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FARM FOOD CHAIN MODULE: BACKGROUND AND IMPLEMENTATION FOR THE MULTIMEDIA, MULTIPATHWAY AND MULTIPLE RECEPTOR RISK ASSESSMENT (3MRA) MODEL FOR HWIR 99

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Steve Beaulieu, Terry Pierson, Anne Lutes, and Hwong-Wen Ma of Research Triangle Institute developed the farm food chain module. Randy Williams, Jennifer Drake, and Amy Cole of Research Triangle Institute tested and implemented the current version of the model.

DISCLAIMER

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1.1 Overview

The Farm Food Chain (FFC) Module calculates the concentration of a chemical in homegrown produce (fruits and vegetables), farm crops for cattle (forage, grain, and silage), beef, and milk. The concentrations in homegrown produce, beef, and milk are inputs to the Human Exposure Module and are used to calculate the applied dose to human receptors who consume them. The modeling construct for the FFC module is based on recent and ongoing research conducted by the U.S. Environmental Protection Agency (EPA) Office of Research and Development (ORD) and presented in *Methodology for Assessing Health Risks Associated with Multiple Exposure Pathways to Combustor Emissions* (U.S. EPA, in press).

The module is designed to predict the accumulation of a contaminant in the edible parts of a plant from uptake of contaminants in soil and through transpiration and direct deposition of the contaminant in air. Concentrations are predicted for three main categories of food crops presumed to be eaten by humans: exposed fruits and vegetables (i.e., those without protective coverings, such as lettuce), protected vegetables (e.g., those with protective covering, such as corn), and root vegetables (e.g., potatoes). In addition, the module estimates the contaminant concentration from the biotransfer of contaminants in feed (i.e., forage, grain, and silage), soil, and drinking water to beef and dairy cattle through ingestion.

The Farm Food Chain Module contains two separate programs; one predicts the concentration of contaminants in produce grown by home gardeners and the other predicts the concentration of contaminant in food crops, beef, and milk produced on farms. The module was designed with this functionality because not all study areas contain farms and the methodology developed for farms is different than that developed for the home gardener. The program for home gardeners uses point estimates of air and soil concentrations at the residential receptor location assigned to each census block. In contrast, the program used for farms calculates an area-weighted average soil concentration for the farm and uses an interpolation subroutine to estimate the average air concentration across the area of the farm. Thus, the predicted concentrations in farm food crops reflect the spatial average for the farm. Similarly, the feed concentrations for the cattle are derived using spatial averages. In predicting concentrations in beef and milk, the contribution from contaminated drinking water sources, such as farm ponds or wells on the farm, is also considered. However, irrigation of crops and home gardens is not modeled.

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Because the behavior of each chemical constituent is, to a large degree, determined by chemical properties, the module includes a series of chemical-specific switches that turn on the appropriate subroutines, depending on whether the chemical is an organic (O), metal (M), special (S), or dioxin-like (D). For most organic chemicals the industrial exposure module calculates chemical-specific values for the biotransfer factors used in the various equations, including air-to-plant biotransfer factor, root concentration factor, and soil-to-plant biotransfer factor. Metals, dioxin-like chemicals, and special chemicals generally use literature values for these various biotransfer factors, when available. For dioxin-like compounds and special chemicals, the biotransfer factors will be calculated in the same way as for organics if literature values are not available.

1.2 Summary of Functionality

The major computational functions performed by the Farm Food Chain Module are the following:

- *Concentrations of contaminants in homegrown produce.* The concentrations of contaminants in fruits and vegetables are calculated for home gardens and for farms.

- *Concentrations of contaminants in cattle feed.* The concentrations of contaminants in pasture grass (i.e., forage), silage, and grain are calculated for beef and dairy farms.

- *Concentrations of contaminants in locally grown beef and milk.* The concentrations of contaminants in beef and milk produced on local farms are calculated.

These functions are described in detail in Section 3.0.

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2.0 Assumptions and Limitations

The contaminant concentration calculations used in the Farm Food Chain Module reflect a number of assumptions and/or limitations:

- *Study area is bounded at 2 km.* It is assumed that all significant contaminant concentrations occur within 2 km of the source. Concentrations are not determined outside the 2-km study area.

- *Homogeneous concentrations in fruits and vegetables are assumed.* For unprotected fruits and vegetables, the exposure methodology makes no provision for the possible chemical concentration gradients within the produce that might result in different concentrations in edible portions.

- *Resuspension and redeposition on plants are not considered.* Plant concentrations are a function of the deposition of the contaminants that have been emitted from the waste management unit (WMU). Plant concentrations do not consider resuspension and redeposition. These processes can occur due to tillage, wind erosion, vehicular resuspension, and rainsplash, but will not be examined by this model.

- *Inhalation and dermal exposure are not considered in cattle.* Beef and dairy cattle calculations consider only contaminant pathways of food, soil, and water ingestion. Other pathways such as inhalation or dermal exposure are not considered in this module.

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3.0 Methodology

The concentration of contaminant in fruits and vegetables is calculated in different ways depending on the type of produce and on the location (i.e., residential home garden or farm). Fruits and vegetables are categorized as aboveground or root (i.e., belowground) and as protected or exposed. The calculations for each are described in the sections below. In addition, media concentrations used for garden home produce are based on a single point estimate, and media concentrations used for produce grown on farms are based on spatial averages.

3.1 Aboveground Plant Concentration

Plant vegetation consumed by humans is separated into three main categories: "exposed" fruits and vegetables, "protected" fruits and vegetables, and root vegetables. The terms "exposed" and "protected" refer to whether or not the edible portion of the produce is exposed to the atmosphere. Examples include tomatoes (exposed vegetables), bananas (protected fruit), and potatoes (root vegetables). Final calculations give a contaminant concentration for each type of plant.

Vegetation consumed by animals includes grain, forage, and silage. Grain is considered to be a protected vegetation and forage an exposed vegetation. Silage refers to any plants harvested for animal consumption, whether protected or exposed. Thus, silage is calculated as exposed vegetation but is given an empirical parameter, VG_{ag}, to account for being partly protected and partly exposed. A description of VG_{ag} is provided in Section 3.1.3.

Waste management units release contaminants into the air that then redeposit to the ground or move through the air and redeposit on plants by wet or dry deposition. The contaminant in the soil can then be taken up through a plant's roots. The three mechanisms by which contaminants can bioaccumulate in vegetation are: deposition of particle-bound contaminants to exposed plant tissues, deposition of vapor-phase contaminant to exposed plant tissues, and root uptake. Particle-phase depositions and vapor-phase depositions are calculated for exposed fruits and vegetables but not for protected fruits or vegetables or root vegetables, since the edible portion of the vegetation is not in direct contact with air. Accumulation can occur by root uptake of contaminants through water for protected vegetables and fruit grown aboveground or by absorption into the outer parts of the root vegetables.

The following equation is used to calculate total exposed aboveground plant concentration.

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$$P_{xxx\_xxx_{DW}} = PD_{xxx\_xxx_{DW}} + PV_{xxx\_xxx_{DW}} + PR_{xxx\_xxx_{DW}} \quad (3\text{-}1)$$

where

$P_{xxx\_xxx\_DW}$ = total concentration in plant (mg/kg DW)

In Equation 3-1, the FFC module calculates the total exposed aboveground plant concentration for the farm and the home garden by summing the plant concentrations due to direct deposition of particle-bound contaminants ($PD_{xxx\_xxx\_DW}$), direct deposition of vapor-phase contaminants ($PV_{xxx\_xxx\_DW}$), and root uptake ($PR_{xxx\_xxx\_DW}$). Each of these is discussed in the following sections.

3.1.1 Deposition of Particle-Bound Contaminants

Equation 3-2 is used in the Farm Food Chain Model to estimate the concentration of contaminant in above ground, unprotected plants due to direct deposition. Particle-bound contaminants from the air are deposited by wet and dry deposition; thus they affect only exposed vegatation. The air dispersion module calculates the wet and dry deposition rates for the particle-bound contaminants ISCST3. The contaminants from dry deposition are assumed to remain on the surface until weathering occurs. Only a fraction of contaminant from wet deposition remains on the plant's surface; the rest washes off immediately. The variable F_w is the fraction of wet deposition that adheres to a plant's surface.

Not all airborne particles will settle on a plant's edible surface; some will fall to the ground, others will fall on other surfaces that will undergo weathering processes such as wind removal, water removal, and growth dilution, and most will end up in the soil or runoff. The interception variable in Equation 3-2, R_p, determines the actual amount of airborne particles that contacts the edible portion of the plant. The plant's surface can also lose contaminants due to weathering. Plant-surface loss is determined over time by the coefficient k_p. The length of exposure to contaminants is measured by T_p. One determination of the length of exposure is the growing season. For instance, the time from when a tomato begins to grow until it is harvested would equal the length of exposure. The last variable in Equation 3-2 is plant biomass, Y_p, or the productivity level of the plant. Biomass is determined by the amount of standing crop for the average farm. Equation 3-2 is calculated by adding the amount of deposition by wet and dry processes, multiplying by the interception fraction, and dividing by the standing crop biomass.

The Farm Food Chain Module estimates an annual average ParDDepAve and ParWDepAve from the $ParDDep_{xy}$ and $ParWDep_{xy}$ set of points that represents the farm or residential area. The aboveground plant concentration due to direct deposition of particle-bound contaminants is calculated for exposed vegetables, exposed fruit, silage, and forage at the farm. These concentrations are represented by $PD_{exveg\_farm\_DW}$, $PD_{exfruit\_farm\_DW}$, $PD_{silage\_farm\_DW}$, and $PD_{xxx\_xxx\_DW}$, respectively. Concentration values are calculated for exposed fruit and vegetables for the home gardens and are represented by $PD_{exveg\_garden\_DW}$ and $PD_{exfruit\_garden\_DW}$.

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Plant Concentration Due to Direct Deposition

$$PD_{xxx\,xxx_{DW}} = \frac{1{,}000 \cdot 365 \cdot [ParDDepAve + (Fw_{xxx} \cdot ParWDepAve) \cdot Rp_{xxx}(1.0 - \exp^{(-kpPar_{xxx} \cdot Tp_{xxx})})]}{Yp_{xxx} \cdot kpPar_{xxx}} \quad (3\text{-}2)$$

where

$PD_{xxx\_xxx\_DW}$	=	concentration in plant due to direct deposition (mg/kg DW)
1,000	=	units conversion factor (1,000 mg/g)
365	=	units conversion factor (365 d/yr)
ParDDepAve	=	average dry deposition rate (g/m^2-yr)
Fw_{xxx}	=	fraction of wet deposition that adheres to plant surface (unitless)
ParWDepAve	=	average wet deposition rate (g/m^2-yr)
Rp_{xxx}	=	interception fraction (unitless)
$kpPar_{xxx}$	=	plant surface loss of particle-bound constituent (1/yr)
Tp_{xxx}	=	length of plant exposure (yr)
Yp_{xxx}	=	yield or standing crop biomass (kg DW/m^2).

3.1.2 Deposition of Vapor-Phase Contaminants

The FFC module treats various categories of chemicals differently for vapor-phase calculations. Most metals do not exist in vapor form and thus are not assessed for this pathway. Constituents that have low log K_{ow} (<5) use a similar equation (3-3) to that used for particle-bound contaminants (Equation 3-2). The main difference is that vapor concentration data are used instead of particle data and the plant loss coefficient is for vapor not particle contaminants. For constituents that have a high log K_{ow} (>5), evidence shows that wet deposition is negligible; therefore, a different equation (3-4) is used.

The vapor-phase calculation multiplies the average air concentration, the air-to-plant biotransfer factor, and an empirical correction factor, then divides by the density of air, which is a standard constant. The air-to-plant biotransfer factor is defined as the ratio of contaminant concentration in exposed plant parts to the vapor-phase concentration of contaminant in air. The volume-based transfer factor, Bvol, is calculated using the log K_{ow} and Henry's law constant with the universal gas constant and the air temperature. The volume-based equation can be transformed to a mass-based transfer factor, Bv, that considers leaf density, density of air, and percent of wet leaf that is dry matter (see equations 3-5 and 3-6). The empirical correction factor, VG_{ag}, is used to consider the difference between outer-surface and whole-plant concentrations, as with silage. Washing and peeling fruits and vegetables reduces the outer surface residues, which VG_{ag} takes into effect. Because silage is assumed to be partly protected and partly exposed, the correction factor takes into account that some of the vegetation is not contaminated due to vapor deposition onto plant surfaces.

The average vapor concentration (C_vAve) is calculated in a manner similar to the calculation of ParDDepAve and the ParWDepAve in Equation 3-2. $PV_{xxx\_xxx\_DW}$ is calculated for

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exposed vegetables, exposed fruit, silage, and forage for the farm and exposed vegetable and exposed fruit for the home garden. These concentrations are represented by $PV_{exveg\_farm\_DW}$, $PV_{exfruit\_farm\_DW}$, $PV_{silage\_farm\_DW}$, $PV_{forage\_farm\_DW}$, $PV_{exveg\_garden\_DW}$, and $PV_{exfruit\_garden\_DW}$ respectively. The calculation performed will vary depending on the type of chemical. The following two calculations are for a nonmetal; the appropriate calculation is selected based on the K_{ow}.

Plant Concentration Due to Vapor-Phase Contaminants

Calculated for a nonmetal with a $K_{ow} < 100{,}000$ (or $\log K_{ow} < 5$):

$$PV_{xxx\,xxx_{DW}} = \frac{1000 \cdot 365 \cdot [VapDDepAve + (Fw_{xxx} \cdot VapWDepAve) \cdot Rp_{xxx}(1.0 - \exp^{(-kpVap_{xxx} \cdot Tp_{xxx})})]}{Yp_{xxx} \cdot kpVap_{xxx}} \quad (3\text{-}3)$$

where

$Pv_{xxx\_xxx\_DW}$	=	concentration in plant due to direct deposition (mg/kg DW)
1,000	=	units conversion factor (1,000 mg/g)
365	=	units conversion factor (365 d/yr)
VapDDepAve	=	average dry deposition rate (g/m^2-yr)
Fw_{xxx}	=	fraction of wet deposition that adheres to plant (unitless)
VapWDepAve	=	average wet deposition rate (g/m^2-yr)
Rp_{xxx}	=	interception fraction (unitless)
Tp_{xxx}	=	length of plant exposure (yr)
Yp_{xxx}	=	yield or standing crop biomass (kg DW/m^2)
$kpVap_{xxx}$	=	degradation loss of vapor-phase constituents (1/yr)

and VapDDepAve is estimated using the CvAve as in the following equation:

$$VapDDepAve = 0.31536 \cdot CvAve \cdot VapDdv$$

where

VapDDepAve	=	areal average yearly dry deposition rate (g constituent/m^2-yr)
0.31536	=	units conversion factor ((m/yr)/cm/s and (g/µg))
CvAve	=	spatial average vapor-phase concentration in air (µg/m^3)
VapDdv	=	default factor of 1 for vapor phase dry deposition velocity (cm/s).

Calculated for a nonmetal with a $K_{ow} \geq 100{,}000$ (or $\log K_{ow} \geq 5$):

$$PV_{xxx\,xxx_{DW}} = \frac{CvAve \cdot Bv_{xxx} \cdot VG_{ag\,xxx}}{1000 \cdot \rho_{air}} \quad (3\text{-}4)$$

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where

$Pv_{xxx\_xxx\_DW}$	=	plant concentration due to vapor (mg/kg DW)
CvAve	=	vapor phase concentration in air (µg/m^3)
Bv_{xxx}	=	air-to-plant biotransfer factor ([µg/g DW]/[µg/g air])
Vg_{ag_xxx}	=	empirical correction factor (unitless)
1,000	=	units conversion factor (g/m^3)
ρ_{air}	=	density of air (constant at 1.19 g/L).

Volume-Based Air-to-Plant Biotransfer Factor

Calculated for exposed fruits and vegetables, forage, and silage for organic constituents only. This parameter is calculated for use in Equation 3-6:

$$\log Bvol = 1.065 \log K_{ow} - \log\left[\frac{HLC}{RT}\right] - 1.654$$

$$Bvol = antilog\ [\log Bvol] \qquad (3\text{-}5)$$

where

Bvol	=	biotransfer factor ([µg/L F_W leaf]/[µg/L air])
K_{ow}	=	octanol/water partition coefficient (unitless)
HLC	=	Henry's law constant (atm-m^3/mol)
R	=	universal gas constant (constant at 8.205E-05 atm-m^3/mol-K)
T	=	air temperature (constant at 298.1 K).

Mass-Based Air-to-Plant Biotransfer Factor

Calculated for exposed fruits and vegetables, forage, and silage for organic constituents only:

$$Bv = \left(\frac{\rho_{air} \cdot Bvol}{\left(\frac{(100 - MAF_{leaf})}{100}\right) \cdot \rho_{leaf}}\right) \cdot \frac{1}{Bv_{ecf_{plant}}} \qquad (3\text{-}6)$$

where

Bv	=	biotransfer factor ([µg/g DW plant]/[µg/g air])
ρ_{air}	=	density of air (constant at 1.19 g/L)
Bvol	=	biotransfer factor ([µg/L F_W leaf]/[µg/L air])
MAF_{leaf}	=	moisture content in leaf (percentage)
ρ_{leaf}	=	density of the leaf (g/L F_W)
$Bv_{ecf_{plant}}$	=	empirical correction factor for Bv (unitless).

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Equations 3-5 and 3-6 are for organic and special constitutes only, otherwise use the value in the Chemical Properties Processor (CPP).

3.1.3 Root Uptake

Plants can take up contaminants through their roots by translocation. Water, which contains contaminants from the soil and ground water, moves up the roots moving contaminants to the aboveground shoots. The aboveground root equation (3-7) multiplies the plant-soil bioconcentration factor by the depth-averaged soil concentration. The plant-soil bioconcentration factor, Br, measures the chemical's ability to accumulate in plant tissue and is the ratio of contaminant concentration in plants to the concentration in soil.

Aboveground Plant Concentrations Due to Root Uptake

$$PR_{xxx\,farm_{DW}} = CTdaAve \cdot Br_{xxx} \qquad (3\text{-}7)$$

where

$Pr_{xxx\_farm\_DW}$	=	plant concentration due to root uptake and translocation (mg/kg DW)
CtdaAve	=	depth-averaged soil concentration across farm area (µg/g soil)
Br_{xxx}	=	soil-to-plant biotransfer factor ([µg/g DW]/[µg/g soil]).

Chemical constituents are classified as dioxin-like (D), mercury (Hg), metal (M), organic (O), or special (S); the module selects the equations and values needed to calculate the results. For organics, an equation has been developed to calculate Br; for other constituents, the module has to rely on measured data collected from various sources. The equation for Br (Equation 3-8), derived for organic chemicals, is dependent on the solubility of a chemical in water, which is inversely proportional to the octanol-water partition coefficient, K_{ow}. In constituents that are more lipophilic and do not take in as much contaminants through the roots, Br is assumed to account for possible resuspension and redeposition, which may add to the contaminant concentration.

The depth-averaged soil concentration comes from the watershed and source modules. Depending on the type of WMU, the regional soil information is used or both regional and local soil information are used in the calculation as shown in Equations 3-9 and 3-10. To calculate the soil concentration, the fraction of the farm or home garden located in the watershed is multiplied by the soil concentration. The farm or home garden fraction is available from the site layout developed by the Site Definition Processor (SDP).

Biotransfer Factor for Soil to Plant

Calculated for exposed and protected fruits and vegetables, forage, silage, and grain for organic (nondioxin) constituents only:

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$$\log Br = 1.588 - 0.578 \log K_{ow}$$
$$Br = antilog\ [\log Br] \quad (3\text{-}8)$$

where

Br = biotransfer factor ([µg/g DW plant]/[(µg/g soil])
K_{ow} = octanol/water partition coefficient (unitless).

Aboveground Plant Concentrations Due to Root Uptake - Local Watershed

$$PR_{xxx\ garden_{DW}} = CTda \cdot Br_{xxx} \quad (3\text{-}9)$$

where

$PR_{xxx\_garden\_DW}$ = plant concentration due to root uptake and translocation (mg/kg DW)
CTda = depth-averaged soil concentration in local watershed (µg/g soil)
Br_{xxx} = soil-to-plant biotransfer factor ([µg/g DW]/[µg/g soil]).

Aboveground Plant Concentrations Due to Root Uptake - Regional Watershed Only

$$PR_{xxx\ garden_{DW}} = CTdaR \cdot Br_{xxx} \quad (3\text{-}10)$$

where

$Pr_{xxx\_garden\_DW}$ = plant concentration due to root uptake and translocation (mg/kg DW)
CtdaR = depth-averaged soil concentration in regional watershed (µg/g)
Br_{xxx} = soil-to-plant biotransfer factor [µg/g DW]/[µg/g soil].

The following equations show the subroutines used to calculate the soil concentrations for the farm and home garden.

Farm

The module first calculates CTdaAVE using subroutine WAVEda as described below. Then the module calculates PR_{xxx} and P_{xxx} for the farm equations.

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Subroutine WAVEda

For $FarmNum_{xy\_Coord}$,
Lookup CTdaR and CTda dimensioned on FarmWSSubIndex and Nyr,
Get FarmWSSubFrac.

Calculate CTdaAve as:

$$CTdaAve = \sum (CTdaR \times FarmWSSubFrac) + \sum (CTda \times FarmWSSubFrac)$$

The FFC module calculates PR_{xxx}, the aboveground plant concentrations due to root uptake (Equation 3-7), for the farm. PR_{xxx} is calculated for exposed vegetables, exposed fruit, silage, forage, protected vegetables, protected fruit, and grain at the farm. These concentrations are represented by $PR_{exveg\_farm\_DW}$, $PR_{exfruit\_farm\_DW}$, $PR_{silage\_farm\_DW}$, $PR_{forage\_farm\_DW}$, $P_{proveg\_farm\_DW}$ $P_{profruit\_farm\_DW}$, and $P_{grain\_farm\_DW}$, respectively.

Home Garden

The module obtains CTda (either CTdaR or CTda) dimensioned on HumRcpWSSubIndex for each x,y coordinate and calculates PR_{xxx} for exposed vegetables, exposed fruit, protected vegetables, and protected fruit ($PR_{exveg\_garden\_DW}$, $PR_{exfruit\_garden\_DW}$, $P_{proveg\_garden\_DW}$, and $P_{profruit\_garden\_DW}$) in home gardens.

3.2 Belowground Plant Concentration

For belowground plants, roots can take in contaminants from the soil that may accumulate in the edible portion of the plant. The belowground root uptake equation will vary depending on the constituent being evaluated; the same aboveground uptake equation is used for all constituents. The calculation of concentrations in root vegetables varies depending on the chemical type; if the chemical is organic or special, the Farm Food Chain Module retrieves a value for K_{oc} and calculates the concentration as shown in Equations 3-11 and 3-14. If the chemical type is a metal the module retrieves a value for the soil-to-root uptake factor in the Chemical Properties File and calculates the concentration as shown in Equations 3-12 and 3-15. All other constituents are calculated using Equations 3-13 and 3-16.

The soil-water partition coefficient, K_d, is also used to calculate concentrations in root vegetables for organic constituents. K_d reflects the degree to which contaminant can be absorbed in combination with the soil and is a function of the contaminant organic-carbon partition, K_{oc}, and the soil organic carbon fraction, f_{oc}. The weighted average soil-water partition coefficient, K_dS_{Ave}, is calculated by the K_{oc} and the weighted fraction of organic carbon in depth-averaged soil, $f_{oc}S_{Ave}$. The $f_{oc}S_{Ave}$ is determined by performing a subroutine with the fraction of organic carbon and the fraction of the farm that is located in the watershed. The root concentration factor (RCF) is defined as the ratio of the contaminant concentration in roots to that in the soil water. Two equations are defined, one (3-18) for organic and special compounds with log $K_{ow} < 2.0$ and the second (3-19) for organic and special compounds with log $K_{ow} > 2.0$. If the constituent is not an organic or special chemical, then the RCF is retrieved from the Chemical Properties Processor. An empirical belowground correction factor, Vg_{bg}, was developed to account for the

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volumetric differences among roots of different types of plants. This correction factor also adjusts for peeling, cooking, or cleaning, which can all reduce the contaminant concentration.

If the chemical type is metal, the module retrieves values for Broot from the Chemical Properties Processor and calculates Proot as shown in Equation 3-12.

Concentrations in Root Vegetables—Organic and Special Chemicals

$$Proot_{farm\ DW} = \frac{CTdaAve \cdot RCF \cdot VG_{bg}}{\frac{(100 - MAFroot)}{100} K_dS_{Ave}} \quad (3\text{-}11)$$

where

$Proot_{farm\_Dw}$ = concentration in root vegetables (mg/kg DW)

CTdaAve = depth-averaged soil concentration calculated using subroutine WAVEda (µg/g soil)

RCF = root concentration factor ([µg/g WW plant]/[µg/mL soil water])

Vg_{bg} = empirical correction factor (unitless)

MAFroot = percent of moisture in belowground vegetation (unitless)

K_dS_{Ave} = weighted average soil-water partition coefficient (mL/g)

with K_dS_{Ave} defined by

$$K_dS_{Ave} = K_{oc} \cdot focS_{Ave}$$

where

K_{oc} = organic carbon partition coefficient (mL/g)

$focS_{Ave}$ = watershed area-weighted fraction of organic carbon in depth-averaged soil calculated using WAVEf_{oc}S subroutine (unitless):

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Subroutine WAVEfocS:

For FarmNumWSSub,
Lookup focS dimensioned on Nb and Nsa,
Match with FarmWSSubFrac.
Calculate $focS_{Ave}$ as:

$$\sum (focS \times FarmWSSubFrac) = focS_{Ave}$$

The equation for metals calculates the concentration by multiplying the depth-averaged soil by the soil-to-root uptake factor, Broot. The equation for chemicals other than metals multiplies the depth-averaged soil, a root concentration factor, and an empirical correction factor for belowground plants, then the value is divided by the percent of moisture in the belowground vegetation multiplied by the weighted average soil-water partition coefficient. If the chemical is not an organic or metal, then the module retrieves the values for RCF and K_dS_{Ave}. This is essentially the same method as shown in Equation 3-11, except the value for K_dS_{Ave} is retrieved and not calculated from the K_{oc}.

Concentrations in Root Vegetables—Metals

$$Proot_{farm\_DW} = CTdaAve \cdot Broot \qquad (3\text{-}12)$$

where

$Proot_{farm\_DW}$ = concentration in root vegetables (mg/kg DW)

CtdaAve = depth-averaged soil concentration calculated using subroutine WAVEda (µg/g soil)

Broot = soil-to-root uptake factor ([µg/g WW plant]/[µg/mL soil water]).

If neither Equation 3-11 nor 3-12 is appropriate, the module uses the Chemical Abstracts Service (CAS) number to retrieve values for RCF and K_d from the CPP, and calculates Proot as shown in Equation 3-13. This is essentially the same method as Equation 3-11, except the value for K_d is retrieved from CPP and not calculated from the K_{oc}.

Concentrations in Root Vegetables–Other

$$Proot_{farm\_DW} = \frac{CTdaAve \cdot RCF \cdot VG_{bg}}{\frac{(100 - MAFroot)}{100} K_dS_{Ave}} \qquad (3\text{-}13)$$

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where

$Proot_{farm\_Dw}$	=	concentration in root vegetables (mg/kg DW)
CtdaAve	=	depth-averaged soil concentration calculated using subroutine WAVEda (µg/g soil)
RCF	=	root concentration factor ([µg/g WW plant]/[µg/mL soil water])
Vg_{bg}	=	empirical correction factor (unitless)
MAFroot	=	percent of moisture in belowground vegetation (unitless)
K_dS_{Ave}	=	weighted average soil-water partition coefficient (mL/g)

Concentrations in Root Vegetables—Organic and Special Chemicals

$$Proot_{garden\,DW} = \frac{CTda \cdot RCF \cdot VG_{bg}}{\frac{(100 - MAFroot)}{100} K_{dS}} \quad (3\text{-}14)$$

where

$Proot_{garden\_DW}$	=	concentration in root vegetables (mg/kg DW)
$CTda_{ws}$	=	depth-averaged soil concentration in a local watershed containing the x,y coordinate for the home gardener (µg/g)
RCF	=	root concentration factor ([µg/g WW plant]/[µg/mL soil water])
Vg_{bg}	=	empirical correction factor (unitless)
MAFroot	=	percent of moisture in belowground vegetation (unitless)
K_{dS}	=	soil-water partition coefficient (mL/g)

with K_{dS} defined by

$$K_{dS} = K_{oc} \cdot focS$$

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where

K_{oc} = organic carbon partition coefficient (mL/g)

focS = fraction of organic carbon in depth-averaged soil dimensioned on Nb (unitless).

If the receptor is local and the chemical type is metal, the module retrieves values for Broot from the CPP and calculates Proot as shown in Equation 3-15.

Concentrations in Root Vegetables—Metals

$$Proot_{garden\_DW} = CTda \cdot Broot \quad (3\text{-}15)$$

$Proot_{garden\_DW}$ = concentration in root vegetables (mg/kg DW)

$CTda_{ws}$ = depth-averaged soil concentration in a local watershed containing the x,y coordinate for the home gardener (µg/g)

Broot = soil-to-root uptake factor ([µg/g WW plant]/[µg/mL soil water]).

If neither Equation 3-14 nor 3-15 is appropriate, the module uses the CAS number to retrieve values for RCF and K_d from the CPP and calculates Proot as shown in Equation 3-16. This is essentially the same method as Equation 3-14, except the value for K_d is retrieved from the CPP and not calculated from the K_{oc}.

Concentrations in Root Vegetables—Other

$$Proot_{garden\_DW} = \frac{CTda \cdot RCF \cdot VG_{bg}}{\frac{(100 - MAFroot)}{100} K_d} \quad (3\text{-}16)$$

where

$Proot_{garden\_Dw}$ = concentration in root vegetables (mg/kg DW)

$Ctda_{ws}$ = depth-averaged soil concentration in a local watershed containing the x,y coordinate for the home gardener (µg/g)

RCF = root concentration factor ([µg/g WW plant]/[µg/mL soil water])

Vg_{bg} = empirical correction factor (unitless)

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MAFroot = percent of moisture in belowground vegetation (unitless)

K_d = soil-water partition coefficient (mL/g).

Because concentrations for $PR_{exveg\_xxx\_DW}$, $PR_{exfruit\_xxx\_DW}$, $P_{proveg\_xxx\_DW}$, $P_{profruit\_xxx\_DW}$, and $Proot_{xxx\_DW}$ are presented in terms of dry weight, they must be converted to whole weight as shown in Equation 3-17.

Convert DW Concentrations to WW Concentrations

$$P_{xxx\,farm} = \left(\frac{100 - MAF_{xxx}}{100}\right) \cdot P_{xxx\,farm_{DW}} \qquad (3\text{-}17)$$

where

P_{xxx_farm} = concentration in plant tissue group xxx (mg/kg WW)

MAF_{xxx} = plant tissue-specific moisture adjustment factor to convert DW concentration into WW (percent)

$P_{xxx\_farm\_DW}$ = plant tissue concentration (mg/kg DW).

Root Concentration Factor

Calculated for root vegetables for organic and special constituents whose log K_{ow} values are $\leq$2.0:

$$\log(RCF - 0.82) = 0.77 \log K_{ow} - 1.52$$
$$RCF = antilog[\log\ RCF] \qquad (3\text{-}18)$$

where

RCF = root concentration factor ([µg/g WW plant]/[µg/mL soil water])
K_{ow} = octanol/water partition coefficient (unitless).

Calculated for root vegetables for organic and special constituents whose log K_{ow} values are >2.0:

$$\log\ RCF = 0.77 \log K_{ow} - 1.52$$
$$RCF = antilog[\log\ RCF] \qquad (3\text{-}19)$$

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where

RCF = root concentration factor ([µg/g WW plant]/[µg/mL soil water])
K_{ow} = octanol/water partition coefficient (unitless).

Farm

The calculation of concentrations in root vegetables (Proot) varies depending on the chemical type; if the chemical type is O or S, the FFC module retrieves a value for K_{oc} from the CPP and calculates Proot as shown in Equation 3-11.

Home Garden

If the $HumRcpLoc_{xy}$ is in a local watershed, then use $CTda_{ws}$ in Equations 3-14 to 3-17, however, if the HumRcpLocxy is in a regional watershed, then subsitute the CTda (depth-averaged soil concentration in a regional watershed containing the x,y coordinate for the home gardener (μg/g)) for $CTda_{ws}$.

The calculation of concentrations in root vegetables (Proot) varies depending on the chemical type and the location of the receptor. If the chemical type is O or S, the Farm Food Chain Module retrieves a value for K_{oc} from the CPP and calculates Proot as shown in Equation 3-14.

3.3 Animal Tissue Concentration

The animal products that are evaluated by this module come from beef and dairy cattle. Their contaminant concentrations result from plant and water ingestion. The water concentrations come from the surface water module and are dimensioned based on watershed and reaches. The contaminant level found in the water plays a major role in the final concentration. If the farm has at least one reach within the farm's boundaries, then the surface water is used, otherwise the dissolved concentration in ground water is used as the drinking water source for cows. Plant ingestion comes from forage, grain, and silage. Forage is considered an exposed vegetation, grain a protected vegetation, and silage has both properties. The animals are assumed to ingest soil, with which they come in contact during grazing or other activities on untilled soils. The soil concentration used is that of the top layer of soil, which can be from either the local or the regional watershed. Equations 3-20 and 3-21 are used to calculate the concentration of contaminate in beef in the regional watershed and local watershed respectively. Similarly, Equations 3-22 and 3-23 are used to calculate the concentration of contaminant in milk in the regional watershed and local watershed respectively.

Subroutine WAVEss

For $FarmNum_{xy\_Coord}$,
Lookup CTssR and CTss dimensioned on FarmWSSubIndex and Nyr,
Get FarmWSSubFrac.
Calculate CTssAve as:

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$$\sum (\text{CTssR x FarmWSSubFrac}) + \sum (\text{CTss x FarmWSSubFrac}) = \text{CTssAve}$$

Beef Concentration—Regional Watershed

$$Abeef = 1000\ [[[(P_{forage_{farm_{DW}}} \cdot Qp_{forage_{beef}} \cdot f_{forage_{beef}}) + (P_{grain_{farm_{DW}}} \cdot Qp_{grain_{beef}} \cdot f_{grain_{beef}}) + (P_{silage_{farm_{DW}}} \cdot Qp_{silage_{beef}} \cdot f_{silage_{beef}})] + [CTssAve \cdot Qs_{beef} \cdot Bs]]\ Ba_{beef}] + [(WBNRchConcWaterDiss \cdot Qw_{beef} \cdot Ba_{water})] \quad (3\text{-}20)$$

where

$P_{forage\_farm\_DW}$, $P_{grain\_farm\_DW}$, $P_{silage\_farm\_DW}$ are defined in Equation 3-2

and

Abeef	=	concentration of contaminant in beef (µg/g whole weight)
1,000	=	units conversion factor (1,000 g/kg)
Qp_{forage_beef}	=	quantity of forage eaten by beef cattle (kg plant DW/d)
f_{forage_beef}	=	fraction of forage grown in contaminated area (unitless)
Qp_{grain_beef}	=	quantity of grain eaten by beef cattle (kg plant DW/d)
f_{grain_beef}	=	fraction of grain grown in contaminated area (unitless)
Qp_{silage_beef}	=	quantity of silage eaten by beef cattle (kg plant DW/d)
f_{silage_beef}	=	fraction of silage grown in contaminated area (unitless)
CtssAve	=	average concentration in surficial soil from across farm area (µg/g soil)
Qs_{beef}	=	quantity of contaminated soil eaten by beef cattle (kg soil/d)
Bs	=	bioavailability fraction of contaminant in soil relative to vegetation (unitless)
Ba_{beef}	=	biotransfer factor for beef cattle from plants and drinking water (d/g tissue whole weight)
WBNRchConcWaterDiss	=	dissolved concentration in surface water used as drinking water source by beef cattle (mg/L)
Qw_{beef}	=	quantity of drinking water consumed by beef cattle (L/d)
Ba_{water}	=	default biotransfer factor of dissolved contaminant in drinking water set at 1 (d/g)

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Beef Concentration—Local Watershed

$$Abeef = 1000\ [[[(P_{forage_{farm_{DW}}} \cdot Qp_{forage_{beef}} \cdot f_{forage_{beef}}) + (P_{grain_{farm_{DW}}} \cdot Qp_{grain_{beef}} \cdot f_{grain_{beef}}) + (P_{silage_{farm_{DW}}} \cdot Qp_{silage_{beef}} \cdot f_{silage_{beef}})] + [CTssAve \cdot Qs_{beef} \cdot Bs]]\ Ba_{beef}] + [(1000\ AquWellConc \cdot Qw_{beef} \cdot Ba_{water})] \quad (3\text{-}21)$$

where

AquWellConc = dissolved concentration in ground water used as drinking water source by beef cattle (mg/L).

Milk Concentration—Regional Watershed

$$Amilk = 1{,}000\ [[[(P_{forage_{farm_{DW}}} \cdot Qp_{forage_{dairy}} \cdot f_{forage_{dairy}}) + (P_{grain_{farm_{DW}}} \cdot Qp_{grain_{dairy}} \cdot f_{grain_{dairy}}) + (P_{silage_{farm_{DW}}} \cdot Qp_{silage_{dairy}} \cdot f_{silage_{dairy}})] + [CTssAve\ Qs_{dairy} \cdot Bs]]\ Ba_{dairy}] + [(WBNRchConcWaterDiss \cdot Qw_{dairy} \cdot Ba_{water})]] \quad (3\text{-}22)$$

where

$P_{forage\_farm\_DW}$, $P_{grain\_farm\_DW}$, $P_{silage\_farm\_DW}$ are defined above

and

Amilk	=	concentration of contaminant in dairy cattle (µg/g whole weight)
1,000	=	units conversion factor (1,000 kg/kg)
Qp_{forage_dairy}	=	quantity of forage eaten by dairy cattle (kg plant DW/d)
f_{forage_dairy}	=	fraction of forage grown in contaminated area (unitless)
Qp_{grain_dairy}	=	quantity of grain eaten by dairy cattle (kg plant DW/d)
f_{grain_dairy}	=	fraction of grain grown in contaminated area (unitless)
Qp_{silage_dairy}	=	quantity of silage eaten by dairy cattle (kg plant DW/d)
f_{silage_dairy}	=	fraction of silage grown in contaminated area (unitless)
CtssAve	=	average concentration in surficial soil from across farm area (µg/g soil)
Qs_{dairy}	=	quantity of contaminated soil eaten by dairy cattle (kg soil/d)
Bs	=	bioavailability fraction of contaminant in soil relative to vegetation (unitless)

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Ba_{dairy} = biotransfer factor for dairy cattle from plants and drinking water (day/g tissue whole weight)

WBNRchConcWaterDiss = dissolved concentration in surface water used as drinking water source by dairy cattle (mg/L)

Qw_{dairy} = quantity of drinking water consumed by dairy cattle (L/d)

Ba_{water} = default biotransfer factor of dissolved contaminant in drinking water set at 1 (d/g)

Milk Concentration—Local Watershed

$$Amilk = 1000\ [[[(P_{forage_{farm_{DW}}} \cdot Qp_{forage_{dairy}} \cdot f_{forage_{dairy}}) + (P_{grain_{farm_{DW}}} \cdot Qp_{grain_{dairy}} \cdot f_{grain_{dairy}}) + (P_{silage_{farm_{DW}}} \cdot Qp_{silage_{dairy}} \cdot f_{silage_{dairy}})] + [CTssAve\ Qs_{dairy} \cdot Bs]]\ Ba_{dairy}] + [(1000\ AquWellConc \cdot Qw_{dairy} \cdot Ba_{water})] \quad (3\text{-}23)$$

where

CRW = dissolved concentration in ground water used as drinking water source by dairy cattle (mg/L).

Beef Biotransfer Factor

Soil bioavailability is the ratio between biotransfer factors for soil and vegetation for a given contaminant. The efficiency of transfer from soil may differ from the efficiency of transfer from plant material for some chemicals. Vegetation is a more efficient vehicle of transfer for organic and inorganic contaminants than is soil, since vegetation is digested and soil passes through the system. The module calculates a beef biotransfer factor based on the chemical type. If the chemical is organic or special and has a log K_{ow} value between 1.3 and 6.9, the module calculates the beef biotransfer factor as shown in Equation 3-24. Equation 3-4 is only valid for chemicals with a log Kow between 1.3 and 6.9. For organic and special chemicals that have a log Kow less than 1.3 or greater than 6.9 only empired biotransfer factors are used. In the absences of empirical data for such chemicals the beef biotransfer factors are set to 0. In all other cases, the module retrieves a value from the Chemical Properties Processor.

$$\log\ Ba_{beef} = -7.6 + \log K_{ow}$$
$$Ba_{beef} = antilog\ [\log Ba_{beef}] \quad (3\text{-}24)$$

where

Ba_{beef} = beef biotransfer factor (d/g tissue whole weight)
K_{ow} = octanol/water partition coefficient (unitless).

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In all other cases, the module uses the CAS number to retrieve a value for the beef biotransfer factor from the CPP.

The module then uses the WAVEss subroutine to estimate a beef concentration due to ingestion of contaminated plant, soil, and drinking water (Abeef).

Milk Biotransfer Factor

Milk concentrations are calculated in the same way as beef concentrations except the quantity numbers are for dairy cattle not beef cattle. The milk biotransfer factor is calculated as shown in Equation 3-25. If the chemical is organic or special and has a log K_{ow} value between a minimum of 2.8 and maximum of 6.9, the module calculates the milk biotransfer factor.

$$\log Ba_{milk} = -8.1 + \log K_{ow}$$
$$Ba_{milk} = antilog\ [\log Ba_{milk}] \qquad (3\text{-}25)$$

where

Ba_{milk} = milk biotransfer factor (d/g tissue whole weight)
K_{ow} = octanol/water partition coefficient (unitless).

If the chemical is organic or special and has a log K_{ow} less than 2.8 or greater than 6.9, an empirical milk biotransfer factor is used. In all other cases, the module uses the CAS number to retrieve a value for the milk biotransfer factor from the CPP. If no empirical data exists then the Milk Biotransfer factor is set to zero.

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4.0 Implementation

The flowchart shown in Figure 4-1 illustrates the generalized structure of the Farm Food Chain Module.

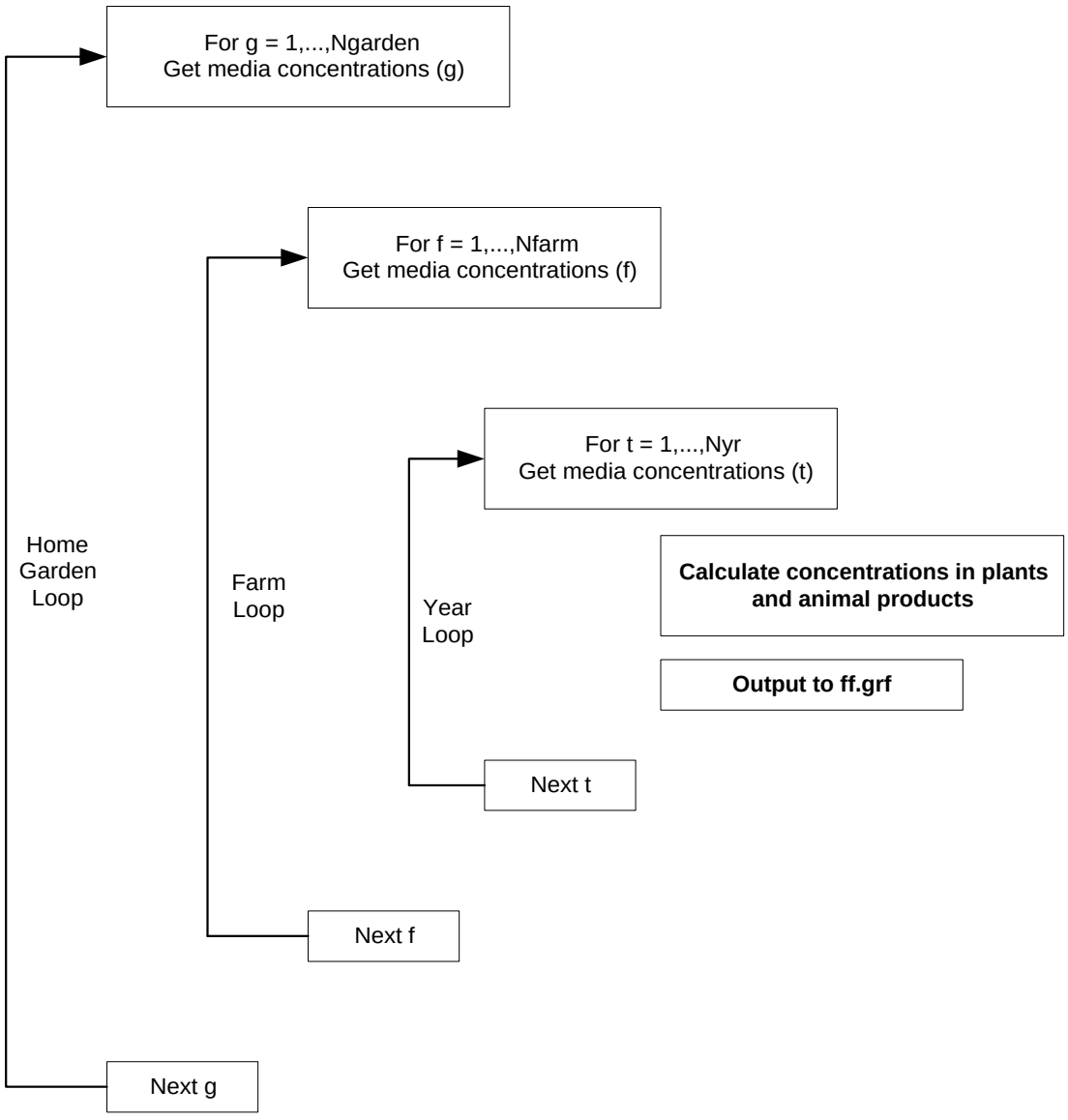

Figure 4-1. Conceptual flow diagram of major functionality of Farm Food Chain Module.

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5.0 References

U.S. EPA (Environmental Protection Agency). In press. *Methodology for Assessing Health Risks Associated with Multiple Exposure Pathways to Combustor Emissions*. EPA/600/6-90/003. National Center for Environmental Assessment, Cincinnati, OH.

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Appendix A

Inputs and Outputs

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Appendix A

Inputs and Outputs

The Farm Food Chain Module receives inputs from its module-specific input file (Ff.ssf), the generic site layout file (Sl.ssf), the generic chemical properties file (Cp.ssf), and modeled inputs from the following other modules: Aquifer Module (Aq.grf), Air Module (Ar.grf), Surface Water Module (Sw.grf), Watershed Module (Ws.grf), and those source modules outputting (to a common grf file, Sr.grf) a "true" for the soil-presence logical flag, SrcSoil. These sources are the Land Application Unit, Landfill, Wastepile, and Surface Impoundment. The Farm Food Chain Module outputs are written to the Ff.grf file. The soil, plant, invertebrate, and worm concentration outputs are 3-dimensional arrays indexed on time, space, and receptor. The small birds, small herpetofauna, small mammals, herbivertes, and omniverts are two-dimensional arrays indexed on time and space.

All input and output variables are listed and described in Tables A-1 through A-9.

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Table A-1. Ff.ssf Input Parameters (Module-Specific Inputs)

Input Parameters	Units	Description
Fforage_<cattle type>	Fraction	Fraction of forage grown in contaminated soil. (Note: "<cattle type>" is replaced with beef and milk.)
Fgrain_<cattle type>	Fraction	Fraction of grain grown in contaminated soil. (Note: "<cattle type>" is replaced with beef and milk.)
Fsilage_<cattle type>	Fraction	Fraction of silage grown in contaminated soil. (Note: "<cattle type>" is replaced with beef and milk.)
Fw_<plant type>	Unitless	Fraction of wet deposition that adheres to the plant. (Note: "<plant type>" is replaced with exfruit, exveg, forage, and silage.)
MAF<plant type>	Percent	Moisture adjustment factor to convert DW into WW. (Note: "<plant type>" is replaced with exfruit, exveg, leaf, profruit, proveg, and root.)
MAFleaf	Percent	Moisture content in leaf.
Qp_forage_<cattle type>	kg DW/d	Consumption rate of forage by cattle. (Note: "<cattle type>" is replaced with beef and milk.)
Qp_grain_<cattle type>	kg DW/d	Consumption rate of grain by cattle. (Note: "<cattle type>" is replaced with beef and milk.)
Qp_silage_<cattle type>	kg DW/d	Consumption rate of silage by cattle. (Note: "<cattle type>" is replaced with beef and milk.)
Qs_<cattle type>	kg/d	Consumption rate of contaminated soil. (Note: "<cattle type>" is replaced with beef and milk.)
Qw_<cattle type>	L/d	Consumption rate of water. (Note: "<cattle type>" is replaced with beef and milk.)
rho_leaf	g/L	Density of the leaf.
Rp_<plant type>	Unitless	Interception fraction. (Note: "<plant type>" is replaced with exfruit, exveg, forage, and silage.)
tp_<plant type>	Year	Length of plant exposure to deposition. (Note: "<plant type>" is replaced with exfruit, exveg, forage, and silage.)
VapDdv	cm/s	Vapor-phase dry deposition velocity.
VGag_<plant type>	Unitless	Empirical correction factor. (Note: "<plant type>" is replaced with exfruit, exveg, forage, and silage.)
VGbg_root	Unitless	Empirical correction factor for roots.
Yp_<plant type>	kg DW/m^2	Yield or standing crop biomass. (Note: "<plant type>" is replaced with exfruit, exveg, forage, and silage.)

NA = Not applicable.

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Table A-2. Sl.ssf Input Parameters (Module-Specific Site Layout Inputs)

Input Parameters	Units	Description
FarmAirFrac	Fraction	Fraction of farm or crop area impacted by air points.
FarmAirIndex	NA	Index of points that impacts farm or crop area.
FarmAquIndex	NA	Index of aquifer that impacts farm or crop area.
FarmAquWellFrac	Fraction	Fraction farm uses aquifer well as animal DW source.
FarmAquWellIndex	NA	Index of contributing subarea in local watershed indices associated with each farm.
FarmLWSIndex	NA	Local watershed indices associated with each farm.
FarmLWSSubAreaFrac	Fraction	Fraction of contribution of subarea in local watershed indices associated with each farm.
FarmNumAir	Unitless	Number of air points that impact farm or crop area.
FarmNumAquWell	Unitless	Number of wells in each aquifer impacting farm.
FarmNumLWS	Unitless	Number of local watersheds impacting farm or crop area.
FarmNumWBNRch	Unitless	Number of WBN reach that impact farm or crop area.
FarmNumWSSub	Unitless	Number of watersheds that impact farm or crop area.
FarmWBNIndex	NA	Index of WBN that impacts farm or crop area.
FarmWBNRchFrac	Fraction	Fraction of farm or crop area impacted by WBN reach.
FarmWBNRchIndex	NA	Index of WBN reach that impacts farm or crop area.
FarmWSSubFrac	Fraction	Fraction of each watershed on farm.
FarmWSSubIndex	NA	Index of watershed on farm.
focS	Mass fraction	Fraction organic carbon (soil).
HumRcpAirIndex	NA	Index of air points that impact receptor.
HumRcpLWSAreaIndex	NA	Local watershed index for each human receptor.
HumRcpLWSSubAreaIndex	NA	Local watershed subarea index for each human receptor.
HumRcpWSSubIndex	NA	Index of watershed that impacts receptor.
NumFarm	Unitless	Number of farm or crop areas.

NA = Not applicable.

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Table A-3. Cp.ssf Input Parameters (Module-Specific Chemical Inputs)

Input Parameters	Units	Description
ChemBa_<#>	d/g	Biotransfer factor. (Note: "<plant type>" is replaced with beef and milk.)
ChemBa_water	d/g	Biotransfer factor for dissolved contaminant in surface water.
ChemBr_<plant type>	(μg/g DW plant) / (μg/g soil)	Soil-to-plant bioconcentration factor. (Note: "<plant type>" is replaced with exfruit, exveg, forage, grain, profruit, proveg, root, and silage.)
ChemBs	Fraction	Bioavailability fraction of contaminant in soil relative to vegetation.
ChemBv_ecf_plant	Unitless	Empirical correction factor for Bv.
ChemBv_<plant type>	(μg/g DW plant) / (μg/g air)	Mass-based air-to-plant biotransfer factor. (Note: "<plant type>" is replaced with exfruit, exveg, forage, and silage.)
ChemHLC	(atm-m^3)/mol	Henry's law constant.
ChemKoc	mL/g	Organic carbon partition coefficient
ChemKow	Unitless	Octanol/water partition coefficient
ChemkpPar_<plant type>	1/ yr	Plant surface loss of particle-bound constituent. (Note: "<plant type>" is replaced with exfruit, exveg, forage, and silage.)
ChemkpVap_<plant type>	1/ yr	Degradation loss of vapor-phase constituents. (Note: "<plant type>" is replaced with exfruit, exveg, forage, and silage.)
ChemRCF	(μg/g WW plant) / (μg/mL soil water)	Root concentration factor.
ChemType	NA	Chemical type (O, M, Hg, S, or D)

NA = Not applicable

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Table A-4. Aq.grf Input Parameters (Aquifer Module Inputs)

Input Parameters	Units	Description
AquWellConc	mg/L	Concentration of contaminant in the water of an aquifer well.
AquWellConcNY	Year	Number of years in the time series corresponding to this variable.
AquWellConcYR	Unitless	Time series of years corresponding to this variable.

Table A-5. Ar.grf Input Parameters (Air Module Inputs)

Input Parameters	Units	Description
CVap	$\mu g/m^3$	Concentration of chemical in air vapor.
CVapNY	Unitless	Number of years in the time series corresponding to this variable.
CVapYR	Year	Time series of years corresponding to this variable.
ParDDep	g/m2/d	Particle dry deposition rate.
ParDDepNY	Unitless	Number of years in the time series corresponding to this variable.
ParDDepYR	Year	Time series of years corresponding to this variable.
ParWDep	$g/m^2/d$	Particle wet deposition rate.
ParWDepNY	Unitless	Number of years in the time series corresponding to this variable.
ParWDepYR	Year	Time series of years corresponding to this variable.
VapWDep	$g/m^2/d$	Vapor wet deposition rate.
VapWDepNY	Unitless	Number of years in the time series corresponding to this variable.
VapWDepYR	Year	Time series of years corresponding to this variable.

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Table A-6. Sr.grf Input Parameters (Source Module Inputs)

Input Parameters	Units	Description
CTda	μg/g	Depth-averaged soil concentration across farm area.
CTdaNY	Year	Number of years in the time series corresponding to this variable.
CTdaYR	Unitless	Time series of years corresponding to this variable.
CTss	μg/g	Surficial soil concentration across farm area.
CTssNY	Year	Number of years in the time series corresponding to this variable.
CTssYR	Unitless	Time series of years corresponding to this variable.

Table A-7. Sw.grf Input Parameters (Surface Water Module Inputs)

Input Parameters	Units	Description
WBNConcWaterDiss	mg/L	Dissolved concentration in surface water used as drinking water source by cattle.
WBNConcWaterDissNY	Year	Number of years in the times series corresponding to this variable.
WBNConcWaterDissYR	Unitless	Time series of years corresponding to this variable.

Table A-8. Ws.grf Input Parameters (Watershed Module Inputs)

Input Parameters	Units	Description
CTdaR	μg/g	Depth-averaged soil concentration for the regional watershed area.
CTdaRNY	Year	Number of years in the time series corresponding to this variable.
CTdaRYR	Unitless	Time series of years corresponding to this variable.
CTssR	μg/g	Surface soil concentration for the regional watershed area.
CTssRNY	Year	Number of years in the time series corresponding to this variable.
CTssRYR	Unitless	Time series of years corresponding to this variable.

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Table A-9. Ff.grf Output Parameters (Farm Food Chain Module Outputs)

Output Parameters	Units	Description
Abeef_farm	mg/kg WW	Concentration of contaminant in beef.
Abeef_farmNY	Year	Number of years in the time series corresponding to this variable.
Abeef_farmYR	Unitless	Time series of years corresponding to this variable.
Amilk_farm	mg/kg WW	Concentration of contaminant in milk.
Amilk_farmNY	Year	Number of years in the time series corresponding to this variable.
Amilk_farmYR	Unitless	Time series of years corresponding to this variable.
CTssAve_farm	μg/g	Chemical concentration in surficial soil averaged over farm area.
CTssAve_farmNY	Year	Number of years in the time series corresponding to this variable.
CTssAve_farmYR	Unitless	Time series of years corresponding to this variable.
P<plant type>_farmYR	Unitless	Time series of years corresponding to this variable.
P<plant type>_farm	mg/kg WW	Concentration of contaminant for specific fruit and vegetable categories grown on a farm. (Note: "<plant type>" is replaced with exfruit, exveg, profruit, proveg, and root.)
P<plant type>_farmNY	Year	Number of years in the time series corresponding to this variable.
P<plant type>_garden	mg/kg WW	Concentration of contaminant for specific fruit and vegetable categories grown in a garden. (Note: "<plant type>" is replaced with exfruit, exveg, profruit, proveg, and root.)
P<plant type>_gardenYR	Unitless	Time series of years corresponding to this variable.
P<plant type>_gardenNY	Year	Number of years in the time series corresponding to this variable.

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