December 3, 2003

Lecture 23 Ecological Risk Characterization—Deterministic Methods

I. Overview of Ecological Risk Assessment (RA)

A. Discussions of ecological risk characterization will stem from an overview of EPA's current approach to ecotoxicological RA of pesticides

B. When considering human health and ecological RA, the EPA "publishes" its decision about whether to register a pesticide in a document called the RED (Registration Eligibility Decision Document).

1. The RED has several chapters or parts, but the two main ones are the contributions from the HED (Human Health Effects Division) and the EFED (Ecological Fate and Effects Division). Thus, an ecotox. RA is conducted by EFED, and the "final" chapter is the discussion of the risk characterization.
   a. The RED has been issued first as drafts (that are announced in the Federal Register), open to comments, and then revised and/or finalized.
   b. The final RED usually has a risk management section in it that discusses changes in use patterns or requirements that EPA will mandate on the product label to be consistent with assuring a "reasonable certainty of no harm".

C. As an example of what is covered in the EFED portion of a RED, below is the outline of chapters and subchapters in the draft RED released for the OP insecticide diazinon (Note: diazinon has been registered for over thirty years, so the draft RED is really a Re-registration Eligibility Decision Document; also there is a significant amount of monitoring data available). (Next to each chapter I've placed in red the corresponding step of risk assessment represented by the chapter)

1. Use Characterization (i.e., where is the pesticide used; rates of usage) **(Exposure Assessment)**

   Exposure Characterization **(Exposure Assessment)**
   a. Environmental Fate Assessment
   b. Data Gaps and Uncertainties in the Exposure Assessment
   c. Environmental Fate and Transport Data
2. Water Resources Assessment **(Exposure Assessment)**
   a. Summary
   b. Major Conclusions
   c. Drinking Water Exposure Assessment
   d. Monitoring Study Summaries
   e. Modeling
3. Exposure to Nontarget Terrestrial Animals **(Exposure Assessment)**
4. Exposure to Nontarget Freshwater Aquatic Animals **(Exposure Assessment)**
5. Ecological Effects Characterization **(Hazard Identification and Dose-Response Assessment)**
   a. Ecological Toxicity Data
6. Environmental Risk Assessment **(Risk Characterization)**
   a. Risk Presumptions and Levels of concern
7. Ecological Incidents Summary **(Hazard Identification)**

8. References (these are comprised almost solely of data reports submitted by the manufacturer or entity requesting registration)
9. Appendices
   a. For pesticides that have been commercialized for many years, there is likely to be quite a bit of monitoring data, especially from local municipalities that have to abide by the Safe Drinking Water Act (SDWAO) or the Clean Water Act (CWA).
      1. Thus public water distribution facilities might be monitoring routinely for diazinon (SDWA concern) or publicly operated treatment works (POTWs) might be looking for diazinon in its treated discharge, which is permitted under the auspices of the CWA NPDES (National Pollutant Discharge Elimination System Permit).
   b. Appendices will also contain information about data requirements not met by the prospective or current pesticide registrant.

D. EPA uses a point or deterministic RA strategy for determining whether a pesticide has a "reasonable certainty" of causing no environmental harm.
   1. Find the most sensitive species
   2. Estimate exposure
   3. Define Levels of Concern (LOC) and use a risk quotient (RQ) approach to characterize risk.
      a. RQ = Exposure / (LC50 or NOEL)

E. The more "modern" approach to ecotox. RA is probabilistic (EPA has sponsored workshops for probabilistic ecological RA, but the OPP [Office of Pesticide Programs] does not employ it yet, largely because its is still "experimental" (i.e., under development). The ecological risk assessment of atrazine is the exception rule. This topic will be covered in Lecture 24.

II. Hazard Identification Process in EPA's Ecological Risk Assessments of Pesticides

A. As we've discussed in this course, there are many possible hazards that have been studied in wildlife (euphemism for all non-human biota), but when it comes to ecological risk assessments, the EPA relies on two types of hazards—acute toxicity and developmental/reproductive toxicity (applicable to invertebrate and vertebrate animals)
   1. For plants, EPA relies on tests of seed germination, root growth elongation, and reduction in growth.

B. The organisms can vary depending on what a manufacturer wants to submit to support their registration petition, but at least one species of fish and one species of aquatic invertebrate is tested.
   1. Compounds that have been commercialized for a long time can have tests for many organisms available to use in a risk assessment.
      a. Indeed, EPA will occasionally rely on published literature for hazard identification if a manufacturer hasn't submitted enough data to determine a distribution of sensitivity among birds, fish, invertebrates, and plants.

C. In contrast to ecological RA, human health risk assessments rely largely on subchronic (90-day dietary exposure) and chronic studies (2-year dietary exposure) with rodents primarily, and secondarily with dogs.
   1. Other tests include dermal exposure for 7-21 days, and inhalational exposures (~7 days).
   2. For human health risk assessment, acute lethality in which a single dose is administered to determine the median death rate, is not used in risk characterization.
   3. The difference in human and ecological risk assessment in hazard identification with respect to the significance of the LD50/LC50 is probably related to "respect" for a single human individual in contrast to a realization that most wildlife, especially, Arthropods have comparatively high reproduction rates, may reproduce more than once per year, and lay a comparatively large number of eggs.

III. Dose-Response Assessment in Ecological Risk Assessment of Pesticides

A. The end result of the acute lethality test for birds, fish, and invertebrates (aquatic crustaceans and bees) is the statistical calculation of the LC50 (or LD50 if the eact dose is known, such as would be for avian toxicity testing).
   1. The most sensitive LC50 for the array of tested organisms becomes the most sensitive toxicological endpoint that represents acute toxicity in the subsequent risk characterization.
   2. For plants, EPA would estimate a dose that reduces growth of the plants by 25%, which is also called the GR25 (Growth Reduction 25%).
      a. This level may be expressed as a pesticide application rate; for example, grams or kilograms sprayed per hectare (pounds sprayed per acre)

B. The end result of the chronic toxicity tests for birds, fish, and invertebrates is the empirical observation of a concentration that causes no adverse effect on development or reproductive success (NOAEC). The NOAEC of the most sensitive species in the database becomes the toxicological endpoint that represents chronic toxicity in the subsequent risk characterization.
   1. Note that the NOAEC is empirical.
   2. Note that the chronic tests can last throughout the developmental and reproductive life cycle of the organism.

C. For human health risk assessment, the toxicological endpoints are the NOAELs (as mg/kg/day) for short-term dermal and inhalational exposure tests, subchronic systemic toxicity tests, developmental toxicity tests, multi-generation reproductive toxicity tests, chronic tests (systemic toxicity and tumorigenicity).

IV. Exposure Assessment for Ecological Risk Assessment of Pesticides

A. Exposure assessment is perhaps the most error prone part of the RA process applied to pesticides.

B. EPA almost always uses modeled data of residues in water to assess exposure to aquatic organisms.

C. For terrestrial organisms, EPA uses a nomogram of plant residues constructed over 30 years ago and then updated about a decade ago (Table 2). The nomogram is known as the Kenaga nomogram, which is named after a key principal in its creation. (Fletcher, J. S., J. E. Nellessen, and T. G. Pfleeger. 1994. Literature review and evaluation of the EPA food-chain (Kenaga) nomogram, an instrument for estimating pesticide residues on plants. Environ. Toxicol. Chem. . 13:1383-1391.)

1. The data for the nomogram came from industry studies wherein plants were oversprayed with different products at specific application rates (expressed as kg/ha or lbs/acre).
2. Note that the resulting residues represent direct overspray. Any residues resulting from drift out of the targeted crop would likely be much lower.

Table 2. Estimated environmental concentration as on avian and mammalian food items (pm) following a single application of 1 lb AI/acre

Food Items	EEC (ppm)—Predicted Maximum Residue	EEC (ppm)—Predicted Mean Residue
Short Grass	240	85
Tall Grass	110	36
Broadleaf/forage plants & small insects	135	45
Fruits, pods, seeds, and large insects	15	7

3. To determine exposure to mammals or birds, one would need to know the body weight of the organism and the estimate of either the proportion of body weight consumed per day or the actual amount of food consumed per day.
   a. For example, if a 10-gram bird is consuming 50% of its body weight per day, and its food sources are seeds having a maximum pesticide concentration estimated to be 15 ppm, than the bird is eating (15 μg/g) x 5 grams = 75 μg.
      1. The exposure therefore is 75μg/10g = 7.5 μg/g (which is the same as 7.5 mg/kg.

D. For aquatic organisms, EPA uses data from a combination of computer models—PRZM (Pesticide Root Zone Model) and EXAMS (Exposure Analysis Modeling System)
   1. PRZM models the movement of the pesticide from a 10 ha watershed to a 1 ha pond, 2 meters deep.
      a. Parameters that have to be input into the model include meteorological data, soil characteristics, slopes, and erosivity factors, pesticide characteristics among others.
      b. The meteorological data can represent data collected over a long period of time, and thus the modeling can be run repeatedly by “sampling” the data using the Monte Carlo technique.
      c. PRZM models leaching as well as runoff

2. In addition to PRZM for runoff, EPA can input a standard amount of drift during spraying. The magnitude is usually chosen to be around 5% of the applied spray.
3. EXAMS models the fate of the chemical in the pond after arriving in runoff and drift.
   a. EXAMS depends on having data for aquatic dissipation kinetics, which remarkably is not always submitted by a pesticide manufacturer, especially if older compounds are being re-registered.
4. The combined PRZM/EXAMS modeling output usually represent the 90th percentile of residues (as ppb) expected (i.e., the residues are greater than residues in 90% of the model runs; each model run represents a new set of meteorological data). (Table 2)
   a. Note that the persistence of diazinon in the modeling scenarios is quite long. The reason is that EPA lacked kinetic data from an aerobic aquatic metabolism study.

Table 2. Example of modeled residue data from a PRZM/EXAMS run for the OP insecticide diazinon

Location/Crop	**Peak (Acute) ppb**	**4-Day ppb**	**21-Day ppb**	**60-Day ppb**	**90-Day ppb**	**Yearly Average (Chronic ppb)**
GA Sweet Corn	71.1	68.1	57.3	39.0	33.8	11.6
ME Potatoes	72.7	68.7	58.9	45.7	37.0	11.6
NY Apples	25.1	23.8	20.5	15.4	12.8	4.60

V. Risk Characterization for Ecological Risk Assessment of Pesticides

A. EPA has set Levels of Concern (LOCs) based on the magnitude of a ratio called the Risk Quotient (RQ).
   1. The RQ is the ratio of the EEC (estimated or expected environmental concentration of a chemical) relative to the toxicological endpoint (LC50/LD50/NOEC).
B. The magnitude of the RQ determines whether an estimated exposure exceeds the LOC according to the guidelines in Table 3.

Table 3. EPA Risk Characterization Guidelines

Risk Presumption Category	**Risk Quotient Calculation [1]**	**Level of Concern**	**Effective Safety Factor**
Acute High Risk	EEC/LC_{50}	0.5	2
Acute Restricted Use	EEC/LC_{50}	0.1	10
Acute Endangered Species	EEC/LC_{50}	0.05	20
Chronic Risk	EEC/NOEC	1	1

[1] EEC = estimated environmental concentration; LC_{50} = concentration of pesticide lethal to 50% of test subjects in 96 hours; NOEC = no observable adverse effect concentration

VI. Example of Risk Characterization: Comparison of the Use of Modeled Data and the Use of Empirical Data

A. EPA has conducted an ecological RA for the OP insecticide diazinon, which formerly had significant urban uses as well as agricultural uses.
B. Although the USGS NAWQA Program database contains significant number of samples analyzed for diazinon in all major watersheds of the U.S., EPA conducted its RA using modeled data.
    1. The RA is shown graphically in Figure 1 for two land use scenarios (apples/pears & lawns).
        a. The height of the bars represent the concentration of diazinon estimated from modeling and from actual USGS measurements.
        b. Overlain on the bar graphs are horizontal lines representing the most sensitive fish and invertebrate species in the EPA database and the magnitude of the toxicological endpoints.
            1. The ratio between the height of the bar (representing exposure) and the line representing the toxicological endpoint must not exceed the RQ guidelines shown in Table 3.
    2. The resulting aquatic RQs based on the modeled data and the USGS are shown in Table 4 for the two land use scenarios.
        a. Note that for the modeled residue data in the apple/pear scenario, the invertebrate RQs were exceeded for all aquatic invertebrates and for the acute toxicity RQs for fish.
        b. For the lawn scenario all RQs exceeded EPA's LOCs
        c. Note, however, that if actually measured residue data are used, the RQs for the agricultural sites are below the EPAs LOC for acute toxicity, but the LOC is still exceeded for the measured residue data from urban sites.
            1. If EPA wanted to protect endangered species of invertebrates, then the RQ must be 0.05 or less. Based on the 95^{th} percentile of exposure from measured residues, all scenarios would still exceed EPAs LOCs.

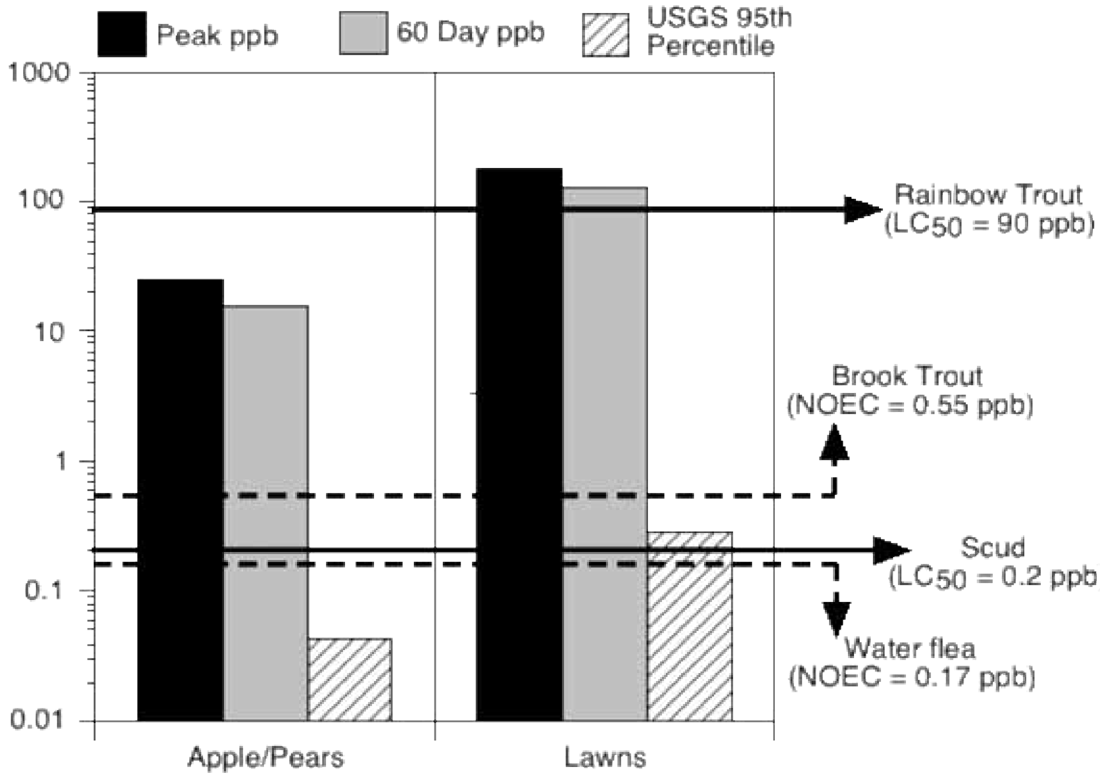

Figure 1. Diazinon residues in pond water following application to orchards and to lawns, and the most sensitive fish and aquatic invertebrate species that EPA used to characterize risk. The concentrations were estimated by EPA using computer simulation models (Dye, L. et al. 1999). Actual data measured (expressed as the 95th percentile residue) by the USGS are shown for 40 U.S. streams draining agricultural watershed (shown with apple/pears) and for 11 U.S. streams draining urban watersheds (shown with lawns). Risk is characterized by the ratio of the estimated or measured environmental concentration to the most sensitive species for acute (96 hours) and chronic (21-60 days) exposures. If the residue concentrations bars are below the line representing the no observable adverse effect concentration (NOEC), then EPA considers the risk of adverse effects from chronic toxicity below their level of concern. However, for acute toxicity to endangered species, the lines for the LC50 must be at least 20 times lower than the bars depicting concentration.

Table 4. Calculated Risk Quotients for Acute and Chronic Exposures to Diazinon. Apple/Pear and Lawn exposure scenarios from (Dye, L. et al. 1999. EFED RED Chapter for Diazinon. US EPA Office of Pesticide Programs and Toxic Substances (downloaded May 2000 from http://www.epa.gov/pesticides/op/diazinon.htm); RQs for USGS 95th percentile were calculated using the data from Larson, S. J., R. J. Gilliom, and P. D. Capel. Pesticides in streams of the United States—Initial Results from the National Water Quality Assessment Program. US Geological Survey Water-Investigations Report 98-4222 (downloaded December 2000 from http://usgs.gov/pubs/).

Exposure Scenario	Exposure Duration	Fish	Aquatic Invertebrates
Apple/Pear	Acute	0.28	126
Apple/Pear	Chronic	28	121
Lawns	Acute	2.0	912
Lawns	Chronic	235	928
USGS 95th percentile			
Urban sites	Acute	0.01	1.2
Urban sites	Chronic	0.44	1.4
Agricultural Sites	Acute	0.0005	0.21
Agricultural Sites	Chronic	0.08	0.25