map Units for SAM

For the Spatial Aquatic Model (SAM), OPP made two modifications in processing the soil inputs in order to reduce computer processing and storage demands needed to run national-scale risk assessments on a routine basis. The modifications resulted in minimal impact on estimated pesticide concentrations in water (USEPA OPP, 2015). The SAP panel noted that, while the modifications are defensible and do not impact model outputs, OPP should remain open to technological advances that may negate the need for condensing data in the future (FIFRA SAP, 2015).

Depth Weighting

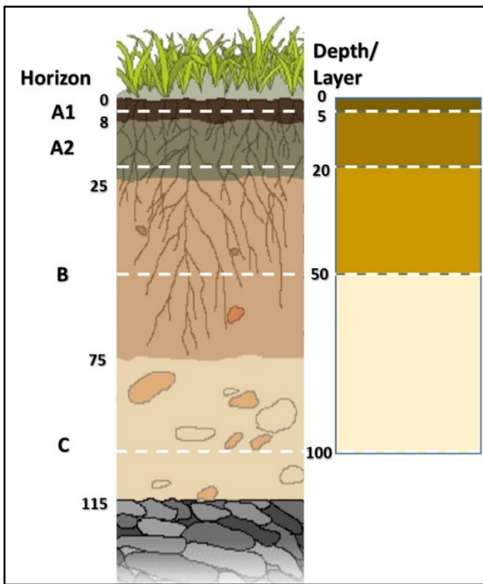
PWC scenarios use data for individual horizons, leaving a variable number of columns for each soil map unit, based on the number of horizons present. For SAM, four standardized layers of fixed depth intervals – 0-5, 5-20, 20-50, and 50-100 cm – are used for processing millions of soil map unit inputs. Properties for the 0-5 cm layer are based on the surface horizon data in SSURGO. Properties for the remaining three layers are depth-weighted averages of the soil properties by horizon (see Figure 6 for illustration):

$$S\_layer = \frac{sum(S\_hor \times thickness\ of\ horizon)}{total\ thickness\ of\ layer}$$

Where

S_layer = soil property (orgC, bd, fc, wp, s, c, ph) value calculated for the layers used for SAM inputs (0-5, 5-20, 20-50, 50-100 cm)

S_hor = soil property (orgC, bd, fc, wp, s, c, ph) value for the soil horizon identified by SSURGO



Calculating depth-weighted values for soil property S:

$S\_5 = S\_{A1}$

$S\_20 = \frac{(S\_{A1} \times 3cm) + (S\_{A2} \times 12cm)}{15\ cm}$

$S\_50 = \frac{(S\_{A2} \times 5cm) + (S\_B \times 25cm)}{30\ cm}$

$S\_100 = \frac{(S\_B \times 25cm) + (S\_C \times 25cm)}{50\ cm}$

Figure 5: Illustration for calculating depth-weighted values for soil horizon data, standardized to four layers (0-5, 5-20, 20-50, 50-100 cm).

Aggregating Soil Map Units

For the 2015 SAP, USEPA OPP (2015) explored grouping individual soil map units into classes based on USDA's soil water quality index (WQI) values for hydrologic soil group, slope, soil erodibility and surface organic matter content (Lal and McKinney, 2012). Initial analyses found no impacts on estimated pesticide concentrations for hydrologic soil groups and slope classes; no appreciable impacts for organic matter classes >2%, and limited impacts on high-sorbing pesticides for soil erodibility classes. The SAP Panel noted that the aggregated soil classes were a viable option for reducing the number of scenarios in a national model, but suggested that OPP reconsider those simplifying assumptions if the driving rationale is current storage/computational limitations (FIFRA SAP, 2015).

OPP revisited the soil grouping classes/criteria, exploring the relationships between independent soil variables (e.g., organic carbon content, sand, clay) in the 0-5 cm and 5-20 cm layers. Properties for the surface (0-5 cm) layer had the greatest impacts on runoff estimates. Correlations were evident between organic C content and bulk density and between clay and sand content and minimum/maximum water capacity. The revised soil groupings are based on hydrologic soil group, slope, surface organic C content, sand, and clay content for the surface (0-5 cm) layer (Table 9).

Table 9 - Soil Parameter Classes Used to Derive Aggregated Soil Groups.

Soil Parameter	No. Classes	Class Breaks (Aggregated Soil ID)
Hydrologic soil group	7	A, AD, B, BD, C, CD, D
Slope (%)	6	0-2 (sl1), 2-5 (sl2), 5-10 (sl3), 10-15 (sl4), 15-25 (sl5), >25 (sl6)
Organic C (%)	11	0-0.5 (o1), 0.5-1 (o2), 1-1.5 (o3), 1.5-2 (o4), 2-3 (o5), 3-4 (o6), 4-5 (o7), 5-6 (o8), 6-12 (o9), 12-20 (o10), >20 (o11)
Sand content (%)	10	0-10 (s1), 10-20 (s2), 20-30 (s3), 30-40 (s4), 40-50 (s5), 50-60 (s6), 60-70 (s7), 70-80 (s8), 80-90 (s9), 90-100 (s10)
Clay content (%)	10	0-5 (c1), 5-10 (c2), 10-15 (c3), 15-20 (c4), 20-25 (c5), 25-30 (c6), 30-40 (c7), 40-60 (c8), 60-80 (c9), 80-100 (c10)