ADDENDUM 2

to "Communicating Recent Pesticide Research Findings to Inform Stakeholders, 2010-2021"

2025 PESTICIDE RESEARCH UPDATE 2022-2025

Prepared by the **Pesticides & the Chesapeake Bay Watershed Project, Research & Data Gaps Working Group**

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In 2025, the Pesticides & Chesapeake Bay Watershed Project's Research & Data Gaps Working Group produced a white paper entitled "Communicating Recent Pesticide Research Findings to Inform Stakeholders" that summarized important research published/produced from 2010 to 2021. This updated the 2009 report "Understanding the Problem and Identifying Solutions to Reduce the Impact of Pesticides on the Watershed." The decision was made by the group to update our review of research products on an annual basis, rather than waiting 10 years. Hence this report summarizes pesticide and related emerging contaminant studies from 2022-2025.

Chesapeake Bay Watershed Studies

1. Miller, S.A., Faunce, K.E., Barber, L.B., Fleck, J.A., Burns, D.W., Jasmann, J.R. and Hladik, M.L., 2024. **Factors contributing to pesticide contamination in riverine systems: The role of wastewater and landscape sources.** Science of The Total Environment 954:174939. https://doi.org/10.1016/j.scitotenv.2024.174939

Although agricultural runoff is considered a major source of pesticides to the aquatic system, wastewater treatment plants (WWTP) discharging into waterbodies can also be a significant source of pesticides. This study used an accumulated wastewater percentage of stream flow model for predicted environmental concentrations, as well as measured environmental concentrations in the Potomac River to better understand WWTP discharges as sources and identify other landscape sources. Using the accumulated wastewater model, predicted concentrations were a low proportion of measured concentrations suggesting other sources are important. Dinotefuran and fipronil (insecticides), carbendazim and thiabendazole (fungicides) and prometon (herbicide) were related to WWTP sources. Imidacloprid (insecticide), azoxystrobin, propiconazole and tebuconazole (fungicide) and diuron (herbicide) were related to urban runoff. Metolachlor and atrazine (herbicides) and clothianidin (insecticide) were related to mixed land use sources while simazine was related to agricultural sources. The chronic freshwater invertebrate benchmark for imidacloprid was exceeded in 72% of the samples and three sites had concentrations with the potential of acute toxicity. Overall, imidacloprid and fipronil accounted for most of the potential toxicity. Potential chronic ecotoxicity was generally higher for sites with the greatest accumulated wastewater or developed watersheds.

2. Walsh, H.L., Gordon, S.E., Sperry, A.J., Kashiwagi, M., Mullican, J. and Blazer, V.S., 2022. **A case study: temporal trends of environmental stressors and reproductive health of smallmouth bass (*Micropterus dolomieu*) from a site in the Potomac River Watershed, Maryland, USA.** Ecotoxicology 31(10):1536-1553.
3. Walsh, H.L., Smith, G.D., Schall, M.K., Gordon, S.E. and Blazer, V.S., 2024. **Temporal analysis of water chemistry and smallmouth bass (*Micropterus dolomieu*) health at two sites with divergent land use in the Susquehanna River watershed, Pennsylvania, USA.** Environmental Monitoring and Assessment 196(10):922.

The two above studies summarize monitoring of smallmouth bass health, land use change and water quality, including surface water pesticide concentrations over multiple years at one site in the Potomac River (Antietam Creek) and two sites in Susquehanna River (Pine Creek, Mahantango Creek). Surface water samples were collected monthly (bimonthly in spring) and analyzed for 105 current use pesticides as well as other contaminants. At all sites, while many pesticides were occasionally detected, atrazine, metolachlor and simazine were commonly detected throughout the year. Concentrations often peaked after high flow events and concentrations varied among years, with the highest concentrations in the spring/early summer. This corresponds to the presence of early life stages of bass and many fish species, generally considered the most sensitive stage for long term reproductive and immune system adverse effects. The variation seasonally indicates sampling period is important to accurately assess sublethal effects. At Antietam Creek, with a mixed land use, atrazine peak concentrations were the highest. At the Susquehanna sites, concentrations and detections were lower at the most forested site (Pine Creek) and higher at Mahantango Creek which has high agricultural land-use. Pesticide application rates correlated with the severity of testicular oocytes or intersex in bass.

Pesticide Effects

4. Douglas, M.R., Baisley, P., Soba, S., Kammerer, M., Lonsdorf, E.V. and Grozinger, C.M., 2022. **Putting pesticides on the map for pollinator research and conservation.** Scientific Data 9(1):571. https://doi.org/10.1038/s41597-022-01584-z

Declines of both wild and managed pollinator species have been documented. Exposure to pesticides can directly kill pollinators and herbicides can reduce food availability. This paper provides a synthesis of large, publicly available databases on pesticide use patterns, land use and toxicity to describe pesticide use by active ingredient from 1997-2017, insecticide load and honey bee lethal doses for state-crop combinations in the US. Their approach allows the generation of maps of predicted bee toxic load and individual active ingredients at 30 m resolution.

5. Moreau, J., Rabdeau, J., Badenhausser, I., Giraudeau, M., Sepp, T., Crépin, M., Gaffard, A., Bretagnolle, V. and Monceau, K., 2022. **Pesticide impacts on avian species with special reference to farmland birds: a review.** Environmental Monitoring and Assessment 194(11):790. https://doi.org/10.1007/s10661-022-10394-0

While farmland birds have been decreasing worldwide, the contribution of pesticides to the decline is controversial and not well studied. This review compiles information on the effects of pesticides on bird physiology, behavior and life history traits. Interspecies variability in sensitivity are important and delayed nonlethal effects can have major consequences on bird populations and communities.

6. Garud, A., Pawar, S., Patil, M.S., Kale, S.R. and Patil, S., 2024. **A scientific review of pesticides: Classification, toxicity, health effects, sustainability, and environmental impact.** Cureus 16(8):e67945 https://doi.org/10.7759/cureus.67945

This review article provides a summary of the classification, mode of action, uses, benefits and potential adverse effects. Benefits include controlling agricultural pests and boosting production, managing vectors of plant, livestock and human diseases. Utilizing inappropriate pesticides or in excess of recommended dosage can lead to effects such as development of pest resistance and health risks to humans as well as ecosystems. Human exposure to pesticides has been linked to chronic diseases such as heart conditions, cancer, respiratory disorders and neurological problems. Both acute and chronic effects are reviewed with a focus on disruption of hormonal function. Future strategies such as integrated pest management with biological controls and crop rotation that balance pest management with environmental and public health concerns are needed.

7. Bartling, M.T., Brandt, A., Hollert, H. and Vilcinskas, A., 2024. **Current insights into sublethal effects of pesticides on insects.** International Journal of Molecular Sciences, 25(11):6007. https://doi.org/10.3390/ijms25116007

Declining insect populations have been widely reported although this review recognizes that many of the studies have geographic and species bias and hence can be contradictory. In addition to pesticides, factors contributing to these declines include habitat loss, agricultural monocultures, climate change and disease. The paper does a good job of reviewing the various pathways through which insects are exposed to pesticides as well as the sublethal effects (physiological, immunological, reproductive and developmental, behavioral), that have been observed. Generally, pesticides are regulated as single compounds, however, numerous examples of synergistic effects with other pesticides as well as other stressors exist.

8. Klátyik, S., Simon, G., Oláh, M., Takács, E., Mesnage, R., Antoniou, M.N., Zaller, J.G. and Székács, A., 2024. **Aquatic ecotoxicity of glyphosate, its formulations, and co-formulants: evidence from 2010 to 2023.** *Environmental Sciences Europe*, *36*(1), p.22.
9. Klátyik, S., Simon, G., Oláh, M., Mesnage, R., Antoniou, M.N., Zaller, J.G. and Székács, A., 2023. **Terrestrial ecotoxicity of glyphosate, its formulations, and co-formulants: evidence from 2010–2023.** *Environmental Sciences Europe*, *35*(1), pp.1-29.
10. Klátyik, S., Simon, G., Takács, E., Oláh, M., Zaller, J.G., Antoniou, M.N., Benbrook, C., Mesnage, R. and Székács, A., 2025. **Toxicological concerns regarding glyphosate, its formulations, and co-formulants as environmental pollutants: a review of published studies from 2010 to 2025.** *Archives of Toxicology*, pp.1-35.

The above three papers provide an extensive summary of the toxicological and environmental effects of glyphosate, one of the most heavily applied herbicides. There are numerous glyphosate based formulations used in both agricultural and non-agricultural settings. The co-formulants alter absorption, distribution, metabolism, excretion and toxicity and need to be considered in risk assessments. It has become a frequent contaminant in drinking water and food chains. Human exposure has been associated with carcinogenicity, metabolic syndromes and reproductive and endocrine system effects. In addition to numerous toxicological and ecosystem impacts its use has also led to glyphosate-resistant weeds.

Pesticide Management

11. Toth, J., Fugère, V. and Yargeau, V., 2024. **Relationship between stream size, watershed land use, and pesticide concentrations in headwater streams.** Environmental Pollution 349:123940. https://doi.org/10.1016/j.envpol.2024.123940

This study on headwater streams was conducted in Quebec, however has application to headwater streams in the Chesapeake Bay watershed. Concentrations of 29 pesticides and 2 degradation products of atrazine were measured in water and sediment from 32 sites with a gradient of land use and stream size. The herbicides atrazine and metolachlor and insecticide carbaryl were the most widely detected. There were more detections in water than sediment. The concentrations of three most detected compounds were significantly higher at these headwater sites than previously reported for larger rivers. It was suggested this may be due to proximity to agricultural lands and less dilution due to lower flows. As the proportion of agricultural land use increased the average number of pesticide detection increased, raising the concern of synergistic toxicity. Findings suggested sampling small, agriculture-adjacent streams may be especially important for detecting pesticides in environmental monitoring programs. Corn and soybean monoculture crops most significantly correlated with pesticide detections. Followed by cereal crops and then pastureland.

12. Jayaprakash, V., Rufer, S., Panat, S. and Varanasi, K.K., 2025. **Enhancing spray retention using cloaked droplets to reduce pesticide pollution.** Soft Matter 21(19):3688-3699. https://doi.org/10.1039/D4sm01496k

Spraying is the most common method of pesticide delivery but spray retention is one of the most important inefficiencies in pesticide application. Sprayed droplets bounce or roll off the hydrophobic plant leaves resulting in the majority of sprayed pesticides ending up as environmental pollution. Currently surfactants, many of which themselves can be toxic, are the most widely used adjuvants to enhance spray coverage and retention. The paper reports on a novel development to enhance pesticide spray retention by creating droplets cloaked with an ultra-thin food and environmentally safe oil layer to encapsulate droplets. It is suggested this spray approach could greatly reduce pollution from spraying pesticides as well as reduce pesticide and surfactant usage.

13. Rundlöf, M., Stuligross, C., Lindh, A., Malfi, R.L., Burns, K., Mola, J.M., Cibotti, S. and Williams, N.M., 2022. **Flower plantings support wild bee reproduction and may also mitigate pesticide exposure effects.** Journal of Applied Ecology 59(8):2117-2127. https://doi.org/10.1111/1365-2664.14223

There is a declining diversity and abundance of many wild bee species that has been attributed, at least in part, by pesticide usage and loss of flower resources due to agricultural intensification. This study evaluated nesting and reproduction of two bee species with different life-history traits, at replicated sites in intensively farmed landscapes, with and without multi-year flower plantings to support pollinators. Local and landscape flower resources were quantified and bee-collected pollen used to determine forage resources and pesticide exposure. The solitary bee species was six times more likely to nest at sites with flower plantings, however offspring production was not influenced by pesticide risk, local flower resources or their interaction. Conversely, bumblebee production was higher at sites with flower production and decreased with pesticide risk and with rising pesticide risk the flower resource availability became increasingly beneficial for queen production. Optimizing planting placement to reduce probability of pesticide drift is important.

PFAS and Pesticides

14. Donley, N., Cox, C., Bennett, K., Temkin, A.M., Andrews, D.Q. and Naidenko, O.V., 2024. **Forever pesticides: A growing source of PFAS contamination in the environment.** Environmental Health Perspectives 132(7):075003. https://doi.org/10.1289/EHP13954

This commentary article identifies the multiple ways PFAS can be introduced into and associated with pesticide products. They found active ingredients and their degradates were the biggest contributors to PFAS contamination, followed by fluorination of plastic containers and subsequent leaching. Fluorination of adjuvants and inert ingredients may also contribute but this is identified as a major data/knowledge gap. “Inert” ingredients are not required to be publicly disclosed but can alter toxicity and affect bioavailability of the active ingredient or on their own have adverse effect on humans and the environment. In the last 10 years 61% of active ingredients in pesticides approved were organofluorines and 30% were PFAS. A number of the PFAS inert ingredients are approved for food use. High density polyethylene containers used for pesticide storage as well as personal care products and food are fluorinated and hence can potentially leach PFAS. The paper summarizes data to date and provides regulatory recommendations.

15. Sehgal, N., Barr, D.B. and Eick, S.M., 2024. **Invited Perspective: The Far Reach of PFAS—Inert Ingredients and Adjuvants in Pesticide Formulations.** Environmental Health Perspectives, 132(7):071304. https://doi.org/10.1289/EHP15445

This is a commentary associated with the above Donley paper, emphasizing that manufacturers are not required to list inert or adjuvant ingredients on labels and hence the true risk associated with pesticide exposures cannot be fully addressed. Notes that regulations for pesticides are outdated and ineffective. There is a need for understanding cumulative risk associated with pesticide formulation cocktails – mixtures of active ingredients as well as the additives.

16. Reetz, S., Tallaksen, J., Larson, J. and Wetter, C., 2025. **Making the Connection Between PFASs and Agriculture Using the Example of Minnesota, USA: A Review**. Agriculture 15: 1676. https://doi.org/10.3390/agriculture15151676

This study focused on the heavily agricultural state of Minnesota to assess the association of agricultural activities with PFAS contamination. An important route of human exposure is consumption of contaminated foods. Due to the high number of PFAS compounds that interact differently with air, water, soil and biological systems making risk assessments is challenging. There is a lack of field studies and monitoring of agricultural sites, however this paper reviews information on sources, contamination in various agricultural products, transfer through the food web, policy and regulations, future research recommendations and challenges for PFAS mitigation.

17. Shurson, G.C., 2025. **The Alarming Effects of Per-and Polyfluoroalkyl Substances (PFAS) on One Health and Interconnections with Food-Producing Animals in Circular and Sustainable Agri-Food Systems**. Sustainability 17(15):6957. https://doi.org/10.3390/su17156957

The review addresses PFAS in a circular bioeconomy and food system – meaning by-products and waste materials are recycled and reused. Uptake of PFAS by plants and food animals leads to exposure through consumption. Contaminated meat, milk and eggs are some main sources for human exposure. There are no international monitoring systems for food or guidelines to prevent consumption of contaminated foods. Use of biosolids, contaminated water from irrigation water and atmospheric deposition can all be sources for plants. The paper reviews types of PFAS, toxic effects of exposure on human health and technologies for removing PFAS from water and soils. Unfortunately, there are limited options for altering agricultural practices to reduce PFAS contamination in plant and animal-derived foods.

Pesticides and Microplastics

18. Smith, C.A., Drichko, N., Lorenzo, M. and Pramanik, S., 2025. **Contaminants of emerging concern on microplastics found in the *Chrysaora chesapeakei* of the Patuxent River, Chesapeake Bay, MD.** Microplastics *4*(2):32.

The presence of contaminants of emerging concern, including pesticides, were detected on the hydrophobic surface of microplastic particles extracted from a jellyfish in Chesapeake Bay. Compounds were detected using Raman spectroscopy. This method does not analyze concentrations of pesticides but rather chemicals used in agrochemical and pesticide formulations. However, it does raise the issue of pesticides attaching to microplastics and moving through the food web by this mechanism.

19. Fatema, M. and Farenhorst, A., 2022. **Sorption of pesticides by microplastics, charcoal, ash, and river sediments.** Journal of Soils and Sediments 22(6):1876-1884. https://doi.org/10.1007/s11368-022-03218-8

The study investigated the sorption of DDT as well as current use pesticides 2,4-D, atrazine and glyphosate microplastics. Microplastics sorbed > 50% of DDT while the current use pesticides tested had less sorption, however 32-36% of the glyphosate was sorbed by PVC particles depending on the solution – less when river water was used.