TECHNICAL DESCRIPTION

AND USER'S GUIDANCE DOCUMENT

FOR THE

TERRESTRIAL INVESTIGATION MODEL (TIM)

Version 3.0 BETA

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1. Introduction

1.1. Purpose of Document

The purpose of this document is to provide technical information on version 3.0 of the Terrestrial Investigation Model (TIM v.3.0). TIM derives quantitative estimates of the probability (or likelihood) and magnitude of mortality to birds (of the same species) exposed to the simulated pesticide. This document describes how TIM derives joint distributions of exposure and toxicity to calculate the risk of mortality to birds.

1.2. When to Use TIM

Conceptually, the ecological risk assessment framework includes four levels, which differ in level of information, effort and assumptions. (See **Appendix J** for more details). When assessing the Tier 1 level of risks from acute and chronic exposures of birds, EFED uses the T-REX model, which provides a conservative estimate of exposure through diet. Tier I assessments are based on risk quotients (RQs), which are calculated by dividing a point estimate of exposure by a point estimate representing effects (*e.g.,* LD_{50}). After RQs are calculated, they are compared to levels of concern (LOCs) in order to determine whether a pesticide use poses a risk to birds and mammals through acute and chronic dietary exposure.

For probabilistic assessments, EFED uses TIM, a refined risk assessment model (Tiers II-IV, see **Appendix I**) that focuses on acute exposures to birds. If acute RQs exceed LOCs for non-listed or listed species, and the risk manager needs additional information on the risk posed by a pesticide use, TIM may be used to quantify the probability and magnitude of mortality, to characterize uncertainties and to explore mitigation options that may be implemented in a manner specified on pesticide labels. The decision to run TIM and the purpose of the specific analysis should follow discussions with the risk manager. The analysis carried out by the risk assessor should be tailored to address the questions of the risk manager and to quantify the influence of uncertainty associated with the existing dataset.

In addition to quantifying the probability and magnitude of mortality to a species of bird, TIM may also be used to provide information for the MCnest (Markov Chain nest productivity) model, a refined risk assessment model for estimating the chronic impact of pesticides on the reproductive success of bird populations. In this case, the MCnest model may be run when chronic avian RQs generated by the T-REX model exceed the chronic LOC. OPP/EFED is currently working with ORD to integrate the TIM and MCnest models so that exposure estimates generated by TIM (for individual birds and their offspring) may be used for determining the potential decrease in fecundity associated with a pesticide exposure. Together, the outputs from TIM and MCnest may be used to parameterize a population model for a species to determine potential population-level impacts associated with declines in survival of adults and their offspring and declines in fecundity.

1.3. Overview of Terrestrial Investigation Model (v.3.0)

TIM (v.3.0) is a multimedia exposure/effects model that can be used to address avian mortality levels from acute pesticide exposure in generic or specific species over a user-defined exposure window. This time frame corresponds to one growing season of the treated crop or a single sub-annual pesticide application window. The spatial scale is at the field level, but specific field dimensions are undefined. It is assumed that the field and surrounding area meet habitat and dietary requirements for the modeled species. During the simulation, birds use the treated field and edge habitat to meet their requirements for food and water. TIM also accounts for exposure via dermal and inhalation routes for birds on the field or for adjacent habitat that receives spray drift. It is expected that the relative importance of these routes of exposure will vary based on the properties of the pesticide, its use, as well as the characteristics of the simulated bird species. Risk, expressed as a function of exposure (dose) and toxicity, is assessed for liquid spray applications of a pesticide made to vegetation or bare ground in the field. Pesticide application methods that may be modeled in TIM v.3.0 include: aerial, ground broadcast, airblast, ground banded and ground in furrow. For all of these application methods, exposure can be assessed on the treated field and edge habitat where spray drift is transported. The model does not currently account for exposures due to seed treatments or granular formulations. Additional model limitations are described in **Section 10**.

As described in this technical manual, TIM relies upon distributions of parameter values in order to consider variability in bird behavior, body size and exposure. Values for individual birds are randomly selected from these distributions. Although there are inherent uncertainties associated with this model through assumptions and lack of information (see **Section 10**), the model does not account for uncertainty in each simulation. The impact of uncertainty on the probability associated with mortality should be explored by the model user through selection of alternative input parameters. For instance, the avian oral LD_{50} has a major impact on the model's results. Thus, the model user should run scenarios using the best estimate of the LD_{50} as well as upper and lower confidence bounds in order to understand the range of probabilities associated with levels of mortality of interest for the assessment.

The major parameters addressed in the model are:

- Concentration estimates in/on vegetation, arthropods, water, and air for oral, inhalation, and dermal routes of exposure;
    - Concentration estimates in the model are distributions of residues as a function of application rates and degradation/dissipation;
- Proportions of diet composed of each food type, defined by the food habits of defined generic or selected specific species;
- Frequency of feeding on the treated field, determined in hourly time steps;
- Hourly ingestion rates of food and water as a function of body weight;
- Hourly inhalation rates of air as a function of body weight;
- Hourly dermal residue transfer rates from contaminated vegetation as a function of body weight;
- Exposures in adjacent habitats receiving spray drift deposition from the treated field;
- Acute toxicity dose-response relationship based either on a specific species, when data are available, or on inter-species extrapolations.

Each run of TIM (v.3.0) involves simulating pesticide exposure for a user-defined number of birds, with a minimum of 10,000. This number was selected because it is sufficiently large to capture the variability in model outputs and will allow for stable results upon repeat of the simulation. For each individual bird simulated, a random selection of values is made for the major exposure parameters. These parameters are then used to establish pesticide dose through diet, drinking water, inhalation and dermal exposure routes. The pesticide dose from each exposure route is converted to an oral-dose equivalent. This conversion is accomplished using relative toxicity data for the different routes of exposure.

Equation 1.1 depicts the approach for determining the total body dose ($D_{total(t)}$) of a pesticide at time t. The pesticide body load is modeled over the simulation period at hourly time steps, with the body load at any step consisting of any newly ingested dose (*i.e.,* $D_{diet(t)} + D_{drinking(t)} + D_{inhalation(t)} + D_{dermal(t)}$) plus the remaining fraction of doses ingested in previous time steps (*i.e.,* $D_{total(t-1)}$), accounting for the fraction of pesticide retained after elimination (*i.e.,* $F_{retained}$). The relative contributions of each exposure pathway are not equivalent, varying based on the properties of the chemical, application, bird's behavior and time step. Doses account for the location of the bird relative to the treated field. In the case that the bird is not located on the field at the simulated time step, the bird receives a fraction of the on-field exposure, with that fraction depending upon the spray drift deposition at the bird's location relative to the edge of the treated field.

Equation 1.1. $D_{total(t)} = D_{diet(t)} + D_{drinking(t)} + D_{inhalation(t)} + D_{dermal(t)} + D_{total(t-1)} * F_{retained}$

The status of an individual bird (dead or alive) for each time step is assigned by comparing the estimated body load ($D_{total(t)}$) to an unique threshold ($T_{mortality}$) that is randomly selected for that bird from the dose/response curve obtained from the acute oral LD_{50} test. If the internal dose is below the threshold, the bird is considered to be alive at that time step and the bird survives to the next hour, where the process is repeated (*i.e.,* if $D_{total(t)} < T_{mortality}$, bird survives to t+1). If the dose exceeds the threshold, the bird is considered dead, and is no longer included in the simulation (*i.e.,* if $D_{total(t)} \geq T_{mortality}$, bird dies during t). As long as the bird is alive, the bird continues to the next step until the body load is greater than the threshold or the user-defined model duration is reached.

This procedure is repeated using Monte Carlo sampling methodology, and after multiple iterations of individuals, a probability density function of percent mortality is generated. **Figure 1.1** provides a conceptual diagram of TIM (v.3.0).

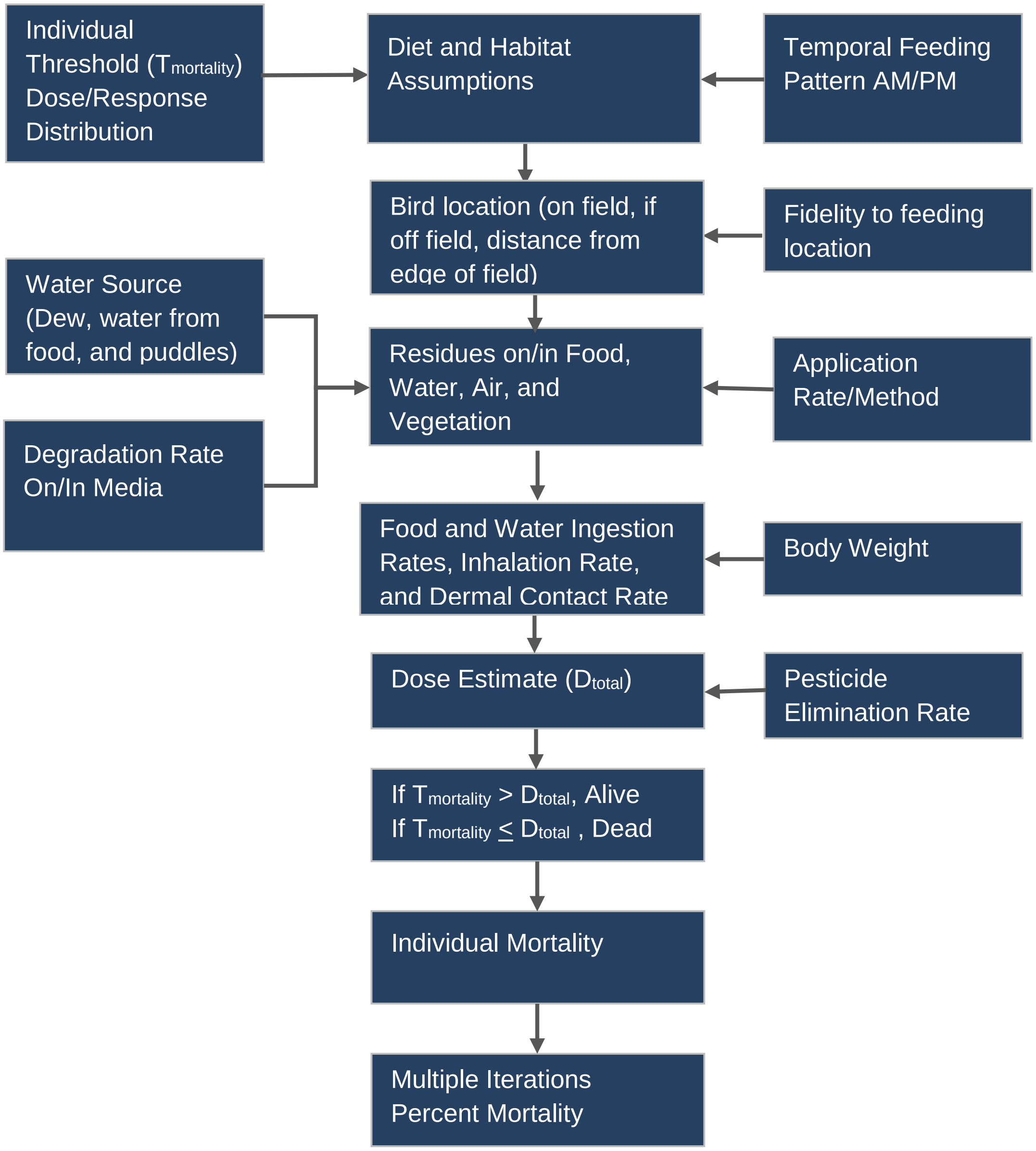

Figure 1.1. Conceptual Diagram of TIM (v.3.0)

Exposure routes modeled in TIM v.3.0 include dietary, inhalation (spray droplets and volatilized pesticide), dermal (direct spray and contact with vegetation) and drinking water (dew and puddles). Specific exposure routes included in the model differ by application method. (See **Table 1.1).** All of the exposure routes are included in the model simulation for aerial and airblast applications. Exposure routes for ground applications depend upon the height of the crop. If the crop is ≥0.152 m (6 in), it is assumed that the birds can hide under the crop when the tractor applies the pesticide, and therefore all exposure routes are included. When the crop height is

<0.152 m, it is assumed that the birds on the field will be flushed by the tractor and thus will not be on the field at the time of the application. As noted by the FIFRA Scientific Advisory Panel (SAP) in 2004, “Birds certainly could, and probably usually do, move out of the way of application machinery. If for no other reason than that the application equipment is noisy.” It is also assumed that the birds land in an area beyond the spray drift exposure area (*i.e.,* >304 m from the edge of the field) and do not receive exposures via inhalation of droplets or direct spray (dermal). Therefore, for ground applications where crop height is <0.152 m, relevant exposure routes include dietary, drinking water, inhalation of volatilized pesticide and dermal contact with treated vegetation. For pesticides applied to the ground via banded and in furrow methods, pesticide exposure through drinking water, inhalation and dermal contact are assumed to be negligible and thus are not included, meaning that dietary exposure is the only route for these application methods. It is also assumed that there is no spray drift transport for banded and in furrow applications.

Table 1.1. Summary of Exposure Routes Considered by Application Method.

Exposure route	**Aerial broadcast**	**Airblast**	**Ground broadcast (crop height ≥ 0.152 m)**	**Ground broadcast (crop height <0.152 m)**	**Ground banded**	**Ground in furrow**
Diet	Yes	Yes	Yes	Yes	Yes	Yes
Inhalation –spray	Yes	Yes	Yes	No	No	No
Inhalation - volatiles	Yes	Yes	Yes	Yes	No	No
Dermal - spray	Yes	Yes	Yes	No	No	No
Dermal – contact with foliage	Yes	Yes	Yes	Yes	No	No
Drinking – puddle	Yes	Yes	Yes	Yes	No	No
Drinking - dew	Yes	Yes	Yes	Yes	No	No

In addition, the Graphical User Interface (GUI) includes pathway switches that allow the user to turn off any of the exposure routes and spray drift exposure. The user may choose to turn off a pathway switch if the route of exposure is not relevant to the application scenario, to explore risk mitigation options (*e.g.,* spray drift reduction) or to explore the model’s sensitivity to a specific pathway. For example, if the application is applied preplant (crop height is 0) and the field is tilled (*i.e.,* there are no weeds), inhalation, dermal and dew exposure routes may be turned off for aerial and ground applications. If weeds may be on the field, the user should consider leaving these exposure routes on. The model user may also wish to turn off a pathway based on the life history of a specific species that is being simulated. For example, if the species does not drink water, the dew and puddle switches could be turned off. If the species is an aerial feeder, and is not expected to be beneath the crop canopy, the dermal and inhalation pathways could be turned off.

1.4. The Evolution of TIM

TIM has evolved over time in response to FIFRA SAP comments and recommendations. **Table 1.2** provides an overview of the evolution of the key features of TIM, from its early stages to present.

Table 1.2. Components of Different Versions of TIM.

Model Component	version 1.0 (2-21-2001)[1]	version 2.0 (3-10-2004)[2]	version 3.0
Species considered	Focal	Generic	Generic or focal (specific)
Duration of exposure	7 days	User defined	User defined
Time step	User defined	Hourly	Hourly
Exposure routes considered	Dietary Drinking water	Dietary Drinking water Inhalation Dermal	Dietary Drinking water Inhalation Dermal
Spray drift	No	No	Yes
Feeding pattern	Unimodal	Bimodal[3]	Bimodal[3]
Serial correlation between foraging events	None	Yes	Yes
Dew	Organic-carbon based equilibrium	Organic-carbon based equilibrium	Octanol-water based equilibrium
Drinking water exposure from puddles	Addressed using PRZM[4] outputs	Addressed using complex model comparable to PRZM[4] conceptual model	Addressed using equilibrium partitioning approach
Number of pesticide applications modeled	1	1	Up to 5
User has ability to turn on/off exposure routes	Yes	No	Yes
Model platform	Excel and Crystal Ball	C executable with Excel GUI	C executable with Matlab GUI

[1]Presented to FIFRA SAP in 2001
[2]Presented to FIFRA SAP in 2004
[3]The bimodal distribution simulates morning and evening feeding patterns of birds.
[4]Pesticide Root Zone Model.

In 2001, EPA presented two case studies (*i.e.*, terrestrial and aquatic) to the SAP for review. These case studies used probabilistic methods to assess the ecological risk from a generic chemical (ChemX). The terrestrial case study (USEPA, 2001) was based on the characterization of exposure and effects by defining the distributions of the major variables and combining these into joint distributions to estimate the probability and magnitude of effects. TIM v.1.0 was utilized as a species-specific model, which addressed acute mortality levels over a defined exposure window. The spatial scale was at the single treated field where the field and surrounding areas were assumed to meet the habitat requirements for each focal species. The temporal scale was for exposure during and immediately following a single application of a pesticide. The major parameters addressed in the model were as follows:

- food habits;
- ingestion rates of food and water;
- frequency of feeding and drinking on sprayed field;
- distribution of residues on food and water;
- dissipation rates; and
- inter- and intra-species dose response variability.

For each run of the model, a random selection of values was made for the major exposure input parameters to estimate a dose to an individual of a focal species. The likelihood (probability) of mortality from this individual's estimated dose was calculated using the dose-response curve, and a binomial probability approach was used to determine if an individual modeled bird survives. This procedure was repeated using Monte Carlo simulations for a set of individuals to generate an estimate of the percent of birds affected. After multiple iterations of sets of individuals, a probability density function of percent mortality was generated.

Exposure pathways considered were from dietary and drinking water routes. Exposure was divided into two equal time steps per day. At the onset of each time step, a binomial probability function was used to determine if an individual modeled bird uses the treated field as a source of food and water.

To estimate the acute toxicity of ChemX to focal species, an inter-species distribution-based approach was used. The parameters of the distribution were determined from the available toxicity values for the pesticide that is being assessed. For each focal species, three estimates of its LD_{50} were made, 5^{th}, 50^{th}, and 95^{th} percentile, to account for inter-species toxicity uncertainty. Use of the slope of the dose response distribution addresses the establishment of a sensitivity threshold for each modeled individual of a species (intraspecies variability).

To estimate the mortality distribution for a selected focal species, the likelihood of mortality for the maximum estimated body burden, based on the external dose for the duration of the exposure, was calculated from the dose response curve derived for the selected focal species. The distribution of mortality of cohorts of individuals was determined through multiple iterations using Monte Carlo simulations, thus, providing an estimate of the probability and magnitude of effects.

Following the case study with ChemX, EPA considered the SAP's comments (SAP, 2001), which strongly supported the EPA's efforts in developing both the aquatic and terrestrial case studies. The terrestrial model was subsequently modified, and EPA returned to the SAP in April 2004 for an additional review of TIM (v.2.0). The major changes that were incorporated into the revised model were in response to the SAP's comments (SAP, 2004) and included the following:

- establishment of generic birds that represent species occurring in and around agro-environments;
    - TIM (v.2.0) used generic attributes to represent the more vulnerable species, yet retained the ability to address specific focal species, when appropriate;
- incorporation of inhalation and dermal exposures;
- incorporation of a 1-hour exposure time step to allow the inclusion of a bimodal feeding pattern, as well as a higher resolution simulation of daily feeding behavior between treated and untreated areas;
- incorporation of an algorithm (Markov Chain) to address serial correlation between sequential foraging events; and,
- development of a model for estimating pesticide residues in on-field drinking water sources (puddles) that accounts for a number of parameters that affect the formation of puddles after a rainfall event (*i.e.,* rainfall amount, rainfall duration, soil infiltration rates, evaporation, degradation).

In reference to the inhalation and dermal models, limited data are available regarding these two routes of exposure, which results in uncertainty in the estimates of risks. However, if these routes of exposure are ignored or assumed to be minimal, the uncertainty in risk estimates is not addressed. This is of concern because dermal and inhalation routes may contribute significantly to total dose in some situations (Driver *et al.*, 1991). The incorporation of the dermal and inhalation exposure models provides an important initial step to evaluate the potential significance of these routes of exposure relative to others in the overall risk estimates.

Following the 2004 SAP, TIM (v.2.0) was modified to TIM (v.3.0). Major modifications reflected in latest version of the model (TIM v.3.0) and its documentation include:

- allowing for the assessment of up to five applications of a pesticide in a growing season;
- allowing for model run durations exceeding 15 days;
- review of avian census studies in multiple crops and locations in North America for parameterization of generic and specific species (**Appendix D**);
- addition of generic species that consume 100% fruit, 100% grass or 100% broadleaf forage;
- revised distribution of initial pesticide residues on arthropods (**Appendix E**);
- the respirable droplet size was increased from 7 to 100 µm;
- modification of dew exposure model that replaces the Koc-based equilibrium approach (partitioning between total leaf and dew) with one that is based on Kow (partitioning between dew and cuticle wax);
- simplified puddle model;
- exposure of off-field birds to pesticide from spray drift transport; and
- simulation of pesticide exposures to juvenile birds for use in MCnest model.

1.5. Model Executable

The TIM (v.3.0) executable is coded in C and has been compiled using Microsoft® Visual Studio 2010 C++ Express. The model code is composed of 9 files. The main file is titled “TIM3.0.c.” The names and purposes of the other files are summarized in **Table 1.3**. Details of the contents of each of these files are contained within comments provided at the beginning of each file.

Table 1.3. TIM v.3.0 Code Files

Name*	Contents
Arrays.c	functions used to allocate and free memory for vectors and matrices
declarations.h	declares the functions that are used by TIM
default_values.c	functions that call default values
Exposure.c	functions that estimate pesticide exposures to birds
macros.h	function-like macros
RANDOM.c	random numbers generated using different distributions
Report.c	functions that print to screen or to output files
Statistics.c	statistical functions
TIM3.0	main code for the Terrestrial Investigation Model (TIM) v3.0

*” .h” extension denotes a header file. “.c” extension denotes a source file.

The TIM executable is run using a GUI that was developed in Matlab®. See **Appendix A** for user’s guidance on how to install and run the model. TIM requires up to 97 input parameters that define the model assumptions related to the simulated bird species, as well as pesticide specific parameters related to the use, fate and toxicity. **Appendix A** provides detailed guidance to the user on how to select input parameters, including information on default values, when no chemical-specific or species-specific information are available. As described later, the model has the ability to simulate generic bird species. In that case, no species-specific parameters are needed. The GUI develops an input text file (TIM_inputs.txt) that is read by the executable.

Once TIM is executed, it generates several output files. The names and descriptions of these output files are included in **Table 1.4.** The two output files that are generated specifically for the TIM user (*i.e.,* Model_Results.txt and Dead_per_hour.txt) are described in **Section 9**.

Table 1.4 lists the Quality Control (QC) files that may be generated by the model. These outputs were used in the the QC test of the model code. These outputs are not needed by the model user.

The TIM v.3.0 executable also has the capability of estimating exposures to the juvenile offspring of those exposed adults. The purpose of this exercise is to couple TIM and MCnest so that they are using the same exposure profiles for adult and juvenile birds. While the focus of TIM is to assess the risk of mortality to adult birds exposed to a pesticide, the focus of MCnest is to determine potential impacts of a pesticide on the fecundity of a species. This technical manual describes TIM's method for estimating exposures to adult birds. When relevant, the manual also discusses approaches for determining exposures to juveniles that will be used by MCnest. The juveniles simulated by TIM do not influence the model results generated by TIM. **Table 1.4** identifies files that may be generated by the model if the MCnest switch is turned on. The output files generated for MCnest are comma-delimited text files and thus can be easily converted into Microsoft® Excel format if so desired. The MCnest output files include daily exposure values for individual adult birds and their juvenile (hatchling) offspring. The MCnest files also include the tolerances for those birds and information on whether or not the adults died during the TIM simulation, and if so, when those deaths occurred.

Table 1.4. Summary of Output Files (.txt extensions) Generated by TIM v.3.0

File name**	Purpose of output file	Description
adult_acquired_doses	Input for MCnest	Daily acquired doses for juvenile birds* (each row represents daily doses for individual adult birds)
bird_death	Input for MCnest	Includes the individual threshold for each adult and its associated off spring (juveniles) as well as the simulation day when the adult birds died
Dead_per_hour	TIM results for model user	Reports the number of dead birds for each hour of the simulation (column 1 = hour, column 2 = # dead birds)
juvenile_acquired_doses	Input for MCnest	Daily acquired doses for juvenile birds* (each row represents daily doses for individual juveniles)
Model_Results	TIM results for model user	Includes input parameters and model results (number of birds killed, relative contributions of exposure routes to mortality, probabilities)
QC_section2	QC review of TIM code	Calculations from section 2 of manual (species parameters)
QC_section3	QC review of TIM code	Calculations from section 3 of manual (feeding times, movement, spray drift)
QC_ section4	QC review of TIM code	Hourly dietary pesticide dose, section 4 of manual
QC_ section4_1_ap1	QC review of TIM code	Concentrations on food items at time of application 1, section 4 of manual
QC_ section4_1_ap2	QC review of TIM code	Concentrations on food items at time of application 2, section 4 of manual
QC_ section4_1_ap3	QC review of TIM code	Concentrations on food items at time of application 3, section 4 of manual
QC_ section4_1_ap4	QC review of TIM code	Concentrations on food items at time of application 4, section 4 of manual
QC_ section4_1_ap5	QC review of TIM code	Concentrations on food items at time of application 5, section 4 of manual
QC_ section4_2	QC review of TIM code	Daily food intake rate, section 4 of manual
QC_ section4_HLap1	QC review of TIM code	Testing half-life for application 1, section 4 of manual
QC_ section4_HLap2	QC review of TIM code	Testing half-life for application 2
QC_ section4_HLap3	QC review of TIM code	Testing half-life for application 3
QC_ section5	QC review of TIM code	Hourly inhalation doses (for birds 1-10) section 5 of manual
QC_ section5_2	QC review of TIM code	Hourly vapor concentrations, section 5.2 of manual
QC_ section6	QC review of TIM code	Hourly dermal doses (for birds 1-10), section 6 of manual
QC_ section7	QC review of TIM code	Hourly drinking water doses (for birds 1-10), section 7 of manual
QC_ section8_death	QC review of TIM code	Summary of bird specific thresholds, section 8 of manual
QC_ section8_threshold	QC review of TIM code	Hourly total doses and thresholds for birds 1-10, section 8 of manual

*Total daily dose generated for MCnest is the sum of all hourly pesticide doses through all routes of exposure included in the model. This does not account for elimination.

**The QC files were used in the Quality Control review of the executable and are not expected to be of interest to the model user. These files are generated only when the QC switch is turned “on” in the input file

1.6. Quality Assurance and Quality Control

The quality assurance and quality control (QA/QC) review of TIM (v.3.0) involved three major steps. The first step involved development of this document, which represents the technical documentation describing the model, its equations, assumptions, parameters and uncertainties. The technical documentation for TIM (v.3.0) was developed by compiling documentation from SAP meetings held in 2001 and 2004, where TIM versions 1 and 2 were presented. Model components were checked against their original sources (*e.g.*, publications in the literature). All model parameters and their underlying assumptions were described and unit balances were verified for each equation.

The second step involved a review of the model executable. This QC review was completed using only the executable and text input files. Version 3.0 of the executable reflects changes made to version 2.1 (September 16, 2008). Parameter values included in the input file were documented (see **Appendix B**). The model executable was run in order to verify that all input values were read correctly, that switches were turned on/off based on user inputs and that default parameters were correctly assigned when generic bird species were selected. Correct contents of output files were verified. The variables, arrays, matrices, and functions of the model code were described using comments embedded within the code. The functioning of the model code was verified by two separate approaches: first, the code was reviewed and compared to the parameter and equations provided in the technical manual; and secondly, the model calculations for each section of the technical manual (**Sections 2-9**) were output to QC files (**Table 1.4**) and compared to independent calculations carried out in Microsoft® Excel (where the user input parameter values and equations of the technical manual were implemented). If an error was identified, the code was modified to correct the error. The code was then recompiled and checked again. The QA/QC review confirms that the final version of the model executable correctly calculates the equations described in this technical manual.

The third step involved verification of the GUI. In this approach, model outputs generated by the stand alone executable and GUI for the same input files were compared. Since the model outputs were equal, it was concluded that the GUI is operating correctly.

1.7. Organization of This Document

This Technical Guidance Document is organized into 10 sections, beginning with an introductory section (Section 1). **Section 2** provides a review of how TIM represents avian species. **Section 3** discusses the determination of a bird's location on or off the treated field and the fraction of on field exposure a bird receives when off-field (due to spray drift). **Sections 4, 5, 6 and 7** describe how TIM estimates hourly pesticide exposures through dietary, inhalation, dermal and drinking water routes, respectively. **Section 8** discusses establishing sensitivity and mortality of individuals, and **Section 9** discusses the model's results. **Section 10** discusses the uncertainties associated with TIM v.3.0. The ten appendices of this document include:

- user's guidance for running the model and determining input parameters (**Appendix A**);
- example input file (**Appendix B)**;
- summary of the parameters used in TIM v3.0 (**Appendix C**);

- summary of avian census field studies that support the parameterization of generic and custom species (**Appendix D**);
- analysis of empirical data from studies measuring initial pesticide residues on arthropods (**Appendix E**);
- description of the basis for the food intake equation for juveniles (**Appendix F**);
- information used to calculate the home range for insect eating birds (**Appendix G**);
- data used to generate the equation to estimate an acute dermal toxicity endpoint (**Appendix H**; from USEPA, 2004);
- overview and history of the tiered risk assessment framework (**Appendix I**); and
- method for deriving species sensitivity distributions that may be used to establish toxicity endpoints and explore uncertainty (**Appendix J**).

2. Avian Species

In TIM v.3.0, an avian species is represented by several parameters, including diet, body weight (BW), home range, frequency on field (FOF) and fidelity factor (determined by residency status). BW is a particularly important parameter because it is used in the allometric equations that derive intake rates for all exposure routes (*i.e.*, food consumption, inhalation rate, surface area and drinking water consumption).

The model user has the choice between using a generic species or a specific/custom species, which can be parameterized by the user to represent an avian species of interest. The generic species can be used to identify groups of species that may be at risk. In addition, generic species that predominate agricultural areas, such as small to medium sized insectivores and omnivores, may be simulated to consider potential indirect effects to predatory birds or mammals. Specific species and species of interest, including federally-listed endangered and threatened species, may be simulated as a refinement in the assessment.

BW, diet information and frequency on field data for specific species occurring in agricultural areas in North America are provided in **Appendix D**. Data from these species were used to derive default parameters for the generic species, including BW, diet and FOF. Data from these studies were also used to derive default parameters for 56 specific species. It should be noted that the parameters selected to represent species are generally representative of the breeding season. During times when birds are not nesting, diets and FOF may change. The model user should consider whether alternative assumptions for diet and FOF are necessary if simulating a pesticide application before or after the breeding season.

2.1. Diet Composition

In TIM v.3.0, birds consume terrestrial food items, including grass, broad leaf plants, fruit, seeds, and arthropods (*e.g.*, insects, spiders, millipedes). Of the commonly observed species (n = 117) in the avian census studies described in **Appendix D**, the majority have diets that are predominantly insects (*i.e.*, insectivores) or seeds (*i.e.*, granivores), or the species have diets composed of multiple food times (*i.e.*, omnivores). Some of the species predominantly consume other food items, including fruit, nuts, plant matter, small animals (mammals, birds, amphibians and reptiles), aquatic invertebrates and nectar (**Table D28**).

Specific species (referred to as "custom species") can be parameterized by the model user so that the diet is represented by a combination of food items and the sum of these food items is 100%. The section below includes recommended input parameters to represent 56 species[1] that are known to use agricultural areas and their adjacent habitats. These species are also part of the library used by MCnest. As described below, a bird's home range is determined by its diet. The user must define whether a modeled species is an insectivore, herbivore, granivore or omnivore. As a general rule, a species may be defined as insectivore, herbivore or granivore if >70% of its diet is represented by the appropriate food item. If no food item represents >70% of the diet, the species is identified as an omnivore.

For generic species that are insectivores, herbivores, granivores and frugivores, 100% of the adult bird's diet consists of a single food item. For omnivores, the diet is distributed equally between the available food items (*i.e.,* 20% insects, 20% seeds, 20% fruit, 20% grass and 20% broadleaf). For generic species, it is assumed that 100% of the juveniles' diet consists of arthropods.

2.2. Body Weight (BW)

2.2.1. Adults

To represent the distribution of BWs of birds in a simulated field, TIM requires input values for mean, standard deviation (SD), minimum (min) and maximum (max) weight values. These values are used to generate a *beta* distribution of BWs that represent the BWs of the simulated birds. The minimum and maximum values rescale the distribution. A description of the *beta* distribution can be found in USEPA 2007a. The upper and lower bounds of the *beta* distribution (*i.e., alpha* and *beta*, respectively) are calculated according to **Equations 2.1 and 2.2,** respectively. A *beta* distribution was chosen because of its ability to retain meaningful central tendency measures in the face of a distribution with finite limits on both ends.

Equation 2.1. $\alpha = (mean - min) * z$ Where: $z = \frac{mean^2 - mean*min - mean*max + sd^2 + min*max}{(min - max)*sd^2}$

Equation 2.2. $\beta = -(mean - max) * z$

EFED's screening level model for birds, T-REX (USEPA, 2012a), uses three generic BWs to represent small, medium and large-sized birds (*i.e.,* 20, 100 and 1000 g, respectively). These values are consistent with species that have been documented as visiting agricultural fields. Consistent with T-REX, TIM v.3.0 also has three generic BW distributions (**Table 2.1)**, with the mean values set to the small, medium and large BWs. The standard deviations are based on the

[1] Three of these species, the American kestrel, bobolink and mallard, are not included in **Appendix D** because they were not observed in the available avian census studies.

average coefficient of variance in BWs of birds that have been documented as visiting agricultural fields (CV = 7.3%). The 90th percentile of the minimum and maximum BW values for individuals within species are 66% and 152% of the mean, respectively. These percentages are used to determine the minimum and maximum values of the *beta* distributions for the generic species used in TIM (**Section D.3.3 of Appendix D**).

Table 2.1. BW Parameters Used for Generic Birds

BW Distribution Parameter (in g)	Small bird	Medium bird	Large bird
Mean	20	100	1000
Standard Deviation (=mean * 0.073)	1.5	7.3	73
Minimum (=mean * 66%)	13	66	660
Maximum (=mean * 152%)	30	152	1520

As discussed in **Appendix D**, for the commonly observed species in the available avian census studies, BWs range 3.2-2943 g, with a mean of 103 g. The majority of species (67%) have mean BWs <50 g. When the mean BWs are distributed, the 80th percentile is 97 g, suggesting that the majority of the birds commonly found on agricultural fields and their adjacent habitats would be represented by the 20 and 100 g (mean) BWs of the generic species used in TIM. Few birds would be represented by the large generic bird category (*i.e.,* 1000 g).

2.2.2. Juveniles

In simulating juveniles, BW of an individual juvenile is set to 0.5 times the BW of its parent. This assumption is based on an analysis that indicates that the food intake rate of juveniles is highest when they weigh approximately 0.5 times the BW of their parents. (See **Appendix F** for details**)**.

2.3. Home Range Size

The area (A) of the home range in square meters (where the factor of 10,000 is used to convert hectares to square meters) is determined according to **Equations 2.3-2.6**, depending upon the diet of the simulated bird (*i.e.,* granivores, herbivores, omnivores, or insectivores). Equations for granivores, herbivores and omnivores are from Mace and Harvey (1983). Since no equation is available for frugivores, the herbivore equation is used as a surrogate. The equation for insectivores was generated in Microsoft® Excel, using home range data from Schoener (1968) (**Appendix G**). This equation was based on data for species that are identified in field surveys associated with agricultural fields/orchards and adjacent habitats that are described in **Appendix D**. The R^2 values associated with each of these equations ranges 0.27-0.51, indicating that there is variability associated with the home ranges of different species used to generate these equations. This leads to uncertainty in the home range prediction for a simulated species.

Equation 2.3. $A = 0.05 * BW^{1.12} * 10{,}000$ (Granivores; $R^2 = 0.37$)
Equation 2.4. $A = 0.003 * BW^{1.23} * 10{,}000$ (Herbivores; $R^2 = 0.38$)
Equation 2.5. $A = 0.004 * BW^{1.33} * 10{,}000$ (Omnivores; $R^2 = 0.27$)
Equation 2.6. $A = 0.003 * BW^{1.64} * 10{,}000$ (Insectivores; $R^2 = 0.51$)

2.4. Frequency on Field and Residency Status

Frequency on field (FOF) is the amount of time in a simulation that a bird spends on the treated field. TIM requires input values for mean, minimum and maximum FOF values in order to generate a *beta pert* distribution of FOF values for the simulated species of birds. A standard assumption of 4 is used for the height of the mode. A description of the *beta pert* distribution is available in USEPA (2004). For each simulated bird, a unique FOF value is selected from this distribution.

There are multiple factors that can influence the FOF of individuals of a species. Some of these factors include foraging preference, range, composition of edge habitat and time of season (Best *et al*., 1990; Boutin *et al*., 1996). Therefore, the crop being studied and the geographic location of the study site can influence the species observed as well as their frequencies on the field relative to edge habitats. In order to account for some of these variables, 26 avian census studies in agricultural fields and edge habitats were considered from 9 different crops (alfalfa, apples, cabbage, citrus, corn, cotton, grapes, potatoes and soybeans) in different geographic locations in North America (Alabama, Arizona, California, Florida, Kansas, Illinois, Iowa, Mississippi, Nebraska, New Mexico, Oklahoma, Ontario, Texas and Wisconsin). These studies are described in **Appendix D**. These studies reported observations of individuals of the same bird species within an agricultural field and its edge habitat. The percent of the total number of individuals observed at one time period that were observed within the agricultural field is used as a surrogate for the mean FOF of individual birds within a species. On-field observations can be highly variable for some species among different avian census studies (*e.g.,* range of 1-89% for the red-winged blackbird (*Agelaius phoeniceus*); range of 3-100% for brown-headed cowbird (*Molothrus ater*)). In TIM, the mean FOF values for generic species were set to represent a reasonable high-end value based on these observed values. For specific species, the model user may use a default mean FOF value (and range) or select values based on species-specific data.

In TIM, avian species are distinguished as field and edge residents. These classifications impact the FOF values used to represent the species time on the treated field. In order to derive FOF values for the generic species in TIM, it is necessary to define the residency of the commonly observed species in avian census studies. Residency is based on the nesting habits of a species. For agricultural fields species that build their nests on the ground in grassland areas are defined as field residents, while other species are edge residents. For orchards and vineyards, field residents are those that build their nests on the ground in grasslands and woodlands as well as those that build their nests in the mid-story and canopy, while other species are edge residents.

The empirical on-field percent observations for field and edge residents are used to estimate mean default FOF values for generic species using agricultural fields and orchards/vineyards. These default means are based on 90th percentile estimates of available data. The data presented in **Appendix D** represent mean values of FOF for individual species at specific sites. The 90th percentile mean FOF values were selected as defaults for the generic species in order to present a conservative mean FOF values. For field and edge residents using agricultural fields, the default mean FOF values are 97% and 69%, respectively. The 90th percentile FOF values for field and edge resident species using orchards and vineyards are similar (*i.e.,* 87 and 85%, respectively) and are based on a limited number of species and observations relative to the species observed on agricultural fields. Therefore, default FOF values are not distinguished for field and edge residents visiting vineyards and orchards, and the mean default value for both field and edge species visiting orchards and vineyards is 87%. Since FOF values for individual species range 0-100%, this range determines the minimum and maximum values of the *beta pert* distribution used to describe FOF in TIM.

2.5. Fidelity Factor

The fidelity factor (Q) is the serial correlation between sequential foraging events. This parameter represents the tendency of a bird to return to a specific area (field or edge) to feed. The fidelity factor for field residents is 0.8. This value, which represents a relatively strong tendency to return to a site to feed, was suggested by the SAP (SAP, 2001) as an appropriate scenario to model. For edge species, the fidelity factor is 0.6. This value was selected because it is somewhat lower than field resident species, but still allows for some tendency to return to the same area to feed. **Section 10.2** includes a discussion of the model sensitivity of this parameter.

2.6. Taxonomy

The majority of species observed on agricultural fields, orchards and vineyards in avian census studies, described in **Appendix D,** are in the Passeriform order. In TIM, species are defined as either “passerine” or “non-passerine.” This distinction impacts the prediction of food and water intake rates. Passerines have higher intake rates, resulting in higher dietary and drinking water exposures relative to non-passerine species.

Since most bird species that visit agricultural areas are passerine and they generate higher exposure values, it is assumed that all generic species are passerines. The model user may distinguish between passerine and non-passerine species when modeling custom species.

2.7. Species

2.7.1. Generic

With the full combination of diet type, BW and residency status, a total of 30 generic species are available to the user for modeling purposes (**Table 2.2**). The generic omnivore was established with equal portions of each food item included in its diet.

Of the available generic species in **Table 2.2**, the highest estimated exposures are for small, field-resident birds eating grass since field residents have the highest FOF and grasses have the highest estimated initial pesticide residues. Small birds are assumed to be more sensitive to pesticide exposure and are assumed to receive higher body burdens relative to larger birds. Although this generic species may be useful as a screen, its representativeness may be limited to small birds with small plants and grass in their diets for some period of time. Based on avian survey data, the generic species that are most representative of species that occur on agricultural areas and adjacent habitats are the small- and medium-sized insectivores, omnivores and granivores. It is likely that feeding on short grass is not sustainable for a long period of time if grass energy content value used in the model is assumed; however, young shoots are much higher in protein and lipid than mature grasses.

2.7.2. Custom

Tables 2.3 - 2.5 contain input parameters that may be used to represent 56 different species that are also part of the MCnest species library. With the exception of American kestrel, bobolink and mallard, all of these species were observed in avian census studies discussed in **Appendix D.** BW values for these species are based on Dunning (1984).

Dietary fractions were assigned based on the MCnest library, which includes diets of breeding females and juveniles. In order to assign feeding categories for determination of the appropriate home range equation, it was assumed that a diet of ≥70% of one food item would designate a specific feeding category (*e.g.*, insectivores have a dietary fraction for insects that is ≥70% of the total diet). Omnivores did not have a food item that exceeded 70%.

Mean FOF values included in **Table 2.3** may be used to represent the species. These values represent the highest observed occurrence of a particular species on the agricultural field in the available avian census studies discussed in **Appendix D.** The model user should exercise caution when selecting the mean FOF because of the uncertainty associated with the limited number of studies associated with these studies. Another uncertainty is the expectation that different species could have different affinities for different crops (*i.e.*, FOF would vary by crop for the same species). **Table 2.3** also includes the range of FOF values that may be representative of the species given the available avian census data and the crops where the species was observed to occur on field and in-edge habitats. The model user may choose to explore uncertainty associated with the mean FOF value for a species by simulating the range of FOF values in separate model runs.

Table 2.2. Generic Birds Available in TIM v.3.0

Bird #	Description	Example species (Appendix D)	Diet	Mean BW (g)			FOF (%)		Fidelity Factor (Q)
				Mean	SD	Range	Field crops	Orchards and vineyards	
1	Small insectivore field resident	Dickcissel *(Spiza americana)*	100% arthropods	20	1.5	13-30	97	87	0.8
2	Small insectivore edge resident	Tree swallow *(Tachycineta bicolor)*					69		0.6
3	Medium insectivore field resident	Killdeer *(Charadrius vociferus)*		100	7.3	66-152	97		0.8
4	Medium insectivore edge resident	Northern flicker *(Colaptes auratus)*					69		0.6
5	Large insectivore field resident	None		1000	73	660-1520	97		0.8
6	Large insectivore edge resident	None					69		0.6
7	Small granivore field resident	Horned lark *(Eremophila alpestris)*	100% seeds	20	1.5	13-30	97		0.8
8	Small granivore edge resident	American goldfinch *(Carduelis tristis)*					69		0.6
9	Medium granivore field resident	Mourning dove *(Zenaida macroura)*		100	7.3	66-152	97		0.8
10	Medium granivore edge resident	Northern bobwhite *(Colinus virginianus)*					69		0.6
11	Large granivore field resident	None		1000	73	660-1520	97		0.8
12	Large granivore edge resident	None					69		0.6
13	Small herbivore field resident	None	100% grass	20	1.5	13-30	97		0.8
14	Small herbivore edge resident	None					69		0.6
15	Medium herbivore field resident	None		100	7.3	66-152	97		0.8
16	Medium herbivore edge resident	None					69		0.6
17	Large herbivore field resident	None		1000	73	660-1520	97		0.8
18	Large herbivore edge resident	Canada goose *(Branta canadensis)*					69		0.6
19	Small frugivore field resident	Cedar waxwing *(Bombycilla cedrorum) (orchard)*	100% fruit	20	1.5	13-30	97		0.8
20	Small frugivore edge resident	Cedar waxwing *(Bombycilla cedrorum)* (field)					69		0.6
21	Medium frugivore field resident	None		100	7.3	66-152	97		0.8
22	Medium frugivore edge resident	None					69		0.6
23	Large frugivore field resident	None		1000	73	660-1520	97		0.8
24	Large frugivore edge resident	None					69		0.6
25	Small omnivore field resident	Vesper sparrow *(Pooecetes gramineus)*	20% arthropods, 20% seeds, 20% grass, 20% broadleaf, 20% fruit	20	1.5	13-30	97		0.8
26	Small omnivore edge resident	Dark-eyed junco *(Junco hyemalis)*					69		0.6
27	Medium omnivore field resident	Blue jay *(Cyanocitta cristata)* (orchard)		100	7.3	66-152	97		0.8
28	Medium omnivore edge resident	Blue jay *(Cyanocitta cristata)* (field)					69		0.6
29	Large omnivore field resident	None		1000	73	660-1520	97		0.8
30	Large omnivore edge resident	None					69		0.6

Table 2.3. Custom Species Parameters for Specific Species: Basic Species Information, Residency Status and Frequency on Field. Based on Information Provided in Appendix D

Species (scientific name)	Passerine?	Altricial/ Precocial	Residency (ag. field)	Residency (orchard)	Mean FOF	Range of mean FOF	Crops where a species was observed (in field studies used for FOF)
American crow *(Corvus brachyrhynchos)*	Yes	Altricial	edge	field	0.74	0.03-0.74	Apples, cabbage, corn, potatoes, soybeans
American goldfinch *(Carduelis tristis)*	Yes	Altricial	edge	field	0.84	0.02-0.84	apples, cabbage, corn, grapes, potatoes
American kestrel *(Falco sparverius)*	No	Altricial	edge	edge	0.69/0.89*	none	none
American robin *(Turdus migratorius)*	Yes	Altricial	edge	field	0.87	0.02-0.87	alfalfa, apples, cabbage, citrus, corn, grapes, potatoes, soybeans
Ash-throated flycatcher *(Myiarchus cinerascens)*	Yes	Altricial	NA	edge	0.23	0.23	citrus
Barn swallow *(Hirundo rustica)*	Yes	Altricial	edge	field	0.99	0.01-0.99	alfalfa, apples, cabbage, corn, cotton, potatoes, soybeans
Black-capped chickadee *(Poecile atricapillus)*	Yes	Altricial	edge	NA	0.48	0-0.48	alfalfa, cabbage, corn
Blue jay *(Cyanocitta cristata)*	Yes	Altricial	edge	field	0.67	0.01-0.67	alfalfa, apples, cabbage, corn, cotton, potatoes
Blue-gray gnatcatcher *(Polioptila caerulea)*	Yes	Altricial	edge	NA	0.01	0.01	cotton
Blue-winged Teal *(Anas discors)*	No	Precocial	edge	NA	0.65	0.65	corn
Boat-tailed Grackle *(Quiscalus major)*	Yes	Altricial	edge	NA	0.68	0.68	corn
Bobolink *(Dolichonyx oryzivorus)*	Yes	Altricial	field	field	0.97/0.89*	none	none
Brewer's blackbird *(Euphagus cyanocephalus)*	Yes	Altricial	edge	field	0.4	0-0.4	citrus, corn
Canada goose *(Branta canadensis)*	No	Precocial	edge	NA	1	100	corn
Carolina chickadee *(Poecile carolinensis)*	Yes	Altricial	edge	NA	0.08	0-0.08	alfalfa, cotton, potatoes
Carolina wren *(Thryothorus ludovicianus)*	Yes	Altricial	edge	NA	0.01	0-0.01	cotton, potatoes
Cassin's sparrow *(Aimophila cassinii)*	Yes	Altricial	field	NA	0.07	0.07	cotton
Cedar waxwing *(Bombycilla cedrorum)*	Yes	Altricial	edge	field	0.8	0-0.80	apples, cabbage, corn
Chipping sparrow *(Spizella passerina)*	Yes	Altricial	edge	field	0.15-0.88	0.15-0.88	alfalfa, apples, grapes, corn, soybeans
Common grackle *(Quiscalus quiscula)*	Yes	Altricial	edge	NA	0.97	0.02-0.97	alfalfa, cabbage, corn, cotton, potatoes, soybeans
Common yellowthroat *(Geothlypis trichas)*	Yes	Altricial	edge	NA	0.46	0-0.46	cabbage, corn, cotton, potatoes
Dark-eyed junco *(Junco hyemalis)*	Yes	Altricial	edge	NA	0.11	0.11	alfalfa
Dickcissel *(Spiza americana)*	Yes	Altricial	field	NA	1	0.16-1	alfalfa, corn, cotton
Eastern bluebird *(Sialia sialis)*	Yes	Altricial	edge	field	0.79	0.76-0.79	apples, corn
Eastern kingbird *(Tyrannus tyrannus)*	Yes	Altricial	edge	field	0.45	0.01-0.45	alfalfa, corn, grapes
Eastern meadowlark *(Sturnella magna)*	Yes	Altricial	field	NA	0.89	0.88-0.89	alfalfa, corn

Eastern phoebe *(Sayornis phoebe)*	Yes	Altricial	edge	NA	0	0	corn
Field sparrow *(Spizella pusilla)*	Yes	Altricial	edge	NA	1	0.03-1	corn
Grasshopper sparrow *(Ammodramus savannarum)*	Yes	Altricial	field	NA	0.56	0.15-0.56	alfalfa, corn
Great-tailed Grackle (*Quiscalus mexicanus*)	Yes	Altricial	edge	NA	0.35	0.35	corn
Horned lark *(Eremophila alpestris)*	Yes	Altricial	field	NA	0.88	0.36-0.88	corn, cotton, soybeans
House finch *(Carpodacus mexicanus)*	Yes	Altricial	edge	field	0.32	0.02-0.32	citrus, cotton
House sparrow *(Passer domesticus)*	Yes	Altricial	edge	NA	0.63	0.13-0.63	alfalfa, corn, soybeans
House wren *(Troglodytes aedon)*	Yes	Altricial	edge	NA	0.24	0-0.24	alfalfa, corn, potatoes
Killdeer *(Charadrius vociferus)*	No	Precocial	field	field	1	0.65-1	alfalfa, cabbage, corn, grapes, soybeans
Lark bunting *(Calamospiza melanocorys)*	Yes	Altricial	edge	NA	0.07	0.07	corn
Lark sparrow *(Chondestes grammacus)*	Yes	Altricial	edge	NA	0.79	0.33-0.79	corn, cotton
Mallard *(Anas platyrhynchos)*	No	Precocial	edge	edge	0.69/0.89*	none	none
Mourning dove *(Zenaida macroura)*	No	Altricial	edge	field	0.73	0-0.73	alfalfa, apples, citrus, corn, cotton, potatoes, soybeans
Northern bobwhite *(Colinus virginianus)*	No	Precocial	edge	NA	0.53	0.01-0.53	alfalfa, corn, cotton, potatoes
Northern cardinal *(Cardinalis cardinalis)*	Yes	Altricial	edge	NA	0.68	0.01-0.68	alfalfa, corn, cotton, potatoes, soybeans
Northern flicker *(Colaptes auratus)*	No	Altricial	edge	NA	0.29	0-0.29	cabbage, corn, potatoes
Northern mockingbird *(Mimus polyglottos)*	Yes	Altricial	edge	edge	0.35	0.04-0.35	citrus, cotton, potatoes
Ovenbird *(Seiurus aurocapillus)*	Yes	Altricial	edge	NA	0	0	potatoes
Red-winged blackbird *(Agelaius phoeniceus)*	Yes	Altricial	edge	edge	0.89	0.01-0.89	alfalfa, cabbage, citrus, corn, cotton, grapes, potatoes, soybeans
Savannah sparrow *(Passerculus sandwichensis)*	Yes	Altricial	field	field	0.87	0.14-0.87	alfalfa, apples, cabbage, corn, grapes
Tree swallow *(Tachycineta bicolor)*	Yes	Altricial	edge	NA	0.69	0-0.69	cabbage, cotton
Verdin (*Auriparus flaviceps*)	Yes	Altricial	edge	NA	0.57	0.57	cotton
Vesper sparrow *(Pooecetes gramineus)*	Yes	Altricial	field	NA	0.5	0.13-0.50	alfalfa, corn, soybeans
Western meadowlark *(Sturnella neglecta)*	Yes	Altricial	field	NA	0.33	0-0.33	alfalfa, corn
White-crowned sparrow *(Zonotrichia leucophrys)*	Yes	Altricial	edge	NA	0.48	0.48	corn
White-winged dove (*Zenaida asiatica*)	No	Altricial	edge	NA	0.06	0.06	cotton
Willow flycatcher *(Empidonax trailii)*	Yes	Altricial	edge	NA	0	0	corn
Wood thrush *(Hylocichla mustelina)*	Yes	Altricial	edge	NA	0.01	0.01	potatoes
Yellow warbler *(Dendroica petechia)*	Yes	Altricial	edge	NA	0.29	0-0.29	corn, potatoes
Yellow-rumped warbler *(Dendroica magnolia)*	Yes	Altricial	edge	NA	0.09	0.09	corn

*No data are available from avian census studies. Default values are used for field/orchard.

Table 2.4. Custom Species Parameter Values for BW[2]

Species (scientific name)	Female BW (g)				Male BW (g)			
	Mean	SD	Min	Max	Mean	SD	Min	Max
American crow *(Corvus brachyrhynchos)*	438	32.0	289	666	458	33.4	302	696
American goldfinch *(Carduelis tristis)*	12.6	0.81	10	17.1	13.2	1.13	8.6	20.7
American kestrel *(Falco sparverius)*	120	9.2	79	182	111	9.3	73	169
American robin *(Turdus migratorius)*	77.3	0.38	63.5	103	77.3	0.38	63.5	103
Ash-throated flycatcher *(Myiarchus cinerascens)*	27.2	2.0	24	31	27.2	2.0	24	31
Barn swallow *(Hirundo rustica)*	18.6	1.49	13.4	23.4	18.6	1.49	13.4	23.4
Black-capped chickadee *(Poecile atricapillus)*	10.8	1.38	8.2	13.6	10.8	1.38	8.2	13.6
Blue jay *(Cyanocitta cristata)*	86.8	8.08	64.1	109	86.8	8.08	64.1	109
Blue-gray gnatcatcher *(Polioptila caerulea)*	6	0.13	4.8	8.9	6	0.13	4.8	8.9
Blue-winged Teal *(Anas discors)*	363	26	240	545	409	29.9	270	590
Boat-tailed Grackle *(Quiscalus major)*	119	8.7	102	132	214	15	175	253
Bobolink *(Dolichonyx oryzivorus)*	37.1	2.71	26.5	44.3	47	3.4	28.5	56.3
Brewer's blackbird *(Euphagus cyanocephalus)*	58.1	4.9	50.6	67	67.2	3.2	60	73
Canada goose *(Branta canadensis)*	3514	257	3062	3912	4181	305	3799	4727
Carolina chickadee *(Poecile carolinensis)*	9.8	0.59	6.5	14.9	10.5	0.72	6.9	16.0
Carolina wren *(Thryothorus ludovicianus)*	21	1.15	14	32	21	1.15	14	32
Cassin's sparrow *(Aimophila cassinii)*	18.9	1.51	14	23.5	18.9	1.51	14	23.5
Cedar waxwing *(Bombycilla cedrorum)*	33.1	1.07	28	40.2	30.6	1.72	25.5	39.6
Chipping sparrow *(Spizella passerina)*[3]	12.5	1.47	10.2	16.5	12.5	1.47	10.2	16.5
Common grackle *(Quiscalus quiscula)*	100	7.3	66	152	127	9.3	84	193
Common yellowthroat *(Geothlypis trichas)*	9.9	0.78	7.6	15.3	10.3	0.66	7.6	15.5
Dark-eyed junco *(Junco hyemalis)*	18.8	0.78	14.3	25.1	20.4	1.21	14.3	26.7
Dickcissel *(Spiza americana)*	24.6	1.8	16	37	29.3	2.1	19	45
Eastern bluebird *(Sialia sialis)*	31.6	0.92	21	48	31.6	0.92	21	48
Eastern kingbird *(Tyrannus tyrannus)*	39.5	1.85	35.8	40.8	39.5	1.85	35.8	40.8
Eastern meadowlark *(Sturnella magna)*	76	5.5	50	116	102	11.2	67	155
Eastern phoebe *(Sayornis phoebe)*	19.8	7.47	11.4	24.4	19.8	7.47	11.4	24.4
Field sparrow *(Spizella pusilla)*	12.5	1.47	10.2	16.5	12.5	1.47	10.2	16.5
Grasshopper sparrow *(Ammodramus savannarum)*	17	1.34	15	20.3	17	1.34	15	20.3
Great-tailed Grackle *(Quiscalus mexicanus)*	107	11.4	96	140	191	22.8	157	234
Horned lark *(Eremophila alpestris)*	30.8	2.2	20	47	31.9	2.3	21	48
House finch *(Carpodacus mexicanus)*	21.4	1.29	10	25.5	21.4	1.29	10	25.5
House sparrow *(Passer domesticus)*	27.4	2.24	20.1	34.5	28	1.55	20	34
House wren *(Troglodytes aedon)*	10.9	0.8	8.9	14.2	10.9	0.8	8.9	14.2
Killdeer *(Charadrius vociferus)*	101	7.37	87.7	121	92.1	10.4	83.9	109
Lark bunting *(Calamospiza melanocorys)*	37.6	3.66	29.5	51.5	37.6	3.66	29.5	51.5
Lark sparrow *(Chondestes grammacus)*	29	1.94	24.7	33.3	29	1.94	24.7	33.3
Mallard *(Anas platyrhynchos)*	1082	129	720	1580	1082	129	720	1580
Mourning dove *(Zenaida macroura)*	115	1.76	76	175	123	1.85	81	187
Northern bobwhite *(Colinus virginianus)*	178	13.0	117	271	178	13.0	117	271
Northern cardinal *(Cardinalis cardinalis)*	43.9	4.53	33.6	64	45.4	4.29	33.7	63.2
Northern flicker *(Colaptes auratus)*	129	7.67	106	164	135	6.37	114	160
Northern mockingbird *(Mimus polyglottos)*	48.5	3.5	36.2	55.7	48.5	3.5	36.2	55.7
Ovenbird *(Seiurus aurocapillus)*	19.4	1.22	14	28.8	19.4	1.22	14	28.8
Red-winged blackbird *(Agelaius phoeniceus)*	41.5	2.74	29	55	63.6	4.43	52.9	81.8

[2] Body weights from Dunning (1984). If standard deviations, minimum and maximum values were not available, these values were calculated by multiplying the mean by 0.073, 0.66 and 1.52, respectively. (See chapter 2).

[3] Data not available in Dunning (1984) for chipping sparrow. Body weight information for field sparrow (same genus) used.

Species (scientific name)	Female BW (g)				Male BW (g)			
	Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Savannah sparrow *(Passerculus sandwichensis)*	19.5	2.29	13	30	20.6	1.35	14	31
Tree swallow *(Tachycineta bicolor)*	20.1	1.58	15.6	25.4	20.1	1.58	15.6	25.4
Verdin *(Auriparus flaviceps)*	6.8	0.69	5.5	8.5	6.8	0.69	5.5	8.5
Vesper sparrow *(Pooecetes gramineus)*	24.9	1.8	16	38	26.5	1.9	17	40
Western meadowlark *(Sturnella neglecta)*	89.4	6.5	59	136	106	7.7	70	161
White-crowned sparrow *(Zonotrichia leucophrys)*	32	2.18	27	35.5	32	2.18	27	35.5
White-winged dove *(Zenaida asiatica)*	153	13.2	125	187	153	13.2	125	187
Willow flycatcher *(Empidonax trailii)*	13.7	1.46	11.3	16.4	13.1	1.37	12	15.7
Wood thrush *(Hylocichla mustelina)*	47.4	4.17	39.2	57.7	47.4	4.17	39.2	57.7
Yellow warbler *(Dendroica petechia)*	9.2	0.59	7.4	16	9.8	0.68	7.9	12.8
Yellow-rumped warbler *(Dendroica magnolia)*	8.5	0.35	6.6	12.6	8.9	0.58	7	12.9

Table 2.5. Custom Species Parameters for Diet. Based on MCnest Species Library

Species (scientific name)	Feeding category[4]	Adult diet					Juvenile diet				
		insects	seeds	fruit	grass	broadleaf	insects	seeds	fruit	grass	broadleaf
American crow *(Corvus brachyrhynchos)*	Omnivore	0.28	0.54	0.18	0	0	0.165	0.835	0	0	0
American goldfinch *(Carduelis tristis)*	Granivore	0	1	0	0	0	0	1	0	0	0
American kestrel *(Falco sparverius)*	Insectivore	1	0	0	0	0	1	0	0	0	0
American robin *(Turdus migratorius)*	Insectivore	0.72	0	0.28	0	0	0.7	0	0.3	0	0
Ash-throated flycatcher *(Myiarchus cinerascens)*	Insectivore	1	0	0	0	0	1	0	0	0	0
Barn swallow *(Hirundo rustica)*	Insectivore	1	0	0	0	0	1	0	0	0	0
Black-capped chickadee *(Poecile atricapillus)*	Insectivore	0.9	0.05	0.05	0	0	1	0	0	0	0
Blue jay *(Cyanocitta cristata)*	Omnivore	0.4	0.6	0	0	0	0.4	0.6	0	0	0
Blue-gray gnatcatcher *(Polioptila caerulea)*	Insectivore	1	0	0	0	0	1	0	0	0	0
Blue-winged Teal *(Anas discors)*	Insectivore	0.91	0.09	0	0	0	1	0	0	0	0
Boat-tailed Grackle *(Quiscalus major)*	Insectivore	0.92	0	0.08	0	0	1	0	0	0	0
Bobolink *(Dolichonyx oryzivorus)*	Omnivore	0.57	0.43	0	0	0	1	0	0	0	0
Brewer's blackbird *(Euphagus cyanocephalus)*	Insectivore	0.82	0.18	0	0	0	1	0	0	0	0
Canada goose *(Branta canadensis)*	herbivore	0	0	0	1	0	0	0	0	1	0
Carolina chickadee *(Poecile carolinensis)*	Insectivore	0.9	0.05	0.05	0	0	1	0	0	0	0
Carolina wren *(Thryothorus ludovicianus)*	Insectivore	0.98	0.02	0	0	0	1	0	0	0	0
Cassin's sparrow *(Aimophila cassinii)*	Insectivore	1	0	0	0	0	1	0	0	0	0
Cedar waxwing *(Bombycilla cedrorum)*	Frugivore	0.2	0	0.8	0	0	0.2	0	0.8	0	0
Chipping sparrow *(Spizella passerina)*	Omnivore	0.38	0.62	0	0	0	0.2	0.8	0	0	0
Common grackle *(Quiscalus quiscula)*	Granivore	0.3	0.7	0	0	0	1	0	0	0	0
Common yellowthroat *(Geothlypis trichas)*	Insectivore	1	0	0	0	0	1	0	0	0	0
Dark-eyed junco *(Junco hyemalis)*	Omnivore	0.6	0.4	0	0	0	1	0	0	0	0
Dickcissel *(Spiza americana)*	Insectivore	0.7	0.3	0	0	0	1	0	0	0	0
Eastern bluebird *(Sialia sialis)*	Insectivore	0.93	0	0.07	0	0	1	0	0	0	0
Eastern kingbird *(Tyrannus tyrannus)*	Insectivore	0.855	0	0.145	0	0	1	0	0	0	0
Eastern meadowlark *(Sturnella magna)*	Insectivore	0.9	0.1	0	0	0	1	0	0	0	0
Eastern phoebe *(Sayornis phoebe)*	Insectivore	1	0	0	0	0	1	0	0	0	0
Field sparrow *(Spizella pusilla)*	Omnivore	0.5	0.5	0	0	0	1	0	0	0	0
Grasshopper sparrow *(Ammodramus savannarum)*	Omnivore	0.61	0.39	0	0	0	1	0	0	0	0
Great-tailed Grackle *(Quiscalus mexicanus)*	Insectivore	1	0	0	0	0	1	0	0	0	0
Horned lark *(Eremophila alpestris)*	Granivore	0.27	0.73	0	0	0	1	0	0	0	0
House finch *(Carpodacus mexicanus)*	Granivore	0.05	0.88	0.07	0	0	0.02	0.98	0	0	0

[4] If species' diets are ≥ 70% insects, they are identified as insectivores. This same cutoff applies to herbivores and granivores. If no dietary item represents ≥ 70% of the overall diet, the species is considered an omnivore.

Species (scientific name)	Feeding category[4]	Adult diet					Juvenile diet				
		insects	**seeds**	**fruit**	**grass**	**broadleaf**	**insects**	**seeds**	**fruit**	**grass**	**broadleaf**
House sparrow *(Passer domesticus)*	Granivore	0.04	0.96	0	0	0	0.68	0.32	0	0	0
House wren *(Troglodytes aedon)*	Insectivore	1	0	0	0	0	1	0	0	0	0
Killdeer *(Charadrius vociferus)*	Insectivore	1	0	0	0	0	1	0	0	0	0
Lark bunting *(Calamospiza melanocorys)*	Omnivore	0.64	0.36	0	0	0	1	0	0	0	0
Lark sparrow *(Chondestes grammacus)*	Omnivore	0.5	0.5	0	0	0	1	0	0	0	0
Mallard *(Anas platyrhynchos)*	Insectivore	0.72	0.28	0	0	0	0.9	0.1	0	0	0
Mourning dove *(Zenaida macroura)*	Granivore	0	1	0	0	0	0	1	0	0	0
Northern bobwhite *(Colinus virginianus)*	Granivore	0.2	0.8	0	0	0	0.9	0.1	0	0	0
Northern cardinal *(Cardinalis cardinalis)*	Omnivore	0.61	0.39	0	0	0	1	0	0	0	0
Northern flicker *(Colaptes auratus)*	Insectivore	0.9	0	0.1	0	0	0.9	0	0.1	0	0
Northern mockingbird *(Mimus polyglottos)*	Insectivore	0.85	0	0.15	0	0	1	0	0	0	0
Ovenbird *(Seiurus aurocapillus)*	Insectivore	1	0	0	0	0	1	0	0	0	0
Red-winged blackbird *(Agelaius phoeniceus)*	Insectivore	0.71	0.29	0	0	0	1	0	0	0	0
Savannah sparrow *(Passerculus sandwichensis)*	Insectivore	1	0	0	0	0	1	0	0	0	0
Tree swallow *(Tachycineta bicolor)*	Insectivore	1	0	0	0	0	1	0	0	0	0
Verdin *(Auriparus flaviceps)*	Insectivore	1	0	0	0	0	1	0	0	0	0
Vesper sparrow *(Pooecetes gramineus)*	Omnivore	0.56	0.44	0	0	0	1	0	0	0	0
Western meadowlark *(Sturnella neglecta)*	Insectivore	0.9	0.1	0	0	0	1	0	0	0	0
White-crowned sparrow *(Zonotrichia leucophrys)*	Omnivore	0.36	0.64	0	0	0	1	0	0	0	0
White-winged dove *(Zenaida asiatica)*	Granivore	0	1	0	0	0	0	1	0	0	0
Willow flycatcher *(Empidonax trailii)*	Insectivore	1	0	0	0	0	1	0	0	0	0
Wood thrush *(Hylocichla mustelina)*	Omnivore	0.65	0	0.35	0	0	1	0	0	0	0
Yellow warbler *(Dendroica petechia)*	Insectivore	1	0	0	0	0	1	0	0	0	0
Yellow-rumped warbler *(Dendroica magnolia)*	Insectivore	0.85	0	0.15	0	0	1	0	0	0	0

3. Modeling Bird Behavior: Feeding and Location

Hourly pesticide exposures through all pathways (*i.e.*, feeding, inhalation, dermal and drinking) are a function of the time relative to the feeding pattern and the presence or absence of the simulated bird on the treated field. When a bird is on a treated field during a time step, it is assumed that the bird may be exposed to the pesticide through any of the exposure pathways considered in TIM. When the bird is off of the field, it is exposed to a fraction of the on-field exposure that is based on the spray drift deposition relative to the bird's location with respect to the edge of the treated field. TIMv.3.0 uses a bimodal feeding period to represent the feeding behavior of birds during the day. In one day, a bird feeds during the morning and afternoon. A Markov chain is used to model the movement of birds on and off of the field during feeding hours. The location of an individual bird during non-feeding hours is different for field- and edge-resident species. Edge species are assumed to be off of the treated field during non-feeding hours, while field species are assumed to be located on the treated field during non-feeding hours.

3.1. Bimodal Feeding Model to Describe Feeding Behavior

TIM incorporates a flexible, probability-based, algorithm to represent bird feeding behavior. The bimodal feeding model is based on the assumption that birds have two distinct feeding periods during the day (based on a recommendation of the 2001 SAP); *i.e.*, a morning feeding period and an afternoon feeding period (**Figure 3.1**). Each day is represented by a 24-hour clock, with hour 0 representing midnight to 1 am.

The beginning and ending times of both the morning and afternoon feeding periods are assumed to vary randomly each day, within specified time windows, and vary from bird to bird. These windows are based on sunrise and sunset times, as well as the heat of the day. Uniform distributions are established for the morning start, morning end, afternoon start and afternoon end times, using the minimum and maximum start/stop values entered by the model user. A description of the uniform distribution is available in USEPA (2007a). TIM also assigns uniform distributions to represent the mean of the morning and the afternoon feeding periods, using the uniform distributions of the start and ending periods for each feeding time. For each bird, the following times are assigned from their respective uniform distributions:

- morning start (am_{min})
- morning end (am_{max})
- morning mode (am_{mode})
- afternoon start (pm_{min})
- afternoon end (pm_{max})
- afternoon mode (pm_{mode})

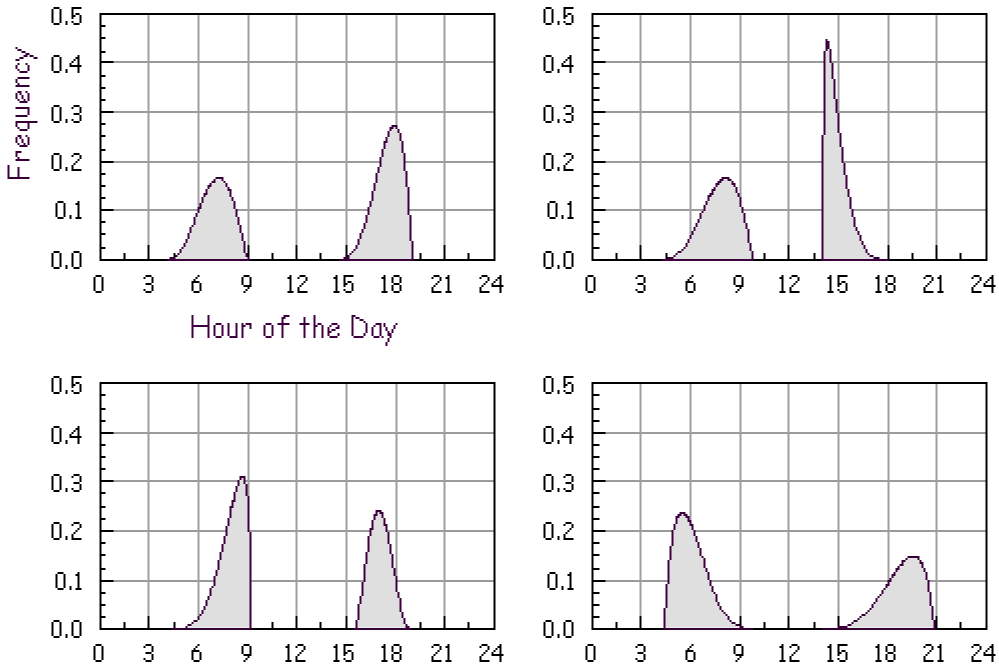

Figure 3.1. Hypothetical Examples of the Avian Bimodal Feeding Pattern. X-axis is hour of day; Y-axis is daily dietary fraction.

Each day of a simulation, the proportion of daily feeding is divided between the morning and afternoon feeding periods (**Figure 3.1**). This distribution of feeding is determined by a variable termed “Split” (S). Each day of a simulation, a different S value is selected for an individual bird from a uniform distribution with minimum and maximum values established by the model user.

On a given hour that occurs during a feeding period, the proportion of the daily diet consumed during that hour ($HF_{(t)}$) is determined from *beta pert* (β_p) distributions (See Vose, 1996; **Equations 3.1 and 3.2**). These values are generated using the minimum, maximum and mode feeding times selected for each bird, where time (t) is in hours. If t is outside of the morning and afternoon feeding times of the simulated bird, $HF_{(t)}$ is equal to 0. **Figure 3.2** illustrates several random bimodal feeding patterns as they may be incorporated into TIM. A general description of equations used to derive a *beta pert* distribution is provided in USEPA (2004).

Equation 3.1. $\mathrm{HF}_{(t)} = S * \beta_p(t\,;am_{\min}\,,am_{\mathrm{mode}}\,,am_{\max})$ [Morning feeding time period]

Equation 3.2. $\mathrm{HF}_{(t)} = (1-S) * \beta_p(t\,;pm_{\min}\,,pm_{\mathrm{mode}}\,,pm_{\max})$ [Afternoon feeding time period]

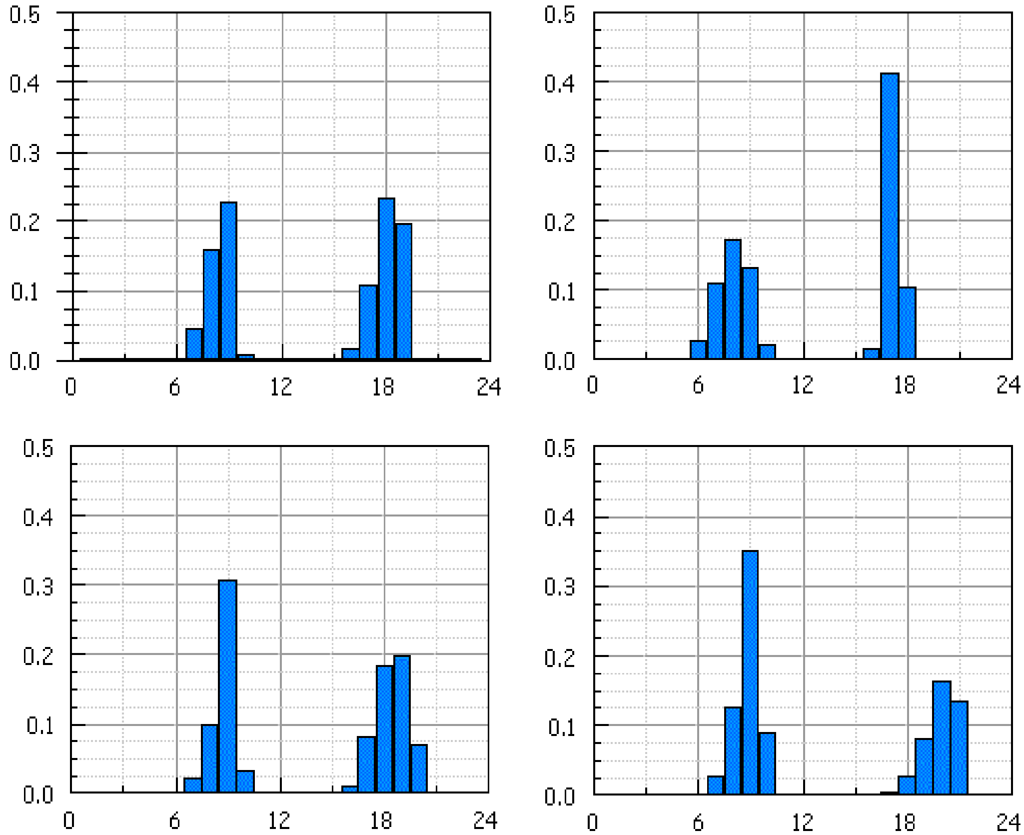

Figure 3.2. Examples of Hourly Feeding Fractions Used in TIM. X-axis is hour of day; Y-axis is daily dietary fraction.

3.2. Markov Chain Model to Describe Adult Movement during Feeding Periods

The presence on-field, off-field parameter (ε_t), is modeled as a first-order, two-state Markov chain model. In 2004, the SAP agreed that the Markov chain allowed “a realistic characterization of serial behavior.” The Markov chain model is a statistical model for the persistence of binary events, in this case, whether or not an individual bird is on or off the field in any particular hour during feeding hours. In this application, two-state refers to the state $X = 0$, where the bird is off the field, or state $X = 1$, where the bird is on the field. First-order means that the probability of whether a bird is on the field or off the field in any hour depends only on the state (location) of the bird in the previous hour. A first-order, two-state Markov chain is specified by four transitional probabilities for a bird's state at time t+1, given the bird's state at time t, $\begin{bmatrix} p_{00} & p_{01} \\ p_{10} & p_{11} \end{bmatrix}$,where:

- $P_{00} = \text{Prob}\{X_{t+1} = 0 \mid X_t = 0\}$ = probability that a bird, now off the field, will remain off the field in the next hour;
- $P_{01} = \text{Prob}\{X_{t+1} = 1 \mid X_t = 0\}$ = probability that a bird, now off the field, will be on the field in the next hour;
- $P_{11} = \text{Prob}\{X_{t+1} = 1 \mid X_t = 1\}$ = probability that a bird, now on the field, will remain on the field in the next hour;
- $P_{10} = \text{Prob}\{X_{t+1} = 0 \mid X_t = 1\}$ = probability that a bird, now on the field, will be off the field in the next hour.

These transitional probabilities are illustrated in **Figure 3.3**. As usual in Markov Chain theory, the rows of the transition matrix sum to unity, *i.e.*, $P_{00} + P_{01} = 1$, and $P_{10} + P_{11} = 1$.

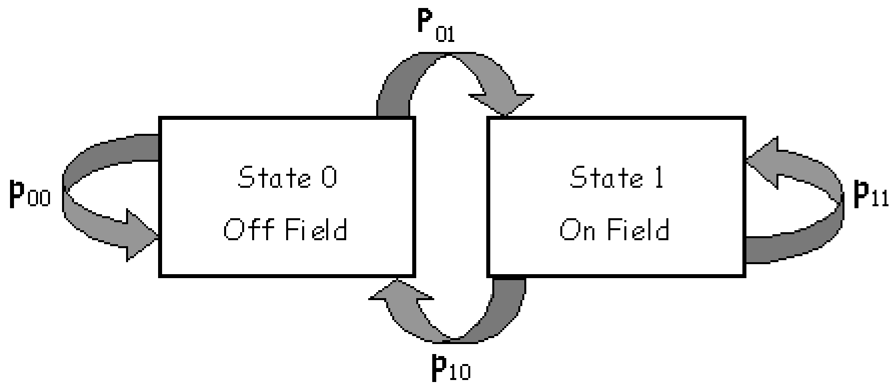

Figure 3.3. The Two-state, First-order Markov Chain Model for Avian Location on or off a Treated Field.

The location of a bird on or off of the treated field at time t (ε_t) is determined considering the bird's location in the previous hour and P_{00} and P_{11}. TIM estimates this value by first selecting a random number (U) from a uniform distribution ranging from 0 to 1.

If the bird is OFF of the treated field in the previous time step (t-1), U is compared to P_{00}. If $U \leq P_{00}$, then the bird is off of the treated field at time t (*i.e.*, $\varepsilon_t = 0$). If $U > P_{00}$, then the bird is on the treated field at time t (*i.e.*, $\varepsilon_t = 1$). Therefore, the lower the value of P_{00}, the more likely it is that the bird will move from the edge at time t-1 to the field at time t.

Likewise, if the bird is ON the treated field in the previous time step (t-1), U is compared to P_{11}. If $U \leq P_{11}$, then the bird is on the treated field at time t (*i.e.*, $\varepsilon_t = 1$). If $U > P_{11}$, then the bird is off of the treated field at time t (*i.e.*, $\varepsilon_t = 0$). Therefore, the higher the value of P_{11}, the more likely it is that the bird will stay on the field from time t-1 to time t.

The long run probability of a bird being on the field (FOF) is represented by **Equation 3.3**. P_{11} is the probability that a bird on the field will remain on the field the following hour. This parameter is treated as a random variable with a triangular distribution (P_{11} ~ Triangular(P_{11} Min, 1.0, P_{11} mode)). A description of this distribution is available in USEPA 2007a. Given an estimate of FOF for an individual bird (selected from a *beta pert* distribution), the minimum value that the conditional probability P_{11} can assume is derived according to **Equation 3.4.** The mode of P_{11} is derived using **Equation 3.5.** Note that *Q*, the fidelity factor, is the fraction of the range of permitted values for P_{11}, which helps specify the location of the mode. Q is discussed in more detail below. With an estimate of P_{11}, P_{01} is calculated using **Equation 3.6.** P_{00} can be calculated using P_{01} and **Equation 3.7**. P_{10} can be calculated using P_{11} and **Equation 3.8**.

Equation 3.3. $FOF = \frac{P_{11}}{1+P_{01}-P_{11}}$

Equation 3.4. $Min\ of\ P_{11} = Max\ of\left[\left\{\frac{2*FOF-1}{FOF}\right\}, 0\right]$

Equation 3.5. $\text{mode } P_{11} = Min\ of\ P_{11} + Q*\Delta P_{11}$

Where: $\Delta P_{11} = 1 - \min\ of\ P_{11}$

Equation 3.6. $P_{01} = \frac{FOF*(1-P_{11})}{1-FOF}$

Equation 3.7. $P_{00} = 1 - P_{01}$

Equation 3.8. $P_{10} = 1 - P_{11}$

As discussed below in **Section 3.4**, birds that are off field receive a fraction of the on-field exposure that is determined by the spray drift deposition at their location relative to the edge of the treated field. For birds that are located entirely within the edge habitat (*i.e.,* FOF = 0), the Markov Chain is not necessary for tracking movement. Rather, these birds move to random locations within the edge habitat.

3.3. Juvenile Locations

During the simulation, juvenile locations depend upon whether the species is altricial or precocial. Altricial birds are those that do not leave the nest until they are essentially adults (*e.g.,* passerines are altricial). On the other hand, the young of precocial birds leave the nest when they are hatchlings. Examples of precocial birds include waterfowl and upland game birds. In TIM (v.3.0), it is assumed that altricial birds are located at their nest site and that the precocial birds follow their parents, thus having the same location.

Whether a species is precocial or altricial impacts the exposures received by the juveniles. Precocial juveniles receive similar exposures as the parents. Altricial juveniles do not receive dermal contact or drinking water exposures. If altricial nests are located off of the treated field, the juveniles receive only a fraction of the on-field exposure from inhalation and direct dermal spray.

3.4. Accounting for Off-Field Exposures Due to Spray Drift

When birds are off of the field, spray drift transport and off-field deposition may result in pesticide exposures that are a fraction of what they would receive on the treated field. This fraction is determined based on the bird's location relative to the edge of the treated field. The bird's location relative to the edge of the field is calculated by considering the area of the bird's home range and the extent of overlap between the home range and the treated field.

Figure 3.4 depicts an example of three scenarios that may occur with overlaps between the home ranges of simulated birds and the treated field and edge habitat. This figure depicts the treated field, the spray drift zone and areas that do not receive pesticide exposure either because they are beyond the spray drift zone (*i.e.,* >304 m from the edge of the field), or the adjacent edge habitat does not receive spray drift. In this example, the range of bird #1 overlaps with the treated field, the spray drift transport area and the area receiving no pesticide exposure. The range of bird #2 overlaps with the spray drift area and the area receiving no pesticide exposure, but not the treated field. The range of bird # 3 overlaps with the treated field and the edge habitat that does not receive spray drift. Although not depicted in this figure, it is also possible that the home range of a bird may overlap only with the treated field and the area receiving spray drift.

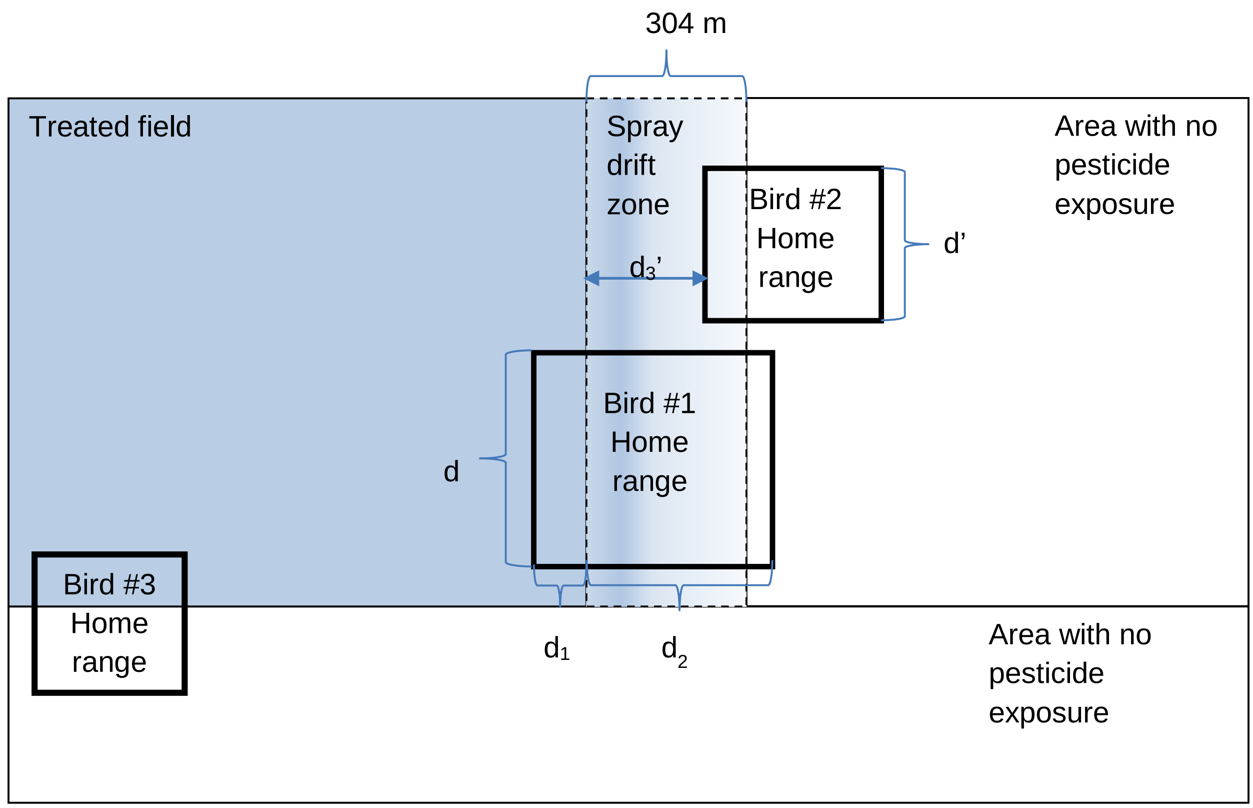

Figure 3.4. Example Overlap between Treated Field and Bird Home Ranges.

In this scenario, it is assumed that 100% of the edge habitat receives spray drift. This assumption may be the case where there is a limited area of non-cropped habitat and other sides of the treated field are represented by cropped fields. In this case, scenarios represented by bird #3 would not be included in a simulation. The model user may choose to alter this assumption by entering an input parameter to represent the fraction of the edge habitat that receives spray drift. For example, this assumption may be altered to represent fields with prevailing winds that reach only a portion of habitat that is suitable for birds. If this is the case, the model randomly assigns a proportion of the simulated birds' home ranges to overlap with edge habitats that do not receive spray drift. This approach assumes that the birds are uniformly distributed and the proportion of birds in the edge habitat receiving spray drift matches the model user's assumed fraction.
This approach also focuses on the risks to birds that feed on treated fields and in adjacent habitats and assumes that all birds visit these areas at some point during the simulation. There are

no birds simulated that have home ranges entirely outside of the treated site and spray drift zone. In the context of a population of birds, TIM assumes that all birds are being exposed to the pesticide. TIM does not account for risks where a portion of the population is not exposed to the pesticide.

3.4.1. Determining an Individual Bird's Distance from the Edge of the Field

The bird's distance from the edge of the field is determined based on the dimensions of the home range (**Section 2.3**) and FOF (**Section 2.4**). In this approach, it is assumed that the home range is a square with each side equal to the square root of the area. In **Figure 3.4**, bird #1 is d; bird #2 is d', in meters. This section describes how TIM calculates a bird's distance from the edge of the field using birds 1, 2 and 3 as examples.

A bird that has a frequency on field (FOF) value >0 has overlap between some portion of its home range and the treated field (*e.g.,* bird #1). Portions of the bird's range also overlap with the area receiving spray drift deposition and possibly the area where it is assumed that there is no spray drift deposition. For bird #1, d is represented by two segments: d_1, which is the portion of d that overlaps with the treated field and d_2, which is the portion of d that is off of the treated field. The farthest distance from the edge of the field that the bird will travel is d_2, which is calculated by subtracting d_1 from d. d_1 is calculated using the area of the portion of the bird's range that overlaps with the field. This area ($A_{overlap}$) is calculated by multiplying the bird's home range (A) by its FOF. Since the area of a rectangle is calculated by multiplying the lengths of its sides (*i.e.,* d and d_1), d_1 can be calculated by rearranging **Equation 3.9** into **Equation 3.10**. When a bird is located off of the treated field, its distance from the edge of the field at time t (d_t) is determined by randomly selecting a distance from a uniform distribution of values between 0 and d_2 in meters.

Equation 3.9. $A_{overlap} = A * FOF = d * d_1$

Equation 3.10. $d_1 = \frac{A*FOF}{d}$

For birds that do not have home ranges overlapping with the treated field (*e.g.,* bird #2), it is assumed that some portion of their home range overlaps with the area receiving spray drift deposition from the treated field. In this case, the FOF of the bird is 0. For these birds, some or all of their home range may overlap with the area receiving spray drift from the field. The distance between the bird's home range and the edge of the treated field (*i.e.,* d_3') varies by bird. This value is selected as a random value from a uniform distribution, ranging from 0 to 303 m. Because 304 m is the predictive limit of the AgDRIFT model (Tier 1) used to predict spray drift deposition, a maximum of 303 m was selected as the farthest distance for the edge of the home range. For birds with FOF = 0, at time t, the maximum distance a bird may be located away from the treated field is calculated by adding d_3' to the length of the home range (*i.e.,* d'). During the simulation, the bird's location at any time point is determined by selecting a random value from the uniform distribution of values between d_3' and d_3'+d'.

In cases where the model simulation assumes that only a portion of the edge habitat receives spray drift when birds are on the treated field, they receive pesticide exposure. When those birds are off of the field, they receive no additional pesticide. For example, see Bird #3 in **Figure 3.4**.

When adults are not feeding, it is assumed that they are located in the center of their home ranges. For altricial species, this is akin to sitting on the nest. The use of the center of the home range as the birds' locations during non-feeding hours is a simplifying assumption that does not explicitly take into account the particular land attributes. Although precocial birds do not use a nest once the offspring have hatched, it is assumed that they will rest in the center of their home range. It is assumed that during non-feeding hours, juveniles are in the same location as their parents. During all hours of the simulation, altricial juveniles are located in the center of the home range (*i.e.*, on the nest).

For field residents, it is assumed that the birds are located on the field during non-feeding hours. For edge residents, the bird's distance from the edge of the field during non-feeding periods ($d_{non\text{-}feeding}$) is calculated using d and d_1 or d_3 (depending upon the bird's FOF). If the adult's home range overlaps with the treated field (*i.e.*, FOF>0), the nest location is calculated by subtracting d_1 from the central point of the home range (*i.e.*, d/2) (**Equation 3.11**). If this value is ≤0 (meaning that the non-feeding location would be on the field), $d_{non\text{-}feeding}$ is assumed to be 1 m because the species is an edge resident. If FOF = 0, meaning that the adult's home range does not overlap with the treated field, $d_{non\text{-}feeding}$ is determined by adding the distance between the edges of the field and the center of the home range (*i.e.*, d_3) and d/2 (**Equation 3.11**).

Equation 3.11. If FOF>0, $d_{non-feeding} = \frac{d}{2} - d_1$

If FOF=0, $d_{non-feeding} = d_3 + \frac{d}{2}$

3.4.2. Determining the Fraction of Exposure Compared to Field

For birds that have home ranges that overlap with edge habitat that receives spray drift deposition (*e.g.*, birds 1 and 2 in **Figure 3.4**) when they are off of the field, the birds receive a fraction of the on-field exposure (F_{field}). This fraction is determined using the spray drift deposition that corresponds to the bird's randomly selected distance from the edge of the treated field (d_t). The pesticide dose received by the bird when it is off of the field is calculated by multiplying the on-field exposure by F_{field}. When a bird is located beyond the spray drift area, exposure is zero (*i.e.*, if $d_t > 303$ m, then $F_{field} = 0$). When the bird is on the field (*i.e.*, $\varepsilon_t = 1$), $F_{field} = 1$.

Spray drift deposition at different distances from the edge of the field was calculated using the Tier I AgDRIFT model (v. 2.1.1)[5]. Spray drift deposition differs by application method, droplet spectra and release height. The standard equation used by the developers of AgDRIFT is

[5] http://www.epa.gov/oppefed1/models/water/

calculated using **Equation 3.12.** This equation can be used to calculate F_{field}. In this equation, a factor of 3.28 is used to convert the units of d_t from meters to feet.

Equation 3.12. $F_{field} = \frac{c}{(1+a*d_t*3.28)^b}$

An analysis of the deposition curves generated from AgDRIFT 2.1.1 yielded the following parameters found in **Table 3.1**. For some application methods, the curves were split at a particular distance in order to get a better fit to the data. The break point distances were determined by visual observation.

Table 3.1. Parameters for Spray Drift Equations, Based on Application Method

Application method	Droplet spectrum (distance from edge of field)	a	b	c
Aerial	Very Fine to Fine (< 43 m) Very Fine to Fine (≥ 43 m) Fine To Medium (< 16 m) Fine To Medium (≥ 16 m) Medium to Coarse Coarse to Very Coarse	0.0204 0.0292 0.1187 0.0241 0.0721 0.1014	0.7278 0.8220 0.5699 0.8689 1.0977 1.1344	0.5001 0.6539 0.5000 0.1678 0.4999 0.4999
Ground*, high boom	Very Fine to Fine Fine to Medium/Coarse	0.1913 2.4154	1.2366 0.9077	1.0552 1.0128
Ground*, low boom	Very Fine to Fine Fine to Medium Coarse	1.0063 5.5513	0.9998 0.8523	1.0193 1.0079
Airblast, vineyard	Not applicable	0.1349	1.4405	0.0376
Airblast, orchard	Not applicable (<26 m) Not applicable (≥ 26 m)	0.0414 6.7728	2.1054 1.2788	0.2223 27.027

*Equations generate 90th percentile deposition values.

The model user can simulate the effects of an infield spray drift buffer on potential risks associated with decreased spray drift deposition in the edge habitat. In this approach, the length of the in-field buffer (B; in m) is added to d_t prior to calculating the spray drift deposition at the bird's location (**Equation 3.13**). If d_t + B >303 m, F_{field} is 0. In this approach, if the bird is on the field, it still receives the full on-field exposure. Decreased exposure in the portion of the field that is represented by the buffer is not quantified.

Equation 3.13. $F_{field} = \frac{c}{(1+a*(d_t+B)*3.28)^b}$

4. Estimating Pesticide Exposure through Diet

In TIM v.3.0, an individual bird's pesticide dose through diet at time t ($D_{diet(t)}$) is calculated according to **Equation 4.1.** This equation considers several variables (**Table 4.1**), including pesticide concentrations on individual food items (k), fraction of the diet attributed to each food item (DF_k), the fraction of each food item that is contaminated (FC_k), the total daily ingestion rate (TDIR), the fraction of that total daily intake rate that can be attributed to the time step that is being considered (*i.e.*, the hourly fraction; $HF_{(t)}$, described in **Section 3.1**), the bird's BW and the food matrix adjustment factor (FMA). As discussed in **Section 3**, the dose is adjusted based on the bird's location. If the bird is on the field, then F_{field} = 1. If the bird is off field and within an area receiving spray drift, then F_{field} is assigned a value <1 based on the spray drift deposition at the bird's location during that hour. The FMA is a constant that is intended to account for the difference in dose-based and dietary-based toxicity of a chemical, where this difference can be attributed to effects of the food on the toxicity of the chemical. The equations and assumptions used to generate $C_{k(t)}$, TDIR, and FMA are provided below. Uncertainties associated with **Equation 4.1** and the individual input parameters are described in **Section 10**.

Equation 4.1. $\boldsymbol{D_{diet(t)} = F_{field} * \frac{(TDIR*HF_{(t)})*\Sigma(C_{k(t)}*DF_k*FC_k)}{BW*FMA}}$

Table 4.1. Parameters Used for Equations in Section 4 to Estimate Pesticide Exposure Concentrations through Diet.

Symbol	Definition	Variable type*	Units
AE_k	Assimilation efficiency	Random	none
BW	Body weight	Random	g/bird
$C_{k(t)}$	Pesticide concentration on food item k at time t	Random	µg pesticide/g food
DF_k	Fraction of diet attributed to food item k	Constant	none
$D_{diet(t)}$	Estimated exposure concentration through diet for a pesticide at time t	Random	µg pesticide/g-bw
FC_k	Fraction of food that is contaminated	Constant	none
F_{field}	Fraction of on field exposure	Random	none
FIS	Food ingestion scale factor	Random	none
FMA	Food matrix adjustment factor	Constant	none
FMR	Field metabolic rate	Random	kcal/bird-day
GE_k	Gross energy	Random	Kcal / g food (wet wt)
ME_k	Metabolizable energy of food item k	Random	kcal/bird-day
ME_{total}	Total metabolizable energy	Random	kcal/g food
TDIR	Total daily intake rate (for food)	Random	g food/bird-day

* "Constant" indicates that the parameter is set to one value. "Random" indicates that the parameter's value varies based on a distribution of possible values.

In TIM v.3.0, the diet of the simulated bird is defined by five categories of dietary food items: arthropods, seeds, fruits, grass, and broadleaf forage. Each food item is assigned a fraction of the total diet of the model bird, where the sum of all fractions totals 1. The fraction of each item in the total diet (DF_k) is dependent on the species being modeled. As described in **Section 2,** the user may select one of the generic species for which dietary fractions are preset, or choose to define a custom species and assign dietary fractions for each food category. The bird's pesticide dose at time t is calculated by considering pesticide concentrations at that time ($C_{k(t)}$) for each food item (k) in the bird's diet.

4.1. Pesticide Concentrations on Food Items (Ck(t))

4.1.1. Pesticide Residues on Food items at the Time of Application ($C_{k(t=0)}$)

The initial pesticide residue on the food items ($C_{k(t=0)}$) is normalized to represent the µg pesticide/g food resulting from 1 lb pesticide/A. For plants (grass, broadleaf, seeds and fruit), initial residue concentrations on plants are from Fletcher *et al*. (1994). Initial residue concentrations on arthropods are based on an analysis of data from the scientific literature and registrant-submitted studies (**Appendix E)**. The mean and standard deviations from these data sets are used in TIM (**Table 4.2**) to represent the initial pesticide concentration on different food items that results from an application of 1 lb a.i./A.

Table 4.2. Mean and Standard Deviations (SD) of Initial Concentrations of Pesticide on Different Food Items Relevant to TIM. Values are normalized to µg pesticide/g food (ppm) per 1 lb a.i./A applied.

Food Item (k)	Mean	SD	Source
Arthropods*	65	48	**See Appendix E**
Seeds	4.0	5.9	Fletcher *et al*. (1994)
Fruit	5.4	9.8	Fletcher *et al*. (1994)
Grass	84.8	60.3	Fletcher *et al*. (1994)
Broadleaf forage	45.0	56.7	Fletcher *et al*. (1994)

*Also referred to in TIM documentation as "insects." This food item is intended to represent terrestrial insects as well as spiders, centipedes, millipedes, *etc*.

In TIM, the initial residue concentration of pesticide on each food item is transformed to be representative of the specific pesticide application by multiplying the mean and standard deviation of the initial residue concentration by the application rate of the pesticide (in lbs a.i./A). For each food item, a lognormal distribution is derived using the transformed mean and standard deviation of the initial residue concentration on the food items. A description of the lognormal distribution is available in USEPA (2007a). Each bird in the simulation is assigned a set of initial pesticide residue values on the five modeled food items that are normalized to 1 lb a.i./A. These initial residue values are selected randomly from the five different distributions based on the mean and standard deviations provided in **Table 4.2**. These values are converted to the initial residues by multiplying by the application rate (**Equation 4.2**).

Equation 4.2. $C_{k0} = C_{k(normalized)} * A_{rate}$

4.1.2. Pesticide Residues on Food Items After First Application ($Ck_{(t)}$)

In modeling exposures over multiple days, it is necessary to account for dissipation of pesticide residues from avian food sources over time. In the case that dissipation half-life data are available for different food items, TIM allows the model user to enter separate dissipation half-life values for all food items. Dissipation half-life values should be obtained from the open literature or from registrant-submitted studies. In the case that data are only available for the foliar dissipation half-life, this value should be used to represent the dissipation half-life for all food items. If no foliar dissipation half-life is available, then a default value of 35 days is used based on the work by Willis and McDowel (1987), which represents a high-end foliar dissipation value from that source (where the maximum $t_{1/2}$ = 36.9 days). The user's manual of T-REX (USEPA 2012) includes guidance for selecting the appropriate foliar dissipation half-life.

To derive the pesticide residue dissipation half-life values for a food item, model users should input chemical-specific, measured dissipation half-lives from available sources if suitable data are available. The mean half-life value ($t_{½\ k}$ in days) for a food item (k) is used to calculate a mean dissipation rate for that food item (r_k in hours) using **Equation 4.3**. The half-life value is converted from days to hours by multiplying by 24 (hours/day).

Equation 4.3. $r_k = \ln(0.5)/(-t_{1/2k} * 24)$

To calculate residues in wildlife food items at the first time steps after the first application of a pesticide to the field ($Ck_{(t)}$), the exposure model randomly selects an hour 0 residue concentration from the distributions described in sections above and dissipates this residue using **Equation 4.4.** TIM allows the user to simulate up to 5 pesticide applications. In the case that multiple applications are simulated, residues from all applications are added to determine the total residue value at time t.

Equation 4.4. $C_{k_{(t)}} = C_{k_0} * e^{-r_k t}$

4.1.3. Contaminated Fraction on Food Items (FC_k)

For broadcast applications, the entire treated field is assumed to be exposed to the applied pesticide and therefore each of the avian food items found on such fields are judged to be contaminated with the pesticide (*i.e.*, FC_k values for all food items is assumed to be 1). For in-furrow or banded spray applications, the pesticide application is assumed to be limited to the portion of the treated field constituting the furrows or bands. For plant food items (*i.e.*, seeds, fruit, grass, broadleaf), FC_k should be set at a fixed value representing the area proportion of the treated field to which pesticide is directly applied. For example, for an in-furrow treatments with 40-inch row spacing and 2-inch wide furrows, FC_k is 0.05 for seeds. For insects, FC_k should be set to 1 for all applications because insects are assumed to be mobile across the entire field; thus the application of pesticide to only furrow or bands is not assumed to affect the fraction of the food item assumed to be contaminated.

4.2. Total Daily Food Intake Rate (TDIR)

TDIR is calculated using **Equation 4.5.** The total daily intake rate (TDIR; g food/bird-day) for food is calculated by considering the field metabolic rate (FMR; kcal/bird-day), the total metabolizable energy (ME_{total}; kcal/g food) of the food consumed by the model bird as well as a scaling factor (S_F) that introduces variability in the total amount of food consumed within a day. **Equations 4.5-4.10** are used to derive TDIR. **Table 4.1** provides descriptions of the variables used to calculate TDIR.

Equation 4.5. $TDIR = \frac{FMR}{ME_{total}} * S_F * G$

S_F is a random variable that is selected from a *beta* distribution that is established, assuming that the mean is 1.0, and the minimum and maximum values are 0.9 and 1.1, respectively. The scaling factor allows the daily intake rate of a bird to vary ±10%. This variability may be attributed to factors such as physiological differences among individuals within a species or availability of food.

G is the gorging factor. A value >1 is intended to account for an increase in feeding that may occur when a bird is migrating or when excessive prey may be available. An appropriate value should be selected to represent the increase in feeding of a species based on available data. ECOFRAM (1999) suggests that total daily intake increases by a factor of 2-3 after starvation due to poor weather. ECOFRAM (1999) also indicates that the upper limit of zinc uptake for nutritional requirements is thought to be 5-fold of normal daily consumption. A value of 1 represents normal feeding (*e.g.*, during the breeding season). It should be noted that by increasing the amount of food consumed through the use of the gorging factor will result in the amount of drinking water that is consumed by the bird. As a result, a larger fraction of the bird's total daily water requirement will be met through water contained in the diet. See Section 7 for details on how the drinking water intake rate is calculated.

Avian-specific food ingestion rates are based on the allometric equations of Nagy (1987) for passerine and non-passerine birds, relating BW to the free-living metabolic rate. (FMR units are expressed in kcal/bird-day, using **Equations 4.6 and 4.7,** respectively). **Equation 4.6** results in a higher FMR value compared to the FMR generated for non-passerine birds, using **Equation 4.7**. Since the majority of species observed with high frequency on agricultural fields are passerines (**Appendix D**), the use of the FMR equation that is representative of passerines was chosen for the generic birds. If the model user chooses to simulate a custom species that is not a passerine, then **Equation 4.7** is used by the model. For juveniles, **Equation 4.8** is used to determine FMR. See **Appendix F** for details.

Equation 4.6. $FMR = 2.123 * BW^{0.749}$ (Adult passerines)

Equation 4.7. $FMR = 1.146 * BW^{0.749}$ (Adult non-passerines)

Equation 4.8. $FMR = 1.197 * BW^{0.782}$ (Juveniles)

The total amount of metabolizable energy in the food of a bird is determined by considering the fractions of the different food items (DF_k is unitless) that make up the bird's diet and the amount of metabolizable energy in each food item (ME_k in kcal/bird-day) (**Equation 4.9**).

Equation 4.9. $ME_{total} = \Sigma(DF_k * ME_k)$

The metabolizable energy of food item k (ME_k) is estimated based on values for the gross energy (GE_k) and assimilation efficiency (AE_k) for that food item (**Equation 4.10** from USEPA (1993)). GE_k (kcal/g food (wet weight)) is based on individual fresh food items and is independent of the organism consuming the food. AE_k (unitless) of fresh food items is that portion of gross energy that can be assimilated by the bird. The AE_k values are based on assimilation efficiencies of individual food items by birds. The AE_k values for seeds can be selected to represent passerine and non-passerine birds.

Equation 4.10. $ME_k = GE_k * AE_k$

Distributions of GE_k and AE_k are based on mean and standard deviation (SD) values from USEPA (1993) (**Tables 4.3 and 4.4**). For each bird, GE_k values are selected from lognormal (truncated) distributions. In TIM, it is assumed that AE_k values form a *beta* distribution, with minimum and maximum values set to 0 and 1, respectively. In TIM, GE_k and AE_k values vary for each bird, each day of the simulation.

Table 4.3. Mean and Standard Deviation (SD) Values for Gross Energy (Kcal / g food (wet wt)) Content of Fresh Avian Food Items (from USEPA (1993)).

TIM Food Item (k)	Food item description in USEPA 1993	GE_k	
		Mean	SD
Arthropods	Grasshoppers, crickets, beetles	1.6	0.26
Seeds	Dicot seeds	4.6*	1.0*
Fruit	Pulp and skin of fruit	1.1	0.30
Grass	Young grasses	1.3	0.13**
Broadleaf forage	Dicot leaves	0.63*	0.074*

*Calculated using gross energy content on dry weight basis and water composition of food item.
**No SD is available for this food item; therefore, this value was calculated as 10% of the mean.

Table 4.4. Mean and Standard Deviation (SD) Values for Assimilation Efficiency (unitless) of Fresh Avian Food Items (from USEPA (1993)). Values are based on assimilation efficiency of each food item by birds.

TIM Food Item (k)	Food item description in USEPA (1993)	AE_k	
		Mean	SD
Arthropods	Terrestrial insects	0.72	0.051
Seeds	Wild seeds	0.75* 0.59**	0.090* 0.13**
Fruit	Fruit pulp, skin	0.64	0.15
Grass and broadleaf forage	Grasses, leaves	0.47	0.096

*Value is specific to passerines.
**Non-passerine birds.

4.3. Food Matrix Adjustment Factor (FMA)

The food matrix adjustment factor (FMA) is a constant that is intended to account for the difference in dose-based and dietary-based toxicity of a chemical where this difference can be attributed to effects of the food matrix on the toxicity of the chemical. It should be noted that the use of the term "matrix" does not relate to mathematics, but rather to the food medium. This parameter is useful because effects to birds from a chemical (*i.e.*, the threshold for individual simulated birds) are determined from available dose-based toxicity studies, where birds are exposed to the pesticide through gavage. The simulated pesticide exposure, however, is based on dietary exposure.

The default assumption for this parameter value is 1, meaning that the food matrix does not alter the dose-based toxicity of the chemical. This default should only be altered by the user when chemical-specific data are available to quantify the effects of the food matrix on the dose-based toxicity of the chemical. A FMA value >1 indicates that the dietary matrix decreases the dose-based toxicity of the chemical, while a FMA value <1 indicates that the dietary matrix increases the dose-based toxicity of the chemical.

A pesticide specific FMA can be obtained from two methods. The first and most reliable method is to compare the results of two acute, dose-based exposures of birds to the pesticide. In one dose-based toxicity test, birds should be dosed with the pesticide via a typical carrier (*e.g.,* corn oil). In the other dose-based toxicity test, the birds should be dosed with the pesticide contained in food. If a statistically significant difference is observed in the two LD_{50} values, the FMA can be derived by dividing the LD_{50} resulting from the food dose by the LD_{50} obtained using the typical carrier.

The second method for obtaining a pesticide-specific FMA is to convert an available dietary LC_{50} value obtained from a sub-acute, dietary study to a LD_{50} value and compare that to the LD_{50} obtained from an acute oral toxicity study. There are two major uncertainties associated with this approach that should be considered by the user. First, the LC_{50} value from the sub-acute dietary toxicity study is influenced by food spillage, which may result in an overestimated LC_{50}. Second, birds involved in the sub-acute, dietary study (age 5-14 days) are younger than those involved in the acute, dose-based study (age >16 weeks).

5. Estimating Pesticide Exposure through Inhalation

The inhalation exposure model considers two inhalation pathways: the direct inhalation of airborne droplets immediately following pesticide application, and inhalation of vapor phase pesticide from plant surfaces. For both inhalation routes, the exposure is expressed as an inhaled dose at time t ($D_{spray(t)}$ and $D_{vapor(t)}$), which is converted to an acute oral basis using an equivalency factor (F_{re}; **Equation 5.1; Section 5.3**). As discussed already, for all routes of exposure, the bird's dose is adjusted based on its location relative to the treated field using the F_{field} parameter.

Equation 5.1. $$D_{inhalation(t)} = \left(D_{spray(t)} + D_{Vapor(t)}\right) * F_{re} * F_{field}$$

5.1. Calculating Pesticide Exposure through Inhalation of Airborne Droplets

Inhalation exposure from applied pesticide droplets is considered for the first exposure time step immediately following the pesticide application for aerial, airblast and ground applied sprays. The pesticide dose inhaled by the bird in airborne droplets from a spray application ($D_{spray(t)}$) is estimated using **Equation 5.2.** (See **Table 5.1** for parameter descriptions). This equation accounts for the pesticide concentration in the volume of air under the release height ($C_{air(t)(drops)}$;

see **Section 5.1.1**), the volume of air respired by the bird during the time step ($V_{inhalation}$; see **Section 5.1.2**) and the fraction of droplets that can be respired by birds ($F_{respired}$; see **Section 5.1.3**). These factors considered together result in a mass of pesticide (µg) respired by the bird in 1 hour. This number is converted to a dose basis by dividing by the BW of the bird.

Equation 5.2. $D_{spray(t)} = \frac{C_{air(t)(drops)} * V_{inhalation} * F_{respired}}{BW}$

Exposure through inhalation from applied pesticide droplets is considered only for the first exposure time step immediately following the pesticide application. It is assumed that a suspended droplet will have either settled or cleared from the application area by the next time step, which is 60 minutes after application. Since TIM v.3.0 allows the model user to simulate up to 5 pesticide applications, a bird could potentially be exposed to a pesticide in airborne droplets for a total of 5 (separate) hours of the simulation.

Table 5.1. Parameters Used for Equations in Section 5 to Estimate Pesticide Exposure through Inhalation

Symbol	Parameter Description	Variable Type*	Units
A_{rate}	Application rate from label	Constant	lb a.i./A
B_{vol}	The volume-based biotransfer factor; function of Henry's law constant and Log Kow	Constant	µg/L fresh weight leaf/ µg/L air
BW	Body weight	Random	g/bird
$C_{air(drops)(t)}$	Pesticide concentration in a volume of air for the time step immediately following the pesticide application	Constant	µg/mL
$C_{air(t)(vol)}$	Concentration of the pesticide in air at time t (resulting from volatilization); function of $M_{pesticide,}$ $m_{plant,}$ and B_{vol}	Random	µg/mL
CH	Height of crop	Constant	m
D	Fraction of hour where pesticide is applied	Constant	none
$D_{inhalation(t)}$	Dose through inhalation for a pesticide at time t	Random	µg pesticide/g-bw
$D_{spray(t)}$	Droplet Inhalation Dose	Random	µg pesticide/g-bw
$D_{vapor(t)}$	Volatilization inhalation dose; function of pesticide concentration in air, volume of inhaled air, and body weight of the bird	Random	µg pesticide/g-bw
F_{AM}	The ratio of avian to mammalian pulmonary membrane diffusion rates from USEPA 2004	Constant	none
F_{field}	Fraction of on field exposure	Random	none
F_{re}	The avian route equivalency factor	Constant	none
$F_{respired}$	Volumetric fraction of droplet spectrum not exceeding the upper size limit of respired particles for birds	Constant	none
H	Henry's law constant	Constant	atm-m^3/mol
IS	Inhalation scale factor	Random	none
Kow	Octanol-water partition coefficient	Constant	none
LD_{50}	Lethal dose sufficient to kill 50% of exposed individuals	Constant	mg/kg= µg/g
$M_{pesticide}$	The pesticide concentration on the treated field at time t (accounting for dissipation); function of application rate	Random	mg
m_{plant}	The mass of plant (crop) per hectare based on user input	Constant	kg
R	Universal gas constant (8.205 e^{-5})	Constant	atm-m^3/mol-K
RH	Height of spray release	Constant	m
R_{rate}	Respiration rate	Random	mL/h
T	Air temperature	Constant	K
V_{air}	The volume of air in 1 ha to a height equal to the height of the crop canopy	Constant	L
$V_{inhalation}$	Volume of air respired	Random	mL
ρ_{plant}	The density of the crop tissue assumed as fresh leaf (0.77)	Constant	kg/L

* "Constant" indicates that the parameter is set to one value. "Random" indicates that the parameter's value varies based on a distribution of possible values.

5.1.1. Pesticide Concentration in a Volume of Air ($C_{air(drops)}$)

The pesticide concentration in a volume of air ($C_{air(t)(drops)}$) for the time step immediately following the pesticide application is calculated according to **Equation 5.3.** (See **Table 5.1** for parameter descriptions). For all other time steps, $C_{air(t)(drops)} = 0$.

Equation 5.3. $C_{air(t)(drops)} = \frac{D*A_{rate}*0.112}{RH}$

Equation 5.3 uses the application rate of the pesticide (A_{rate}), the release height (RH) of the application and the fraction of the time step where the pesticide is being applied (D). For aerial applications, it is assumed that D = 0.025 based on 90 s duration of direct spray inhalation and for ground spray applications, D = 0.0083 based on 30 s duration of direct spray applications. For ground and aerial applications, RH is assumed to be a constant value of 1 m and 3.3 m, respectively. D (hours) is calculated by dividing the duration of the application (in minutes) by 60 minutes to give a fraction in hours, which is the duration of the time step of interest. In this equation, the factor of 0.112 is used to convert the units of the application rate, which are lb a.i./A, to the metric units needed to generate a concentration value expressed in µg a.i./mL of air.

5.1.2. Calculation of Inhaled Air Volume ($V_{inhalation}$)

For each bird, in any given exposure time step within the model where inhalation exposure is calculated, a volume of inhaled air ($V_{inhalation}$) is determined according to **Equation 5.4.** (See **Table 5.1** for parameter descriptions). Based on the recommendation of USEPA (1993), the respiration rate (R_{rate}) is multiplied by 3 to adjust the laboratory derived R_{rate} value to represent a field respiration rate. $V_{inhalation}$ is varied using the inhalation scale factor (S_I), which is randomly selected from a *beta* distribution that is established, assuming that the mean is 1.0 and the minimum and maximum values are 0.9 and 1.1, respectively. This factor is intended to allow for variability in the $V_{inhalation}$ from one hour to the next, which may be attributed to varying amounts of activity from one time to the next. The S_I can allow the volume of respired air of a bird to vary by up to 10% of the maximum hourly value.

Equation 5.4. $V_{inhalation} = 3 * R_{rate} * S_I$

The respiration rate (R_{rate}) is calculated using an allometric relationship from USEPA (1993) that relates avian resting respiration rate to BW (**Equation 5.5**). Since this equation uses BW values that are in kg, the BW of a bird is divided by 1000 to convert from g to kg. The original equation for R_{rate}, as provided in USEPA (1993), generates values in units of mL/minute, which are in turn converted to an hourly time step by multiplying by 60 (min/hour).

Equation 5.5. $R_{rate} = 60 * \left(284 * \left({}^{BW}/_{1000}\right)^{0.77}\right)$

5.1.3. Fraction of Applied Pesticide Spray ($F_{respired}$)

The inhalation exposure model for airborne pesticide application droplet considers exposure only to those droplets that may enter the avian lung. The size of the spray droplet spectrum that can be inhaled into the lungs is conservatively assumed to be up to 100 µm in diameter. The fraction of applied pesticide spray ($F_{respired}$) is therefore assumed to be the fraction of the spray droplet spectrum that is ≤100µm. This value varies based on the application scenario of the pesticide being modeled, with variability attributed to nozzle types. **Table 5.2** includes the default values for $F_{respired}$ that were determined using the Tier III aerial module of AgDRIFT for aerial and ground spray applications (Teske *et al*., 2001). For airblast applications, droplet spectra are not available in AgDRIFT. Therefore, for airblast applications, a default value of 0.28 is used for $F_{respired}$, which is the most conservative value of the droplet spectra included in **Table 5.2**.

Table 5.2. $F_{respired}$ Values for Different Droplet Spectra for Ground and Aerial Applications.

Droplet spectra	$F_{respired}$
Very fine to fine	0.28
Fine to medium	0.067
Medium to coarse	0.028
Coarse to very coarse	0.02

5.2. Calculating Pesticide Exposure through Inhalation of Vapor Phase Pesticide

Inhalation exposure for a vapor phase pesticide is calculated for every time step following the first pesticide application. The on-field dose of volatilized pesticide inhaled by the bird is estimated using **Equation 5.6.** (See **Table 5.1** for parameter descriptions). This equation accounts for the pesticide concentration in air as a result of volatilization from plant leaves ($C_{air(t)(vol)}$) and the volume of air respired by the bird during the time step ($V_{inhalation}$; **Equation 5.4**). These factors considered together result in a mass of pesticide (mg) respired by the bird per hour. This number is converted to a dose basis by dividing by the BW of the bird.

Equation 5.6. $D_{vapor(t)} = \frac{C_{air(t)(vol)} * V_{inhalation}}{BW}$

Air concentrations in treated agricultural fields are calculated using a two-compartment model (**Equation 5.7**). These compartments include the crop foliage and the air that is between the crop canopy and the soil of the treated field. The total pesticide mass applied to a 1-ha treated field ($M_{pesticide}$; **Equation 5.8**) combined with dissipation between the time of application and time t are used to estimate the total mass of pesticide available for partitioning between crop leaf and canopy air. The density of the crop tissue (ρ_{plant}) assumed to be fresh leaf is 0.77 kg/L, based on the Hazardous Waste Identification Rule (HWIR) Farm Food chain Model (USEPA, 1999). The air compartment volume (V_{air}) is represented by a 1-ha area, with a height set at the top of the canopy at time of application (**Equation 5.9**). The available pesticide residue is then partitioned between the two compartments (air and leaf mass) through the application of the volume-based biotransfer factor (B_{vol}) developed for the HWIR model (**Equation 5.10**). It is assumed that the air temperature (T) is a constant value of 298.1 K (equivalent to 25^{o}C, 77^{o}F). A temperature of 25^{o}C was chosen because Henry's law constant and octanol-water partition coefficient (K_{ow}) values for pesticides are frequently available at this temperature; however, the relevance to the actual environment at the time of pesticide application is an uncertainty. The total available residues establish an upper limit of available pesticide concentration in the air as a result of volatilization from (treated) leaf surfaces. Variables are further described in **Table 5.1**.

Equation 5.7. $C_{air(t)(vol)} = \frac{M_{pesticide}}{V_{air}+\left(\frac{m_{plant}*B_{vol}}{\rho_{plant}}\right)} * e^{-rt}$

Equation 5.8. $M_{pesticide} = A_{rate} * 1.12 * 10^6$

Equation 5.9. $V_{air} = CH * 10^7$

Equation 5.10. $Log\ B_{vol} = 1.065 * Log\ K_{ow} - Log\left(\frac{H}{RT}\right) - 1.654$

Over time, dissipation of the pesticide is considered in the calculation of the pesticide concentration in air. Degradation of the pesticide at every time step following a pesticide application is based on the foliar dissipation half-life for broadleaf plants. The degradation rate constant (r) used in **Equation 5.7** is calculated using **Equation 4.2**. At each time step, pesticide mass that remains from all previous applications (accounting for dissipation) is added.

5.3. Relating External Inhalation Dose to Oral Dose Equivalents

In cases where avian inhalation toxicity data are available for a specific chemical, they may be used to derive the oral dose equivalence factor (F_{re}) using **Equation 5.11.**

Equation 5.11. $F_{re} = \frac{LD_{50(oral;avian)}}{LD_{50(inhalation;avian)}}$

Generally, avian inhalation toxicity endpoints are expressed as concentration and specific duration based on the exposure period of the test (*e.g.*, 4-hour LC_{50} in mg a.i./L). The user must convert the LC_{50} to a dose-based endpoint (*i.e.*, LD_{50} in mg a.i./kg-bw) using **Equation 5.12.** It should be noted that the BW and respiration rate used in this equation should be derived based on the test species (BW_{test} and $R_{rate(test)}$). The variable h represents the duration of the exposure period (in h) and is used to derive the total volume of contaminated air inhaled by the bird during the study. This approach assumes that the birds that died during the study did so after the 4-hour exposure period.

Equation 5.12. $LD_{50(inhalation)} = \frac{LC_{50}*R_{rate(test)}*h}{BW_{test}}$

When avian inhalation toxicity data are not available, TIM uses the relationship between rat acute oral and acute inhalation LD_{50} values to establish a route equivalency factor. This factor is applied to avian inhalation dose estimates to calculate an oral dose equivalent exposure for subsequent comparison with avian oral dose acute toxicity endpoints. In order to account for differences between the physiology of mammals and birds, the EPA evaluated the differences between avian and mammalian respiratory physiology that might be considered in establishing a more taxonomically appropriate route equivalency factor. USEPA (2004) includes a comparison of basic aspects of avian and mammalian lung physiology and how these differences may influence the bioavailability of inhaled pesticide through taxonomic differences in diffusion rate across the pulmonary membrane. Based on pulmonary membrane diffusion rate estimates for birds and mammals, USEPA (2004) indicates that the relative diffusion rates across the pulmonary membrane (F_{AM}) is between 2.4 and 3.4 times greater in birds than in mammals of similar BWs (weight range 1 to 2,000 g). These differences in diffusion rate can be used to modify the relationship of oral to inhalation toxicity endpoints in mammals to produce a route equivalency factor F_{re} that would at least account for the expected higher diffusion rates across avian pulmonary membranes (**Equation 5.13; Table 5.1**). In TIM v.3.0, values of 2.7, 2.9 and 3.3 are used to represent F_{AM} for the small, medium, and large generic birds, respectively. These values are based on the relative diffusion rates of chemicals across the pulmonary membranes of birds and mammals (USEPA, 2004, **Appendix D**, **Table D1**) and the mean BWs of these 3 generic birds (*i.e.,* 20, 100 and 1000 g). The route equivalency factor is then multiplied by estimated avian inhalation exposure doses (*i.e.,* $D_{spray(t)}$ and $D_{vapor(t)}$) to derive an estimate of the equivalent oral dose. Using the oral equivalent dose to describe inhalation exposure allows the available oral toxicity studies to describe potential risks resulting from estimated inhalation exposures.

Equation 5.13. $$F_{re} = \frac{LD_{50(oral;mammal)} * (\mathrm{F}_{\mathrm{AM}})}{LD_{50(inhalation;mammal)}}$$

6. Estimating Pesticide Exposure through Dermal Contact

The general dermal exposure model considers two pathways: direct interception of applied material during pesticide application and incidental contact with dislodgeable pesticide residues on treated foliage (**Equation 6.1**). As described below, these exposures are converted to an acute oral basis using a dermal equivalency factor (F_{red}). **Table 6.1** defines the input parameters used in the equations included in **Section 6**.

Equation 6.1. $$D_{dermal(t)} = \left(D_{intercept(t)} + D_{contact(t)}\right) * F_{red} * F_{field}$$

Table 6.1. Parameters Used for Equations in Section 6 to Estimate Pesticide Exposure Concentrations through Dermal Exposure.

Symbol	Parameter Description	Variable Type*	Units
A_{rate}	Application rate from label	Constant	lb a.i./A
BW	Body weight	Random	g/bird
$C_{plant(t)}$	Concentration of the pesticide in crop foliage at time t	Random	mg/kg
DAF	Dermal absorption fraction	Constant	none
$D_{contact(t)}$	Incidental Dermal Contact Dose	Random	µg pesticide/g-bw
$D_{dermal(t)}$	Dose through dermal exposure for a pesticide at time t	Random	µg pesticide/g-bw
$D_{intercept(t)}$	Intercepted Dermal Dose	Random	µg pesticide/g-bw
DPR	Dislodgeable pesticide residues	Constant	mg/m^2
F_{dfr}	Dislodgeable foliar residue adjustment factor	Constant	kg/m^2
F_{field}	Fraction of on field exposure	Random	none
F_{red}	Dermal route equivalency factor	Constant	none
$R_{foliar\ contact}$	Rate of foliar contact (6.01)	Constant	cm^2foliage/cm^2body surface (per hour)
SA_{total}	Total surface area of bird	Random	cm^2
TPR	Total pesticide residues	Constant	mg/kg

* "Constant" indicates that the parameter is set to one value. "Random" indicates that the parameter's value varies based on a distribution of possible values.

6.1. Dermal Exposure through Direct Interception

Dermal exposure from applied pesticide droplets is considered for each time step representing a pesticide application for aerial, airblast and ground applied sprays (See **Section 1.4.2**). The dermal exposure dose from direct interception ($D_{intercept(t)}$) is calculated by considering the pesticide application rate relationship to the surface area and BW of the bird (**Equation 6.2; Table 6.1**). The dermal interception model assumes that pesticide deposition occurs in a manner consistent with a horizontal surface in the treatment area. Surface area calculation of a bird for the interception model assumes that the upper half of the bird in the field is exposed as a result of either ground or aerial spray applications. Therefore, the total surface area of the bird is multiplied by 0.5. The total surface area of a bird is calculated using the allometric equation for relating BW to surface area (USEPA, 1993; **Equation 6.3**). The dermal adsorption fraction (DAF) is used to account for pesticide specific data that define a fraction of the pesticide mass present on the bird that is actually absorbed by the bird. These data may be submitted by the registrant (non-guideline study) or obtained from the literature. When no data are available to parameterize DAF, the default value is 1. In this equation, a factor of 11.2 is used to convert the units of the application rate, which are lb a.i./A, to the metric units needed to generate a concentration value expressed in µg a.i./g-bw.

Equation 6.2. $$D_{intercept(t)} = \frac{(A_{rate} * 11.2) * (SA_{total} * 0.5) * DAF}{BW}$$

Equation 6.3. $$SA_{total} = 10 * BW^{0.667}$$

6.2. Dermal Exposure through Dislodgeable Pesticide Residues on Foliage

During feeding hours, dermal contact with foliage is modeled using **Equation 6.4.** During non-feeding periods for both edge and resident species, dermal exposure is assumed to be negligible because birds are assumed to be relatively inactive; therefore, during non-feeding hours, $D_{contact(t)}$ = 0. The dermal exposure doses from contact with dislodgeable pesticide residues on treated foliage (*i.e.*, incidental dermal contact dose) is calculated by considering the concentration of pesticide on treated foliage, fraction of total residues that are dislodgeable, the rate of foliar contact of the bird, the surface area of the bird that is contacted by dislodgeable foliar residues, and BW of the bird (**Equation 6.4; Table 6.1**). $C_{plant(t)}$ is the same residue value used for the broadleaf foliage concentration in the assessment of dietary exposure, which is described in detail in **Section 4.1.** (Note that this value accounts for the fraction of contaminated foliage $FC_{broadleaf}$). The dislodgeable foliar residue adjustment factor (F_{dfr}), surface area and rate of foliar contact ($R_{foliarcontact}$) are discussed in detail below. In this equation, a factor of 0.1 is used to generate $D_{contact(t)}$ value with units in µg a.i./g-bw.

Equation 6.4. $$D_{contact(t)} = \frac{C_{plant(t)} * F_{dfr} * R_{foliar\ contact} * (SA_{total} * 0.079) * 0.1}{BW}$$

6.2.1. Dislodgeable Foliar Residue Adjustment Factor (F_{dfr})

Dislodgeable foliar residues are assumed to be a fraction of the total residues in and on a plant for pesticides applied externally to plant surfaces. The dislodgeable foliar residue adjustment factor (F_{dfr}) is necessary because total residues are commonly expressed in terms of mass of pesticide per unit fresh mass of vegetation, while dislodgeable residues are commonly expressed in terms of mass of pesticide per unit surface area of the vegetation. Dislodgeable pesticide residues (DPRs) are from measured data immediately following pesticide application to the target crop and reported in submissions to the EPA (Guideline 875.2100). A factor to relate total residues (distributed at time zero and dissipated over the course of the model run) to corresponding dislodgeable residues is established by the user with **Equation 6.5,** which requires information on measured total and dislodgeable residues immediately following pesticide application. Total pesticide residues (TPR) are based on residues measured immediately following pesticide application to the target crop. If available studies do not include residues at day 0, they should not be used to derive F_{dfr}.

Equation 6.5. $$F_{dfr} = \frac{DPR}{TPR}$$

When no day 0 dislodgeable foliar residue data are available to derive a chemical-specific DPR value, a default value of 0.62 can be used for the F_{dfr}. This value is derived by using 28 mg/m^2 for the DPR, which is based on the Health Effects Division's default assumption that at day 0, the dislodgeable foliar residue value is 25% of the application rate (in lb a.i./A) (**Section D.6.2** of **Appendix D** of USEPA, 2012b). Note that this value was converted from lb a.i./A to mg/ m^2. For the default F_{dfr}, a TPR value of 45 mg/kg is used. This value is the mean for the total pesticide residue value on broadleaf plants.

6.2.2. Surface Area of Bird that Contacts Foliar Residues

The dermal incidental contact model predicts transfer of pesticide residues from foliage to the bird foot and lower leg. The model does not include transfer of residues to other areas of the bird surface where feathers would provide a barrier to exposure of pesticides to the skin (Smith et al. 2007). The surface area calculation for dermal exposure of birds for the interception model uses a point estimate of leg/foot surface area of 7.9 percent of the total body surface (USEPA, 1993). Therefore, the total surface area of the bird (calculated using **Equation 6.3**) is multiplied by 0.079 to represent the surface area of the bird that contacts foliage. This value is different from the fraction of the surface area exposed through direct spray (*i.e.,* 0.5) because, in this case, only the leg/foot of the bird is exposed to contaminated foliar residues, whereas for direct spray, it is assumed that the upper half of the bird is exposed.

6.2.3. Rate of Foliar Contact ($R_{foliar\ contact}$)

The foliar contact rate is the surface area of vegetation that is contacted by a given surface area of a bird over the course of a time step. Experimental measurements of such contact rates for birds have not been identified in the literature to date. In the absence of data specific to incidental foliar contact for birds, the model presently makes use of the data in USEPA (2004) to develop a surrogate foliar contact rate. The model quantifies incidental contact exposure to the foot/lower leg as it is assumed that incidental contact might be the most significant for birds as they move about the foliage while foraging. Consequently, a surrogate value from the data in USEPA (2004) (farm worker hands) was selected to represent a contact rate functionally equivalent to a bird foot grasping vegetation. The range of mean contact values for the hand wash measurements from farm workers, as they relate to foliar contact reported in USEPA (2004), is 11.9 to 5,050 cm^2/hr. The model currently employs the value of 5,050 cm^2/ hr. This value is not adjusted for duration of contact, as the avian exposure model is based on an hourly time step. The total foliar contact rate for farm workers' hands cannot be used without adjustment for the relative surface area differences between farm workers and birds. A typical surface area value for adult male hands of 840 cm^2 was used to make this normalization. The result is a default value of 6.01 cm^2 foliage/cm^2 body surface for $R_{foliar\ contact}$.

6.3. Relating External Dermal Dose to Oral Dose Equivalents

The dermal route equivalency factor (F_{red}) is applied to estimated avian dermal exposures in order to derive an estimate of the equivalent oral dose (**Equation 6.6**). In situations where avian dermal and oral LD_{50} data are available for a pesticide, F_{red} is calculated by dividing the oral LD_{50} by the dermal LD_{50}. Since EPA does not have a data requirement for avian acute toxicity testing via the dermal route, it is expected that a chemical-specific dermal LD_{50} will rarely be available. In cases where a chemical-specific dermal LD_{50} value is not available, it can be generated automatically by TIM using **Equation 6.7** (**Appendix H**, reproduced from USEPA, 2004). This equation is based on available avian dermal and oral toxicity data. Although the data set is limited to 25 chemicals (primarily organophosphate insecticides), it has the advantage of being based on avian toxicity data for both routes of exposure. Therefore, there is no need to extrapolate across taxa using mammalian toxicity data.

Equation 6.6. $F_{red} = \frac{LD_{50(avian\ oral)}}{LD_{50(avian\ dermal)}}$

Equation 6.7. $\log LD_{50(\text{dermal})} = 0.84 + 0.62 * \log LD_{50(\text{oral})}$

7. Estimating Pesticide Exposure through Drinking Water

In TIM, it is assumed that two sources of drinking water are available to birds on treated fields: puddles and dew. Selection of water sources by birds is not well characterized in the scientific literature. The most likely strategy is one of opportunistic exploitation of whatever water source is immediately available (pers. comm. Louis Best, 2000). In TIM, it is assumed that puddles are more likely to be immediately available and thus utilized as drinking water sources.

In the simulation, birds only drink during two hours of a 24-hour period, specifically, the last hour of the morning and last hour of the afternoon feeding periods. In this approach, birds consume water through their food throughout the morning and afternoon feeding periods. They then make up the balance of their daily water requirement through drinking water from puddles or dew. If a simulated bird's total daily water requirement is met by consuming food (based on assigned diet discussed previously), it does not drink water from puddles or dew, and is, therefore, not exposed to the pesticide through drinking water.

It is assumed that puddles are present at the time of each application and for 48 hours following each application. If puddles are not present, the bird will consume dew during the morning and no drinking water in the afternoon. Simulated birds can only consume dew on the last hour of the morning feeding period because dew is not expected to be present in the afternoon.

The dose of pesticide ingested by a bird through drinking water ($D_{\text{drinking(t)}}$) is calculated with **Equation 7.1.** If t is within 48 hours of an application, the concentration in water is based on puddles (*i.e.*, $C_{\text{w(t)}} = C_{\text{w(puddle(t))}}$). Otherwise, it is assumed that the puddles have dried up and that the drinking water source is dew (*i.e.*, $C_{\text{w(t)}} = C_{\text{w(dew(t))}}$). When the concentration in water is above the limit of solubility in water, $C_{\text{w(t)}}$ is equivalent to the water solubility limit.

As noted above in this approach, it is assumed that the bird acquires its daily drinking water during two hours of the simulation. The bird's daily drinking water rate, DWIR, is equally distributed throughout the two hours when the bird consumes water. Therefore, during the last hours of the morning and afternoon feeding periods, pesticide doses received by drinking is calculated by multiplying DWIR by 0.5. During all other hours of the simulation, $D_{\text{drinking(t)}}$ is 0.

Equation 7.1. $D_{drinking(t)} = \frac{C_{w(t)} * DWIR * 0.5}{BW} * F_{field}$

As discussed in **Section 3**, the dose is adjusted based on the bird's location. If the bird is on the field, $F_{\text{field}} = 1$. If the bird is off field and within an area receiving spray drift, F_{field} is assigned a value <1 based on the spray drift deposition at the bird's location during that hour.

Section 7 includes the equations for calculating $C_{w(puddle(t))}$, $C_{w(dew(t))}$ and the drinking water intake rate (DWIR). **Table 7.1** defines the input parameter values used in the equations provided in this section.

Table 7.1. Parameters Used for Equations in Section 7 to Estimate Pesticide Exposure Concentrations through Drinking Water.

Symbol	Parameter Description	Variable Type*	Units
A_{rate}	Application rate from label	Constant	lb a.i./A
BW	Body weight	Random	g/bird
$C_{w(dew)(t)}$	Concentration of the pesticide in dew at time t	Random	mg/L = µg/mL
$C_{plant(t)}$	Concentration of the pesticide in crop foliage at time t	Random	mg/kg = µg/g
$C_{w(puddle)(t)}$	Concentration of the pesticide in puddle at time t	Random	mg/L = µg/mL
$D_{drinking(t)}$	Dose through drinking water for a pesticide at time t	Random	µg pesticide/g-bw
DF_k	Fraction of diet attributed to food item k	Constant	none
DWIR	Drinking water intake rate	Random	mL/day
d_{soil}	Depth of soil at equilibrium with water (in puddle)	Constant	cm
d_w	Depth of puddle water	Random	cm
e	Base of natural logarithm (2.7182)	Constant	none
F_{dfr}	Dislodgeable foliar residue adjustment factor	Constant	kg/m^2
F_{field}	Fraction of on field exposure	Random	none
$Flux_{water}$	Total daily water flux rate	Random	mL/day
$f_{oc(soil)}$	Fraction of organic carbon in soil	Constant	none
FW_k	Fraction of water in a fresh food item k	Constant	none
Koc	Organic carbon:water partition coefficient	Constant	L/kg-oc
m_{wax}	Mass of wax per surface area of leaf cuticle	Constant	kg/m^2
r	Degradation rate constant	Constant	$hour^{-1}$
t	Time of simulation	Sequential value	hour
TDIR	Total daily intake rate (for food)	Random	g food/bird-day
S_W	Water adjustment scale factor	Random	none
$Water_{food}$	Water from dietary items	Random	mL/day
ρ_b	Bulk density of soil	Constant	kg/L
ρ_p	Density of soil particles	Constant	kg/L
ρ_{water}	Density of water (1)	Constant	kg/L
θ_{soil}	Porosity of soil	Constant	none

* "Constant" indicates that the parameter is set to one value. "Random" indicates that the parameter's value varies based on a distribution of possible values.

7.1. Pesticide Concentrations in On-field Puddles

Pesticide concentrations in puddles are estimated using a simple partitioning approach (**Equation 7.2; Table 7.1**) that is based on the Tier I rice model (USEPA, 2007b), with modifications. In this equation, the pesticide concentration in the water of the puddle is dependent upon the pesticide application rate (A_{rate}), mean organic carbon-water partitioning coefficient of the pesticide (K_{oc}; L/kg), and the puddle depth and soil properties. A factor of 11.2 is used to convert the units of the application rate, which are lb a.i./A, to the metric units needed to generate a concentration value expressed in µg a.i./mL.

Equation 7.2. $$C_{w(puddle)(t)} = \left(\frac{A_{rate}*11.2}{d_w+d_{soil}(\theta_{soil}+\rho_b*K_{oc}*f_{oc(soil)})}\right)*e^{-rt}$$

Puddle depth is assumed to vary across the field. Anytime within 48 hours of the application, a bird may encounter a puddle. At each hour, the depth of the puddle (d_w) has a different random water depth, selected from a uniform distribution, ranging 1.3-15 cm (0.5 and 6 inches). The soil depth (d_{soil}) that contains pesticide at equilibrium with the puddle is set to 2.6 cm (1 inch). Default parameter values for soil properties, including bulk density (ρ_b) and fraction of organic carbon ($f_{oc(soil)}$), are based on EFED scenarios for the Pesticide Root Zone Model (PRZM). The default values of 1.5 kg/L for ρ_b and 0.015 for $f_{oc(soil)}$ are based on the mean values from the field crop and orchard scenarios. The user may select alternative values to represent specific scenarios or fields. Porosity (θ_{soil}) and bulk density are related (**Equation 7.3**), where ρ_p is the density of soil particles (kg/L). A typical value of 2.65 (Smettem 2006) is used for soil particle density.

Equation 7.3. $$\theta_{soil} = 1 - \frac{\rho_b}{\rho_p}$$

Over time, degradation of the pesticide is assessed in the puddle and on the field after the puddle has dried up. Degradation of the pesticide at every time step following a pesticide application is based on the aerobic soil metabolism half-life. The degradation rate constant (r) used in **Equation 7.2** is calculated using **Equation 4.2** and the soil metabolism half-life. At each time step, pesticide mass from all previous applications is added. It is assumed that after a pesticide application, the pesticide degrades while in the puddle, or in the soil if the puddle is dried up. The mass that remains from the first application is added to the mass from all other relevant applications made prior to the time step.

7.2. Pesticide Concentration in Dew from Contaminated Forage

Pesticide concentrations in dew are estimated through the use of a simple equilibrium partitioning model. This model assumes two compartments, water and leaf cuticle, into which the pesticide may associate. **Equation 7.4** is used to estimate the pesticide concentration in dew ($C_{w(dew)(t)}$). Partitioning between the two compartments is based on the octanol-water partition coefficient of the chemical (K_{ow}), where octanol is a surrogate for the waxy, external (epicuticular) layer of the leaf cuticle. $C_{plant(t)}$ is the total concentration of pesticide in broadleaf forage leaves (mg/kg-ww) at time t after application. (See **Section 4** above for discussion of how this value is calculated; note that this also considers the fraction of contaminated foliage or $FC_{broadleaf}$). F_{dfr} is used to account for the amount of pesticide that is present on the surface of the leaf, and thus may partition between the waxy layer of the leaf cuticle and dew. This approach establishes a distribution of pesticide concentrations in dew that is correlated with random selection of pesticide concentrations on broadleaf forage. The pesticide partitions into the epicuticular layer of the cuticle, which is influenced by the mass of wax (m_{wax}). Available data indicate that the mass of wax in the epicuticular layer varies by species, with ranges of 5-30 µg/cm^2 (Buschhaus and Jetter, 2011). Therefore, a default value of 0.012 kg/m^2 is selected for m_{wax} to represent the central tendency of this parameter. The density of water is used to generate an estimate of the pesticide concentration in water. It is assumed that the density of water is 1 kg/L.

Equation 7.4. $$C_{w(dew)(t)} = \frac{C_{plant(t)} * F_{dfr} * \rho_{water}}{m_{wax} * K_{ow}}$$

7.3. Drinking Water Intake Rate (DWIR)

The total daily water flux rate ($Flux_{water}$; mL/day) for birds is derived from work carried out by Nagy and Peterson (1988) that involved the development of allometric relationships between avian BW and daily water flux rate. According to Nagy and Peterson, water flux represents "…the amount of water moving into an animal each day…" (p. 3). Thus, this includes water intake from all sources, including water from food and from drinking. The daily water flux rate for passerines in the field is estimated according to **Equation 7.5.** Nagy and Peterson (1988) noted that passerines take in 3.7 times more water compared to other birds. The authors attribute this difference to a higher metabolic rate in passerines, as well as differences in behavior related to diet and drinking water. **Equation 7.6** is used for non-passerine birds in order to account for a lower flux.

Equation 7.5. $$Flux_{water} = \left(1.180 * BW^{0.874}\right) * S_W$$

Equation 7.6. $$Flux_{water} = \frac{\left(1.180 * BW^{0.874}\right)}{3.7} * S_W$$

The original Nagy and Peterson (1988) drinking water ingestion equation is modified using a water adjustment scale factor (S_W). The water adjustment scale factor is a random variable that is selected from a *beta* distribution that is established assuming that the mean is 1.0 and the minimum and maximum values are 0.9 and 1.1, respectively. This factor is intended to allow for variability in the $Flux_{water}$ of an individual bird from one day to the next.

The daily water flux rate is assumed for a bird in water equilibrium, such that water balance is maintained each day (*i.e.*, incoming water = outgoing water from all pathways). It is assumed that a proportion of this daily water flux is fulfilled by water obtained through the consumption of each day's dietary items, with the remainder satisfied through daily drinking water intake. The calculation of water from dietary items ($water_{food}$) is made by multiplying the daily fresh mass of each food item consumed by the bird by the corresponding fractional water content of that food item (**Equation 7.7**). As indicated in **Section 4**, TDIR is the total daily intake rate for food items (g/day), DF_k is the constant fraction of TDIR attributed to the *k*th food item, and FW_k is the unit-less and constant fraction of water in a fresh food item as cited in **Table 7.2.** The daily drinking water intake rate (DWIR) is calculated by subtracting the food water intake rate from the total daily water flux rate (**Equation 7.8**). This value assumes a standard density of water of 1 kg/L. Parameters used to calculate DWIR are summarized in **Table 7.1.**

Equation 7.7. $$water_{food} = \sum_k TDIR * DF_k * FW_k$$

Equation 7.8. $$DWIR = Flux_{water} - water_{food}$$

Table 7.2. Fraction of Water in Fresh Food Items (FW_k) of Birds (USEPA, 1993).

Food Item	FW_k
Insects	0.69
Seeds	0.093
Fruit	0.77
Grasses	0.79
Broadleaf forage	0.85

8. Establishing Sensitivity and Mortality of Individuals

8.1. Determining Survival and Mortality

At a given time step, an individual bird is considered either alive or dead. This status is determined by considering the internal dose of the bird at a time step (t) due to all intake sources (**Equation 1.1).** These sources include diet ($D_{diet(t)}$), drinking water ($D_{drinking(t)}$), inhalation ($D_{inhalation(t)}$), and dermal contact ($D_{dermal(t)}$). The dose at a given time step also includes the pesticide dose carried over from the previous time period ($D_{total(t-1)}$), with consideration of the fraction of the pesticide retained after elimination of the pesticide (*i.e.*, $F_{retained}$, discussed in **Section 8.5**). All doses are converted to an oral equivalent.

Equation 1.1. $D_{total(t)} = D_{diet(t)} + D_{drinking(t)} + D_{inhalation(t)} + D_{dermal(t)} + D_{total(t-1)} * F_{retained}$

The internal dose of the pesticide at a given time step is compared to the individual threshold for mortality ($T_{mortality}$) of that bird. The threshold is randomly assigned to each bird based on the log probit dose/response distribution derived from the avian acute oral toxicity data. More information on how the threshold is determined is provided below. If the internal dose is below the threshold, the bird is considered to be alive at that time step, and the bird survives to the next hour, where the process is repeated (*i.e.*, if $D_{total(t)} < T_{mortality}$, the bird survives to t+1). If the dose exceeds the threshold, the bird is considered dead, and is no longer included in the simulation (*i.e.*, if $D_{total(t)} \geq T_{mortality}$, the bird dies during t).

It is assumed that doses from all routes of exposure are comparable to the acute oral dose because the different doses are converted to an oral equivalent using available toxicity data comparing the dermal and inhalation routes to the oral route. It is also assumed that the elimination rate constant may be applied equally to any dose, regardless of exposure route.

8.2. Establishing an Individual Threshold for Mortality ($T_{mortality}$)

The individual threshold of a bird is calculated according to **Equation 8.1.** The Z_{score} is a random number selected from a normal distribution. The slope in this equation is based on the user input defining the slope of the dose-response curve of the acute oral toxicity data available for the assessed pesticide. The intercept of the dose/response curve is calculated according to **Equation 8.2.** In this approach, approximately 50% of birds receiving a dose equivalent to the LD_{50} would die.

Equation 8.1. $T_{mortality} = 10^{\frac{Zscore - intercept}{slope}}$

Equation 8.2. $intercept = -slope * \log_{10}(LD_{50})$

Separate thresholds are calculated for adult birds simulated by TIM and their juvenile offspring that are incorporated into MCnest. This approach assumes that the sensitivity of the juvenile is not the same as its mother since the parental sensitivity is likely different from the mother. If acute oral toxicity data are available to observe a difference in sensitivity of juveniles and adults, the model user may account for this difference by entering an appropriate value to represent the ratio of juvenile to adult toxicity. If these data are not available, the model uses the LD_{50} and slope data for adult birds to determine the individual sensitivity values for juveniles.

8.3. Avian Acute Oral LD_{50}

The avian acute oral toxicity test (OPPTS 850.2100) provides a measurement of acute toxicity to the test population from a single oral dose administered at geometrically spaced doses after a fasting period to groups of individuals. The number of mortalities at each dosage level is recorded over time (usually fourteen days). Probit analysis or another appropriate statistical method is used to estimate the dose response curve and other descriptive statistics, including the LD_{50}, the slope and confidence limits around the estimates. Typically, LD_{50} values are available for only two test species exposed to a pesticide (*i.e.*, mallard and bobwhite quail). Recently, the data requirements for pesticides were altered to include an acute oral study with a passerine species (*e.g.*, zebra finch, (*Taeniopygia guttata*), canary (*Serinus canaria)*). Data for other test species may be available through the scientific literature.

The avian acute oral LD_{50} is one of the most important parameters for determining the risk of a chemical to birds. Therefore, the model user should select an input value with care. If only two or three values are available, the model user may choose to run the model with the high and low LD_{50} values. If the model user is simulating a specific species and toxicity data are available for that species or for one that is closely related (taxonomically), then the single endpoint may be sufficient. The model user may still wish to explore uncertainty associated with this endpoint by simulating LD_{50} values that represent the confidence bounds of the available LD_{50}. Non-definitive LD_{50} values should not be used, as they do not represent the dose-response relationship for the chemical of interest.

If several LD_{50} values are available for different species, the model user may choose to develop a species sensitivity distribution (SSD) to represent the distribution of species responses to the pesticide of interest. If the sensitivity of the species of interest is unknown, the model user can explore the influence of uncertainty associated with the LD_{50} by selecting LD_{50} values that represent sensitive (*e.g.,* 5th percentile of SSD), average (*e.g.,* median of SSD), and tolerant (*e.g.,* 95th percentile of SSD) test species. Guidance on developing SSDs is included in **Appendix J**.

Before LD_{50} values from available studies are used as input parameters, they must be scaled to account for the BW of the assessed species. For SSDs, each endpoint should be expressed in units of mg a.i./kg-bw for the mean BW of the assessed species (AW) and should be normalized according to **Equation 8.3**. The LD_{50} value on the right side of this equation is the endpoint reported from the study (units expressed as mg a.i./kg-bw). TW represents the BW (in g) of the species tested. Generally, acute oral tests involve adult animals. If BW data are not available in the study report, the literature can be cited for species specific BWs. Default BWs for the bobwhite quail and mallard duck are 178 and 1580 g, respectively. BWs for additional bird species can be found in Dunning (1984). The Mineau scaling factor (s) is used to adjust bird BWs. When chemical specific values are available in Mineau (1996), they should be used. If not, the default value of 1.15 should be used.

Equation 8.3. $Normalized\ LD_{50} = LD_{50}\left(\frac{AW}{TW}\right)^{(s-1)}$

8.4. Slope

The slope provides an estimate of the variation of the individual response in the tested sample. Steep slopes (*e.g.,* 9) indicate a low variance among individuals, and shallow slopes (*e.g.,* 2) indicate a greater variance among individuals. If possible, the LD_{50} and slope values should be from the same study. If the LD_{50} is based on a single study, the corresponding slope should be used. If no slope was established, a default of 4.5 (with confidence bounds of 2-9) should be used. If an SSD is used, the slope representing species at the percentile where the LD_{50} is selected may be used. Alternatively, the geometric mean of all available slope values may be used.

8.5. Metabolism ($F_{retained}$)

Elimination is included in TIM using a chemical-specific fraction of the pesticide that is retained in the bird from one hour to the next ($F_{retained}$). This value is generally obtained from empirical data, *e.g.,* residue chemistry studies with chickens (OCSPP guideline 860.1480). Alternatively, data representing recovery of an organism from a pesticide can be used, such as decrease in acetylcholinesterase inhibition as a surrogate for elimination of a carbamate.

9. Model Results

As discussed in **Section 1.5,** the TIM executable generates several output files (**Table 1.4**). This section describes the model's outputs that are intended for the user. Output files for the QC of the code and MCnest are not discussed in this section.

9.1. Model_results.txt Output File

The Model_results.txt output file includes the input values contained in the TIM_inputs.txt file as well as some inputs generated by the model (*e.g.,* species parameters for user selected generic species). This information can be accessed though the GUI by selecting Output -> File -> Model results.

This output file includes summary statistics for the number of dead birds and the percent of total simulated birds that died. This output also includes two tables of values that can be used to characterize the risks of the simulated pesticide use to birds: including information to identify dominant routes of exposure contributing to mortality (**Table 9.1**) and probabilities of mortality to individuals within a flock (**Table 9.2**).

For each bird that dies during a simulation, the relative contributions of each exposure route to the total pesticide dose are calculated. **Table 9.1** provides an example output with the minimum, maximum, mean and standard deviations of the fractions of total pesticide dose by exposure route for those birds. **Figure 9.1** depicts this information in a whisker-box plot. As demonstrated by the figure for this example simulation, pesticide doses received by diet and drinking dew were the major routes of exposure leading to mortality.

Table 9.1. For Dead Birds: Median, Mean, Standard Deviation, Minimum and Maximum of Fractions of Total Pesticide Dose by Exposure Route.

Exposure route	Median	Mean	SD	Minimum	Maximum
Food Ingestion	0.774	0.789	0.136	0.221	1
Drinking: Puddle	0.02	0.022	0.013	0	0.105
Drinking: Dew	0.205	0.187	0.138	0	0.777
Inhalation: Vapor	0.003	0.003	0.001	0	0.005
Inhalation: Spray	0	0	0	0	0
Dermal Contact	0	0	0	0	0
Dermal Spray	0	0	0	0	0

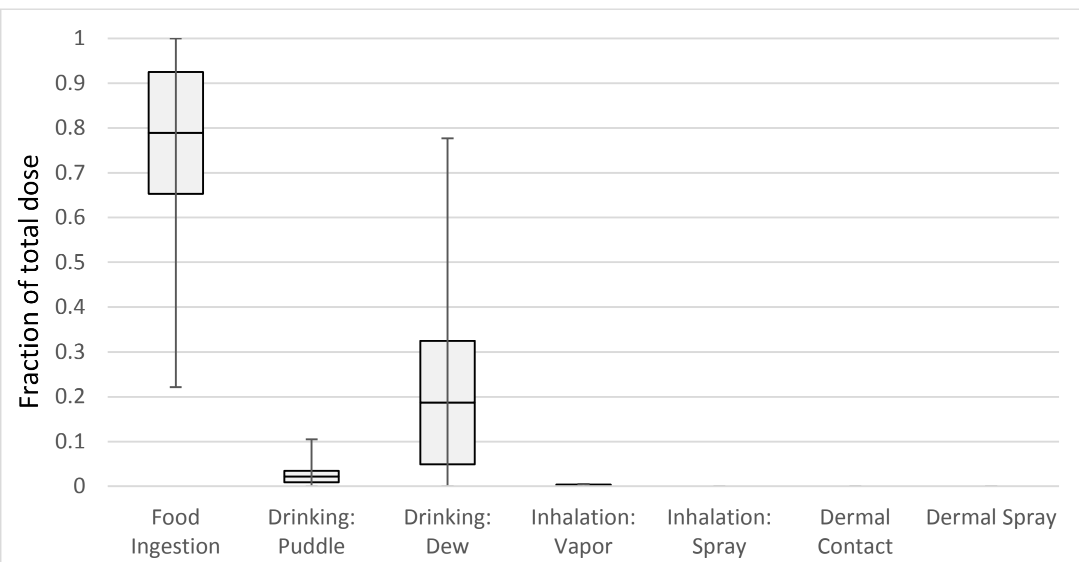

Figure 9.1. Relative Contributions of Different Exposure Pathways to Lethal Doses in Simulated Birds. Box plots represent mean and standard deviations of fractions, with minimum and maximum represented by lines.

Table 9.2 includes the Probability Density Function (PDF), Cumulative Distribution Function (CDF) and Complementary Cumulative Distribution Function (CCDF) associated with all of the simulated birds sorted into flocks of 25, which is based on user input for flock size. **Figure 9.2** depicts the PDF, CDF and CCDFs for the example data provided in **Table 9.2.** The PDF is used to determine the probability associated with killing exactly x birds. The CDF describes the probability of killing x or fewer birds. The CCDF provides the probability of killing greater than x birds.

Table 9.2. Probabilities of Mortality to x Birds out of the Flock. Values generated for PDF, DCF and CCDF. Note that values depicted as 0 or 1 are rounded.

Dead (x)	PDF (probability of killing x birds)	CDF (probability of killing ≤x birds)	CCDF (probability of killing >x birds)
0	0.329882	0.329882	0.670119
1	0.374082	0.703963	0.296037
2	0.203618	0.907581	0.092419
3	0.07081	0.978391	0.021609
4	0.017665	0.996056	0.003944
5	0.003365	0.999422	0.000579
6	0.000509	0.99993	6.96E-05
7	6.26E-05	0.999993	0.000007
8	6.4E-06	0.999999	6E-07
9	5E-07	1	0
10	0	1	0
11	0	1	0
12	0	1	0
13	0	1	0
14	0	1	0
15	0	1	0
16	0	1	0
17	0	1	0
18	0	1	0
19	0	1	0
20	0	1	0
21	0	1	0
22	0	1	0

Figure 9.2. PDF, CDF and CCDF Values Generated by TIM for Risk to All Simulated Birds.

The PDF is useful in telling the risk assessor the most likely magnitude of mortality to birds based on the parameters of the simulation. For example, based on the model results provided in **Table 9.2,** it is most likely that 1 bird out of a flock of 25 will die (probability = 0.37). The results of the PDF may be used to interpret population level effects of avian mortality. For example, the most likely decreases in survival of adult birds could be input to a population model to determine impacts to a species. This information could be useful in interpreting whether a risk that is likely to adversely affect a listed bird species may also result in jeopardy to that population. The results of the CCDF, may be the most relevant when considering risks to listed species of birds. For pesticide effects determinations, EPA determines the potential that a pesticide may affect one individual. The CCDF can be used to describe the likelihood of killing one or more individuals. In the example data provided in **Table 9.2,** the likelihood of killing one individual of more individuals of a flock of 25 birds near and on a treated field is approximately 0.3.

The equation used to determine the probability of mortality to x birds (P(x)) out of the user selected flock size is based on the PDF for a binomial distribution (**Equation 9.1**). In this equation, p is the fraction of the total number of simulated birds that died, n is the flock size and x is the number of dead birds out of the flock for which the probability is being generated. For the CDF, the probability of killing x or fewer birds is calculated by summing the values of P(x) that correspond to the value of x and less. For the CCDF, the probability of killing greater than x birds is calculated by subtracting the probabilities of killing all birds less than or equal to x, in other words, by subtracting the CDF probability from 1.

Equation 9.1. $P(x) = \left(\frac{n!}{x!(n-x)!}\right) * p^x * (1-p)^{n-x}$

9.2 Dead_per_hour.txt

This output file contains two columns that are separated by a space. This information can be accessed though the GUI by selecting Output -> File -> Dead per hour. The first column indicates the simulation hour and the second is the number of birds that died during the simulation. This information can be used to understand the timing of the mortalities relative to the applications. **Figure 9.3** below depicts an example figure generated using the mortalities per hour.

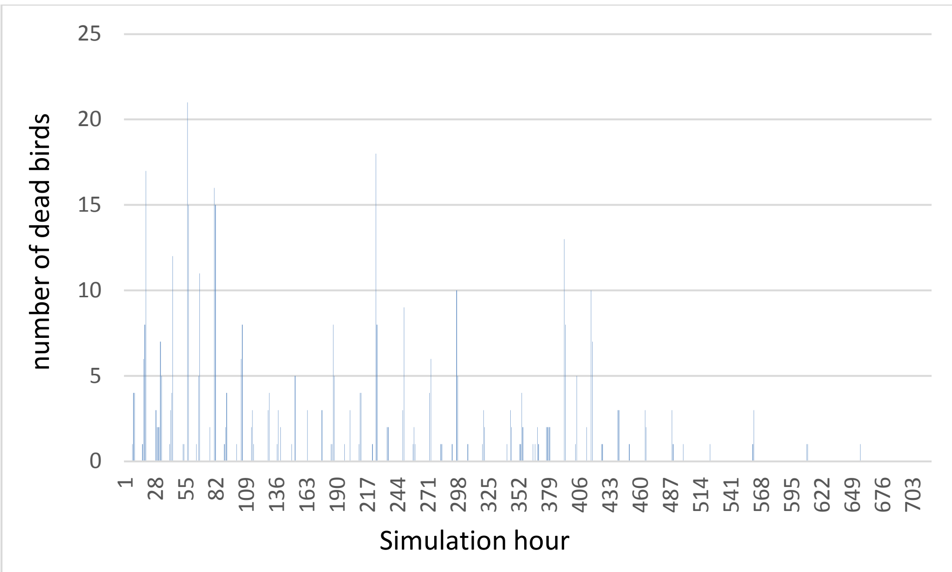

Figure 9.3. Example of Output Depicting the Number of Simulated Birds That Died Per Hour.

10. Uncertainties

This section discusses the uncertainties associated with the assumptions of TIM v.3.0. It is possible that in future versions of the model, refinements can be made to address these uncertainties.

10.1. Exposure Routes Not Considered

At this time, TIM does not consider pesticide uptake through the following routes:
- Dietary consumption of granular formulations or treated seeds;
- Dietary consumption of contaminated small vertebrates (*e.g.*, mammals, birds), carrion, worms or aquatic organisms;
- Incidental ingestion of soil;
- Inhalation of particulate-associated pesticide (fugitive dust emissions associated with soil or seed treatments);
- Dermal contact with soil (*e.g.*, dust baths, foot contact);
- Dermal contact with contaminated water;
- Drinking contaminated guttation fluid from water;

- Drinking from larger water bodies receiving spray drift and runoff from the field (*e.g.,* ponds;
- Oral uptake through preening; and
- Oral uptake through nest building (*i.e.,* collection and manipulation of nest materials that may be contaminated with pesticides).

The model also does not account for soil or seed treatments or tree trunk injections. Therefore, exposures from systemic pesticides that translocate into plant tissues and are associated with consumption of plants are not considered.

In TIM v.3.0, the model user can simulate up to 5 separate pesticide applications. Although the ability to simulate 5 applications represents an upgrade in the capability of TIM, this fact may represent a limitation for model users in cases where pesticide labels allow for more than 5 applications per season.

For ground applications, it is assumed that birds on the field will flush, thus, preventing exposure to direct spray via inhalation and dermal routes (**Section 1.3**). Although this is a reasonable assumption for birds on the treated field, it is possible that birds in the edge habitat will not flush. Therefore, birds in the edge could be exposed to pesticide spray that is transported to the edge habitat via spray drift.

10.2. Avian species

10.2.1. Diet and Feeding

The model assumes a constant diet composition for all individuals of the simulated species over the course of the simulation. It is expected that for many species, diet composition will vary over time based on the availability of food. In addition, it is expected that there will be some variability in diet composition among individuals within a species.

As indicated by **Appendix D**, many species that visit agricultural fields have diets represented predominantly by multiple food items (*i.e.,* omnivores). The generic omnivore species is parameterized so that its diet is equal parts arthropods, seeds, grass, broadleaf and fruit. In reality, the proportions of these items in an omnivore's diet are not equal.

The model does not account for changes in feeding that may be associated with the growth of the crop and plants in adjacent habitat. Also, differences in feeding strategies among birds and potential impacts on pesticide exposure are not considered. For example, aerial feeders are assumed to have the same exposure as ground feeders. It is possible that aerial feeders may have lower exposures if they feed above the canopy, thus not receiving dermal or inhalation exposures. This possibility may be accounted for by the model user by turning off pathways that may not be relevant to a specific modeled species.

10.2.2. Body Weight (BW)

The generic species do not simulate individual birds weighing 30-66 g and 152-660 g. If a bird species represented by these BWs is of interest to the user, the custom species can be used to account for the potential risks to birds within these BW ranges.

The BW of an individual does not vary over time. Therefore, seasonal changes in BW (*e.g.,* in preparation for migration, due to reproduction) are not accounted for. In addition, juvenile BW is set to 0.5 of the value for its parent (see **Appendix F**). Thus, changes in BW due to growth of juveniles is not accounted for.

10.2.3. Frequency on Field and Residency

One notable uncertainty associated with the empirical FOF data used to derive the default mean FOF values for the generic species (and summarized in **Appendix D**) is that the majority of the census studies were conducted during the spring and summer months. Therefore, FOF values representative of fall and winter months are unknown.

As indicated by available avian census studies, use of fields by individuals within the same species varies in time and location. There is also uncertainty associated with the use of avian census studies to represent frequency on field. As noted by the SAP, radio telemetry data tracking movements of individual birds on and off of treated fields would be ideal for determining FOF; however, these data are not generally available. Observations of individuals of a species on agricultural fields and orchards relative to the edge habitat is used as a surrogate to estimate FOF for a species.

The model does not consider impacts of the pesticide on prey availability and alterations to FOF. For example, decreases in availability of insect prey due to application of a pesticide does not result in decreases in FOF of insectivores.

For specific species, residency status was assigned based on the nest location of a bird (*e.g.,* ground nesters in grassland are assumed to be residents). Ideally, these assignments could be confirmed using studies documenting nesting on agricultural fields and orchards; however, these studies were not available.

10.3. Modeling Bird Behavior: Influence of the Fidelity Factor

Although the model incorporates bird behavior into exposure and risk estimates, there are some uncertainties that are difficult to quantify, in particular the fidelity factor, which represents the tendency of a bird to return to a specific area to feed. As noted in **Section 2.6,** no data are available in the literature to support the parameterization of the fidelity factor (Q). Since TIM's outputs are sensitive to the value of this parameter, this represents an uncertainty. **Figure 10.1** illustrates how Q shifts the shape of the triangular distribution of P_{11}. Q influences the central tendency of the distribution of $P_{11}$and thus the probabilities of birds to stay on the treated field from one hour to the next.

When the FOF is kept constant, an increase in Q results in an increase in P_{11} (**Figure 10.2**), indicating that as a bird's fidelity factor increases, the bird is more likely to remain on the treated field from one time step to the next, resulting in higher pesticide exposure. Therefore, the selection of the default fidelity factor value of 0.8 for field residents indicates that individual birds that start out on the treated field at the time of the simulation will most likely stay on the treated field throughout the simulation.

As Q increases, P_{00} also increases (**Figure 10.3**), indicating that as a bird's fidelity factor increases, the bird is more likely to remain in the edge habitat from one time step to the next, resulting in lower pesticide exposure. Therefore, individual field resident birds (Q = 0.8) located in the edge habitat will be more likely to stay there, resulting in lower pesticide exposures to those birds. Lower Q values generate lower P_{00} values, which increase the likelihood that the bird will move from the edge at time t-1 into the field at time t (during feeding hours only). Therefore, the selection of the default fidelity factor value of 0.6 for edge residents indicates that individual edge resident birds will more likely move from the edge to the field than field resident birds and vice versa.

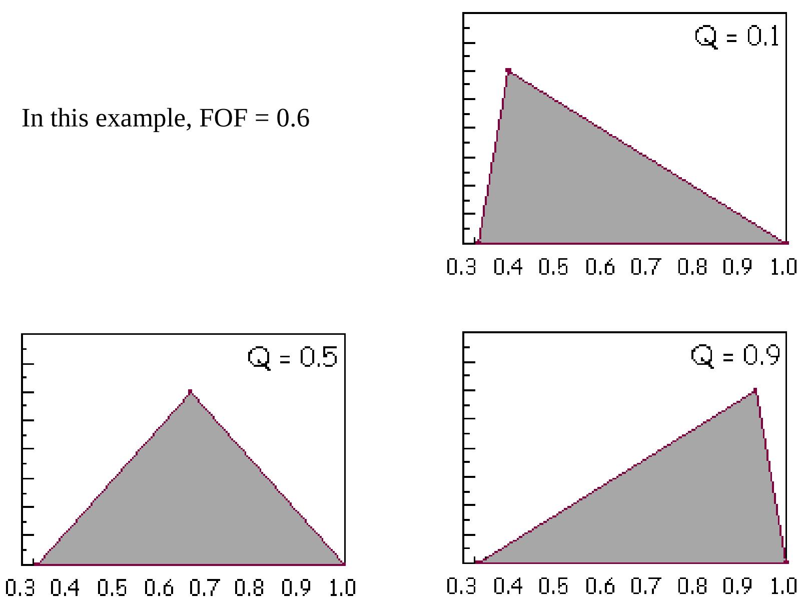

Figure 10.1. Effect of Fidelity Factor (Q) on the Shape of the Triangle Distribution of P_{11} **(**Probability that a bird, now on the field, will be on the field in the next hour**; depicted on x-axis).**

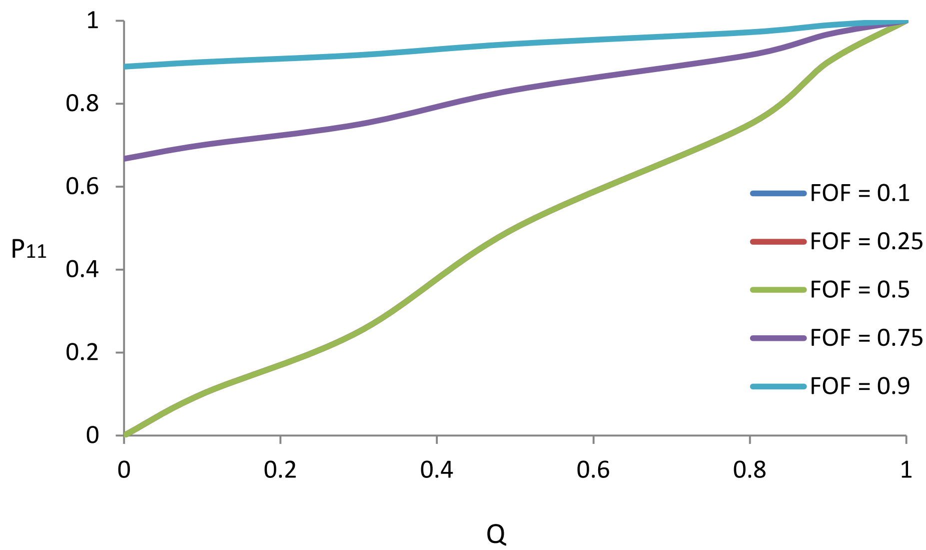

Figure 10.2. Effect of Q on P_{11}. Note that P_{11} values are equivalent for FOF values of 0.1, 0.25 and 0.5 (bottom line).

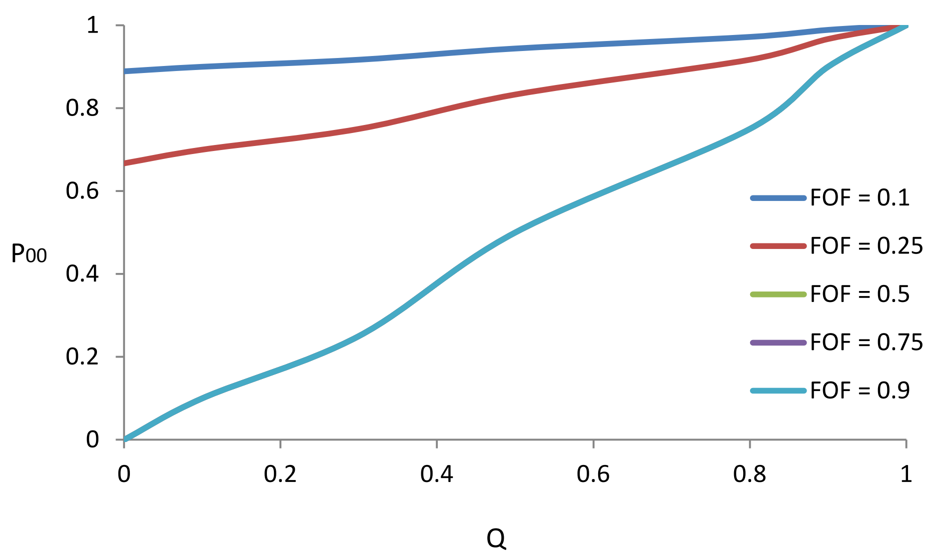

Figure 10.3. Effect of Q on P_{00}. Note that P_{00} values are equivalent for FOF values of 0.5, 0.75 and 0.9 (bottom line).

10.4. Dietary Exposure

The method used in TIM to represent initial pesticide residues on avian food items assumes that all fields exhibit a residue variability comparable to a mixed data estimate of variance (*i.e.*, within field and among field data contributing to the variance estimate), which may represent a somewhat conservative approach. An alternative assumption would be that all variance associated with the underlying avian food item residue data are only attributable to among field variance and that there is no residue variance within a field. EPA has reviewed a number of pesticide residue datasets and has concluded that at best, variance within a field is lower than variance among fields, but under some circumstances, variance within a field could approach variance estimates among fields.

Initial pesticide residues on avian food items are assumed to be linearly related with the application rate of the pesticide. This assumption was examined for residues on plants by Fletcher *et al*. (1994), and the authors found this assumption was consistent with the pesticide residue data from the uptake/accumulation, translocation, adhesion, and biotransformation (UTAB) database that they evaluated. However, most of the data points included in their analysis were for typical application rates between approximately 0.2 and 4 lb a.i./A. The extent to which this relationship holds for pesticides that are applied at exceptionally low rates or exceptionally high rates is unknown. Also, the extent to which the linear relationship holds for insects is unknown.

Data compiled on studies of pesticide residues on insects were used to estimate peak exposure of birds from consumption of terrestrial invertebrates. The extent to which the residues on terrestrial insects represent those of other invertebrates that birds consume (*e.g.*, arachnids and annelids) is unknown. Also, while Day-0 residues were assumed to represent peak levels, residues on some mobile invertebrates may actually peak after Day 0 (Brewer *et al*., 2003).

The model assumes that dissipation of the pesticide from each food item is a constant value. It is likely that there is variability in dissipation across a field and among different fields due to varying weather conditions and other factors. This variability is not accounted for in TIM v.3.0.

The dietary intake model used to estimate daily food intake for birds is based on allometric equations for the average daily field metabolic rate. This model predicts the average intake needed to achieve balance with daily caloric requirements. In addition, the model also does not consider the impact of egg laying on foraging behavior (*e.g.,* duration, intensity) on female birds.

10.5. Inhalation Exposure

The exposure assumptions are based upon a vapor concentration at saturation and at a temperature of 25ºC. Temperatures at the time of pesticide applications could differ from 25°C, with higher temperatures resulting in higher vapor pressures. The value of 25°C is advantageous, however, because vapor pressure data are generally available at this temperature. In addition, it does not seem to be an unreasonable estimate of an environmentally relevant temperature at the time of pesticide application. This estimate does, however, add uncertainty to the calculations.

The model does not consider volatilization from the soil. It also does not consider exposures in edge habitat from volatilization and redeposition.

The respiration rate (R_{rate}) is calculated using an allometric relationship from USEPA (1993) that relates avian resting respiration rate to BW (**Equation 5.5**). This value is multiplied by 3 in order to translate this laboratory based allometric equation into one that is representative of the field. **Equation 5.5** was derived from non-passerine birds with a range of BWs and is associated with standard metabolism (post-digestive, at rest). **Equation 5.5** may underestimate inhalation rates for passerine species because passerines have somewhat higher metabolic rates than non-passerines (USEPA, 1993); however, allometric relationships were not available to allow for estimates of inhalation rates for passerines in USEPA (1993). Although birds may have decreased respiration rates in the field when they are not feeding and are thus less active, the model does not account for a decrease in respiration.

Initial limitations of the air model include the assumption that equilibrium conditions exist. Consequently, the rate of change in exposure as a function of changing meteorological conditions on air concentrations cannot be determined. Also, the model does not alter the height and mass of the crop over time.

The model cannot be applied to situations where pesticides are applied to soils with little or no ground cover; an important limitation because many volatile pesticides, such as soil fumigants, are applied to non-vegetated soils. Finally, the model is limited in the ability to address exposures at varying heights within the canopy.

In TIM v.3.0, it is assumed that birds can inhale particles of 100 μm in diameter or less of the direct spray droplet distribution immediately after application of the pesticide. The review of available literature by the 2004 SAP (USEPA, 2004a) identified limitations with the data and suggested that larger particle sizes may be able to enter the respiratory system of a bird. Therefore, the larger particle size of 100 μm was chosen in order to determine the respirable fraction of spray droplets.

In order to convert the inhalation dose to an oral-equivalent, avian oral and inhalation data are used. If avian inhalation data are not available, the relationship between mammalian oral and inhalation toxicity is used, with use of equivalency factors to account for differences between avian and mammalian lungs. Physiological and biochemical differences in avian and mammalian lungs can lead to uncertainty in equivalency factors (*e.g.,* differences in vascularization influence diffusion rates, enzymatic rates impacting chemical transformation). OPP has been calling in avian inhalation toxicity data as part of registration review. As more avian inhalation toxicity data become available, EFED may be able to derive relationships between avian oral and inhalation toxicity data that can be used to predict acute inhalation toxicity endpoints when they are not available for a specific chemical.

10.6. Dermal Exposure

Contact exposure with contaminated foliage is estimated using exposure values from human hands (workers). The model also assumes that only the bird foot is exposed to these residues. The relationship between exposure values of human hands and bird feet is unknown. In addition, there is no consideration for bird foot morphology.

In calculating the dermal spray dose at the time of an application, the model does not account for a decrease in exposure that may occur due to foliar interception of the pesticide spray. This is a conservative assumption.

There is uncertainty in the approach used to relate external dermal dose response to acute oral dose response. The relationships are based on a limited data set, including only 3 test species and 6 chemicals, all of which are organophosphate pesticides. In addition, a poor correlation was established between available measurements of acute oral and acute dermal toxicity. The correlations were not improved when other physical/chemical properties were considered. However, the simple correlation models used to test for physical/chemical property influences were not mechanistic. It is possible that improved predictive models may be developed in the future that relate pesticide physical/chemical properties to rates of absorption across, and metabolism within, avian skin tissue. A more complete understanding of such mechanisms affecting bioavailability may aid in the establishment of more robust predictive models of avian dermal toxicity. These issues remain topics for further research and future model development.

10.7. Drinking Water Exposure

The relative importance of different sources of drinking water is expected to vary based on environmental factors, weather, geography, climate and species. The model does not account for these potential influences on drinking water source selection. In cases where a bird species of interest does not ingest drinking water, the user may choose to "turn off" the drinking water switches.

Contaminated water sources are not addressed for banded and in-furrow applications. Banded and in-furrow applications present specific modeling challenges for estimating drinking water contamination, and applicable models are not presently available. It is possible that concentrations of water in puddles forming in treated furrow and banded areas could be higher than modeled for aerial sprays. This potential for increased exposure magnitude warrants future field investigation and model refinements to account for these application methods.

The model does not consider pesticide exposures through larger bodies of water, such as ponds and streams. It is expected that exposures through consumption of these drinking water sources will be lower compared to puddles and dew. Since dew exposures are higher than puddles, the lack of consideration of other sources of water is expected to be conservative. The FIFRA SAP (SAP, 2001) indicated that birds are less likely to consume dew if standing water is available (*e.g.,* ponds).

Both the puddle and dew models rely upon equilibrium based partitioning models that are dependent upon a chemical's properties (*i.e.,* Koc and Kow). There are several uncertainties and assumptions associated with these models, including:

- surface characteristics of the soil and vegetation are not accounted for in determining the potential for modifying solubilization of vegetation/associated pesticide residues;
- equilibrium is established quickly between the two compartments of each model; and
- degradation is the only route of dissipation assumed to occur.

The puddle model assumes that puddles are on the field at the time of the application and are present for 48 hours afterword. There are uncertainties associated with these assumptions.

- First, pesticide applicators may not be likely to apply pesticides if 6 inch puddles are present on the field. Especially if the puddles limit the ability of the application equipment to maneuver the field.
- Second, puddles may persist on a field for longer than 2 days, potentially prolonging this exposure route.
- Third, this approach does not account for evaporation of water from puddles that could result in higher concentrations.
- Fourth, in reality, puddles would be expected to be on the field at different times outside of the pesticide application.

In addition, the following assumptions apply to the dew model:

- Pesticide concentrations in dew are based on concentrations of the pesticide applied to the surfaces of broadleaf plants. This approach does not consider concentrations of pesticides in guttation water from plant sap that may be representative of systemic pesticides.
- Relative compartment volumes are assumed unimportant, such that the mass of pesticide initially on the leaf compartment is sufficient to reach maximum equilibrium concentrations in water.

10.8. Determining Mortality

10.8.1. Toxicity Data

One of the largest sources of uncertainty associated with predicting effects of pesticides to nontarget species comes from the large variability in the sensitivity of species to toxic chemicals. A review of toxicity studies for 53 carbamate and organophosphate insecticides showed that the range between LD_{50}'s among birds is from 5 to more than 100 (ECOFRAM, 1999). For 70% of the products, this range extends between 10 and 100. If the species of the assessment is the same as the species tested in a toxicity study, the effects profile may be the same as the dose-response relationship derived from the study. More often the assessment is focused on species that have not been tested. Therefore, the effects profile needs to account for the uncertainty introduced by the high variability in sensitivity among species. In the absence of toxicity data on specific species with unknown sensitivities, uncertainty is introduced into the assessment of risk to individual species.

The SSD approach generates a distribution of species sensitivity from the results of available acute oral toxicity tests. This approach is based on the concept that the sensitivity of species is a stochastic variable that can be characterized by fitting a probability density function to the results of the toxicity tests. This assumes that the distribution of wild species sensitivity closely approximates the estimated distribution from laboratory tests, and the sensitivity of species used in laboratory tests is an unbiased measure of the variance and the mean of the distribution of sensitivity of wild species.

The slope of the dose-response curve is an estimate of the population's variability in individual sensitivities and therefore has inherent statistical uncertainty. Also, the slope of the dose-response curve is thought to differ among species due to the differences in morphology and biochemical and physiological processes, which interact with the inherent pharmacokinetic characteristics of the compound. Information on the extent of the variability of the slope between species is lacking and limits, at this point, predictions about the slope based on taxonomic relationships. Therefore, few species, other than the standard species used for laboratory tests, are tested in such a way that slopes can be determined, which prevents a more thorough evaluation of the species differences in slopes at this time (ECOFRAM, 1999).

Uncertainty is introduced into the model results from the major variables that influence the acute response of individual animals. These include intra- and inter-species variability, age, sex, nutritional status, breeding status, environmental conditions, formulation, routes of exposure and duration and extent of exposure. For the majority of these variables, while data has been developed that indicate they contribute to the variability of the response of an individual to exposure to a toxicant, limited information is available to quantify their influence on the numerous wildlife species exposures under the countless environmental conditions that occur under field conditions.

Acute oral toxicity studies have limitations for estimating the risk to wild avian species exposed to pesticides in the environment. One limitation is that the study includes a fixed exposure period, which does not allow for the differences in response of individuals to different duration of exposure. In the model, exposure occurs over several days or weeks. The study involves a single dose of the pesticide, which does not mimic wild birds' exposure. In addition, for exposure through different environmental matrices, the acute oral LD_{50} does not account for the effect of the matrices on the absorption rate of the chemical into the animal.

The assumption is made that there is no cumulative effect of repeated doses that reduce the sensitivity of an individual to successive doses, and that the peak cumulative dose per day, taking into account the elimination rate of the chemical per day, is equivalent to the single bolus exposure in the acute oral toxicity test. In essence, the foundation of the approach is the toxic response of the individual, which is a function of the body burden of the compound. Likewise, the body burden is a function of the ingestion rate plus the residual from previous exposure periods, using a defined time step.

The construct of the risk assessment model relies on the peak exposure over the course of a series of time steps. That is, the assessment of individual bird survivorship within a cohort of birds is based on the interpolation of a mortality risk for the highest exposure time step that is modeled. In this way, risk of mortality for the highest time step is evaluated independently from previous exposure history. Therefore, the model cannot account for any potential increase or decrease in susceptibility to intoxication that occurs at lower dosages from earlier time steps.

By relying on toxicity data derived under laboratory conditions, mortality is only considered based on exposure under controlled environmental conditions. As a consequence, the potential for additional reduced survivorship as a result of sublethal effects is not considered. These types of sublethal effects may include increased susceptibility to temperature stress, reduced ability to obtain food, reduced ability to care for offspring, and impaired ability to avoid predation.

10.8.2. Elimination

The exposure assessment model assigns a fixed estimate of pesticide clearance rate to every individual bird in the simulation. This rate is based on chemical-specific metabolism data from domesticated chickens. It is possible that other birds will exhibit different metabolic clearance rates for the same pesticide. For instance, smaller birds are likely to have overall higher metabolic rates than chickens. If this is the case, higher clearance rates would mean less carryover from one time step to another, and peak exposures for most individual birds that are modeled would be lower, corresponding to lower risks. It is also uncertain that chickens will be representative of all bird species. It is expected that there will be differences in metabolism and clearance among species.

It is assumed that uptake and elimination kinetics are equivalent for all exposure routes. There is uncertainty in lumping all of the exposure routes into one dose. For instance, this approach does not account for potential differences in elimination via respiratory and dermal routes.

10.9. Other Considerations

The model relies upon data relevant to a pesticide active ingredient. Impacts of components of a formulation on exposure and toxicity are not considered directly. For example, potential increases in dermal uptake due to carriers present in a formulation are not considered. There is some consideration of active ingredients inherent in the food exposure calculations because the initial residue distributions are based on data from field studies that involved formulated products. The model user may choose to account for the toxicity of a formulation of interest using acute avian toxicity data for that formulation.

This model does not consider impacts of indirect effects to birds. For example, reduced availability of invertebrate food items, a variety of food items and suitable drinking water (through conditioned response to avoid chemical contamination) are not considered.

The model does not consider sublethal effects to birds, including decreased feeding or movement. Regurgitation and avoidance of food are not considered.

Changes in weather, including rainfall and temperature, are not considered. Changes in temperature in particular may impact the fate of the chemical (*e.g.,* alter degradation rates, alter partitioning), metabolism of birds and the toxicity of the chemical.

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