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Original Research

Integrated Risk Assessment of Household Chemicals and Consumer Products: Addressing Concerns About Triclosan

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THE CURRENT CHALLENGE

Interest and concern about the human health and environmental impacts of chemicals in personal care products and other consumer products that are released to the environment through wastewater treatment systems are a continuing issue. Examples include detergents and other cleaning agents, solvents, household pesticides, fragrances, pharmaceuticals, biocides, and antimicrobials such as triclosan, the subject of a set of 3 articles that appear in this issue of *Integrated Environmental Assessment and Management* (Bock et al. 2010; Fuchsman et al. 2010; Lyndall et al. 2010). Large quantities of environmental data have been generated and published by scientists from industrial, regulatory, and academic organizations with widely different perspectives concerning the fate and effects of these products and their ingredients. The ''big picture'' integrating sources, fate, and effects of these materials on human health and ecosystems can be clouded by the sheer volume of the observations, many of which may be in apparent or real conflict. Careful and comprehensive critical reviews that seek to integrate the available information into a coherent whole can be invaluable by providing manufacturers, consumers, and regulatory agencies with objective syntheses of the scientific facts.

The 3 articles presented in this issue of *IEAM* addressing the risks posed by the use of triclosan in personal care products and other consumer products can serve as a template for similar integrated comprehensive assessments of other chemicals. Such assessments require certain key information, including:

- Chemical identity and relevant physicochemical properties that determine environmental partitioning and potential for food web transfer and biomagnification
- Chemical reactivity or degradability in relevant media ranging from the atmosphere to biosolids to organisms
- ''Mode of entry'' into the environment, in this case in water effluents destined mainly for wastewater treatment (WWT)
- Fate of the chemical within a treatment plant, including degradation and partitioning between biosolids and treated wastewater
- Quantities used and how these vary both regionally and nationally
- Key characteristics of receiving environments, and how these vary regionally and nationally

From this information, it is usually possible to identify the key environmental pathways of the chemical, hence the processes that control levels in potentially affected environments, and the variability of those levels as functions of key environmental and demographic characteristics. Mass balance models that simulate the fate and transport of the substance are important components of any such assessments.

ADDRESSING CONCERNS ABOUT TRICLOSAN

Triclosan is contained in numerous consumer products and has been found worldwide in municipal and industrial wastewater (Reiss et al. 2002). The percentage of wastewater containing triclosan that is treated, as well as the treatment methods, varies greatly. In a typical wastewater treatment plant in North America, the key pathways for triclosan are sorption to biosolids, biodegradation during secondary treatment, and flowthrough to the water effluent discharged from the plant. Triclosan sorbed to biosolids that are subsequently applied to land may potentially affect terrestrial biota. Triclosan contained in aqueous effluent may potentially affect aquatic biota. At least in principle, bioaccumulation in food chains may be possible.

The wastewater treatment study conducted by Bock et al. (2010) illustrates nicely the use of a relatively simple steady-state WWT fugacity model to support and enhance monitoring data collected either locally or regionally in the vicinity of WWT plants. More complex dynamic models can be applied and indeed should be applied when discharges are more episodic in nature. Discharges of triclosan most likely result from repeated or continuous use; thus, it is doubtful the use of more sophisticated dynamic fate models would add significant insights. The simple model also has the advantage of facilitating more rapid and transparent sensitivity and probabilistic analyses as undertaken by Bock et al. (2010). It is always satisfying when a model yields results that are consistent with observations, because this suggests that the dominant fate processes are well identified and described quantitatively. On the other hand, significant discrepancies between model predictions and observations indicate that the underlying processes are inadequately understood. The results reported by Bock et al. (2010) are consistent with observations reported in WWT effluent outside the United States; however, triclosan concentrations in US effluent are significantly overestimated by their model. Although as applied to US WWT effluents the model is conservative and overstates potential risks, the failure to adequately represent US effluent data suggests that one or more key processes in WWT plants are not adequately understood. Further work to understand this discrepancy is needed and may prove to be of practical significance.

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Another appealing aspect of the Bock et al. (2010) modeling work is that their results are presented not as single values, but as a distribution of results presented as cumulative distribution curves. These curves show both the performance of the modeled processes and the likely range of triclosan concentrations that, in this case, extend over 2 orders of magnitude and depend heavily on the volumes of personal care and consumer products containing triclosan used by consumers who are connected to the WWT plant.

Although the treatment efficiency of WWT plant effluents is high, this is in part attributable to the significant partitioning into sludges. Therefore, the fate of residual levels of triclosan in land-applied biosolids (sludges) must be considered (Fuchsman et al. 2010). The terrestrial ecological risk assessment reported by Fuchsman et al. (2010) addresses ecological risks to soil microorganisms and invertebrates, plants, mammals, and birds. A relatively simple fugacity model is used to estimate biotic concentrations. Regrettably, there is a lack of corresponding monitoring data to validate the risk model results. Hence, the model presented by Fuchsman et al. (2010) serves 2 purposes: first, it yields estimates of concentrations and approximates effect levels, although such estimates must be treated with caution; and second, it identifies species that are likely at risk and should be the focus for further empirical studies of triclosan degradation in biosolid-amended soils. Appropriately, the model is conservative in that it addresses initial post-application steady-state equilibrium partitioning, thus ignoring the effect of triclosan degradation. The BASL 4 model can provide information on the time decay of concentrations, but this feature was not applied by Fuchsman et al. (2010). Fuchsman et al. (2010) also used a probabilistic approach to capture the range of possible exposure and effect levels and identify sensitive model parameters.

Most WWT jurisdictions, particularly in North America, regulate biosolid application rates and frequencies to avoid ''sawtooth'' year-to-year buildup of contamination and adverse effects on nitrogen runoff and nutrient status (EPA 1999; Peterson et al. 2003). These rates vary widely between jurisdictions, and allowable numerical limits are likely based more on professional judgment than on quantitative science. A compelling case can be made that there is a need for more empirical studies, model development, and validation, taking into account the complicating issues of tillage practices, organic carbon partitioning and decay, bioavailability as a function of time, plant uptake, and food chain biomagnification and biotransformation. The study carried out by Fuchsman et al. (2010) is a useful start in this direction. Undoubtedly, triclosan is only one of many substances for which this pathway is significant; brominated flame retardants are another obvious example. A striking observation from comparison of the work by Fuchsman et al. (2010) to Lyndall et al. (2010), perhaps not surprisingly, given the general state of ecological risk assessment practice is that terrestrial risk assessment is a grossly underdeveloped discipline in comparison with aquatic risk assessment in terms of scientific support and research effort.

The Lyndall et al. (2010) aquatic risk assessment for triclosan in WWT effluent discharges to surface waters builds on an earlier assessment by Capdevielle et al. (2008). The study expands further on the previous work and provides a more comprehensive evaluation of the fate of triclosan in water, sediment, and aquatic biota. The 4 models used by Lyndall et al. (2010) (i.e., a simple receiving water dilution model, a multimedia fugacity model, the AQUAWEB bioaccumulation/food web model, and a USEPA dietary exposure model) benefit from the probabilistic approach used in the Bock et al. (2010) and Fuchsman et al. (2010) studies. The exposure-effects distributions and confidence limits reported by Lyndall et al. (2010) provide an excellent depiction of the proximity of expected tissue residue levels in different aquatic species to adverse effects. Likewise, the mammalian and avian exposures predicted by the models and expressed as doses and clearly compared with available toxicity benchmarks reported in the literature provide a foundation on which to focus further study.

A complication in the case of triclosan is its potential ionization (the p*K*a value ranges between 7.9 and 8.14). Dissociation can have a profound effect on partitioning, bioavailability, degradation, and toxicity, and the ultimate effect on risk may not be immediately obvious. In addition to triclosan, methyl triclosan is frequently detected. Formation is probably by methylation of triclosan, and the product is expected to exhibit greater hydrophobicity and bioaccumulation. This finding raises the issue of the need to include related chemical species such as degradation products if a truly complete environmental fate evaluation of triclosan is needed to support future regulatory decision making. The issue of ionization undoubtedly applies to many other substances, including a large number of pharmaceutical compounds, and deserves further attention.

CONCLUDING PERSPECTIVE

Reflecting on the state of the science and the integration of the impressive quantity of literature reviewed and integrated into a triclosan risk assessment, the work by Bock et al. (2010), Fuchsman et al. (2010), and Lyndall et al. (2010) provides an invaluable source of reference material and helps immensely to guide future research by scientists in this field. Collectively, their work also serves as an example to guide future assessments of other chemical substances, something much needed in light of the new directions in chemical management and regulation unfolding in Canada, the European Union, the United States, and other countries. A strength of their approach is the comprehensive treatment of relevant pathways, media, processes, and ecological receptors. The framework illustrated by their work on triclosan clearly demonstrates the benefits of adopting a ''monitoring plus modeling'' approach, each adding credibility to the other. The work demonstrates that for broad or screening-level assessments, the use of fugacity models is particularly appropriate because of their simplicity and transparency and the ease with which they can be incorporated into probabilistic evaluations. The equilibrium assumptions inherent in several aspects of these models are clearly apparent. For example, the bioaccumulation and food webs used by Fuchsman et al. (2010) and Lyndall et al. (2010) provide a starting point for more detailed and accurate modeling simulations and identify specific monitoring data requirements. Further, the work clearly identifies subject areas for further research and assessment.

The ultimate book on triclosan has not yet been written. The present work is certainly not the ''last word'' or ''final

chapter,'' but it represents a very significant and exemplary chapter toward that goal. The study could easily be extended to assess the fate and effects of triclosan in additional environmental settings, such as high-density urban centers, developing nations, and arctic, tropical, or arid environments. The models used could be easily modified to accommodate new data relating to the chemistry and environmental toxicology of triclosan. Because of its simplicity and generality, the risk assessment and modeling framework demonstrated by the work on triclosan could be applied to a wide variety of consumer products and pharmaceuticals for which the primary route of entry to the environment involves releases from WWT plants. We encourage scientists and regulatory agencies interested in these types of products to evaluate the potential applicability of this approach to other chemicals of interest.

Disclaimer—The authors of this commentary served on an independent science panel convened in 2009 to review the work conducted by Bock et al. (2010), Fuchsman et al. (2010), and Lyndall et al. (2010). They were compensated for the review and for preparation of this commentary by the Colgate-Palmolive Company. The views expressed herein are solely those of the authors.

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