Appendix K

Earthworm Fugacity Model
Terrestrial Chronic Exposure Estimates for Birds and Mammals Exposed to Granular Applications of Oxyfluorfen
Terrestrial Acute Exposure Estimates for Earthworms Exposed to Granular Applications of Oxyfluorfen

Oxyfluorfen exposure to terrestrial wildlife from non-granular applications is evaluated by estimating pesticide residues on food items including grasses, plants, insects, fruits, pods, and seeds. For the purposes of this CRLF assessment, terrestrial wildlife is assumed to include birds, which are used as a surrogate for the terrestrial-phase CRLF, and mammals, which are food items for terrestrial-phase CRLFs. For granular applications, terrestrial EECs and acute risks were derived based on an estimation of loadings of pesticide per unit area (ft^2). EFED has no standard methodology for assessing chronic risk to terrestrial organisms from granular applications. The following chronic exposure estimation and risk characterization for terrestrial wildlife considers granular routes of exposures including direct ingestion of soil invertebrates that have bioconcentrated pesticide residues of granules of soil. In addition, acute risks to terrestrial invertebrates exposed to granular applications of oxyfluorfen are estimated using the concentration of oxyfluorfen in earthworms and earthworm toxicity data, which is used as a surrogate for terrestrial invertebrates that may be consumed by the terrestrial-phase CRLF.

Direct Ingestion of Soil Invertebrates

An estimation of oxyfluorfen concentrations potentially accumulated in the tissues of earthworms was required to complete the exposure estimates for insectivorous birds and mammals. This estimation of earthworm concentration was calculated using a fugacity-based (equilibrium partitioning) approach based on the work of Trapp and McFarlane (1995) and Mackay and Paterson (1981). Earthworms dwelling within the soil are exposed to contaminants in both soil pore water and via the ingestion of soil (Belfroid *et al*. 1994). The concentration of oxyfluorfen in earthworms was calculated as a combination of uptake from soil pore water and gastrointestinal absorption from ingested soil:

$$C_{earthworm} = [(C_{soil})(Z_{earthworm}/Z_{soil}]+[(C_{soil\ water})(Z_{earthworm}/Z_{water})]$$

where: C_{soil} is the concentration of chemical in bulk soil (note: a chemical concentration averaged over a 1 cm soil depth was used to reflect a concentration across the earthworm occupied area of soil)

$Z_{earthworm}$ is the fugacity capacity of chemical in earthworms = $(lipid)(K_{ow})(\rho_{earthworm})/H$

Z_{soil} is the fugacity capacity of chemical in soil = $(K_d)(\rho_{soil})/H$

Z_{water} is the fugacity capacity of chemical in water = $1/H$

$C_{soil\ water}$ is the concentration of chemical in soil water = C_{soil}/K_{bw}

K_{bw} is the bulk soil-to-water partitioning coefficient = $(\rho_{soil})(K_d)+\theta+(\varepsilon-\theta)(K_{aw})$

K_{aw} is the air-to-water partitioning coefficient = H/RT

H = Henry's Constant specific to oxyfluorfen (8.21E-07)

R = universal gas constant, 8.31 Joules-m^3/mole-^oK

T = temperature ^oK, assumed to be 298 ^oK

K_d = soil partitioning coefficient for oxyfluorfen (99.38)

ρ_{soil} = bulk density of soil, assumed to be 1.3 g/cm^3
θ = volumetric fraction of the soil, assumed to be 0.30
ε = volumetric total porosity of the soil, assumed to be 0.50
lipid = fraction of lipid in organism 0.01 (Cobb *et al*. 1995)
K_{ow} = the octonal to water partitioning coefficient for oxyfluorfen (2.94E+04)
$\rho_{earthworm}$ = the density of the organism, assumed to be 1 g/cm^3

Table K-1 summarizes the estimated immediate post-treatment soil concentrations of oxyfluorfen, assuming 1 cm averaging depth, a soil density of 1.3 g/cm^3, and the granular application rate of oxyfluorfen (2 lb a.i./acre, CA nursery scenario).

Table K-1 Estimated Soil Concentration for Oxyfluorfen (Immediately Post-treament)

Application Rate (lb a.i./acre)	Soil Concentration (mg/kg-soil) at 1 cm depth
2	17.14

Table K-2 summarizes the model inputs and exposure estimates (*i.e.*, earthworm concentrations in ppm) for insectivorous birds (used as a surrogate for terrestrial-phase CRLFs that consume invertebrates) and mammals (food item of the terrestrial-phase CRLF) based on the granular oxyfluorfen application (2 lb a.i./acre).

Table K-2 Model Input Parameters and Dietary Exposure Estimates for Avian and Mammalian Receptors (for Soil Concentrations Immediately Post-treatment)

Parameter	Application Rate: 2 lb a.i./acre
C_{soil} (mg/kg @ 1 cm depth)	17.14
$C_{earthworm}$ (mg/kg)	77.92
K_d (L/kg)	99.38
Z_{water} (1/H or moles/Pa-m^3)	1.22E+06
Z_{soil} ((K_d)(ρ_{soil})/H)	1.57E+08
$Z_{earthworm}$ ((lipid)(K_{ow})($\rho_{earthworm}$)/H)	3.58E+08
ρ_{soil} (g/cm^3)	1.3
$\rho_{earthworm}$ (g/cm^3)	1
θ (unitless)	0.3
ε (unitless)	0.5
K_{aw} (H/RT)	2.94414E-05
K_{bw} ((ρ_{soil})(K_d)+θ+(ε-θ)(K_{aw}))	129.4940059

Risk Characterization for Terrestrial Wildlife

Chronic risks for birds (used as a surrogate for terrestrial-phase CRLFs) and mammals that consume terrestrial invertebrates as the majority of their diet were estimated based on comparison of the concentration of oxyfluorfen in earthworm tissue ($C_{earthworm}$) with chronic toxicity values for birds and mammals. Although earthworms are likely to be present in the top six inches of soil, a 1 cm soil depth was used because oxyfluorfen cannot be incorporated into the soil and soil concentration estimation is immediately post-treatment. It is important to note that this estimation of risk assumes that 100% of the diet is comprised of terrestrial soil invertebrates. In addition, the model assumes that no metabolism or elimination of the chemical has occurred.

Direct Effects: Insectivorous Bird

Chronic risks for insectivorous birds were estimated by comparing the $C_{earthworm}$ in ppm to the avian chronic NOAEC for oxyfluorfen (124 ppm, based on reproductive effects). Estimated earthworm residues for insectivorous avian receptors (77.92 mg/kg) are less than the avian chronic endpoint for granular oxyfluorfen applications at the rate of 2 lb a.i./acre. Therefore, the chronic RQ value (0.63) for the terrestrial-phase CRLFs associated with ingestion of terrestrial invertebrates (*i.e.,* earthworms) that have bioaccumulated oxyfluorfen granules do not exceed chronic LOCs. However, it is unclear whether other routes of granular oxyfluorfen exposure (*i.e.,* direct consumption of granules, ingestion of granules that adhere to soil invertebrates, partitioning of dissolved oxyfluorfen to on-site sources of wildlife drinking water, and dermal exposure of granules released to surrounding soil and on-site puddles) or combined routes of exposure would result in chronic risk concerns for terrestrial-phase amphibians.

Indirect Effects: Insectivorous Mammals

Chronic risks for insectivorous mammals were estimated by considering both dietary-based and dose-based exposures and effects. In the dietary method, risks were estimated by comparing the $C_{earthworm}$ to the mammalian chronic NOAEC for oxyfluorfen (400 ppm; based on reproductive effects). In the dose-based method, the residue concentration in earthworms was converted to a daily oral dose based on the fraction of body weight consumed as estimated through mammalian allometric relationships. The dose was then compared to the NOAEL (20 mg/kg-bw/day) for mammalian receptors.

Based on the dietary method and the oxyfluorfen granular application rate of 2 lb a.i./acre, the chronic RQ value (0.19) does not exceed the chronic LOC for insectivorous mammals because the earthworm residue concentration (77.92 mg/kg) is less than the NOAEC (400 mg a.i./kg-diet). The earthworm residue concentration, derived based on the dose method, is first converted to a daily dose by multiplying the dietary $C_{earthworm}$ by the percentage body weight consumed for the small mammals (15 g = 95% body weight). In addition, the NOAEL value (20 mg/kg-bw/day) is adjusted to account for the size of the mammals according to the following equation:

$$Adjusted\ NOAEL = NOAEL\ (TW/AW)^{(0.25)}$$

where:

TW = body weight of tested animal (350 g rat); and
AW = body weight of assessed animal (15 g).

As shown in **Table K-3**, the estimated chronic dose for insectivorous mammals, based on the 2 lb a.i./acre application rate and adjusted NOAEL for small mammals exceed chronic LOCs with an RQ value of 1.68. The results of the assessment indicate that, when growth effect risks for mammals are assessed on the basis of daily ingested dietary dose, the accumulation of oxyfluorfen in terrestrial invertebrates may represent, by itself, a biologically significant pathway for exposure. The dose-based RQ value is likely to provide more accurate estimates of risk to insectivorous mammals because they are based on earthworm residues that are consumed by a mammal in a given day and adjusted NOAEL values for three sizes of mammals, while dietary-based RQ values use no such adjustments to account for feeding behavior and varying classes. However, in this case, a definitive mammalian NOAEL was not established; the NOAEL was derived from the NOAEC using the standard FDA lab rat conversion.

Table K-3 Dose-based Chronic RQ Values for Insectivorous Mammals

Application Rate	Body Weight (g)	Dose-adjusted EEC_w (mg/kg)[a]	Adjusted NOAEL (mg/kg-bw/day)[b]	Chronic RQ[c]
2 lb a.i./acre	15	74.02	43.96	**1.68***

[a]Dose-adjusted EEC_w = Dietary EEC_w (ppm) * (%BW consumed/100).
[b]Adjusted NOAEL = $NOAEL(TW/AW)^{0.25}$.
[c]Chronic RQ = Dose-adjusted EEC_w/Adjusted NOAEL.
*Exceeds chronic risk level of concern (RQ ≥ 1.0).

Indirect Effects: Earthworms

Acute risks for earthworms (used as a surrogate for terrestrial invertebrates for quantifying risk) exposed to granular applications of oxyfluorfen that may result in the reduction of the prey base for the terrestrial-phase CRLF were estimated based on comparison of the concentration of oxyfluorfen in earthworm tissue ($C_{earthworm}$) with the LC_{50} for earthworms. The estimated earthworm residue (77.92 mg/kg) divided by the LC_{50} = 89 mg a.i./kg-dry soil results in an acute RQ value of 0.88, which exceeds the acute LOC (**Table K-4)**.

Table K-4 Acute RQ Estimation for Terrestrial Invertebrates

Application Rate	$C_{earthworm}$ (mg/kg @ 1 cm depth)	LC_{50}[1] (mg a.i./kg-dry soil)	Acute RQ
2 lb a.i./acre	77.92	89	**0.88***

[1]Estimation based on earthworm acute contact LC_{50} (MRID 459060-07).
*Exceeds acute LOC (RQ ≥ 0.05).

Uncertainties

There are a number of uncertainties associated with the fugacity model used to estimate oxyfluorfen concentrations in earthworm tissue and subsequent risks to insectivorous terrestrial wildlife, including the terrestrial-phase CRLF. It may be possible to further refine this assessment with additional information that addresses the following uncertainties:

An oxyfluorfen concentration averaged over a 1 cm soil depth was used to reflect a concentration across the earthworm-occupied area of soil. However, it is possible that earthworms may be present at deeper soil depths, resulting in a lower concentration of oxyfluorfen in bulk soil and earthworm tissue.

The fugacity-based model assumes equilibrium partitioning between bulk soil and soil pore water. In addition, the model assumes a fixed value for soil density, earthworm density, temperature, pore space, organic carbon, and the lipid content of the earthworm. Resulting concentrations of oxyfluorfen in earthworm tissue may be either underestimated or overestimated depending on the soil type, temperature, and size/lipid content of the earthworm at the time of exposure. This assessment considers only one route of exposure (*i.e.*, ingestion of terrestrial invertebrates that have bioaccumulated oxyfluorfen from granules in the soil) for insectivorous birds and mammals. In addition, it is assumed that 100% of the diet is comprised of terrestrial soil invertebrates. Given species-specific feeding habits and dietary requirements, this assumption may overestimate risk associated with ingestion of soil invertebrates that have accumulated oxyfluorfen, especially for terrestrial-phase amphibians, which have lower metabolic rates than birds. Other potential routes of exposure including direct ingestion of granules, ingestion of granules that adhere to soil invertebrates, partitioning of dissolved oxyfluorfen to sources of wildlife drinking water, and dermal exposure of granules released to surrounding soil and puddles or combined routs of exposure were not considered. Finally, this model was only capable of modeling a single application of oxyfluorfen rather than the four applications indicated on the label as the maximum rate.

References

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Mackay, D. and S. Paterson. 1981. Calculating fugacity. Environ. Sci. Technol. 15: 1006-1014.

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