California Department of Pesticide Regulation
Environmental Monitoring Branch

Methodology for Evaluating Pesticides for Surface Water Protection: Pesticide degradates

Yuzhou Luo, Nan Singhasemanon, and Xin Deng

May 3, 2016
(Updated on October 5, 2016)

1 Introduction

This report presents a modeling approach to evaluate pesticide degradates for surface water protection. The approach will be incorporated into the main program of registration evaluation originally designed for parent active ingredients (AIs) by the Surface Water Protection Program (SWPP) of California Department of Pesticide Regulation (DPR) (Luo and Deng, 2012a, b; Luo, 2014). Currently, SWPP evaluates parent AIs based on their acute aquatic toxicity, physicochemical properties, and product label information. Indicators (including soil runoff potential, aquatic toxicity, aquatic persistence, use pattern, and risk quotients) are generated from input data and combined for making registration recommendations. Generally, these evaluation indicators and decision-making processes for parent AIs can also be applied to degradates. The major difficulty associated with degradate evaluation is the limited availability of toxicity and environmental fate data.

According to the U.S. Environmental Protection Agency (USEPA) data requirements for ecological risk assessment, only some degradates of a parent AI are required to be reported by registrants: "*Degradates formed at greater than or equal to 10% of the amount of applied pesticide are considered significant (i.e., major degradate) and must be identified in the study. In addition, degradates of known toxicological or ecotoxicological concern must be quantified and identified even when present at less than 10% of the applied pesticide*" (USEPA, 2004a). In this document, such degradates will be referred to as "reported degradates," including major degradates and "degradates of known toxicological or ecotoxicological concern." Submitted data for degradates usually include formation pathways and molecular structures. Other data, such as aquatic toxicity and physicochemical properties for degradates are not currently required by USEPA or DPR. Those data may be occasionally requested by USEPA or DPR for some degradates, but DPR does not have explicit procedures for degradate evaluation.

The objective of this report is to develop a consistent and transparent methodology by which SWPP will evaluate reported degradates of a pesticide AI for their exposure potentials to surface water. An initial screening procedure is developed to identify "degradates for which additional data are needed", which are further refined for "degradates to be modeled":

- For degradates identified as needing additional data, SWPP will request acute aquatic toxicity tests and adsorption/desorption tests. If the data are not submitted and deemed to be scientifically sound and acceptable for the purposes of registration, SWPP will presume that data are insufficient to support registration and request the registrant to provide additional data or justification why the data should not be required. Upon

submission of new data, the Pesticide Registration Branch (PRB) of DPR will evaluate the data, and accepted data will be used in the next round of SWPP evaluation.

- For degradates to be modeled, in addition to data required above, all data submitted by registrants such as molar formation fraction, vapor pressure, and half-lives, from laboratory tests or from computer-based estimations, will be used in the modeling processes once reviewed by PRB. Missing data will be estimated based on conservative assumptions. Estimated environmental concentrations of the parent and degradates will be predicted by USEPA PRZM5 and VVWM at daily time step. Their "total risk quotient" (TRQ) is used for risk characterization in surface water. This is consistent with USEPA "total toxic residues" approach (SFIREG, 2006).

Details on the degradate identification, data requirements and requests, physicochemical property estimation, and model-based evaluation are provided in the following sections. The approach would primarily be used to evaluate new pesticide products containing new AIs, but could also be used to assess new products containing registered AIs.

2 Initial screening and data request

Degradate evaluation is only considered by SWPP if the pesticide product is associated with high-risk use patterns. Descriptive classification of pesticide use patterns is defined in previous registration evaluation methodology documents (Luo and Deng, 2012a, b; Xie and Luo, 2016). An initial screening procedure is developed to identify degradates that have a high potential to cause toxicity in surface water. The initial screening will also check the data availability for degradate evaluation and prepare necessary data for modeling. The procedure can be summarized as:

1. Start with all reported degradates
2. To identify "degradates needing additional data" (a subset of reported degradates) based on properties of the parent AI.
3. To identify "degradates to be modeled" (a subset of degradates needing additional data) based on their acute aquatic toxicity.

Before the introduction of the detailed processes in the initial screening, the following two criteria for descriptive classification should be defined:

- "Quick degradation" of a parent AI is defined based on its reaction half-lives in the treated area. A worksheet to determine quick degradation is provided in Table 1. The critical values of 1 day for photolysis half-life, and 5 days for other reaction half-lives, are generally determined based on the 20^{th} percentiles of half-lives for corresponding half-lives reported in the FOOTPRINT database for about 650 pesticides (FOOTPRINT, 2016).
- "Very high toxicity" to aquatic organisms is defined based on acute aquatic toxicity values to fish and invertebrates. A model input variable "TOX" is first derived as the lowest of acute LC50 or EC50 values of aquatic species from the relevant surface water environment (i.e., freshwater and/or marine/estuarine) (Luo and Deng, 2012a; Xie and

Luo, 2016). A chemical is determined to be very highly toxic if its TOX < 100 ppb in water (Zucker, 1985), or TOX < 10 µg/g[OC] in sediment (Luo and Deng, 2012a).

Table 1. Worksheet for determining if a degradate is produced by quick degradation of its parent compound after application (i.e., a degradate in Group [A], Figure 1)

<table>
<tr><td>[Step 1] check all parent degradation pathways producing the degradate</td><td>[Step 2] for the checked pathways, fill the corresponding reaction half-life of the parent compound (P)</td><td>[Step 3] identify quick degradation processes</td><td>[Step 4] check the proposed use patterns</td></tr>
<tr><td>[ ] aerobic soil metabolism</td><td>AERO(P)= day</td><td rowspan="2">[ ] quick degradation with terrestrial processes, if AERO(P)<5 or ANAER(P)<5</td><td rowspan="2">[ ] terrestrial application</td></tr>
<tr><td>[ ] anaerobic soil metabolism</td><td>ANAER(P)= day</td></tr>
<tr><td>[ ] aquatic photolysis</td><td>AQPHOT(P)= day</td><td rowspan="4">[ ] quick degradation with aquatic processes, if AQPHOT(P)<1, or HYDROL(P)<5, or AQAERO(P)<5, or AQANAER(P)<5</td><td rowspan="4">[ ] aquatic application</td></tr>
<tr><td>[ ] hydrolysis</td><td>HYDROL(P)= day</td></tr>
<tr><td>[ ] aerobic aquatic metabolism</td><td>AQAERO(P)= day</td></tr>
<tr><td>[ ] anaerobic aquatic metabolism</td><td>AQANAER(P)= day</td></tr>
<tr><td colspan="4">[Step 5] if none of the boxes in Step 3 are checked: this degradate is not considered a Group [A] degradate. Stop here.

Otherwise, if the identified quick degradation pathway (Step 3) matches the proposed use pattern (Step 4 - i.e., the pesticide is for terrestrial use and the AI degrades quickly due to terrestrial fate processes, OR the product is for aquatic use and the AI degrades quickly in water systems): this degradate will be considered a Group [A] degradate. Stop here.

If the associated quick degradation pathways do not line up with the proposed use patterns: this degradate is not considered a Group [A] degradate, but the parent AI will be flagged for future evaluation if its use pattern changes.</td></tr>
</table>

Notes: AERO=aerobic soil metabolism half-life (day); ANAER=anaerobic soil metabolism half-life (day); AQPHOT=aquatic photolysis half-life (day); HYDROL=hydrolysis half-life (day); AQAERO=aerobic aquatic metabolism half-life (day); AQANAER=anaerobic aquatic metabolism half-life (day)

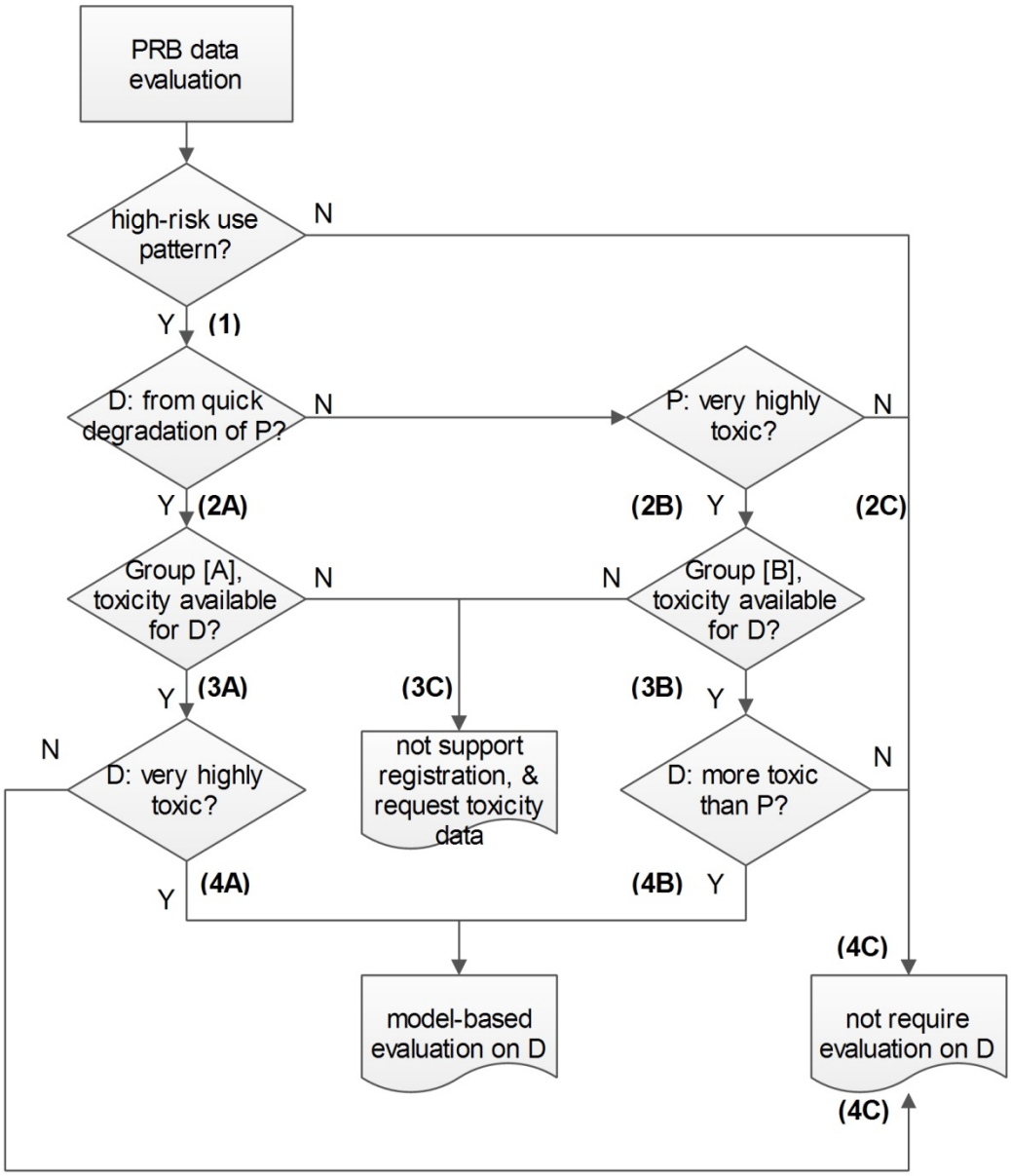

Figure 1. Initial screening and potential data request for registration evaluation on degradates ("P" for the parent compound and "D" for the degradate under evaluation). The process is divided into four key areas (#1-4). More detailed descriptions and discussions are provided in the text.

For each of the reported degradates, SWPP will apply the following initial screening procedures (Figure 1):

(1) SWPP will prepare model input data (physicochemical properties, aquatic toxicity, and label information) of the parent AI, and available data for the degradate by following the input data guideline for SWPP registration evaluation (Luo and Singhasemanon, 2014). Only pesticide products associated with high-risk use patterns are subject to additional evaluations on degradates.

(2) Identification of degradates needing additional data
    A. If the degradate is a product of quick degradation of its parent AI, it will be classified as a Group [A] degradate and further evaluated in (3A). SWPP will notify and consult with PRB upon this determination.
    B. If the parent AI is very highly toxic, the degradate will be classified as a Group [B] degradate and further evaluated in (3B). SWPP will notify and consult with PRB upon this determination.
    C. Otherwise, ***no further data or evaluations are required for this degradate***. SWPP evaluation for this degradate stops here.

(3) Aquatic toxicity data for the degradate
    A. For a Group [A] degradate, if the required toxicity data in Table 2 have been submitted and accepted by PRB, continue to (4A).
    B. For a Group [B] degradate, if the required toxicity data in Table 2 have been submitted and accepted by PRB, continue to (4B).
    C. If the required toxicity data are not available, ***SWPP will presume that data does not support registration and request the registrant to submit additional data*** by following the data requirements in Table 2, or provide justification why the data should not be required. This round of SWPP registration evaluation stops here. Once the registrant submitted the requested data, the data will be evaluated by PRB, and acceptable data will be used in the next round of SWPP evaluation.

(4) With toxicity data for the degradate, SWPP will determine if model-based evaluation is required.
    A. For a Group [A] degradate with very high toxicity, continue to model-based evaluation as described in the next section
    B. For a Group [B] degradate, model-based evaluation is required if it's more toxic than the parent AI. SWPP may also evaluate a Group [B] degradate which is very highly toxic but less toxic than the parent (e.g., cases where the degradate is just marginally less toxic than the parent). Toxicity comparison between the parent AI and degradate is based on their TOX values (i.e., the lowest value of acute LC50 or EC50 values to aquatic species).
    C. Otherwise, ***no further evaluations are required for this degradate***. SWPP evaluation for the degradate stops here.

In summary, if toxicity data for degradates in Group [A] or [B] are not submitted or not accepted, SWPP will presume that the data are insufficient to support registration and request that the registrant provide additional data or provide justifications why the data should not be required. Details on the needed toxicity data are listed in Table 2. Pursuant to California Code of Regulations section 6192, DPR may require data determined to be necessary to carry out the provisions of Food and Agricultural Code section 12824. If registrants are not able to provide some of the requested data, or think it is not necessary to provide some of the requested data, SWPP will consider justifications and other supporting information which can be used to assess acute risk to non-target aquatic organisms. For example, in the previous evaluations SWPP considered the results of preliminary toxicity tests for degradates at screening dose levels.

Table 2. Data needed for degradate evaluation by SWPP

USEPA data requirements for reported degradates (USEPA, 2004a) ▪ chemical name and molecular weight ▪ associated formation pathways
Data needed for degradates in groups [A] and [B] (Figure 1) *General data*: [1] Acute aquatic toxicity tests for freshwater fish, conducted according to OPPTS Guidelines 850.1075 (USEPA, 2014), and for freshwater invertebrates, conducted according to OPPTS Guidelines 850.1010. [2] adsorption/desorption tests (KOC values are required for the conditional data requirements below) [3] If the degradate has a KOC >1000 L/kg[OC], SWPP will also require toxicity tests for invertebrates in bed sediment, conducted according to OPPTS Guidelines 850.1735 [4] Acute toxicity tests for estuarine/marine species may also be required for some degradates according to their physicochemical properties or proposed use patterns (Xie and Luo, 2016). The relevant OPPTS Guidelines are 850.1035 (mysid test, water column), 850.1075 (marine fish species, water column), and 850.1740 (estuarine/marine invertebrate species, bed sediment). The selection of test species for degradates should be consistent to those in the corresponding toxicity tests for the parent AI.

3 Modeling processes for pesticide degradates

3.1 Preparation of model input parameters for degradates

Model-based evaluation will be conducted for degradates identified in the initial screening procedure (Figure 1, "4A"). In addition to the data identified in Table 2, model-based evaluation needs additional input parameters, such as molar formation fraction, aerobic/anaerobic metabolism half-lives in soil and in water, aqueous photolysis half-life, hydrolysis half-life, and vapor pressure.

All registrant submitted data will be considered for model input parameters, including degradate properties from laboratory tests or from estimation programs (such as USEPA EPI suite). Once reviewed and accepted by PRB, the data values could be used in the modeling process. Model input data should be prepared by following the guideline in the model user's manual (Luo and Singhasemanon, 2014). Missing data for degradates will be estimated by the following assumptions,

- 100% of molar formation fraction.

- Low vapor pressure (10^{-15} torr, the 99% lowest value in FOOTPRINT pesticide property database) is assumed.
- Half-lives are assumed to be extremely persistent. This is mathematically implemented with a large half-life (e.g., 9,999 days) or a zero rate constant (0 d^{-1}), according to the required forms of model input data.

3.2 Model-based risk characterization

"Pesticide toxicity index" approach (Nowell et al., 2014) is applied for assessing total toxic residues of parent-degradates mixtures to aquatic organisms. The total risk quotient (TRQ) in water column is the sum of risk quotients (RQ) for all modeled chemicals (P for parent AI and D for degradates to be modeled) at daily time step:

$$TRQ = RQ(P) + \sum_{i=1}^{n} RQ(D_i) = \frac{EEC(P)}{TOX(P)} + \sum_{i=1}^{n} \frac{EEC(D_i)}{TOX(D_i)} \quad (1)$$

where *i* is a running index for each of the degradates (D_1, D_2, …D_n) requiring model-based evaluation according to initial screening, EEC is estimated environmental concentration used in risk characterization, and TOX is the lowest acute aquatic toxicity value. The number of degradates (n) could be zero, indicating that none of the degradates are required for model-based evaluation. In this case, TRQ is only determined by the parent AI. EEC and TOX are with the same unit, e.g., ppb for risk characterization in water column. TRQ in sediment can be defined by similar equations, with estimated environmental concentrations and toxicity values in sediment. Updated USEPA PRZM-EXAMS model, now called PRZM5-VVWM or Surface Water Concentration Calculator (USEPA, 2015), is used for simulating daily concentrations in water and sediment. Based on the modeling capability of PRZM5 and VVWM, each model run will only simulate the parent AI together with one of the degradates. Multiple model run are required if there are more than one degradates to be modeled.

As suggested by USEPA, 1-in-10-year peaks of model-predicted daily concentrations (i.e., the 90^{th} percentile of annual peaks) in receiving water body are used as the EECs in acute aquatic exposure analysis. Specific to this degradate evaluation, 1-in-10-year peaks of TRQ and its individual components of RQ(P) and RQ(D_i) are calculated, as TRQ*, RQ*(P), and RQ*(D_i), separately. Please note that, although daily TRQ is the summation of daily RQ(P) and RQ(D_i) as shown in Eq. (1), TRQ* may not be the same as the summation of RQ*(P) and RQ*(D_i) since peak concentrations of parent AI and degradates may be observed on different dates. Model-based registration recommendations are derived by comparing the resulting TRQ* to the Levels of Concern (LOC) (USEPA, 2004b). If the TRQ*>0.5, SWPP will recommend that the data do not support registration, if 0.1<TRQ*≤0.5, SWPP will recommend conditional registration, and if TRQ*≤0.1, SWPP will recommend support of registration. If conditional registration is recommended, SWPP will require analytical method(s) for the parent AI, and for degradates with individual RQ*(D_i)>0.1. Requirements of analytical methods are specified in our previous documentation (Luo and Deng, 2012b).

3.3 Registration evaluation procedure with consideration of pesticide degradates

Based on available data for pesticide AI and reported degradates, the following two independent evaluations will be conducted first:

(1) SWPP registration evaluation on the parent AI (Luo and Deng, 2012a, b; Luo, 2014). This evaluation will report preliminary modeling results solely based on the parent data.
(2) SWPP initial screening for degradates (Section 2 in this document). This procedure will identified degradates requiring additional data and model-based evaluations.

Once having the results of parent-only evaluation and degradate initial screening, SWPP will perform further evaluations, if applicable, and make registration recommendations (Table 3). In summary:

- If evaluation results on parent data do not support registration, SWPP will make registration recommendations simply based on **parent** evaluation. In addition, SWPP will report the initial screening results for degradates in order to facilitate future submission and evaluation for products with the same AI.

- If evaluation results on parent data support or conditionally support registration, and,
  - If the results of initial screening suggest toxicity **data are needed** for some degradates, SWPP will presume that data are insufficient to support registration and request that the registrant provide toxicity data or provide justification why the data should not be required;
  - If acceptable degradate toxicity data are provided and some degradates require model-based evaluation, SWPP will evaluate **both the parent and the identified degradates**, and make registration recommendations based on resulting TRQ values (Section 3 in this document).
  - If none of the degradates are required for model-based evaluation, SWPP will make registration recommendations simply based on the evaluation results on the **parent** AI.

Table 3. Procedures for SWPP registration evaluation considering both parent AI (P) and degradates (D), based on the results of parent-only evaluation and degradate initial screening

Evaluation results for P only (right) Initial screening results on D (below)		Support, or conditionally support	Not support
Some degradates require evaluation	Degradate toxicity data are not sufficient	Not support, and request data (Section 2)	Evaluation for P only, and report initial screening results
	Some degradates require model-based evaluation	Evaluation for P and D (section 3.2)	
	None of the degradates require model-based evaluation	Evaluation for P only	
None of the degradates require evaluation		Evaluation for P only	

4 Known limitations and proposed solutions

- Some degradates with very high toxicity may not be captured by the group [A] and [B] identification. For example, a very highly toxic degradate product may be formed from a slightly/moderately toxic parent, which is currently not considered for degradate evaluation. For those special cases, SWPP proposes to review degradate toxicity data in the literature (including peer-reviewed papers and pesticide databases) every five years to collect newly published data to assist post-use monitoring.
- Model-based evaluation is only required for two conditions (Figure 1, "4A"): [1] degradates are formed from parent's quick degradation and associated with very high toxicity; and [2] the parent is highly toxic and degradate is more toxic than the parent. SWPP could further improve the methodology by introducing more situations for model-based evaluation once they are observed or predicted with high exposure potentials to surface water in California.
- Soil photolysis is not simulated by PRZM5, thus not included in the current version of degradate evaluation. This process will be considered once the relevant functionality is developed in the next generation of PRZM.
- Pesticide decay on foliage is not considered for parent's quick degradation (Table 1) since associated data are not usually available. With available data, however, this process could be simulated in SWPP registration evaluation, by specifying PRZM parameters for decay rate on foliage (PLDKRT) and associated formation fraction (PTRAN). Otherwise, a zero decay rate is suggested by USEPA (USEPA, 2009).

5 Demonstrations

SWPP reviewed evaluation reports from 2013 and 2014 Thirteen pesticide AIs, associated with high-risk use patterns and evaluated by SWPP Registration Evaluation Model (Luo and Deng, 2012a, b), are selected for demonstration. According to the initial screening procedure, **9** of the 13 AIs (Table 4) would require degradate toxicity data for additional evaluation as determined by degradate initial screening, with more details summarized as follows,

- In the 9 AIs requiring evaluations on degradates, registrants submitted degradate toxicity data for **4** (D, E, G, and M).
- In the 9 AIs requiring evaluations on degradates, toxicity data for degradates were not sufficient for **5** AIs (A, B, C, J, and L), thus results of initial screening suggest data requests for their degradates. This is consistent with the previous evaluation results based on professional judgment where 4 AIs (A, B, C, and L) were subject to data requests or additional evaluations for future products by PRB or SWPP for degradate toxicity.

In summary, results of initial screening are generally consistent with the previous professional judgment-based decisions, and the introduction of the new approach for degradate evaluation would not significantly increase the workloads for pesticide data evaluation.

Table 4. Demonstration of the degradate evaluation on recently evaluated AIs by SWPP: (a) identification of Group A or B degradates (based on parent data) and (b) additional evaluation (based on degradate data)

(a) Group A or B degradates identified based on parent data

Parent AI and use	TOX	HYDRO	AERO_W	AERO	Conclusion
Posted in 2014					
A (herbicide, aquatic)	230	1	0.08		**Require** evaluation on degradates (Group A)
B (insecticide, rice and aquatic)	0.02	N/S	32		**Require** evaluation on degradates (Group B)
C (seed treatments)	20.4	62	66		**Require** evaluation on degradates (Group B)
D (insecticide, urban/residential)	54.2	38	N/S	80	**Require** evaluation on degradates (Group B)
E (fungicide)	64.6	N/S	1.2	8.4	**Require** evaluation on degradates (Group A)
F (fungicide)	290	N/S	N/S	749	Not require evaluation on degradates
G (fungicide)	5.7	N/S	36.7	45.1	**Require** evaluation on degradates (Group B)
H (seed treatment fungicide and in furrow)	103	N/S	157	210	Not require evaluation on degradates
Posted in 2013					
H (herbicide)	14,000	N/S	N/S	433	Not require evaluation on degradates
J (fungicide, turf)	36	4.5	N/S	N/S	**Require** evaluation on degradates (Group A)
K (herbicide, rice)	584	88	N/S		Not require evaluation on degradates
L (miticide)	3.8	27	19.5	88	**Require** evaluation on degradates (Group B)
M (insecticide, rice)	53	N/S	N/S		**Require** evaluation on degradates (Group B)

Notes: Data are retrieved from the SWPP registration evaluation reports posted in DPR internal website. N/S: Not available or Stable TOX: the lowest acute aquatic toxicity in water column, ppb; HYDRO: hydrolysis half-life, day; AERO_W: aerobic aquatic metabolism half-life, day; AERO: aerobic soil metabolism half-life, day, AERO is not required for aquatic or rice uses, see *Table 2*.

(b) Additional evaluation for the identified degradates in panel (a)

Parent AI	Toxicity data	Conclusion
A	Degradate toxicity data were not provided in the initial submission, and SWPP requested the data. The registrant provided preliminary toxicity screening results for two of the three major degradates. They appear not to be highly toxic to test species (>1000 ppb)	Model-based evaluation for degradates is not required
B	Toxicity data for the two major degradates were not completely available.	SWPP may request degradate data and

		evaluation for future products
C	Toxicity data for the three major degradates on *Daphnia magna* have been provided by registrants. None of the degradates are associated with very high toxicity. One of the major degradates has a KOC ranging from 2,683 to 11,007, so sediment toxicity for this degradate is required.	SWPP requested that registrants submit an acute sediment toxicity test on *Hyalella azteca* and *Chironomus tentans* (midge)
D	Degradates are more toxic than the parent, and model-based evaluation for degradates may be required based on the evaluation results for the parent (Figure 1).	Registration was not supported based on the evaluation of the parent. In this case, therefore, model-based evaluation for degradates is not conducted.
E	Toxicity data for the major degradates have been provided by registrants. None of the degradates are associated with very high toxicity.	Model-based evaluation for degradates is not required
G	Degradate toxicity data have been provided by registrants. None of the major degradates are associated with very high toxicity.	Model-based evaluation for degradates is not required
J	Degradate toxicity data are not provided.	Degradate toxicity is required to determine if model-based evaluation is needed
L	Degradate toxicity data were not provided in the initial submission, and PRB requested the data. Additional data are submitted by the registrant and evaluated by PRB, which concluded that degradates of this AI are not more toxic than the parent compound.	Model-based evaluation for degradates is not required
M	Degradate toxicity data have been provided by registrants for 3 of 4 major degradates, and none of the degradates are associated with very high toxicity.	Model-based evaluation for degradates is not required

Acknowledgements

The authors would like to acknowledge Frank Spurlock, Kean S. Goh, and David Duncan (DPR Environmental Monitoring Branch), Ann Prichard, Shelley Lopez, Najme Minhaj, Jon Aspach, Jonathan Sullivan, Theresa Ratto, Debbie Daniels, Rich Bireley, Margaret Reiff, Alexander Kolosovich, Brigitte Tafarella (DPR Pesticide Registration Branch) for their valuable discussions and critical reviews. We are grateful to Dr. Dirk Young (USEPA Environmental Fate and Effects Division) for instructions on the degradate algorithms in PRZM5. This report was also reviewed by the Western Plant Health Association (WPHA). We appreciate their comments and suggestions.

References

FOOTPRINT (2016). The FOOTPRINT Pesticide Properties Database, http://sitem.herts.ac.uk/aeru/footprint/en/index.htm. The Agriculture & Environment Research Unit (AERU) at the University of Hertfordshire. Hatfield, Herts, UK.

Luo, Y., Deng, X. (2012a). Methodology for evaluating pesticides for surface water protection, I: initial screening (http://cdpr.ca.gov/docs/emon/surfwtr/sw_models.htm). California Department of Pesticide Regulation. Sacramento, CA.

Luo, Y., Deng, X. (2012b). Methodology for evaluating pesticides for surface water protection, II: refined modeling (http://cdpr.ca.gov/docs/emon/surfwtr/sw_models.htm). California Department of Pesticide Regulation. Sacramento, CA.

Luo, Y. (2014). Methodology for evaluating pesticides for surface water protection: Urban pesticide uses (http://cdpr.ca.gov/docs/emon/surfwtr/sw_models.htm). California Department of Pesticide Regulation, Sacramento, CA.

Luo, Y., Singhasemanon, N. (2014). User manual for Pesticide Registration Evaluation Model (PREM) (http://cdpr.ca.gov/docs/emon/surfwtr/sw_models.htm). California Department of Pesticide Regulation, Sacramento, CA.

Nowell, L.H., Norman, J.E., Moran, P.W., Martin, J.D., Stone, W.W., 2014. Pesticide Toxicity Index - A tool for assessing potential toxicity of pesticide mixtures to freshwater aquatic organisms. Science of The Total Environment 476–477, 144-157.

SFIREG (2006). Materials relating to Pesticide Degradates: Tracking Table & Program Clarifications (http://www.aapco.org/doc/min2006/attach/06nov06/attachf3.html). SFIREG (State-FIFRA Issues Research and Evaluation Group) Working Committee/Water Quality & Pesticide Disposal (WC/WQ&PD Meeting), Arlington, VA - November 6-7, 2006.

USEPA (2004a). Overview of the Ecological Risk Assessment Process in the Office of Pesticide Programs, U.S. Environmental Protection Agency. Endangered and Threatened Species Effects Determinations (http://www.epa.gov/espp/consultation/ecorisk-overview.pdf).

USEPA (2004b). Overview of the Ecological Risk Assessment Process in the Office of Pesticide Programs (www.epa.gov/espp/consultation/ecorisk-overview.pdf, accessed 11/2010). U.S. Environmental Protection Agency, Office of Prevention, Pesticides, and Toxic Substances, Office of Pesticide Programs. Washington, DC.

USEPA (2009). Guidance for selecting input parameters in modeling the environmental fate and transport of pesticides, version 2.1 (https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/guidance-selecting-input-parameters-modeling). U.S. Environmental Protection Agency, Office of Pesticide Programs, Washington, DC.

USEPA (2014). OCSPP harmonized test guidelines, series 850 ecological effects test guidelines (http://www.epa.gov/ocspp/pubs/frs/publications/OPPTS_Harmonized/850_Ecological_Effects_Test_Guidelines/Drafts/). U.S. Environmental Protection Agency, Office of Chemical Safety and Pollution Prevention, Washington, DC.

USEPA (2015). Water exposure models used by the Office of Pesticide Programs (http://www.epa.gov/oppefed1/models/water/). U.S. Environmental Protection Agency, Office of Pesticide Programs. Washington, DC.

Xie, Y., Luo, Y. (2016). Methodology for screening pesticide products with high exposure potentials to marine/estuarine organisms

(http://cdpr.ca.gov/docs/emon/surfwtr/sw_models.htm). California Department of Pesticide Regulation, Sacaramento, CA.

Zucker, E. (1985). Hazard Evaluation Division, Standard Evaluation Procedure: Acute toxicity test for freshwater fish. EPA-540/9/85-006. U.S. Environmental Protection Agency, Office of Pesticide Programs, Washington, DC.