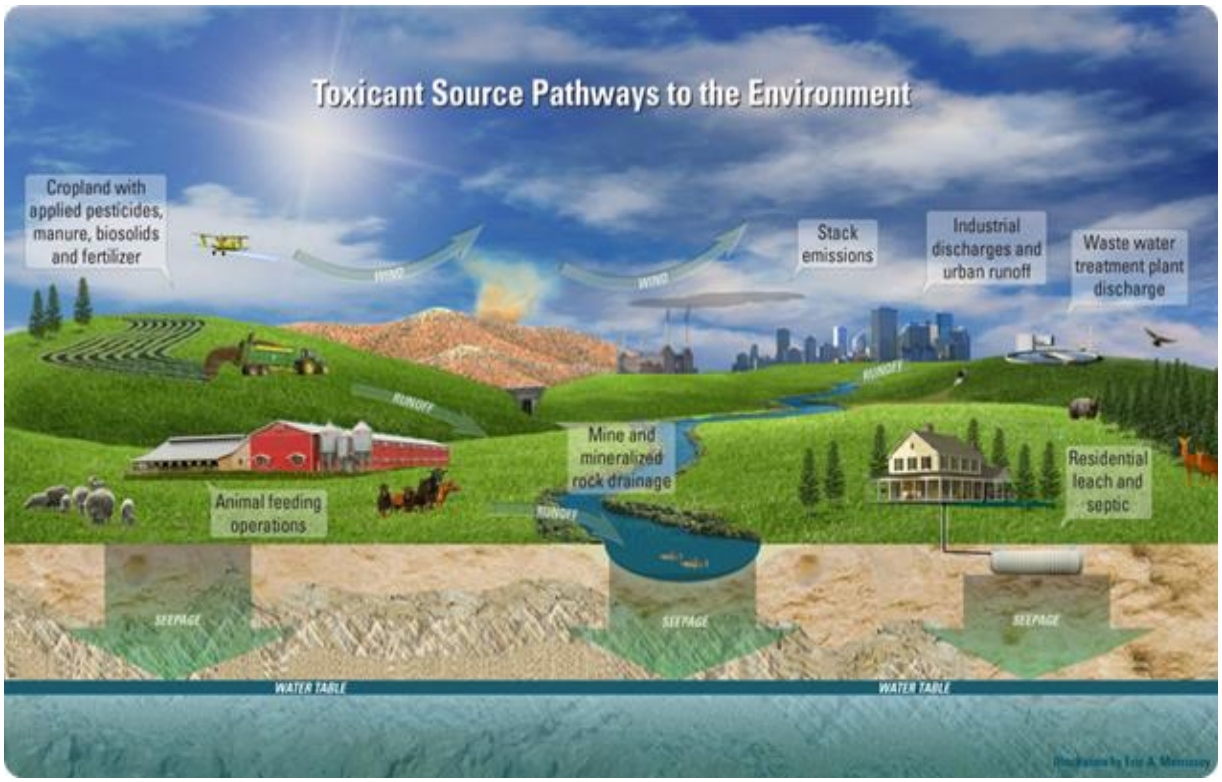
Integrating Science and Developing Approaches to Inform Management for Contaminants of Concern in Agricultural and Urban Settings



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About the Scientific and Technical Advisory Committee

The Scientific and Technical Advisory Committee (STAC) provides scientific and technical guidance to the Chesapeake Bay Program (CBP) on measures to restore and protect the Chesapeake Bay. Since its creation in December 1984, STAC has worked to enhance scientific communication and outreach throughout the Chesapeake Bay Watershed and beyond. STAC provides scientific and technical advice in various ways, including (1) technical reports and papers, (2) discussion groups, (3) assistance in organizing merit reviews of CBP programs and projects, (4) technical workshops, and (5) interaction between STAC members and the CBP. Through professional and academic contacts and organizational networks of its members, STAC ensures close cooperation among and between the various research institutions and management agencies represented in the Watershed. For additional information about STAC, please visit the STAC website at www.chesapeake.org/stac.

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Executive Summary

A wide range of contaminants of agricultural, human, and industrial origin have degraded water quality, and pose a threat to the health of fish and wildlife populations, in the Chesapeake Bay and its watershed. A STAC workshop brought together researchers and water quality managers working in urban and agricultural settings to synthesize the current knowledge on contaminants of concern and discuss opportunities for their reduction. The conclusion section contains major findings and research recommendations from the workshop. Some selected results are summarized below.

Which contaminants are of the greatest concern for humans consuming fish and to the health of fish?

Fish consumption advisories based on human health criteria are widespread in the watershed and are largely due to elevated concentrations of PCBs and mercury and, to a lesser extent, organochlorine pesticides. No fish consumption advisories currently exist for additional contaminants, except for PFAS in Delaware.

Fish health concerns in agricultural settings appear to be associated with a combination of chemical exposure leading to reproductive endocrine disruption and increased susceptibility to infectious agents. In urban areas, fish health concerns include neoplasia (an abnormal growth of tissue) and reduced reproductive success associated with a combination of exposure to legacy contaminants (such as PCBs) and chemicals of emerging concern.

What is known about contaminants of concern in urban areas?

For some of the major contaminants in urban areas, such as PCBs and PAHs, there is adequate information on their sources and transport to formulate reductions strategies. However, many contaminants of emerging concern are still being defined, making it difficult to implement management actions through BMPs.

What are the opportunities to reduce contaminants in urban areas?

Several promising approaches were identified to reduce select toxic contaminants observed in urban areas, including:

1. Sediment capture and reactive filter BMPs can have a positive impact on toxic contaminant concentrations and toxicity related to polluted urban stormwater runoff. Specifically, unamended bioretention facilities (*i.e.*, biologically-active stormwater retention basins without engineered materials) were reported to be effective at reducing PCB concentration and toxicity as a function of the distance from influent and sediment depth. Additional work is underway to enhance reactive media to remove or degrade toxic contaminants such as metals, PCBs, and polycyclic aromatic hydrocarbons (PAHs).
2. Iron-enhanced sand filtration (IESF) was reported to be effective in removing numerous pesticides and wastewater indicators. Additional work is underway to study the BMPs' impact on biological activity.
3. In certain cases, focusing BMPs within streams can be an appropriate choice. In-stream technologies are being tested at pilot and full scale in the watershed and include in-situ

amendment of activated carbon into contaminated sediments to bind contaminants and addition of bioamendments (*i.e.*, activated carbon seeded with microorganisms capable of metabolizing contaminants) to degrade PCBs.

Primary Recommendation: there is a significant gap in compiling and communicating potential removal efficiencies (or the range of removal efficiency) for toxic contaminants to jurisdictions and stakeholders implementing BMPs. Continued expansion and compilation of the BMP studies examining both known and emerging toxic contaminants paired with some site-specific details will allow for jurisdictions to capitalize on possible co-benefits when implementing nutrient and sediment BMPs. Additionally, defining the sources of contaminants, such as where they originate from in a watershed or are present in a stream, is critical to help decide on most effective types of BMPs.

What do we know about contaminants of concern in agricultural areas?

The sources of contaminants on agricultural lands of the Chesapeake Bay Watershed are relatively well defined and include pesticide use (legacy or current), manure application, manure storage, biosolids application, irrigation of treated wastewater, and septic systems. However, information is limited in the Chesapeake Bay Watershed on the direct and indirect effects of toxic contaminant mixtures on fish and other non-target aquatic organisms.

Understanding of the fate and transport of emerging toxic contaminants in agriculture-dominated watersheds is currently limited. It is recommended that more studies are necessary to quantify BMP effectiveness on contaminant removal and potential improvements in fish health. More specifically, investigative studies are needed to understand contaminant interactions with sediment and organic carbon, transport to and from shallow groundwater, environmental degradation, and overall persistence in the environment.

What are the opportunities to reduce contaminants in agricultural areas?

Several promising approaches were identified to reduce select toxic contaminants observed in agricultural areas, including:

1. The addition of activated carbon and potentially low-cost biochar (*i.e.*, a charcoal material generated by pyrolysis of biomass) to established BMPs.
2. Prioritization of BMPs that increase retention/residence times is expected to help reduce surface water loading of contaminants.
3. Proper manure management is essential to minimize the release of antibiotics to the environment and reduce the potential for development of antibiotic resistance. Based on the current research, the best manure management strategies include application of only composted manure, a 120-day waiting period if raw manure is applied prior to harvest, surface application in the fall when runoff potential is lower, subsurface application, and addition of buffer strips.
4. Reduction in the transport of sediment-bound insecticides to receiving waters can be achieved through the installation of retention ponds and vegetative treatment systems.

Major Recommendations: BMPs are a necessary investment to reduce toxic contaminant loads and improve water quality. Some associated recommendations included:

a. Continued research investment to understand the co-benefits or negative impacts of nutrient/sediment BMPs on water quality, ensure habitat quality, and preserve aquatic resources.
b. A close working relationship between researchers and the management community is needed to develop tools to identify sensitive areas/populations that would benefit from improved BMP design, implementation, and/or monitoring.

Introduction

A wide range of contaminants of agricultural, human, and industrial origin have degraded water quality and, as a result, fish and wildlife populations (Figure 1). Additionally, emerging contaminants are being documented in the Bay and its watershed and pose potential threats to the Chesapeake Bay ecosystem. While significant efforts have addressed nutrients and sediment, other contaminants of concern have not been comprehensively or systematically assessed. The 2014 Chesapeake Bay Watershed Agreement includes a goal to reduce the effects of toxic contaminants, with associated outcomes for policy and prevention (focused on PCBs), and research. An important research objective is to better understand the potential co-benefits and risks of nutrient and sediment BMPs on toxic contaminants in agricultural and urban settings. States and local jurisdictions are particularly interested in non-point source practices that can provide multiple benefits for (1) meeting the Chesapeake Bay TMDL for nutrients and sediment, (2) reducing toxic contaminant loads, and (3) improving local water quality for fishing and recreation.

STAC is increasing its focus to better understand contaminants of emerging concern and dedicated much of their December 2017 quarterly meeting to the issue. The STAC discussion revealed the need for a greater understanding of the relationship between fish health (e.g., intersex, lesions, and mortality) and contaminants in urban and agricultural settings. Therefore, a STAC workshop was held to bring researchers together with water quality managers from urban and agricultural settings to synthesize the current knowledge of these contaminants of concern and discuss how selected BMPs and other innovative approaches can collectively reduce contaminants, nutrients, and sediment loads to the Chesapeake Bay.

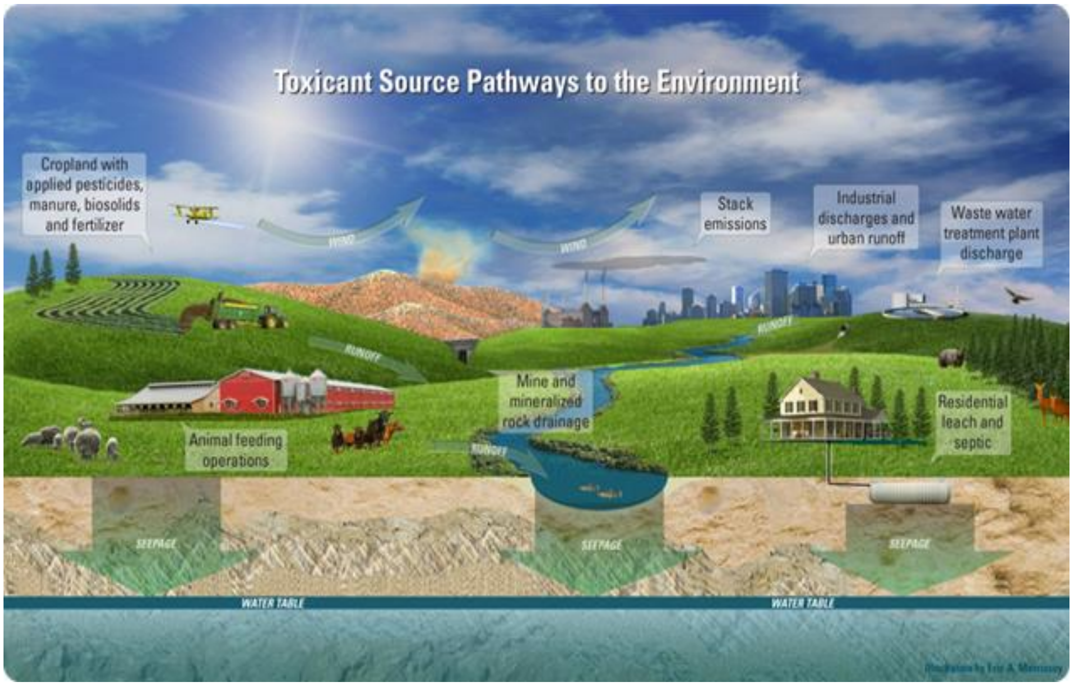

Figure 1: Conceptual diagram showing the source pathways of toxic contaminants to the environment (https://pubs.usgs.gov/circ/1383e/circ1383-E.pdf). (From K. Smalling, USGS)

The purpose of the workshop was to synthesize findings on the occurrence, transport, fate, and impacts of contaminants of concern in agricultural and urban settings and approaches to mitigate the effects of these contaminants.

The specific objectives of the workshop were as follows:

- Present and discuss major findings from recent and ongoing science related to contaminants in agricultural and urban settings. The focus was on toxic contaminants related to fish consumption advisories, fish health, and other ecological and human health concerns.
- Summarize the understanding of the sources, transport, fate, and effects of chemicals of concern. In agricultural settings, the focus included chemicals associated with manure generation and pesticide application. PCBs, pharmaceuticals and, personal care products, and PFAS were the focus for urban areas.
- Characterize opportunities to mitigate the effects of chemical contaminants in each setting by taking advantage of BMPs being implemented to reduce nutrient and sediment loads and other innovative approaches.
- Identify the most pressing research directions that will enable integrated management approaches for nutrients, sediment, and toxic contaminants.

Workshop Summary and Key Discussion Points

Fish consumption advisories and fish health

A panel of representatives from the six states in the watershed and Washington, DC provided a summary of fish consumption advisories occurring in their respective jurisdictions. More information on fish health issues in agricultural and urban areas was provided by several speakers. The information from the panelists and speakers was used to summarize key findings, identify information needs, and recommend research directions.

Summary of consumption advisories and the associated contaminants

Fish consumption advisories are in place throughout the watershed for many different fish species due to an association with contamination and resulting human health risk from PCBs and mercury. States recommend meals-per-month limits based on specific contaminant risks to human health and exceedances of EPA screening values. In Washington, DC, PCBs are frequently present in concentrations that exceed EPA screening values. Chlordane, DDT, dieldrin, and heptachlor epoxide occasionally exceed EPA screening values, while PAHs and metals rarely exceed EPA screening values. According to the DC Department of Energy and Environment (DOEE), contaminant concentrations appear to be trending downward. Maryland reported that Bay-wide fish consumption advisories were primarily driven by PCBs. Advisories range from "no consumption" to "8 meals per month". Fish consumption advisories of "4 meals per month" and below result in an impairment listing. Listings are for non-migratory fish. In Pennsylvania, about 21 percent of total stream miles have fish consumption advisories, primarily due to PCB levels. Identification and remediation of contaminated sites, such as Shenandoah River Valley, is expected to decrease contaminant concentrations and reduce fish consumption advisories. West Virginia manages fish consumption advisories through a workgroup consisting of the Departments of Environmental Protection, Natural Resources, and Health and Human Resources. The primary drivers of consumption advisories are mercury, PCBs, and dioxins. In Delaware, concentrations of PCBs, mercury, dioxins/furans, and other contaminants have dramatically decreased due to mitigation efforts. Consequently, the number and severity of consumption advisories have fallen in recent years.

Overview of fish health and factors in urban settings

In urban areas, fish are exposed to mixtures of toxic contaminants, including PCBs, legacy and current use pesticides, PAHs, and emerging contaminants. Additional stressors, such as low oxygen conditions, high temperatures, and bacteria, are present and likely to adversely affect the health of individuals or populations. Here, we focus on two species, the brown bullhead and yellow perch, that have been studied in urban, suburban, and (for comparative purposes) rural watersheds of the Chesapeake Bay.

Brown bullhead are bottom feeders and have been used for decades in tumor surveys of Chesapeake Bay and Great Lakes tributaries. They are an ideal indicator species because of their tendency to develop tumors (i.e., susceptibility) and their linear home range of about 2 kilometers (i.e., site specificity). Liver tumors are induced by exposure to PAHs, which also results in altered DNA and may be promoted by exposure to PCBs and DDT. Thus, liver tumor prevalence and DNA alteration are indicators of exposure and response to cancer-causing chemicals. The linkage between skin tumors and these contaminants is uncertain. Over the past 25 years, standardized tumor surveys have been conducted in the tidal Potomac River tributaries, including the Anacostia River, one of the three Chesapeake Bay regions of concern. Results have been compared with statistically-derived reference areas, which include rivers on Maryland's Eastern Shore. In 1996 through 2001, the liver tumor prevalence in Anacostia bullheads was the highest reported in North America. Since then, the probability of liver tumors in Anacostia bullheads has declined from 78 percent in 1996-2001 to 42 percent in 2009-2011 to 18 percent in 2014-2016 for female fish, with a similar decline for males (Figure 2.1). Bullheads also had a decreasing probability of developing skin tumors (Figure 2.2). Liver tumor prevalence is still about twice that observed in reference areas. No single action has been identified for these decreases in both types of tumors. Reductions in point and non-point source loadings of PAHs, including illegal disposal of used oil may be part of the explanation. In addition, documented decreases in PCB and DDT concentrations have been reported in bullheads and other fish species in the Anacostia and Potomac Rivers.

Yellow perch, which are found in Chesapeake Bay tributaries at salinities up to about 10 parts per thousand, are an important recreational and commercial species. In the early 1980s, Maryland Department of Natural Resources noted a decline in recreational fishing in the rivers on the Western Shore of the Chesapeake Bay. Surveys of larval presence in the Severn River, once a source of yellow perch for stocking around the Bay, showed few viable larvae. In 2007-2009, Blazer and colleagues (2013) examined the reproductive health of spawning yellow perch from five tributaries with varying degrees of urbanization. In the most urbanized tributaries (Severn and South), eggs had a significantly higher percentage of abnormal yolks and thin, irregular egg envelopes (Figure 3). Choptank eggs had few abnormalities. A follow-up study is in progress (University of Maryland, MacLeod) to track the status of female yellow perch from the Choptank (rural), Mattawoman (intermediate), and Severn (most developed). Fish have been collected in the fall and winter and during spawning to determine when the lesions occur. In addition to tissue alterations, the study is examining hormone concentrations and gene expression. Chemical monitoring of habitats will determine concentrations of legacy contaminants and chemicals of emerging concern. The goal is to gain a clearer understanding of the sequence of events that leads to poor reproductive success so that management actions may be most effective.

Overview of fish health and factors in agricultural settings

A variety of fish health concerns have been correlated to areas dominated by agricultural land-use as compared with urban areas. Health concerns include fish kills, low chronic mortality, skin lesions, and reproductive endocrine disruption as evidenced by intersex (testicular oocytes) and vitellogenin (an egg yolk precursor) in male fishes. The kills of adult Smallmouth Bass and other fishes in areas of the Potomac River from 2002-2009 led to numerous studies by USGS, FWS, state agencies, and universities to identify causes. Findings included viral and bacterial pathogens and high loads of parasites, including trematodes, cestodes, and myxozoans, but there was not one clear culprit in the kills. In 2005, mortality of young-of-the-year Smallmouth Bass were observed in areas of the Susquehanna River. Even though these fish were only 2-4 months of age they had bacterial and viral infections, and numerous parasites. These findings suggested immunosuppression and increased disease susceptibility. Comprehensive fish health assessments, that included microscopic analysis of all tissues, revealed intersex characteristics (including immature eggs within testes) are associated with mortality events. Intersex and plasma vitellogenin in male fishes have been used worldwide as indicators of exposure to estrogenic endocrine disruptors. Additional studies in both the Potomac and Susquehanna drainages indicated a correlation of intersex prevalence and severity with agricultural land use and certain chemicals, such as estrone and atrazine. Numerous chemicals measured in water, sediment, and fish tissue, including estrone, β-estradiol, atrazine, DDE, phytoestrogens, and metformin, have been shown to induce intersex in other species. Other chemicals measured in fish tissue, including arsenic, PCBs, bifenthrin, pendimethalin, metolachlor, and mercury, can adversely affect disease resistance. Nutrients, from any source, can increase bacterial loads, virulence and parasite intermediate hosts. Chemicals, including arsenic, have been measured in fish skin and may be associated with skin lesions and altered skin microbiomes.

Fish are exposed to complex mixtures of legacy and emerging contaminants, among other environmental stressors. A multi-stressor approach to understand exposures during critical life stages is necessary to inform management actions. Understanding the effects of this complex mixture of stressors on food webs, parasite life cycles, pathogen presence and virulence, and the host response are needed.

Summary of Information needs and recommendations for future science

Research is needed to understand the response of economically important and indicator species to the multi-stressors (e.g., complex mixtures of chemicals, environmental stressors, and infectious agents) present in both agricultural and urban watersheds. The needed research includes the following: 1) developing early indicators of sub-lethal effects to identify and potentially manage exposures prior to population declines; 2) understanding the role of chemicals and nutrients in both food webs and pathogen/parasite webs (e.g., intermediate hosts of parasites, role of invasive species); and, 3) identifying management actions that reduce exposure to chemicals of concern.

Some specific needs include:

1. Evaluating the risk factors (e.g., viruses, chemical exposure, environmental) of skin tumors in brown bullhead, as well as skin lesions (e.g., melanistic, raised mucoid) on bass and other species.
2. Continued monitoring of the tidal Potomac River tumor prevalence to see if the apparent decline is consistent with reference areas.
3. Determining specific mechanisms (i.e., adverse outcome pathways) associated with declines of anadromous and semi-anadromous fish populations as Chesapeake Bay tributaries urbanize.
4. Identifying chemical concentrations of concern at sensitive (critical) life stages (i.e., early development, recrudescence) and their long-term effects on reproductive success and disease resistance.
5. Continued monitoring of effects of multiple stressors on smallmouth bass populations.
6. Assessing whether current BMPs are having a positive or negative effect on fish health.

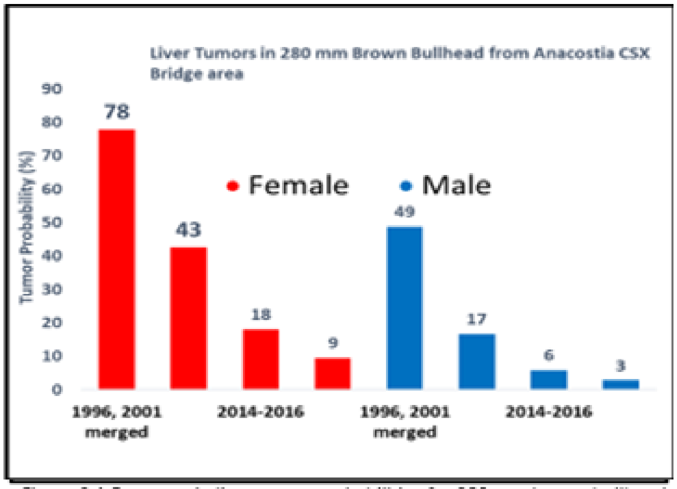

Figure 2.1 Decrease in liver tumor probabilities for 280 mm brown bullhead (Pinkney et al. 2019)

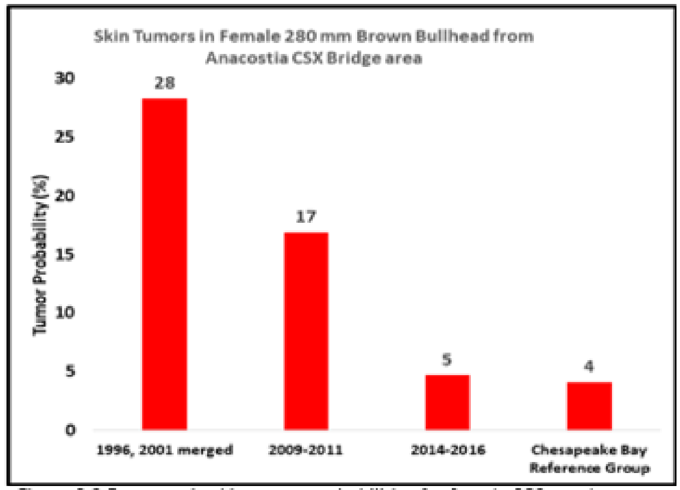

Figure 2.2 Decrease in skin tumor probabilities for female 280 mm brown bullhead from the Anacostia River (Pinkney et al. 2019)

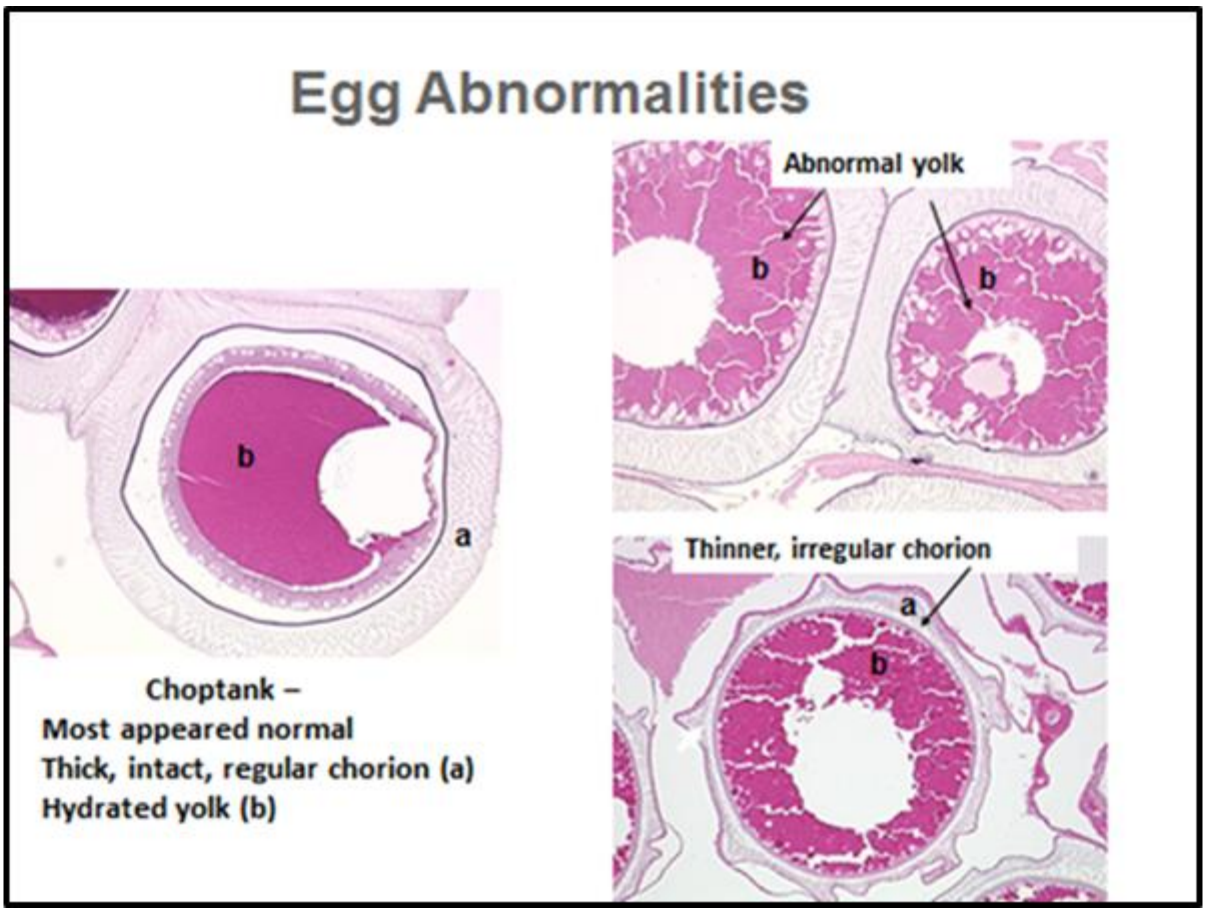

Fig. 3. Egg abnormalities observed more frequently in yellow perch from urbanized rivers (e.g., Severn) (from Blazer et al. 2013)

Sources, fate, and transport of contaminants of concern

The section summarizes the findings, information needs, and research recommendations from presenters and breakout sessions for the sources, fate, and transport of toxic contaminants in urban and agricultural settings.

Urban Settings

Ongoing efforts to monitor contaminants in urban areas, including the Puget Sound, Delaware River, Hudson River, and Chesapeake Bay, highlighted current issues surrounding contaminant source, fate, transport, and toxicity. Andy James (University of Washington) described high-resolution mass spectrometry approaches to build libraries of unique organic molecules from different sources, including wastewater effluent, stormwater runoff, agricultural runoff, boat waste, and tire leachate components. Unique molecules were then used as a measure of the influence of different sources in contributing contaminants to sites of interest by using source "fingerprinting". The tool is being used in coordination with a hydrodynamic model in the Puget Sound.

Kevin Farley (Manhattan College) described efforts to remediate PCBs in the Hudson River. He stressed the need to concurrently consider field monitoring and modeling. The first two years of post-dredging data show mixed results with reductions in PCB fish tissue concentrations in Thompson Island Pool (where the most extensive dredging efforts occurred) and smaller reductions in fish tissue further downstream. Little improvement was reported for low-flow PCB loads to the lower Hudson River. Farley cautioned against overselling sediment removal remedies given the limited reduction observed in fish tissue in the Hudson River despite the massive removal of contaminated sediment.

Ron MacGillivray (Delaware River Basin Commission) described contaminant levels in the Delaware River. Metformin (a diabetes drug) was detected at high concentrations, but several other pharmaceuticals were also detected. PFAS were widely present in the river, but concentrations decreased from 2007 to 2015 partially due to New Jersey's leadership on PFAS regulations. PFAS concentrations in fish fillets generally decreased from 2004 to 2018, except for PFOS in Smallmouth Bass. MacGillivray also indicated that PCB loads in the Delaware River have decreased since 2005, leading to changes in fish consumption advisories.

Lee Blaney (UMBC) described the presence of antibiotics, estrogenic hormones, and UV-filters (sunscreen agents) in urban and agriculturally dominated rivers feeding the Chesapeake Bay. UV-filters, including oxybenzone which has been recently banned in Hawaii and elsewhere, were ubiquitously present in Maryland rivers and the concentrations generally increased downstream of wastewater treatment plants and developed areas. The data suggest possible influences from septic systems, but this source needs to be confirmed. Select antibiotics, including erythromycin which is on the US EPA Contaminant Candidate List 4, showed similar behavior. Animal-use antibiotics were detected and negatively correlated with sucralose (a common wastewater tracer) suggesting alternate sources, such as agriculture. Hydrophobic contaminants, including estrogenic hormones and UV-filters, accumulated in crayfish in urban streams known to be impacted by leaking sewers. Blaney also spoke about the importance of monitoring transformation products, which often retain the same pharmacological/ toxicological activity as the original contaminant.

Major findings from Urban Breakout Session

What are the primary contaminants (long-known and emerging) causing fish consumption advisories, fish health risks, and risks to other aquatic species in urban areas?

Fish consumption advisories in the watershed are primarily due to the presence of PCBs and mercury. Less ubiquitous, but present and cause for less widespread advisories, are legacy organochlorine pesticides (e.g., chlordane and DDT) and dioxins/furans. Fish health effects, including reproductive and survival effects, as well as impacts to community structure and trophic transfer have been reported for these compounds. PAHs and hydrocarbons, while not the driver of consumption advisories, have known fish health effects, including larval toxicity, development of tumors, and impacts to the benthic community. Salts (e.g., chloride from deicers) are also known to be toxic to freshwater species and have impacts on the benthic community.

Fish consumption advisories do not exist for most emerging contaminants and research is ongoing to determine their effects on fish health. Estrogenic hormones are known to have effects on the reproduction of fish and the immune system. Plastics, including microplastics, also have effects on fish survival and respiration. Triclosan has reported effects on the benthic community. More information is needed to assess fish health effects in the Chesapeake Bay watershed for several other emerging contaminants, including PFAS, antibiotics, UV-filters, plasticizers (e.g., bisphenols), and new pesticides like neonicotinoids. (Appendix B, Table B-1).

What are the primary sources of chemicals causing fish consumption advisories or fish health problems in urban areas? Which sources are similar for contaminants, nutrients and sediment in urban areas?

Sources of urban contaminants are highly context- and site-specific; therefore, rather than identifying all the potential sources, the group focused on the conveyance of toxic contaminants and the overlap with nutrients and sediment in the watershed, even if the source of that conveyance differed. The primary overlap between regulated toxic contaminants (e.g., PCBs, dioxins/furans, organochlorine pesticides, and mercury) is in the conveyance of stormwater runoff to streams. Wastewater effluent and wastewater biosolids are also common conveyances of PCBs and dioxins/furans. With the exception of OCPs, these compounds organochlorine pesticides have an atmospheric source that does not overlap with nutrients and sediment. (Appendix B, Table B-1).

What are fate and transport of chemicals causing fish consumption advisories or fish health problems in urban areas?

Similar to the sources of toxic contaminants in urban areas, the fate and transport of these compounds are complex and site-specific. For example, the organic carbon content of the sediment in which the contaminants are present will vary by site and largely influence the fate and transport of contaminants, such as PCBs, OCPs, and other hydrophobic contaminants. Nonetheless, the fate and transport of some of the contaminants causing fish consumption advisories and fish health effects are well understood in a variety of environmental conditions. This understanding includes most of the contaminants with known fish health effects, aside from mercury and other metals.

Little is known about the fate and transport of toxic contaminants with suspected fish health effects. Site-specific information on sources of toxic pollutants is necessary to enable targeting of appropriate management options. A good example is the recent study conducted by D.C. DOEE to identify ongoing sources of pollutants to the Anacostia River (Ghosh et al. 2019). (Appendix B, Table B-1).

What additional information and research is needed to better define the presence, effects, sources and management options in urban areas?

The lack of knowledge about fate and transport of toxic contaminants and their transformation products with suspected fish health effects is a significant gap in the understanding of these compounds and a need was identified for further work to better define their degradation characteristics and distribution preferences (e.g., for surface water or sediment) under different conditions.

More work is needed to identify sources of toxic pollutants that are the primary risk drivers at specific locations. Delineation of the contributions of ongoing watershed sources and release from legacy contaminated sediment is critical to determine whether watershed BMPs will be effective or if in stream remediation of for legacy sediments is necessary.

Agricultural Settings

Ongoing efforts to monitor toxic contaminants in agricultural areas of the Chesapeake Bay Watershed highlighted current sources, fate, and transport including temporal and spatial variability. The US Geological Survey's Chesapeake Bay Endocrine Disrupting Chemical (EDC) Project nested under the purview of the Environmental Health Mission Area has been studying the sources, fate, exposure, and effects of endocrine disrupting chemicals in five agricultural watersheds of the Chesapeake Bay from 2013 to present. Kelly Smalling (USGS) highlighted the results of four years of intensive contaminant monitoring data with respect to contaminant occurrence and relationships with land-use, select landscape variables, and flow. The studied watersheds were a mix of row-crop agriculture, animal feeding operations, and urban/suburban development. Over 200 contaminants were measured and herbicides (e.g., atrazine, metolachlor), cholesterol, and phytoestrogens (e.g., naturally occurring estrogens) were frequently detected. Flow was a dominant predictor for herbicides, cholesterol, and phytoestrogens across sites in the spring during runoff events. In some cases, select landscape variables, including herbicide application, biosolid application, the amount of phytoestrogen crops in the watershed, and land-use, were acceptable predictors of contaminant concentration. Based on preliminary results, management actions designed to reduce surface runoff could have co-benefits for some endocrine disrupting chemicals. To adequately answer this question more process-based research is needed to examine the co-benefits of BMPs for contaminant reduction.

Kang Xia (Virginia Tech) highlighted the dominant contaminants associated with manure. Antimicrobial and other veterinary pharmaceutical compounds used to keep livestock healthy and both natural and synthetic hormones were present in manure. The use of antimicrobial compounds began in the 1950s but has increased substantially in the husbandry of some animals. Some animal agriculture has been converted to confined operations where disease must be intensely monitored and managed. The types of antimicrobial compounds and hormones detected in manure varies by animal type and age, but these operations present a potentially concentrated source of contaminants to surface water and groundwater. The global use of antimicrobial compounds has also resulted in increased prevalence of antimicrobial resistant genes that have the potential to occur in local food sources, such as vegetables grown in proximity to land-applied manure.

<u>Major findings from Agriculture Breakout Session</u>

What are the primary contaminants causing fish consumption advisories, fish health issues, or other aquatic species in agricultural areas? Which emerging contaminants may pose the greatest risk to fisheries and other aquatic organisms in agricultural areas?

Fish consumption advisories are driven by PCBs throughout much of the watershed. PCBs are less of an issue in agricultural watersheds but do still occur less frequently and at lower concentrations than for urban watersheds. DDT and mercury are other contaminants that have the potential to result in health advisories and cause negative effects on fish and other aquatic species. Contaminants, such as PCBs and mercury, pose more of a human health risk but there have been studies showing these contaminants can suppress the immune system and cause endocrine disruption in aquatic species. It is important to note that all studies conducted on these and other contaminants did not show causation but only reported correlations between effects and contaminants.

Less is known about the direct and indirect effects of emerging contaminants on aquatic organisms. Natural and synthetic estrogens have the potential to induce intersex in fish, while other studies have shown that atrazine can modulate the endocrine system. Other contaminants considered to adversely affect aquatic organisms include PAHs, pyrethroid insecticides (e.g. bifenthrin), neonicotinoid insecticides, and metals, such as arsenic and copper. More information on the effects of microplastics, therapeutic drugs, and pesticide adjuvants is needed to really assess the effects of chemical mixtures present in agricultural settings. Furthermore, we need to better characterize sediment bound contaminants. As sediment continues to threaten fisheries and habitat, we need a better understanding of the risk these sediment-bound contaminants pose and their mobilization and fate in the estuary.

What are the primary sources of chemicals causing fish consumption advisories or fish health problems in agricultural areas? What is known for areas dominated by animal

operations? What is known for areas of crop production and associated pesticide applications?

The sources of contaminants in agricultural watersheds are relatively well defined and include pesticide use (legacy or current), manure application, manure storage, biosolids application, irrigation of treated wastewater, and septic systems. Commonly applied pesticides include atrazine, bifenthrin (pyrethroid insecticide), copper, neonicotinoid insecticides, and the proprietary adjuvants co-applied with the active ingredients. In the Chesapeake Bay Watershed legacy signatures of DDT and arsenic still persist. Common contaminants present in manure include antibiotics, natural hormones, and some phytoestrogens. Human influences on the agricultural landscape, including biosolids application, septic systems, and wastewater reuse, have the potential to be sources of a wide variety of contaminants, including PCBs, pharmaceuticals, metals, personal care products, synthetic hormones, PFAS, flame retardants, etc. Other contaminants present in agricultural landscapes include mercury and phytoestrogens.

Although information is readily available regarding contaminant sources, less is known about the effects of toxic contaminants and their mixtures on fish and other aquatic organisms. More information is needed on the exposure, distribution, and effects of certain toxic contaminants, including personal care products, pharmaceuticals, antibiotics, metals, natural hormones, synthetic hormones, PFAS, flame retardants, microfibers/plastics, and engineered nanomaterials. Data are currently lacking on septic systems as a source of contaminants to surface water and groundwater.

Which sources are similar between contaminants and nutrient and sediment, in agricultural areas?

Based on the opinion of the panel, sources that are similar between contaminants and nutrients/sediments include biosolids and manure application, irrigation with treated wastewater, septic systems, and sediments containing hydrophobic contaminants.

What are fate and transport of chemicals causing fish consumption advisories or fish health problems in agricultural areas?

Contaminants like PCBs and DDTs are ubiquitous in the environment, persistent, and transported primarily by sediments. Other contaminants that have an affinity for sediments include bifenthrin, PAHs, and some pharmaceuticals. Pesticides and other water-soluble contaminants like natural hormones and some personal care products can be short-lived in the environment and easily transported to shallow groundwater. However, the history of manure application practices can affect the persistence of compounds that, based on laboratory studies, should have relatively short half-lives. Decades of manure application can lead to the development of legacy sources of hormones, and potentially of other contaminants of emerging concern, such that the flow rate of surface runoff can become a good predictor of hormone loads. The “first-flush” effects of increased transport during the first rainfall event after manure applications appear to be far more important for contaminants present in manure applied via surface broadcasting and far less of a driving factor in the fate and transport of the same contaminants in manure applied via shallow disk injection.

Information needs and recommendations for future science

To adequately address the fate and transport of chemicals in agricultural areas, we need more documentation of contaminants found in manure and relative concentrations from other sources. Investigative studies designed to understand contaminant interactions with sediment and organic carbon, transport to and from shallow groundwater, environmental degradation products, and overall persistence in the environment are still in short supply compared to the list of detected chemicals. The temporal variability of agricultural contaminants has begun to be evaluated; however, we need more information to understand the implications for sensitive fauna in the watershed.

Contaminants need to be considered as part of a multi-stressor system. We also need more studies that adequately identify the mixtures that are most impactful to the health and vitality of fisheries and determine ways to prioritize the management of these contaminants. Contaminants need to be viewed as a piece of the puzzle, and we need to better understand how fate, transport, and exposure relate to other environmental variables. We need the science to determine the synergistic effects of multiple contaminants, as well as other environmental drivers and stressors on living resources in the watershed.

Mitigation and potential interactions with nutrients and sediment

This section summarizes the findings, information needs, and research recommendations from presenters and breakout sessions for the mitigation and potential interactions with nutrient and sediment reductions in urban and agricultural settings.

Summary of approaches currently used to reduce contaminants

As part of the jurisdictional panel at the workshop, each state's representative detailed current approaches used to reduce toxic contaminant loads. Across the watershed, this effort is largely being approached through the TMDL program. All states have PCB TMDLs in the watershed, which are implemented through the Municipal Separate Storm Sewer System (MS4) permits in Washington, DC and Maryland. In addition to the MS4 permits, waste load allocations are managed in states through the NPDES permit issuance to individuals (both industrial and municipal) and the stormwater general permits. Outside of TMDL implementation and Waste Load Allocation (WLA) permitting, Washington, DC implemented a coal tar/high-PAH sealant ban to reduce PAH loads. Delaware has targeted contaminated sites in the Delaware River Basin with success, and the state has initiated a similar program to define loads within Chesapeake Bay drainages. All states, aside from Delaware (through the Watershed Approach to Toxics Assessment and Restoration program), manage their TMDL programs separate from the land cleanup programs. Delaware has reported considerable efficiencies in combining these efforts.

To date, most jurisdictions have not implemented BMPs for toxic contaminants. Several mentioned that they see the best opportunities to use nutrient and sediment reduction efforts to mitigate toxic contaminants through sediment reduction BMPs; however, significant gaps remain in the understanding of removal efficiencies for toxic contaminants in these approaches. Maryland also sees benefit in consideration, where appropriate, of the use of innovative BMPs (e.g., SediMite, which is carbon-based product, in wet ponds) to enhance PCB removal. Delaware has used this approach with success for remediation efforts in the state. Many jurisdictions would like guidance to utilize these tools.

Overview of planned nutrient and sediment reductions

Olivia Devereux (Devereux Consulting) reviewed the existing qualitative assessments of BMP impacts on toxic contaminants. She also showed the BMPs classified as having the highest impact on toxic contaminants. These are primarily agricultural BMPs and include forest and grass buffers, septic connections, shoreline management, amendments for the treatment of agricultural waste, animal waste management systems, barnyard runoff controls, and manure treatment technologies.

Some BMPs have negative effects; for example, cover crops are usually killed in the spring with herbicides, increasing the amount of toxic contaminants in runoff. BMPs are classified by function in order to evaluate the overall impact on the landscape. These classifications include reducing nutrient application, decreasing volatilization, implementing biofiltration and runoff control, and incorporating runoff control to streams.

The effect of agricultural BMPs on toxic contaminants can be integrated with the CAST model and management tool (CAST@chesapeakebay.net). This integration requires a transition to quantitative impacts. Research is currently underway by Vicki Blazer (USGS) and Kelly Smalling (USGS) to assess the impact on fish and stream health.

Urban Settings

Watershed approaches to mitigations**:**

Through their MS4 permits, jurisdictions with primarily urban land use have been implementing many BMPs to reduce loading and comply with state-specific water quality and quantity standards, as well as the Bay Pollution Diet for nutrients and sediment. Although many of these same jurisdictions have local TMDLs that include toxic contaminants, many have not been enforced to date in the watershed. Many BMPs designed for sediment trapping are expected to be effective for hydrophobic toxic contaminants (Toxic Contaminants Workgroup 2018) although limited studies have demonstrated their efficiencies. Recently, work has begun to understand the fate and transport of both regulated and emerging toxic contaminants in BMPs, primarily in contaminated stormwater and some of this work was highlighted at the workshop.

Pollutants, such as PCBs, PAHs, and certain metals, are transported into waterways through stormwater runoff in urban environments. As presented by Birthe Veno Kjellerup (University of

Maryland), PCB concentrations increased in the environment despite the fact that these compounds were banned from use in the 1970s. Sources of PCBs (and other contaminants) remain in the urban environment through building and roadway runoff and atmospheric deposition. Kjellerup and others observed that PCBs in road-side sediment preferentially sorb higher concentrations in the finer fraction, but a greater overall mass of contaminant is transported with the larger particle size sediment. These results suggest that sediment capture in BMPs may be an appropriate approach for mitigation of these contaminants. An investigation of bioretention by Kjellerup and colleagues indicated a decrease in concentration and toxicity with distance from the inlet and with depth. Current studies are looking at ways to enhance the BMP media using granular activated carbon (GAC), biochar, woodash, zero valent iron, and chitosan to promote biodegradation. The media enhancement is contaminant dependent.

Although they are not currently regulated, many contaminants of emerging concern have been detected in urban streams due to stormwater runoff, wastewater overflows, and wastewater discharge. Limited studies on these compounds suggest they may be amenable to BMPs. Richard Keisling (USGS) presented results of a study that investigated the occurrence and removal of various pesticides, personal care products, and pharmaceuticals in iron-enhanced sand filters. An overall reduction in total concentration was observed by Keisling and colleagues in IESF ponds compared to outfalls for both hydrophobic and polar hydrophilic compounds. Some seasonal variation in removal efficiency was observed, but overall IESFs were demonstrated to be an effective BMP for various CECs. Continued studies will further explore the spatial and temporal variations in efficiencies.

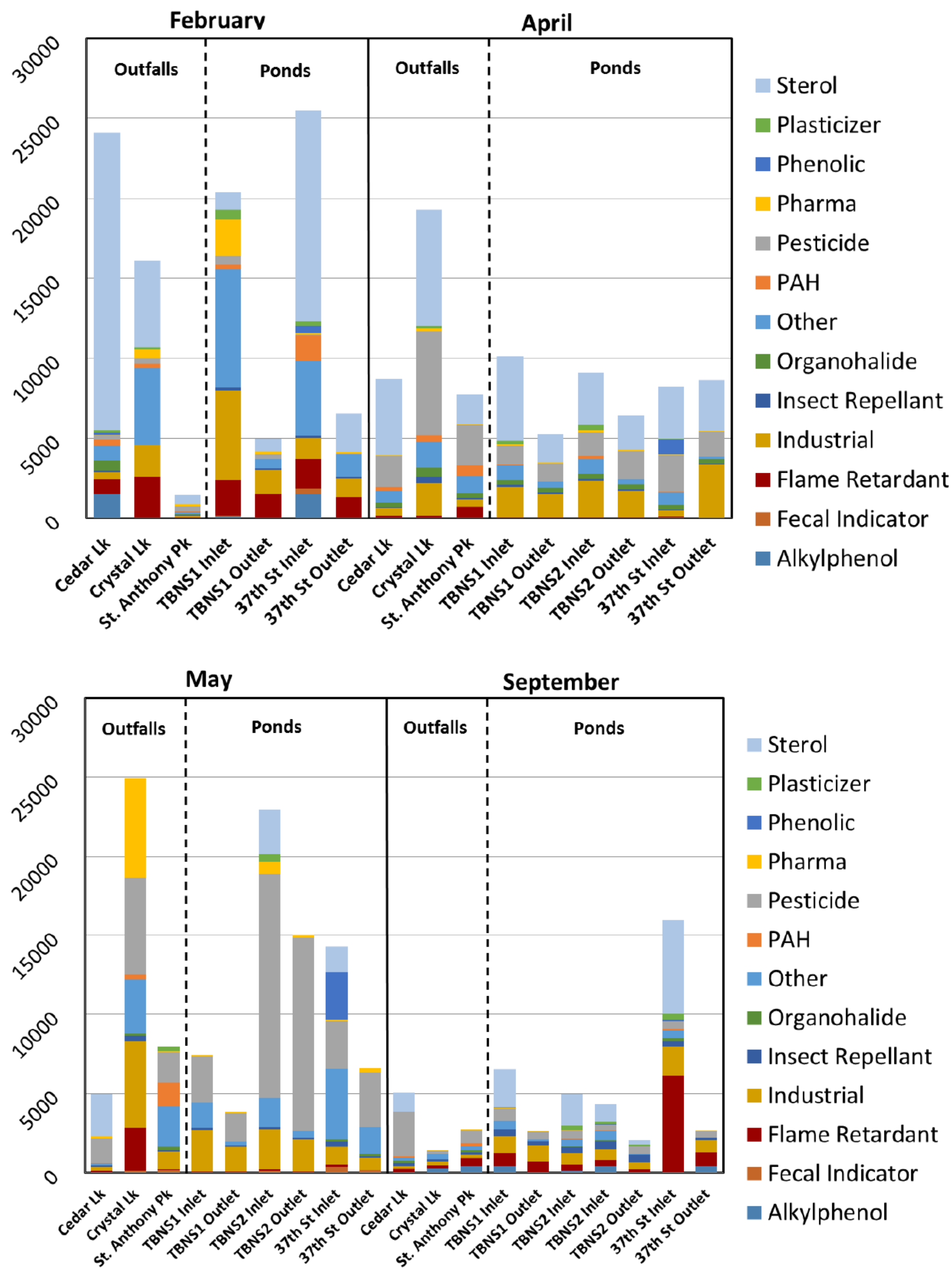

Figure 4. Detailed comparison of Contaminants of Emerging Concern (CEC) category concentration (ng/L) between inflows and outflows. Iron-enhanced sand filters are located in ponds and outflow concentrations shown in Outlets. (Keisling 2019)

In-stream approaches to mitigation:

The use of watershed-based BMPs for either known or emerging toxic contaminants relies on the understanding that the source of both nutrient and sediment inputs overlap with the pollutant. In some cases, traditional BMP approaches in the watershed do not address contaminants that have already been transported to the stream bed and are acting as an ongoing "source". For example, efforts to reduce "clean" sediment transport may negatively impact management of toxic contaminants in contaminated sediment due to slower burial processes. For example, in Lake Onondaga, wastewater treatment plant upgrades in nutrient reduction enhanced sulfate-reducing conditions and increased methylmercury levels in water and fish. To ameliorate this situation, nitrate had to be reinjected to the lake. These examples demonstrate the complex relationships between approaches to manage sediment, nutrients, and toxic contaminants. Managing the dissolved concentration of toxic contaminants is the key to controlling exposure. Passive samplers can be used to measure the freely dissolved concentration. Upal Ghosh (UMBC) presented advances in the use of innovative in-stream technologies to address hydrophobic toxic contaminants, primarily PCBs. The first technology involved amendment of activated carbon into contaminated sediments to bind up the pollutants making them less available to the biota. This technology has been demonstrated through pilot-scale studies in several contaminated sediment locations in the Chesapeake Bay region and applied in full-scale for the remediation of contaminated sediments in Middle River. The second technology discussed involved the use of bioamendments to break down PCBs in sediments which has been recently demonstrated at a sediment site in the Marine Corps Base Quantico and is being used for full-scale remedies at sites in Delaware and Maryland.

Major findings from Urban Breakout session

Opportunities to mitigate toxic contaminants using nutrient and sediment reduction approaches in urban areas

Toxic contaminant behavior is more site-specific and complex than nutrients and sediment with significant variation between contaminant groups and even within the groups themselves at different sites. Decisions about mitigation approaches require an understanding of the site-specific presence, sources, and the fate and transport of the particular contaminant(s) of interest. Critical considerations for the fate and transport of various contaminants include speciation in water, partitioning between water and sediment (both bed and suspended), and persistence (e.g., potential for transformation and degradation) in the environment. While there is an understanding of the fate and transport in this context for regulated toxic contaminants, such as PCBs and PAHs, the site-specific conditions and identification of site-specific sources cannot be overstressed with respect to the effectiveness of mitigation approaches. Additional information on the fate and transport is needed for many of the unregulated contaminants of emerging concern before their behavior can be assessed in stormwater controls. Identification of practices that may lead to unintended negative impacts on the natural recovery of receiving water bodies needs to be conducted for toxic pollutants.

Figure 5. Images of mitigation approaches including watershed BMPs documenting A) PCB removal in bioretention cell (Kjellerup), B) Contaminants of Emerging Concern in iron-enhanced sand filter ponds (Keisling), and C) in-stream applications using bioamended granular activated carbon (Ghosh).

Which of the chemicals are regulated in urban areas? What are the current practices, and their effectiveness, to mitigate the effects of toxic contaminants?

Fish consumption advisories and TMDLs widely exist throughout the watershed for PCBs, whereas other contaminants (i.e., mercury and other metals, PAHs, dioxin/furan, and organochlorine pesticides) are less ubiquitous but are still present in urban areas. Additional state and federal programs (e.g., Superfund, Resource Conservation and Recovery Act [RCRA], and State Superfund programs) regulate the identification and remediation of these compounds due to known sources. In most cases, these programs work independently from the state-based fish consumption advisories/TMDL programs (aside from Delaware).

Many of the compounds that are suspected to have fish health and other ecological impacts (as described in Appendix Table B-1) are not currently regulated. Gaps in the understanding of their fate and transport in the environment need to be filled before BMPs can be adequately assessed. For both regulated and unregulated toxic contaminants of interest, jurisdictions in the watershed have not utilized BMPs for toxic contaminant TMDL compliance; however, research is currently ongoing in this area (Kjellerup, Davis). To date, mitigation of toxic contaminants has largely fallen under the purview of other federal and state regulatory programs. Delaware has uniquely merged their programs (creating Watershed Approach to Toxics Assessment and Restoration [WATAR]) to take advantage of the lessons learned for toxic contaminant investigations and remediation.

What are the best opportunities to use nutrients and sediment practices to also mitigate contaminants? Are there potential risks of nutrient and sediment practices for mitigating toxic contaminants in urban areas?

Although the workshop did not directly highlight the most-predominant BMPs used in urban areas throughout the watershed, participants highlighted the dominance of the following practices relevant to co-benefits of nutrient and toxic contaminant mitigation largely based on the practices most common in Washington DC ,which is dominated by urban land use: bioretention, street sweeping, stream restoration, and surface water performance standards (e.g., reductions in water quantity, new development standards). Previously published documents that were provided as background for the workshop have highlighted the theoretical potential for the use of nutrient and sediment BMPs for addressing toxic contaminants, particularly those associated with sediment reduction, such as those mentioned above, as well as narrow and urban forest buffers, wet and dry ponds, biofiltration, and infiltration practices (Toxic Contaminants Workgroup 2018). The group cautioned that a BMP focus on reducing contaminant loads will not necessarily directly translate to a reduction in fish tissue and, therefore, end points must be considered when selecting BMPs.

Most information presented in the STAC workshop focused on the bioretention/biofiltration approaches to obtaining co-benefits (e.g., Keisling, Kjellerup, and Phillips). Currently, these practices have demonstrated the most opportunity for co-benefits with toxic contaminants in research practices and in areas outside the watershed (e.g., central valley of California, upper mid-west), but have been limited in practice within the Chesapeake Bay watershed.

Site-specific sources of urban contaminants may dictate the level of co-benefit obtained, more so than for nutrients. The group highlighted the importance of the evaluation landscape for sources and related toxic contaminant loading to an impaired segment or water body. Gaps in the methodology used to develop a holistic conceptual site model (CSM) that includes track back and prioritization of efforts based on the evolving CSM were identified. Concerns were raised that failure to fully inform the CSM may result in the inability to identify if suspended sediment is in fact a sink or a source for sediment-bound contaminants. A less than thorough understanding of the CSM and the partitioning between pore water and sediment highlights the conflict in using sediment approaches to meet fish tissue targets for regulatory programs. A clearer understanding of the CSM will help to define the forward progress in targeted areas, particularly if this is coordinated with nutrient and sediment monitoring and restoration efforts.

What are the remaining science and research needs for more effective mitigation of toxic contaminants in urban areas?

1. Fate and transport of priority contaminants in different settings including stormwater control structures.
2. Improved best practices for source evaluation and conceptual model improvement and selection of appropriate mitigation, including risk evaluation for implementation of watershed-based mitigation (e.g., BMPs).
3. Efficiencies and effectiveness of BMPs and in-stream mitigation to also improve aquatic organism health.
4. Communication of results of studies from scientists to practitioners and stakeholders.

While some understanding of the behavior, fate, and transport of toxic contaminants in common stormwater control structures is developing, as was highlighted in the workshop, the group identified that the removal efficiencies for these compounds are largely unknown. It was suggested that the removal efficiencies should be evaluated for both wastewater and stormwater flow conveyance to streams. The group also raised concerns that operation and maintenance practices of these stormwater control structures may result in secondary sources of contaminants in the environment if sediments are dredged or land applied, highlighting a critical gap in understanding how to effectively use the BMPs.

Agricultural settings

Agricultural areas have a litany of available BMPs and, to a large extent, BMPs have been installed to reduce the fate and transport of nutrients and sediment. Sediment-reducing BMPs are not only addressing sediment, but also the contaminants bound to sediment. Sediment-trapping BMPs in the estuarine system, including ditches and streams, have an unknown effect on emerging contaminants because their land use load and in-stream load have not been compared, nor has the fate of these contaminants been explored in an alternating oxic-anoxic environment. Source-control BMPs like Integrated Pest Management, Nutrient Management, and Precision Feeding have an inherently lower risk of failure or bypass with respect to nutrients, sediment, and contaminants. Filter type, efficiency-based practices have a higher risk of bypass and have the potential to cause accumulation (requiring abatement) or enhance the release of contaminants as a result of changes in oxidation state. Mitigating these issues requires more research on general fate and transport of contaminants. Emerging research is investigating compost and digestion to reduce pharmaceutical runoff from manure.

Pesticides, which are applied to the land to increase crop yield by reducing noxious weeds, controlling pests, and reducing fungal infections, are transported off-site to local surface water bodies during runoff events and following regular irrigation practices. Bryn Phillips presented results on 10 years of research on the effectiveness of management practices in California. His work was focused on reduction of insecticide load and toxicity to benthic organisms using retention ponds, vegetated treatment systems, polyacrylamide to reduce suspended sediment bound contaminants, enzyme treatment, and carbon filtration. Integrated vegetated ditches were successful in significantly reducing insecticide load to surface waters. In some instances, toxicity was also reduced. For retention ponds, concentrations of most pesticides, were lower at outlets than at inlets, indicating an overall effectiveness in reducing non-point source pollution to local surface water bodies. However, these ponds did not provide any reduction in overall sediment toxicity to benthic organisms due in part to the types of insecticides (pyrethroid and organophosphate insecticides) used and their known toxicity to benthic invertebrates. The implementation of BMPs to reduce nutrient and sediment loads have the potential to reduce pesticides applied in agricultural areas, but more detailed studies are needed in the Chesapeake Bay.

Animal production is another source of contaminants, including hormones and antibiotics, to local surface water. The use of antibiotics has resulted in an increase in antibiotic resistance, which is considered by the World Health Organization "one of the most critical human health challenges of the 21st century." Continued manure management and understanding the co-benefits of these existing practices is needed to reduce the contaminants from animal production. Kang Xia presented a research project designed to track the flow of antimicrobials through the agroecosystem using a farm-to-fork conceptual model (Figure 6). Manure is applied to 48% of the farmland in the Chesapeake Bay States. The benefits of land application of manure include enhancement of nutrients and soil structure, increases in soil organic matter, and carbon sequestration. Antibiotics in both non-composted and composted manure have the potential to persist in soils at low concentrations, increasing the potential for antibiotic resistance gene formation. Lab and field studies by Xia and her colleagues suggest a 120-day wait period after land application and before crop harvest to reduce the antimicrobial resistance risk. Subsurface injection of manure also reduces surface runoff of antibiotics and antibiotic resistance particularly during spring application. Best manure management strategies include applying only composted manure, a 120-day waiting period if raw manure is applied prior to harvest, surface application in the fall when runoff potential is lower, subsurface application, and the addition of buffer strips.

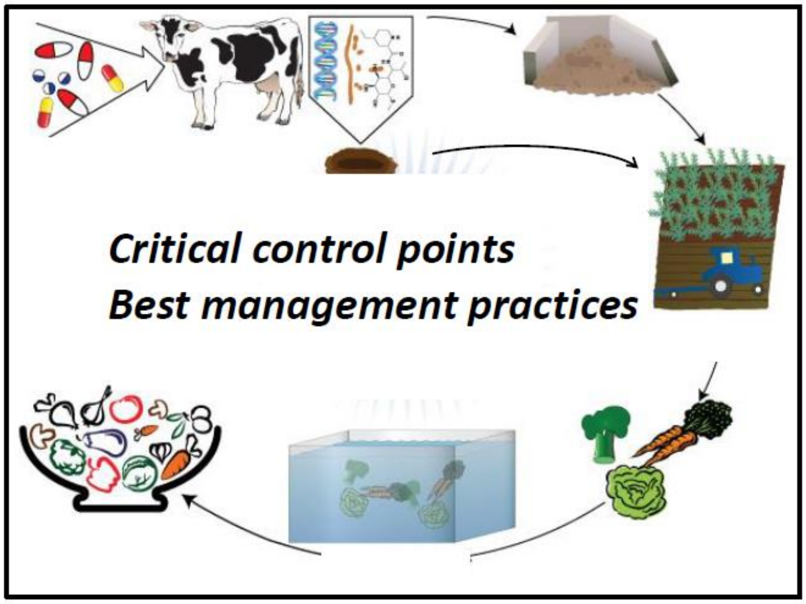

Figure 6: Farm-to-fork conceptual diagram used to track contaminants as they move from the animal through land-application of manure and into the food we eat. (https://args.hort.vt.edu/)

Major findings from Agriculture Breakout Session

Opportunities to mitigate toxic contaminants using nutrient and sediment reduction approaches in agricultural areas - Workshop Breakout session 2

The major takeaway from this breakout session was current management efforts are considered generally effective for toxic contaminant reductions but enhancements to existing efforts to increase effectiveness is feasible. Many of the management efforts have the potential to reduce contaminants even though they are intended for nutrient and sediment reductions. However, further research is needed to fully understand the co-benefits. To support more contaminant-targeted management actions, more research is needed on contaminant-specific BMPs, as well as the fate and transport of contaminants in agricultural watersheds. The breakout session participants attempted to answer the below questions based on the available expertise and experience.

Which of the chemicals are already regulated in agricultural areas? What are the current practices, and their effectiveness, to mitigate the effects of toxic contaminants in agricultural areas?

Many of the contaminants used in agricultural areas are regulated in some fashion. Jurisdictions in the watershed have TMDLs and fish consumption advisories in place for both Hg and PCBs. Federal regulations are in place for antimicrobials and some pharmaceuticals used in animal feeding operations. Pesticide use is heavily regulated through limits on use, crop-type, and application amounts to reduce or minimize environmental harm. These regulations are not specific to the Chesapeake Bay Watershed and tend to be established at the federal level. Due to the complex mixtures and the various sources in the agricultural watersheds, information on unregulated contaminants, their primary sources, and how to minimize and mitigate their effects without established TMDLs has yet to be determined.

What are the best opportunities to use nutrients and sediment practices to also mitigate contaminants in agricultural areas?

There are quite a few BMPs used for nutrient and sediment reductions that have the potential to mitigate contaminants based on their functions. It is important to move forward with these practices based on this potential and simultaneously begin evaluating their effectiveness for contaminant mitigation. Wetlands and riparian buffers/vegetated filter strips that reduce surface runoff and increase residence time could be effective in minimizing dissolved and sediment bound contaminants. Waste management and proper storage and composting of manure has the potential to reduce contaminants in surface waters, as detailed in Kang Xia's talk. Planting of post-harvest was designed to reduce erosion, improve soil quality, sequester nutrients, and suppress weed growth; however, it is unclear if this practice has benefits for contaminant removal/reduction. Cover crops are high in phytoestrogens, which are released into surface water during spring rain events. The effects of natural estrogens on fish health have yet to be determined, but they do have the potential to negatively affect endocrine systems. Other BMPs, like biofilters and exclusion fencing, have the potential to reduce contaminants but again information is lacking. For many of the contaminants observed in agricultural areas, the addition of activated carbon to established BMPs and prioritizing BMPs that increase retention/residence time could be important to help reduce the input of contaminants from agricultural sources.

BMPs are designed to treat the system after contaminants are applied to the land but an alternative approach would be to find ways to reduce the application of chemicals. To prioritize BMP implementation, it is important to determine the types of contaminants that need to be reduced and how the BMPs operate. BMPs that offer co-benefits for both nutrient, sediment, and toxic contaminant reduction are ideal; however, in some cases, co-benefits may not be possible. We should also encourage practices like integrated pest management and organic farming that can be implemented to reduce sources of contaminants in the first place.

Are there potential risks of nutrient and sediment practices for mitigating toxic contaminants in agricultural areas?

The breakout session discussed a variety of BMPs that could pose risks to reducing contaminants, but more research into this topic is needed. To attempt to answer this question, we assessed the function of BMPs and discussed issues related to contaminants. No till with manure application has benefits for sediment and nutrient reduction, but the addition of manure is a source of contaminants that can be transported to local surface water and shallow groundwater. Buffers were highly rated by TetraTech (Devereux talk) for nutrient and sediment reduction; however, the sequestration of contaminants in the buffer might negatively impact the long-term effectiveness of the buffer. Composting is an important practice, but the contaminants sequestered in the composted manure have the potential to move off-site during rain events.

Wetlands, which are designed to increase residence time and reduce runoff, could be a sink for contaminants. Wetland habitats are important for aquatic organisms and the sequestration of contaminants in these important habitats could have detrimental effects to the ecosystem. It is our opinion that all BMPs may hold some risk of failure and may not be fully effective for contaminants, but BMP design and implementation depends on the end goal and identifying target contaminants for mitigation in the ecosystem of concern.

What other innovative approaches should be considered in agricultural areas?
Some of the innovative approaches that were briefly discussed include the following: source minimization (i.e. reducing application), the use of enzymes to degrade contaminants, nutrient recovery such as manure alternative yeast, biogas formation, and pairing contaminants with nutrient/sediment BMPs based on the behavior (fate/transport) of the contaminants. Managers expressed interest in the application of a dashboard or web-based tools to help with BMP implementation guidance and the development of a management reference framework for both nutrients/sediments and contaminants.

What are the remaining science and research needs for more effective mitigation of toxic contaminants in agricultural areas?
The breakout session participants discussed a long list of science needs to more effectively mitigate contaminants:

1. Information on fate and transport of priority contaminants;
2. Effectiveness of new/innovative BMPs;
3. Information on specific pairing of BMPs; and,
4. Science transmission to the management community.

There are still gaps in our knowledge on the fate and transport of these contaminants. For example, there is limited information on the specific metabolites that can be formed, and their overall toxicity compared to the parent compound. We need more information on hydrophobicity and where we expect to find the contaminants, including sorption to sediments, transport to shallow groundwater, and movement into local surface water, to design better mitigation approaches. Nutrients and sediments are monitored, and trends are established on an annual basis but the occurrence and concentrations of many toxic contaminants vary in time and space. To better manage the system, we need to determine our species of concern when they are most susceptible and how can we better manage these pulses. We need more robust information about the effectiveness of biochar and plasticulture (e.g. practice of using plastic materials in agricultural applications). For biochar, we need to compile information on its effectiveness for sequestering a wide variety of contaminants, application on the landscape, and the fate/transport of chemicals associated with spent biochar. Plastic culture is used to reduce nutrients and is intended for high value crops, which receive a steady supply of nutrients and heavy pesticide application. Understanding if used plastic is a source of microplastics to the environment is a notable research gap as well determining effectiveness of BMPs for new or emerging contaminants like microplastics. We need a continued focus on co-benefits between nutrient/sediment BMPs and contaminants, as well as more focused studies on how to pair BMPs based on the physical-chemical properties (e.g., water solubility, persistence, hydrophobicity, etc.) of the contaminant. For example, nitrogen management might be more effective for water

soluble contaminants, while sediment reduction BMPs could facilitate reduction in hydrophobic or sediment bound contaminants. Can we design a qualitative framework based on expert opinion, know contaminant properties and an understanding of BMP utility to better inform management? All these recommendations and future science topics need to be delivered to the management community effectively and with the economics in mind. BMP implementation is expensive and includes a high maintenance cost so building online dashboards and tools easily accessible by managers is necessary to identify sensitive fish habitats and priority populations that would benefit from improved BMP implementation and/or monitoring.
Overall, the breakout session yielded a great discussion, but we were lacking BMP expertise and struggled with the importance of specific BMPs and their utility for contaminants. Ideally, more research is needed to fully determine the co-benefits to improve water quality, increase habitat quality, and preserve aquatic resources. BMPs are an important tool for reducing contaminants and necessary for maintaining fisheries.

Major Findings and Research Recommendations

This section summarizes the major findings and recommendations from each of the report chapters.

Fish consumption advisories and fish health:

1. Fish consumption advisories in the watershed are widespread and are largely due to elevated concentrations of PCBs and mercury, and to a lesser extent organochlorine pesticides, and are based on human health criteria. No fish consumption advisories currently exist for contaminants of emerging concern in Delaware, with the exception of PFAS.
2. Fish health concerns in agricultural settings appear to be associated with a combination of chemical exposure leading to reproductive endocrine disruption and increased susceptibility to infectious agents. Fish health concerns in urban settings include neoplasia and reduced reproductive success associated with a combination of exposure to legacy contaminants and chemicals of emerging concern.
3. In both agricultural and urban settings, research is needed to evaluate the ways that multiple stressors (both chemical and non-chemical) lead to adverse effects at the individual and population level. Such information will help managers focus efforts to minimize these impacts as land use changes. Research is needed to determine the sources of pollutants entering the food chain and the role of ongoing inputs in causing consumption advisories.

Sources, fate and transport of contaminants of concern

Urban settings:

1. In regions outside the Chesapeake Bay, including the Hudson and Delaware River Basins and Puget Sound, ongoing work demonstrates the value in investing in clearly defined system and regulatory endpoints prior to taking management actions. For example, in the Hudson River basin, the first two years of post-dredging data show significant loading of PCBs under baseflow conditions, and limited reductions in fish tissue in downstream waters despite the extensive dredging in the upper portions of the river. In contrast, regulation and actions taken in New Jersey following detailed investigations by the

Delaware River Basin Commission resulted in a decrease in PFAS compounds over a 10 year timeframe.
2. The origin and processes affecting the fate of many of the contaminants of emerging concern (e.g., introduction to the watershed, distribution between aqueous and solid phases, and conditions controlling their degradation) are still being defined, making it difficult to implement management actions through BMPs. For example, the influence of septic systems on emerging contaminant concentrations in Chesapeake Bay tributaries may play a crucial role in introducing these contaminants to the Bay.
3. The application of high-resolution mass spectroscopy and wastewater-based epidemiology tools utilized in Puget Sound to improve the understanding of contaminant sources and loads could be helpful to inform sources and loads to the Chesapeake Bay. The use of source fingerprinting approaches may help to discern complex mixtures of toxic contaminants under different land use conditions.

Agricultural settings:

1. The sources of contaminants in agricultural watersheds within the Chesapeake Bay Watershed are relatively well defined and include pesticide use (legacy or current), manure application, manure storage, biosolids application, irrigation of treated wastewater and septic systems (the latter three being human in origin).
2. Currently, information is limited on the direct and indirect effects of toxic contaminant mixtures that occur in the Chesapeake Bay Watershed on fish and other non-target aquatic organisms. There is a continued need for more information on the exposure, distribution and effects of newer and emerging toxic contaminants including personal care products, pharmaceuticals, antibiotics, metals, natural and synthetic hormones, PFAs, flame retardants, microfibers/plastics, and engineered nanomaterials.
3. Understanding of the field and watershed-scale fate and transport of emerging toxic contaminants in agricultural-dominated watersheds is limited and the panel's opinion is that more studies are necessary to evaluate current BMP effectiveness on contaminant removal and potential improvements in fish health. The panel is not suggesting delay implementation until studies can be conducted but to prioritize research/monitoring efforts related to contaminant mitigation as new BMPs implemented. More specifically, investigative studies should be designed to understand contaminant interactions with sediment and organic carbon, movement to and from shallow groundwater, environmental degradation and overall persistence in the environment. The spatial and temporal variability of agricultural contaminants are currently being evaluated in a select number of watersheds; however, more information throughout the entire Bay Watershed is needed to understand the implications for the health of aquatic organisms during sensitive life-stages.

Mitigation and potential interactions of contaminants with nutrients and sediment

Urban settings:

1. Presentations by researchers within and outside of the watershed showed that sediment capture and reactive filter BMPs can have a positive impact on toxic contaminant concentrations and toxicity related to polluted urban stormwater runoff. Specifically, unamended bioretention was reported effective at reducing PCB concentration and toxicity with distance from influent and with depth (Kjellerup and others). Studies are

ongoing to enhance reactive media to remove additional toxic contaminants such as PAHs, metals, and PCBs. Iron-amended sand filtration was reported to be effective in removing numerous pesticides and wastewater indicators (Keisling and others). Studies are ongoing to further understand the iron-enhanced sand filters impact on biological activity. In certain cases (e.g., when contaminant sources are in the stream or estuary) watershed-based based BMPs may not be an appropriate choice. A presentation highlighted novel technologies being tested and implemented in the Chesapeake Bay aimed at mitigating toxic pollutant impacts from legacy polluted sediment (Ghosh and others). These technologies include in-situ amendment of activated carbon into contaminated sediments to bind up the pollutants and the addition of bioamendments for the degradation of PCBs.

2. While advances on tracking the fate and transport of toxic contaminants in BMPs is occurring, there is a significant gap in compiling and communicating potential removal efficiencies (or the range of removal efficiency) to jurisdictions and stakeholders implementing BMPs. Continued expansion and compilation of the BMP studies examining both known and emerging toxic contaminants paired with some site-specific details will allow for jurisdictions to capitalize on possible co-benefits when implementing nutrient and sediment BMPs.
3. There was recognition that continued investment in understanding the site and context-specific chemistry when considering the impacts of sediment and nutrient regulations on toxic contaminant exposure and reduction is critical to success. These approaches are being implemented (e.g., Anacostia River sediment study) to accurately determine the sources of toxic pollutants in urban rivers that lead to impacts on water quality and accumulation in fish. Accurate targeting of sources are key to development management options and their success. Continued expansion of guidance for site investigation and understanding and how to determine, for example if the sediment is acting as a source or sink of contamination, will ultimately drive the failure or success of a BMP.

Agricultural settings:

1. For many of the toxic contaminants observed in agricultural areas, the addition of activated carbon to established BMPs and prioritizing BMPs that increase retention/residence time could be important to help reduce the input of contaminants from agricultural sources. Presentations by two researchers one within the watershed and one outside the watershed discussed the effectiveness of agricultural BMPs in minimizing toxic contaminants to surface waters. Proper manure management is essential in minimizing the release of antibiotics into the environment and reducing the potential for antibiotic resistance. Based on the current research best manure management strategies include applying only composted manure, 120 day waiting period if raw manure is applied prior to harvest, surface application in the fall when runoff potential is lower, subsurface application and finally the addition of buffer strips. In California reduction in sediment bound insecticides was achieved through the application of retention ponds and vegetative treatment systems. More water-soluble pesticides have the potential to be removed via activated carbon addition to these management practices.
2. There are quite a few BMPs used for nutrient and sediment reductions that have the potential to mitigate toxic contaminants based on their functions but more specific research with contaminants is needed to fully answer this question. Furthermore, to prioritize BMP implementation it is important to determine the types of contaminants that

need to be reduced (exposure), what the desired outcome is (improved fish health) and how the BMPs operate. To better manage the systems and determine which BMP(s) could be effective we need to determine our end member, when they are most susceptible and how can we better manage these pulses. We need a better understanding of contaminant fate and transport more specifically on the persistence, sorption and movement to groundwater. More research on contaminant exposure across time and space is also needed to understand BMP effectiveness.

3. BMPs are a necessary investment to reduce toxic contaminants and improve water quality. Continued investment in research in understanding the co-benefits of nutrient/sediment BMPs to improve water quality, habitat quality and preserve aquatic resources. Work closely with the management community to develop tools to identify sensitive areas/populations that would benefit from improved BMP implementation and/or monitoring. Use expert judgement, known contaminant properties and an understanding of BMP utility to build qualitative frameworks to begin to answer questions related to co-benefits to better inform the management community.

References

Fish Health

Blazer, V.S., L.R. Iwanowicz, C.E. Starliper, D.D. Iwanowicz, P. Barbash, J.D. Hedrick, S.J. Reeser, J.E. Mullican, S.D. Zaugg, M.R. Burkhardt and J. Kelble. 2010. Mortality of centrarchid fishes in the Potomac drainage: Survey results and overview of potential contributing factors. Journal of Aquatic Animal Health 22:190-218.

Blazer, V.S., L.R. Iwanowicz, H. Henderson, P.M. Mazik, J.A. Jenkins, D.A. Alvarez and J.A.Young. 2012. Reproductive endocrine disruption in Smallmouth Bass *(Micropterus dolomieu)* in the Potomac River Basin: Spatial and temporal comparisons of biological effects. Environmental Monitoring and Assessment 184: 4309-4334.

Blazer, V.S., A.E. Pinkney, J. A. Jenkins, L. R. Iwanowicz, S. Minkkinen, R. O. Draugelis-Dale, and J.H. Uphoff. 2013. Reproductive health of yellow perch *Perca flavescens* in selected tributaries of the Chesapeake Bay. *Science of the Total Environment* 447:198-209.

Blazer, V.S., D.D. Iwanowicz, H.L. Walsh, A.J. Sperry, L.R. Iwanowicz, D.A. Alvarez, R.A. Brightbill, G. Smith, W.T. Foreman and R. Manning. 2014. Reproductive health indicators of fishes from Pennsylvania watersheds: Association with chemicals of emerging concern. Environmental Monitoring and Assessment 186:6471-6491.

Fadaei, H., Williams, E., Place, A., Connolly, J., Ghosh, U. 2017. Assimilation Efficiency of Sediment-Bound PCBs Ingested by Fish Impacted by Strong Sorption. Environ. Toxicol. Chem. 36, 3480-3488.

Iwanowicz, L.R., V.S. Blazer, A.E. Pinkney, C.P. Guy, A.M. Major, K. Munney, S. Mierzykowski, S. Lingenfelser, A. Secord, K. Patnode, T.J. Kubiak, C. Stern, C.M. Hahn, D.D. Iwanowicz, H.L. Walsh and A. Sperry. 2016. Evidence of estrogenic endocrine disruption in smallmouth and largemouth bass inhabiting Northeast U.S. National Wildlife Refuge waters: a reconnaissance study. Ecotoxicology and Environmental Safety 124:50-59.

Pinkney, A.E., J.C. Harshbarger, N.K. Karouna-Renier, K. Jenko, L. Balk, H. Skarphéðinsdóttir, B. Liewenborg, and M.A. Rutter. 2011. Tumor prevalence and biomarkers of genotoxicity in brown bullhead (*Ameiurus nebulosus*) in Chesapeake Bay tributaries. *Science of the Total Environment* 410:248-257.

Pinkney, A.E., J.C. Harshbarger, M.A. Rutter, and P.C. Sakaris. 2019 Trends in liver and skin tumor prevalence in brown bullhead (*Ameiurus nebulosus*) from the Anacostia River, Washington, DC, and nearby waters *Toxicologic Pathology* 47:174-189.

Uphoff J.H. Jr., M. McGinty, R. Lukacovic, J. Mowrer, and B. Pyle. 2011. Impervious surface, summer dissolved oxygen, and fish distribution in Chesapeake Bay subestuaries: linking watershed development, habitat conditions, and fisheries management. *North American Journal of Fisheries Management* 31: 554-566.

Walsh, H.L., V.S. Blazer, G. D. Smith, M. Lookenbill, D. A. Alvarez and K. L. Smalling. 2018. Risk factors associated with mortality of age-0 Smallmouth Bass in the Susquehanna River Basin, Pennsylvania. Journal of Aquatic Animal Health 30:65-80.

Primary Contaminant Sources

Ghosh, U., Kane-Driscoll, S., Burgess, R., Maruya, K., Jonker, C., Gala, W., Choi, Y., Beegan, C., Apitz, S., Mortimer, M., Reible, D. 2014. Passive Sampling Methods for Contaminated Sediments: Practical Guidance for Selection, Calibration and Implementation. Integr Environ Assess Manage. 10, 210-223.

Gluberman, M., Mandia, LC., Taylor, R., Gall, H.E. 2016. Development of an endocrine disrupting compounds footprint calculator. ASABE Paper No. 2455889. St Joseph, MI. pp 9.

He, K., Hain, E., Timm, A., Tarnowski, M., Blaney, L. 2019. Occurrence of antibiotics, estrogenic hormones, and UV-filters in water, sediment, and oyster tissue from the Chesapeake Bay. Science of the Total Environment 650(2), 3101-3109.

He, K., Timm, A., Blaney, L. 2017. Simultaneous determination of estrogens and UV-filters in aquatic tissues by sonication assisted liquid extraction and liquid chromatography tandem mass spectrometry. Journal of Chromatography A 1509, 91-101.

He, K., Soares, A.D., Adejumo, H., McDiarmid, M., Squibb, K., Blaney, L. 2015. Detection of a wide variety of human and veterinary fluoroquinolone antibiotics in municipal wastewater and wastewater-impacted surface water. Journal of Pharmaceutical and Biomedical Analysis 106, 136-143.

Hopkins, Z., Blaney, L. 2016. An aggregate analysis of personal care products in the environment: Identifying the distribution of environmentally-relevant concentrations. Environment International 92-93, 301-316.

Sanders, J.P., Andrade, N.A., Ghosh, U. 2018. Evaluation of passive sampling polymers and non-equilibrium adjustment methods in a multi-year surveillance of sediment porewater PCBs. In review, Environ. Toxicol. Chem. 37, 2496–2505.

Van Epps, A.; Blaney, L. 2016. Antibiotic residues in animal waste: Occurrence and degradation in conventional agricultural waste management practices. Current Pollution Reports 2(3), 135-155.

Fate and Transport

Kibuye, KA., Gall, H.E., Elkin, K.R., Ayers, B., Veith, T.L., Miller, M., Jacob, S., Hayden, K.R., Watson, J.E., Elliott, H.A. 2019. Fate of pharmaceuticals in a spray-irrigation system: From wastewater to groundwater. Sci Tot Environ. 654:197-208.

Mangalgiri, K.P., Blaney, L. (2017). Elucidating the stimulatory and inhibitory effects of dissolved organic matter from poultry litter on photodegradation of antibiotics. Environmental Science & Technology 51(21), 12310-12320.

Mina, O., Gall, H.E., Elliott, H.A., Watson, J.E., Mashtare, M.L., Langkilde, T., Harper, J.P., Boyer, E.W. 2018. Estrogen occurrence and persistence in vernal pools impacted by wastewater irrigation practices. Agr Ecosys Environ. 257:103-112.

Mina, O., Gall H.E., Saporito, L.S., Elliott, H.A., Kleinman, P. 2017. Relative role of transport and source-limited controls for estrogen, TDP, and DOC export for two manure application methods. Agr Ecosyst Environ, 247:308-318.

Needham, T.P. and Ghosh, U. 2019. Four decades since the ban, old urban wastewater treatment plant remains a dominant source of PCBs to the environment. Environmental Pollution 246, 390-397.

Mitigation

Beckingham, B., Ghosh, U. 2011. Field scale reduction of PCB bioavailability with activated carbon amendment to river sediments. Environ. Sci. Technol., 45, 10567–10574

Ghosh, U., Patmont, C., et al. 2015. In Situ Sediment Treatment Using Activated Carbon: A Demonstrated Sediment Cleanup Technology. Integr Environ Assess Manage, 11, 195-207

Ghosh, U., et al. In-situ sorbent amendments: A new direction in contaminated sediment management. 2011. Sci. Technol. Feature Article, 45, 1163–1168.

Gilmour, C., et al. 2018. Activated carbon thin-layer placement as an in situ mercury remediation tool in a Penobscot River salt marsh. Science of the Total Environment 621, 839–848

Payne, R.B., Ghosh, U., May, H.D., Marshall, C.W., Sowers, K. 2019. Pilot-Scale Field Study: In Situ Treatment of PCB-Impacted Sediments with Bioamended Activated Carbon. Environ. Sci. Technol., 53, 2626−2634

Sanders, J.P., et al. 2018. Persistent reductions in the bioavailability of PCBs at a tidally inundated Phragmites australis marsh amended with activated carbon. Environ. Toxicol. Chem. 37, 2487–2495

Snowberger, S., Adejumo, H.A., He, K., Mangalgiri, K.P., Hopanna, M., Soares, A.D., Blaney, L. 2016. Direct photolysis of fluoroquinolone antibiotics at 253.7 nm: Specific reaction kinetics and formation of equally-potent fluoroquinolone antibiotics. Environmental Science & Technology 50(17), 9533-9542.

Agricultural BMPs

Anderson BS, Phillips BM, Hunt JW, Largay B, Shihadeh R, Tjeerdema RS. 2011. Pesticide and toxicity reduction using an integrated vegetated treatment system. Environ Toxicol Chem. 30: 1036-1043.

Anderson BS, Phillips BM, Voorhees JP, Siegler K, Tjeerdema RS. 2016. Bioswales reduce contaminants associated with toxicity in urban stormwater. Environ Toxicol Chem. 35: 3124-3144,

Cahn M, Phillips BM. 2019. Best Management Practices for Mitigating Pesticides in Runoff from Vegetable Systems in California. In:Pesticides in Surface Water: Monitoring, Modeling, Risk Assessment, and Management. Goh KS, Gan J, Young DF, Luo Y (Eds).American Chemical Society (invited).

Hunt J, Anderson B, Phillips BM, Largay B. 2007. Effectiveness of Agricultural Management Practices in Reducing Concentrations of Pesticides Associated with Toxicity to Aquatic Organisms; Data Summary and Final Report. California Water Quality Control Board, Central Coast Region.

Hunt JW, Anderson BS, Phillips BM, Tjeerdema RS, Largay B, Hanson E, Beretti M, Bern A. 2008. Use of toxicity identification evaluations in determining the pesticide mitigation effectiveness of on-farm vegetated treatment systems. Environ Poll. 156: 348-358.

Mina O, Gall HE, Saporito LS, Kleinman PJA. 2016. Estrogen transport in surface runoff from agricultural fields treated with two application methods of dairy manure. J Env Qual. 45:2007-2015.

Phillips BM, Anderson BS, Siegler K, Voorhees JP, Tjeerdema RS. 2012. Optimization of an Integrated Vegetated Treatment System Incorporating Landguard A900 Enzyme: Reduction of Water Toxicity Caused by Organophosphate and Pyrethroid Pesticides. Final Report. Resource Conservation District of Monterey County and the United States Department of Agriculture Natural Resources Conservation Service and The California Department of Pesticide Regulation.

Phillips BM, Anderson BS, Cahn M, Budd R, Goh K. 2017. An Integrated Vegetated Ditch System Reduces Chlorpyrifos Loading in Agricultural Runoff. Integ Environ Assess Manage. 13: 423-430.

Urban BMPs

Cao, S., Capozzi, S.L., Kjellerup, B.V., and Davis, A.P., 2019, Polychlorinated biphenyls in stormwater sediments: Relationships with land use and particle characteristics, Water Research, Vol. 163: 114865, https://doi.org/10.1016/j.watres.2019.114865.

David, N., Leatherbarrow, J.E., Yee, D., McKee, L.J., 2014. Removal Efficiencies of a Bioretention System for Trace Metals, PCBs, PAHs, and Dioxins in a Semiarid Environment, J. Environ. Eng., 2015, 141(6): 04014092, DOI: 10.1061/(ASCE)EE.1943-7870.0000921

Devrim Kaya, D., Sowers, K., Demirtepe, H., Stiell, B., Baker, J., Imamoglu, I., Kjellerup, B.V., Assessment of PCB contamination, the potential for in situ microbial dechlorination and natural attenuation in an urban watershed at the East Coast of the United States, Science of The Total Environment, Vol. 683:154-165, 15 September 2019.

DiBlasi*, c., Li, H., Davis, A.P., and Ghosh, U. 2009. Removal and Fate of Polycyclic Aromatic Hydrocarbon Pollutants in an Urban Stormwater Bioretention Facility. ***Environ. Sci. Technol***. 43, 494-502

Jing R., Fusi, S., Chan, A., Capozzi, S., Kjellerup, BV, 2019, Distribution of polychlorinated biphenyls in effluent from a large municipal wastewater treatment plan: Potential for bioremediation? J Environ Sci (China). 2019 Apr;78:42-52. doi: 10.1016/j.jes.2018.06.007. Epub 2018 Jun 21.

Kaya, D., Sowers, K., Demirtepe, H., Stiell, B., Baker, J.E., Imamoglu, I., Kjellerup, B.K., 2019, Assessment of PCB contamination, the potential for in situ microbial dechlorination and natural attenuation in an urban watershed at the East Coast of the United States. Science of the Total Environment 683 (2019) 154–165

Fairbairn, D., Elliott, S.M, Kiesling, R.L., Schoenfuss, H., Ferrey, M., and Westerhof, B. 2018, Contaminants of emerging concern in urban stormwater: Spatiotemporal patterns and removal by iron-enhanced sand filters (IESFs), Water Research 145: 332-345

Wu, J., Kauhanen, P.G., Hunt, J.A., Senn, D.B., Hale, T., and McKee, L.J., 2019, Optimal Selection and Placement of Green Infrastructure in Urban Watersheds for PCB Control. J. Sustainable Water Built Environ., 2019, 5(2): 04018019. DOI:10.1061/JSWBAY.0000876

Appendix A: Workshop Agenda

Integrating Science and Developing Approaches to Inform Management for Contaminants of Concern in Agricultural and Urban Settings

A Scientific and Technical Advisory Committee (STAC) Workshop

Dates: May 22-23, 2019

Location: Sheraton Inner Harbor

300 S Charles St., Baltimore, MD 21201

Workshop Webpage

Day 1 – Wednesday, May 22

Start time (duration, min)		Presentation Topic	Organization	Speaker
10:00 am (20)	**Introduction**	Logistics, Workshop Objectives (listed in table 1)	USGS	Scott Phillips
10:20 am (40, 5 minutes for each panelist and 10 for Q&A)	**Jurisdictional Panel: Overview of issues and mitigation efforts**	Each member will briefly present: • Status and distribution of fish health issues and consumption advisories in their jurisdictions • Current approaches to mitigate contaminants • Opportunities to use sediment and nutrient reduction efforts for Bay TMDL to mitigate toxic contaminants	State agencies and DC	VA: Mark Richards WV: John Writs DE: John Cargill MD: Len Schugam DC: Matt English PA: Tim Wertz
11:00 am (20/10)	**Session I: Primary Contaminants**	Fish health issues and relation to contaminants in agricultural settings	USGS	Vicki Blazer

11:30 am (20/10)	**and their effects on Fish Health and Consumption Advisories**	Fish health issues and relation to contaminants in urban settings	USFWS	Fred Pinkney
12:00 pm (45)	*Lunch (provided)*			
12:45 pm (20/10)	**Session II: Primary Contaminant Sources, Fate, and Transport**	Lessons from other watersheds: Legacy Contaminants and Lessons Learned in Puget Sound and other restoration efforts	UW Tacoma	Andy James
1:15 pm (20/10)		Lessons from other watersheds: Legacy Contaminants and Lessons Learned in the Hudson River and NY-NJ Harbor	Manhattan College	Kevin Farley
1:45 pm (20/10)		Urban sources of contaminants of emerging concern: what is getting into the Chesapeake Bay and how can we reduce that load	UMBC	Lee Blaney
2:15 pm (20/10)		Endocrine Disrupting Chemicals found in agricultural settings of the Chesapeake watershed	USGS	Kelly Smalling
2:45 pm (15)	*Break and move into breakout sessions*			
3:00 pm (90)	**BREAK OUT SESSIONS**: *One group will focus on for agricultural settings, and another on urban settings.* Issues to be discussed include: ● primary contaminants affecting fish health and fish consumption advisories ● the sources and transport of these chemicals ● additional information and research needed ● See questions in table 1 The answers from these breakout sessions will be used to help inform the day 2 breakout sessions on approaches to mitigate the effects of contaminants in urban and agricultural settings, and additional opportunities from nutrients sediment practices.			
4:45 pm (20/10)	**Session III: Mitigation and potential interactions with nutrient and sediment reductions**	Removal of the toxic contaminants PCBs and PAHs by urban BMPs	UMD-CP	Birthe Kjellerup
5:15 pm (15)	Wrap up/Recess	Meet in hotel bar for drinks afterwards		Steering Committee

5:15-5:30 pm	*Steering committee de-brief*

Day 2 – Thursday, May 23

Start time (duration , min)		**Presentation Topic**	**Organization**	**Speaker**
8:30 am (15)	**Welcome and reports from Day 1 breakout sessions**	Reports from Day 1 breakout sessions: agricultural and urban settings; Goals for day 2		Speaker from each session; steering committee
8:45 am (20/10)	**Opening**	Lessons Learned from other watersheds: Delaware River Basin Contaminants of Emerging Concern Surveys	DRBC	Ron McGillivray
9:15 am (20/10)	**Session III: Mitigation and potential interactions with nutrient and sediment reductions**	Overview of nutrient and sediment BMPs being used in Ag and Urban Settings by jurisdictions in Phase III WIP development	Devereux Environmental Consulting	Olivia Devereux
9:45 am (20/10)		Iron-enhanced sand filters for removal of CECs in urban stormwater	USGS Upper Midwest	Richard Kiesling (remote)
10:15 am (20/10)		Introduction to and appropriateness of in-stream innovative approaches to sediment remediation	UMBC	Upal Ghosh
10:45 am (15)	*Break*			
11:00 am (20/10)	**Session (cont.)**	Ten Years of Management Practice Effectiveness Research at the UC Davis Granite Canyon Laboratory	UC Davis	Bryn Phillips (remote)
11:30 am (20/10)		Impact of Manure Best Management Practices on Environmental Input of Emerging contaminants	Virginia Tech	Kang Xia
12:00 pm (120)	*Working lunch (provided) and* BREAK OUT SESSIONS – *One group will focus on for agricultural settings, and another on urban settings.* Issues to be discussed include: • Current practices, and their effectiveness, to mitigate the effects of toxic contaminants in each setting			

	● Best opportunities to use nutrients and sediment practices to also mitigate contaminants in urban and agricultural settings ● Remaining science and research needs for more effective mitigation of toxic contaminants ● See questions in table 1	
2:00 pm (60)	**Workshop Summary and next steps**	Break out reports and wrap up
3:00 pm	*Adjourn*	
3:00-3:30 pm (30)	*Steering Committee meet to discuss workshop report*	

Table 1: Workshop Objectives and suggested questions to be addressed in each breakout session (updated May 20, 2019)		
Workshop Objectives	● Present and discuss major findings from the recent and ongoing science related to toxic contaminants in agricultural and urban settings. The focus will be on contaminants related to fish consumption advisors, affecting fish health, and those of emerging concern. ● Summarize the understanding of the sources, transport, fate, and effects of chemicals of concern. In agricultural settings, the focus will include chemicals associated with manure generation and pesticide application. PCBs will one of the topics in urban areas. ● Identify opportunities to mitigate effects of chemical contaminants in each setting by taking advantage of practices being implemented for nutrients and sediment reduction, and other innovative approaches. ● Identify future needs for the most pressing research directions and more integrated management approaches.	
Breakout sessions	<u>Group 1: Urban setting questions</u> Leaders: Greg Allen and Emily Majcher Note taker: Rachel Dixon	<u>Group 2: Agricultural setting questions</u> Leaders: Kelly Smalling and Chris Brosch Note taker: Annabelle Harvey
Day 1: Fish consumption advisories, fish health, and the associated chemicals	What are the known contaminants (long-known and emerging) causing fish consumption advisories, fish health risks, and risks to other aquatic species in urban areas? Which emerging or suspected contaminants may pose the greatest	What are the known contaminants causing fish consumption advisories, fish health issues, or other aquatic species in agricultural areas? Which emerging or suspected contaminants may pose the greatest risk

	risk to fisheries and other aquatic organisms in urban areas? What are the primary sources of chemicals causing fish consumption advisories or fish health problems in urban areas? Which sources are similar for contaminants, nutrients and sediment in urban areas? What are fate and transport of chemicals causing fish consumption advisories or fish health problems in urban areas? What additional information and research is needed to better define the presence, effects, sources and management options in urban areas?	to fisheries and other aquatic organisms in agricultural areas? What are the primary sources of chemicals causing fish consumption advisories or fish health problems in agricultural areas? Which sources are similar for contaminants, nutrient and sediment in agricultural areas? What are fate and transport of chemicals causing fish consumption advisories or fish health problems in agricultural areas? What is known for areas dominated by animal operations? What is known for areas of crop production and associated pesticide applications? What additional information and research is needed to better define the problems?
Day 2: Mitigation of toxic contaminants, and potential	Which of the chemicals are already regulated in urban areas?	Which of the chemicals are already regulated in agricultural areas?

interactions with nutrient and sediment reductions	What are the current practices, and their effectiveness, to mitigate the effects of toxic contaminants in urban areas? What are the best opportunities to use nutrients and sediment practices to also mitigate contaminants in urban areas? Are there potential risks of nutrient and sediment practices for mitigating toxic contaminants in urban areas? What other innovative approaches should be considered for urban areas? What are the remaining science and research needs for more effective mitigation of toxic contaminants in urban areas?	What are the current practices, and their effectiveness, to mitigate the effects of toxic contaminants in agricultural areas? What are the best opportunities to use nutrients and sediment practices to also mitigate contaminants in agricultural areas? Are there potential risks of nutrient and sediment practices for mitigating toxic contaminants in agricultural areas? What other innovative approaches should be considered in agricultural areas? What are the remaining science and research needs for more effective mitigation of toxic contaminants in agricultural areas?

Appendix B: Table B-1: Fish health and ecological impact of contaminants of concern

Contaminant Class	**Fish Consumption Advisory? (yes/no)**	**Fish Health and Other Ecological Effects?**	**Conveyance (shared with nutrients or sediment – yes/no)**	**Fate and Transport in the Environment (green=well defined, yellow=not as well defined, red=poorly defined)**
Known *(Current fish consumption advisory within the watershed and/or ecological effects threshold exceeded)*				
PCBs	Yes	Reproductive, survival, trophic transfer Impacts on community structure	Stormwater (Y) Wastewater (Y) Atmospheric (N)	
PAHs	No	Larval toxicity, tumors, fish development (cardiac) Benthic community	Stormwater (Y) Atmospheric (Y)	
Dioxins/Furans	Yes	Reproductive, survival, trophic transfer	Stormwater (Y) Biosolids runoff (Y) Atmospheric (N)	
Organochlorine pesticides	Yes	Community impacts	Stormwater (Y)	
Mercury	Yes	Survival/mortality	Atmospheric (N) Stormwater (Y)	
Metals (i.e. Pb, Cu, Zn, Cr, Al)	No	Larval mortality	Stormwater (Y) Atmospheric (N)	
Salts (chlorides)	No	Toxic to freshwater species, benthic Impacts to benthic community	Stormwater (Y) Groundwater (Y)	
Hydrocarbons	No	Larval toxicity, tumors, fish	Stormwater (Y) Wastewater (Y)	

		development (cardiac) Benthic community	Groundwater (Y)	
Suspected (presence and association with fish health effects)				
PFAS	No	Little available data in Chesapeake Bay watershed	Groundwater Stormwater Atmospheric Wastewater	
Antibiotics	No	Little available data in Chesapeake Bay watershed	Wastewater (septic)	
Newer class pesticides (e.g., Neonicotinoids)	No	Little available data in Chesapeake Bay watershed	Stormwater	
Estrogenic hormones	No	Reproduction Immune suppression	Wastewater	
Contaminant Class	**FCA? (yes/no)**	**Fish Health and other ecological Effects?**	**Conveyance (shared with nutrients or sediment – yes/no)**	**Fate and Transport in the Environment (green=well defined, yellow=not as well defined, red=poorly defined)**
Plastics	No	Respiration in larval fish, mortality, impacts to zooplankton	Wastewater Stormwater Litter	
Triclosan/Triclocarban	No	Impacts to benthics	Wastewater	
UV filters	No	Little available data in Chesapeake Bay watershed, study in DE bay on horseshoe crabs	Wastewater Stormwater Recreation	
BPx (plasticizers)	No	Little available data in CB	**Wastewater** **Stormwater** **Litter**	

Appendix C: Selected Findings from Previous Toxic Contaminants Workgroup (TCW) Efforts

The CBP Toxic Contaminant Workgroup has supported several previous efforts to relate nutrient and sediment practices for mitigation of toxic contaminants. Documents related to these efforts were provided to workshop attendees prior to the workshop and are summarized in the following sections.

The Chesapeake Stormwater Network undertook a project to address the potential benefits of nutrients and sediment practices BMPs to reduce toxic contaminants in the Chesapeake Bay watershed. Two reports were produced: Part 1: Removal of urban toxic contaminants (2015), and Part 2: Removal of toxic contaminants in agricultural and wastewater sectors (2016).

The urban report on removal of urban toxic contaminants summarized 12 toxins as urban toxic contaminants (UTC), and provided a summary of the toxin-sediment relationship, and whether sediment BMPs could retain the associated contaminants (Figure4.1/Table E-2). The assumption was made for this evaluation that the primary source of the contaminant was co-occurring with nutrient and sediment sources (e.g., polluted urban stormwater) (https://www.chesapeakebay.net/documents/Final_Report_on_Urban_Toxic_Contaminants.pdf).

Table E-2: Comparison of BMP Treatability for the Seven Urban Toxic Contaminant Groups

Toxin Category	BMP Removal Rate?	Measured or Estimated?	Behaves like Sediment?	BMP Retention?	Sediment Toxicity Concern?
PCBs	TSS	E	Y	Y	PR
PAH	>TSS	E	Y	Y	CR
TPH	>TSS	M	Y	Y	MR
Hg	>TSS	E	Y	Y	PR
UTM	< TSS	M	Y	Y	PR

OTM	< TSS	M	Y	Y	PR
Dioxins	< TSS	E	Y	ND	ND
Toxin: TPH: Total Petroleum Hydrocarbons UTM: Urban toxic metals OTM: Other toxic materials Removal Rate: >TSS: Higher than TSS Removal TSS: Similar to TSS Removal < TSS: Less than TSS Removal M= Measured E= Estimated			Y = Yes, based on strong evidence Y = Yes, limited monitoring data provides support ND = no data available to assess PR: Potential Risk CR: Clear Risk MR: Minimal Risk		

The Chesapeake Stormwater Network report (2016) on agricultural BMPs had major findings focused on (1) conservation tillage and herbicides, (2) biogenic hormones in animal manure and municipal biosolids, and (3) antibiotics in animal manure and municipal biosolids. Find the report text summarizing each topic below:

(https://www.chesapeakebay.net/documents/Final_Report_on_Ag_and_Wastewater_Toxics.pdf)

Conservation tillage and herbicides: Corn and soybeans are planted in about 3 million acres in the watershed in any given year. The changes include a major shift towards conservation tillage and genetically modified crops and greater use of herbicides to control weeds. According to USDA statistics, herbicides are now applied to more than 97% of corn acres and at least 90% of all soybean acres. Conservation tillage is a key practice to reduce sediment and nutrient loads from the agricultural sector. On balance, the increased use of conservation tillage has been an effective strategy to reduce these loads in the Chesapeake Bay watershed. By 2005, most farmers had shifted away from herbicides used in past, such as—atrazine and metolachlor—relying onto glyphosate instead. For several years, this change appears to have improved water quality, as measured by fewer groundwater advisories and exceedances of aquatic life benchmarks for these herbicides. In recent years, however, many weed species have become resistant to glyphosate, which has caused many farmers to switch to a wider spectrum of herbicides for weed control, including atrazine. The water quality implications of this change are still unclear. Glyphosate and its degradant, AMPA, are mobile in the environment and are frequently detected in surface waters but are not as persistent in soil or water as atrazine and other herbicides. Testing has shown that glyphosate and AMPA are much less toxic to bird, fish, and aquatic life, do not bioaccumulate in tissues, and have minimal impacts on human health. In addition, limited monitoring data suggest that vegetated buffers, constructed wetlands, biofilters, and ponds all have a moderate to high capability to remove and degrade glyphosate and AMPA.

Biogenic hormones in animal manure and municipal biosolids: Biogenic hormones are generated by animal feeding operations and are released by wastewater treatment plants. Higher concentrations are often associated with a high watershed density of either animal feeding operations or wastewater treatment plants. Research has shown that agricultural BMPs, such as vegetated buffers, constructed wetlands, and lagoons, are highly effective in removing biogenic hormones in runoff from animal feeding operations. Likewise, wastewater treatment upgrades used for the Bay TMDL, such as biological nutrient removal, have proven to be very effective in removing biogenic hormones in wastewater effluent. Research data suggests that biogenic hormones can become concentrated in animal manure and municipal biosolids. When these manure and treatment residuals are applied to crops as a fertilizer and soil amendment, they can potentially migrate into the aquatic environment. More research is needed to determine the significance of this loss pathway. One important pollution prevention strategy is to keep unneeded hormones out of the food supply chain. Many livestock producers, retailers, and restaurant chains have recently adopted policies to eliminate the use of biogenic hormones in the meat, poultry, and milk they purchase.

Antibiotics: The main concern about these compounds is their potential to increase bacterial resistance to these drugs, which could reduce their therapeutic effect on infectious diseases. Some research also indicates that some antibiotics can degrade negatively impact the soil microbial community and reduce the rate of denitrification, which is a critical process for reducing nitrogen. The analysis of antibiotics was very much limited by data quality problems. While we have learned more about the sources and pathways of antibiotics in the watershed, we lack a basic understanding about whether they are effectively removed by agricultural practices and wastewater treatment upgrades, and whether leaching from animal manure or municipal biosolids are a significant problem or not. There is some evidence that BNR, which is increasingly used to achieve higher nutrient removal, may also be more effective in removing antibiotics from wastewater effluent. It remains unclear whether the antibiotics remaining in municipal biosolids generated by enhanced wastewater treatment can migrate back into the watershed after they are applied to croplands. An encouraging trend has been efforts to phase out the use of antibiotics in poultry, swine, and cattle feeding operations. Several livestock producers, grocery stores, and restaurant chains are now selling meat, poultry, and dairy products that are grown without antibiotics. If these efforts to eliminate antibiotics from the food supply chain are expanded, it would represent a very effective watershed reduction strategy. Another key management strategy is to practice "antibiotic stewardship" to minimize the volume mass that are prescribed for humans and ensure that these pharmaceuticals are properly disposed to prevent their release to the environment.

CBP Fact Sheet: Toxic Contaminants Principles for Phase III Watershed Implementation Plans

The fact sheet was prepared by the CBP in consultation with the Toxic Contaminant Work group. https://www.chesapeakebay.net/channel_files/25480/toxics_2.pdf
Information was used information from CSN reports and a later TetraTech report on effects of nutrient and sediment practices BMPs on other CBP outcomes. Some of the key findings include the following:
Urban areas: Any practices that controls or traps sediment and prevents stormwater runoff can aid in preventing release of UTCs into waterways and aquatic ecosystems. Some of the practices effective urban practices BMPs listed included narrow forest buffers, runoff reduction, and wet ponds.

Agricultural areas: Effective agricultural practices BMPs included forest buffers, streamside forest buffers, and narrow forest buffers.

Appendix D: Workshop Participants

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