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

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STAC Workshop Report
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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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STAC Administrative Support Provided by:

Chesapeake Research Consortium, Inc.
645 Contees Wharf Road
Edgewater, MD 21037
Telephone: 410-798-1283
Fax: 410-798-0816
http://www.chesapeake.org

Workshop Steering Committee:

Scott Phillips, Chesapeake Bay Coordinator, USGS, Co-Chair of STAR (Workshop lead),
Greg Allen, Coordinator of CBP Toxic Contaminant WG, USEPA,
Brian Benham, Professor and Extension Specialist, Virginia Tech (STAC Chair)
Vicki Blazer, Research Biologist, U.S. Geological Survey (USGS),
Lee Blaney, Associate Professor, University of Maryland Baltimore County (UMBC),
Heather Gall, Associate Professor, Penn State University,
Kelly Smalling, Research Hydrologist, USGS,
Kang Xia, Professor, Virginia Tech,
Chris Brosch, Administrator, Delaware Department of Agriculture,
Upal Ghosh, Professor, UMBC,
Emily Majcher, Hydrologist, USGS,
Fred Pinkney, USFWS,

Acknowledgements: (optional)

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Executive Summary

A wide range of contaminants of agricultural, human and industrial origin have degraded water quality and as a result, fish and wildlife populations. Many of these pose a threat to human health in the Chesapeake Bay watershed. A STAC workshop was held that brought researchers together with water-quality managers working in urban and agricultural settings to synthesize the current knowledge on chemicals of concern, and discuss how selected best management practices (BMPs) and other innovative approaches can collectively reduce contaminants, nutrients, and sediment.

The specific objectives of the workshop were to:

- Present and discuss major findings from the recent and ongoing science related to contaminants in agricultural and urban settings. The focus will be on toxic 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 the 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. These are organized into three major topics, with each topic addressing both urban and agricultural settings

The report and executive summary are organized around these objectives.

<u>Fish health and advisories: major findings, gaps, recommendations</u>

1. 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.
2. 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. In agricultural watersheds, research should follow-up on the linkages between agricultural land use, contaminants, immunosuppression, water quality, and disease. In urban areas, research should examine the declines in anadromous and semi-anadromous fish populations associated with urbanization. Such information will help managers focus efforts to minimize these impacts as land use changes.

Understanding of sources fate and transport

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, biosolid 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 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, Per- and polyfluoroalkyl substances (PFAs), flame retardants, microfibers/plastics, and engineered nanomaterials.
3. Fate and transport of emerging toxic contaminants in agricultural watersheds is currently limited and the panel's opinion is that more studies are necessary to really understand BMP effectiveness on contaminant removal and potential improvements in fish health. 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 but we need more information throughout the entire Bay Watershed to understand the implications these may have on the health of aquatic organisms during sensitive life-stages.

Urban settings:

1. In regions outside the Chesapeake Bay, including the Delaware River Basin and Puget Sound, ongoing work demonstrates the value in investing in clearly defining the system and regulatory endpoints prior to taking management actions. For example, in the Hudson River basin, significant loading of PCBs was determined to occur under baseflow conditions, resulting in limited reductions in fish tissue despite the extensive dredging and management efforts. In contrast, regulation and actions taken in New Jersey following detailed investigations by DRBC of PFAS compounds where a decrease has been observed over a 10 year timeframe.
2. The fate and origin of many of the contaminants of emerging concern (e.g., conditions controlling their degradation and predisposition for the aqueous or solid phase and their introduction to the watershed) are still being defined making it difficult to implement management actions such as BMPs. For example, the influence of septic systems on CEC concentrations in Chesapeake Bay tributaries is unknown.
3. 3. The application of high-resolution mass spectroscopy and wastewater-based epidemiology tools may improve the understanding of contaminant sources and loads to the Chesapeake Bay. Use of the source fingerprinting approach may be a way to discern complex mixtures of toxic contaminants under different land use conditions.

Mitigation and potential interactions of contaminants with nutrients and sediment

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 run-off potential is lower, subsurface application and finally the addition of buffer strips. In California reduction in sediment bound insecticides were 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.

Urban settings:

1. Presentations by researchers within and outside of the watershed showed that sediment capture and reactive filter BMPs have a positive impact on toxic contaminant concentrations and toxicity related to urban stormwater runoff. Specifically,

unamended bioretention was reported effective at reducing PCB concentration and toxicity with distance from influent and with depth. 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. Studies are ongoing to further understand the IESF impact on biological activity.

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 in 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 the possible co-benefit 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 successful implementation of BMPs that may reduce toxic contaminants. 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.

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). Many of these pose a threat to human health in the Chesapeake Bay watershed and many more are being detected and documented in literature for the first time. While significant efforts have been made to address nutrients and sediment, other contaminants of concern have yet to be addressed. 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 polychlorinated biphenyls - PCBs), and research. An important objective of research is to better understand the potential co-benefits and risks of managing nutrients and sediment, and getting an additional reduction of 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 Bay Total Maximum Daily Load for nutrients and sediment, (2) reducing toxic contaminants, and (3) improving local waters for fishing and recreation.

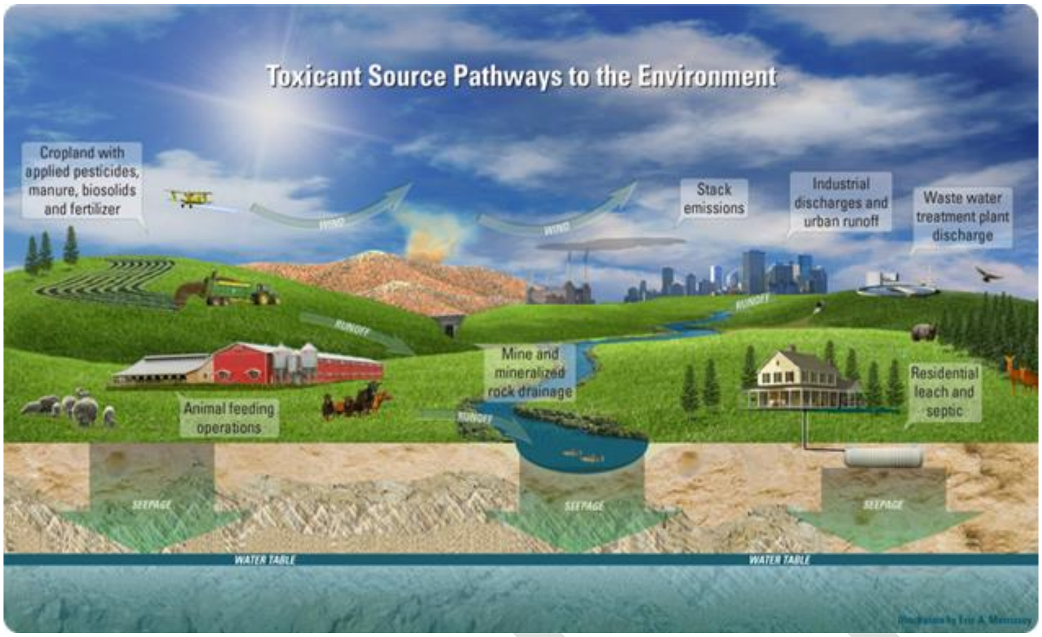

Figure 1.1: Conceptual diagram showing the source pathways of toxic contaminants to the environment. (SOURCE?)

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 problems (intersex, lesions, and mortality), and contaminants in urban and agricultural settings. Therefore, a STAC workshop was held that brought researchers together with water quality managers working in urban and agricultural settings to synthesize the current knowledge on chemicals of concern, and discuss how selected best management practices (BMPs) and other innovative approaches can collectively reduce contaminants, nutrients, and sediment.

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

Specific objectives of the workshop were to:

- Present and discuss major findings from the recent and ongoing science related to contaminants in agricultural and urban settings. The focus will be on toxic 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 the 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.

Fish consumption advisories, fish health, and the associated chemicals

A panel of representations from the 6 states in the watershed and 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 were used to summarize the key findings, and identify information needs, and recommend research directions.

Summary of consumption advisories and the chemicals

Fish consumption advisories are in place throughout the watershed for many different fish species due mostly to contamination from PCBs and mercury. In the District of Columbia, PCBs are frequently present in concentrations that exceed EPA screening values. DDT, Chlordane, Dieldrin, Heptachlor Epoxide occasionally exceed EPA screening values while PAHs and metals do not exceed EPA screening values. According to DDoEE, contaminants appear to be trending downward. Maryland reported Bay-wide fish consumption advisories. Advisories range from "no consumption" to "8 meals per month" Primary driver for Bay advisories is PCBs. Fish consumption advisories of "4 meals per month"and below result in an impairment listing. Listings are for non-migratory fish. In Delaware, concentrations of PCBs, mercury, dioxins/furans and other contaminants have fallen dramatically due to mitigation efforts. Consequently the number and severity of advisories have fallen in recent years.

Overview of Fish health and factors in agricultural areas

A variety of fish health concerns have been correlated to agriculturally dominated land-use as compared with urban, but not forest. Including 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 a cause. Findings included numerous viral and bacterial pathogens and high parasite loads including trematodes, cestodes and myxozoans, but no one "smoking gun". In 2005 mortality of young of year smallmouth bass began to be observed in areas of the Susquehanna River. Again, even though these fish are only 2-4 months of age they have bacterial and viral infections and numerous parasites. These findings suggested immunosuppression and increased disease susceptibility. During comprehensive fish health assessments, including microscopic analyses of all tissues, conducted to identify risk factors, associated with the mortality events, the presence of intersex or immature eggs within the testes, was observed. 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 landuse and certain chemicals such as estrone and atrazine. Numerous chemicals measured in water, sediment and fish tissue, including estrone and 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 can increase bacterial loads and virulence and parasite intermediate hosts. Chemicals including arsenic and triclosan have been measured in skin and may be associated with skin lesions and altered skin microbiomes.

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

Overview of fish health and factors in urban areas (by F. Pinkney)

In urban areas, fish are exposed to mixtures of toxic contaminants including PCBs, legacy and current use pesticides, polynuclear aromatic hydrocarbons (PAHs), and chemicals of emerging concern. 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 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 and 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 1). Bullheads also had a decreasing probability of developing skin tumors (Figure 2). Liver tumor prevalence is still about twice that 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, there are documented decreases in PCB and DDT concentrations 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 (Blazer et al. 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 (Fig. 3). Choptank eggs had few abnormalities. A followup study is in progress, led by University of Maryland Ph.D. student, Alex MacLeod, who is tracking 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 on the spawn 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.

<u>Summary of Information needs and recommendations for future science</u>

Research is needed to understand the response of economically important and indicator species to the multi-stressors (complex mixtures of chemicals, environmental stressors, and infectious agents) present in both agricultural and urban watersheds. This includes 1) developing early indicators of sublethal 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 (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 (viruses, chemical exposure, environmental) of skin tumors in brown bullhead, as well as skin lesions (melanistic, raised mucoid) of bass and other species.
2. Continued monitoring of the tidal Potomac River tumor prevalence to see if the decline continues so that it is no longer elevated vs. reference areas.
3. Evaluate specific mechanisms (adverse outcome pathways) associated with declines of anadromous and semi-anadromous fish populations as Chesapeake Bay tributaries urbanize.
4. Identify chemical concentrations of concern at sensitive (critical) life stages (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. Determine if current Best Management Practices are having a positive or negative effect on fish health

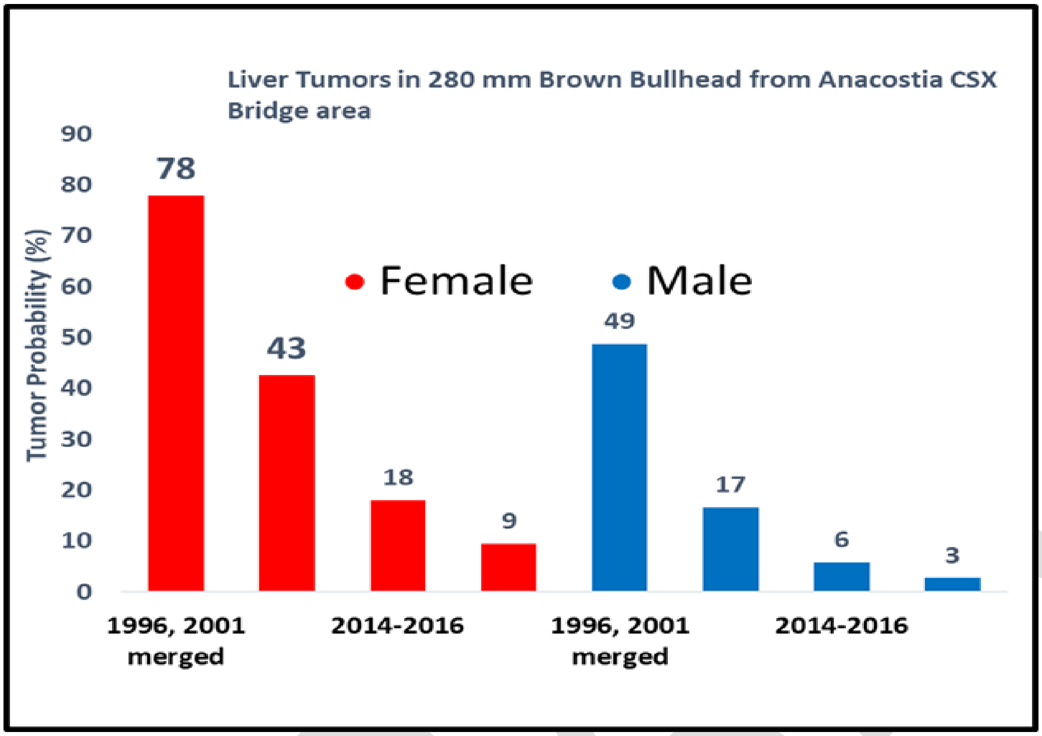

Figure 2.1. Decrease in liver tumor probabilities for 280 mm brown bullhead (Pinkney et al. 2019)

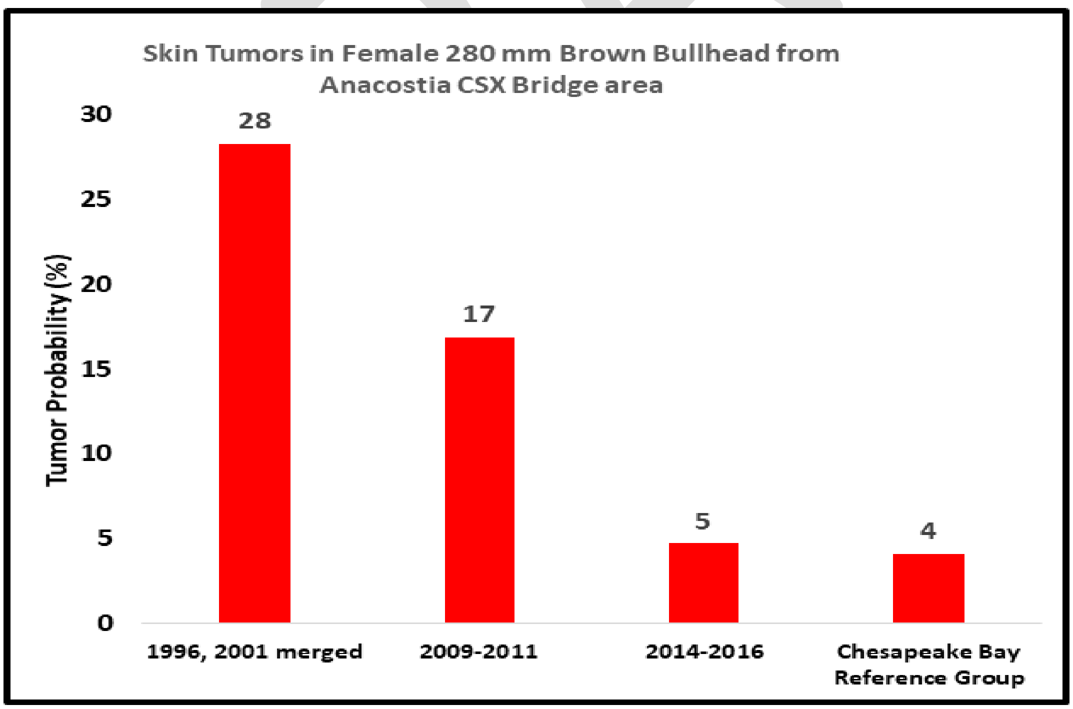

Figure 2.2. Decrease in skin tumor probabilities for female 280 mm brown bullhead from the Anacostia River (Pinkney et al. 2019)

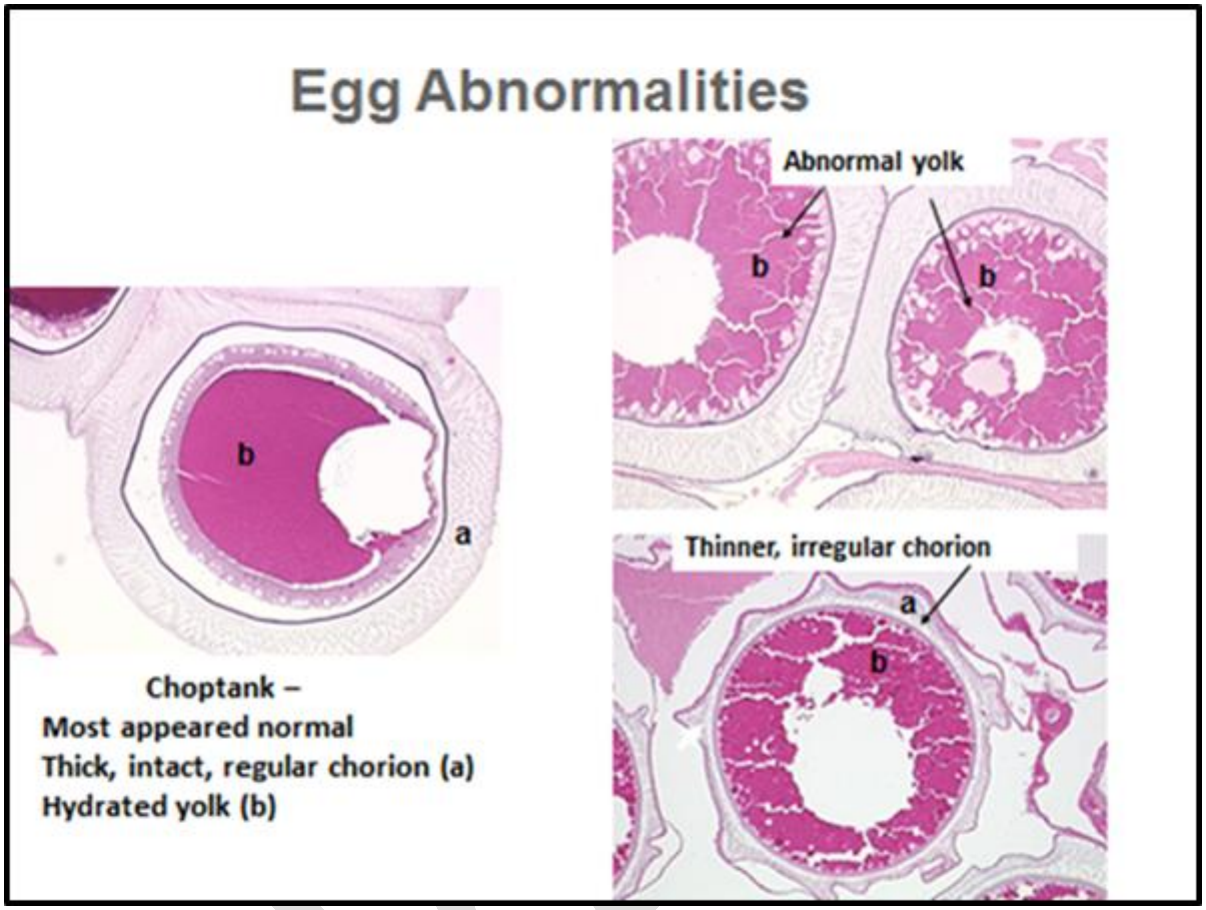

Fig. 2. 3. Egg abnormalities observed more frequently in yellow perch from urbanized rivers (e.g., Severn) (from Blazer et al. 2013). .

Primary Contaminant Sources, Fate, and Transport

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

<u>Urban Areas</u>

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 can then be 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. Mixed results were obtained by dredging PCB-contaminated sediment, with little improvement on the low-flow PCB load in the lower Hudson. Farley cautioned against overselling sediment removal remedy given the limited reduction observed in fish tissue in the Hudson despite the mass removal of sediment. Ron MacGillivray (Delaware River Basin Commission) described contaminant levels in the Delaware River. Metformin (a diabetes drug) was detected at high concentrations, but a number of other pharmaceuticals were also detected. Per- and polyfluoroalkyl substances (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 fillet generally decreased from 2004 to 2018, with the exception of PFOS in smallmouth bass. Ron 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 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. Hydrophobic contaminants, including estrogenic hormones and UV-filters, accumulated in crayfish in urban streams known to be impacted by leaking sewers. Lee also spoke about the importance of monitoring transformation products, which often retain the same pharmacological/toxicological activity as the original contaminant.

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

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 also include legacy organochlorine pesticides (such as chlordane and DDT) and dioxins/furans. Impacts to fish health, including reproductive and survival effects, as well as impact to community structure and trophic transfer are known for these compounds with FCA. PAHs and hydrocarbons, while not the driver of FCA, have known fish health effects including larval toxicity, development of tumors and impact to the benthic community. Salts (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 the 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 effects on the benthic community. More information is needed to assess fish health effects in the Chesapeake Bay watershed of several of the other emerging contaminants including PFAS, antibiotics, UV filters, plasticizers (BPx) and new pesticides such as neonicotinoids.

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 identified the conveyance of the toxic contaminants and the overlap of this conveyance with nutrients and sediment in the watershed, even if the source to that conveyance differed. The primary overlap between regulated toxic contaminants (PCBs, dioxins/furans, organochlorine pesticides (OCP), and mercury) is in the conveyance of stormwater to streams. Lesser than stormwater, wastewater (via treatment plants and biosolids) is a common conveyance of PCBs and dioxins/furans. Several of these compounds (all but the OCP) have an atmospheric source that does not overlap with nutrients and sediment.

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 can be 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, for some of the contaminants causing fish consumption advisories and fish health effects the fate and transport in a variety of environmental conditions is well understood. This includes most of the contaminants with known fish health effects, aside from perhaps mercury and other metals.

For the toxic contaminants with suspected fish health effects is the fate and transport of these contaminants, very little is known about their fate and transport. This is a significant gap in the understanding of these compounds and a need for further work to better define their degradation characteristics, and their preferences for surface water or sediment under different conditions was identified.

What additional information and research is needed to better define the presence, effects, sources and management options in urban areas? GAP HERE _ GREG, CAN WE INFER ANYTHING FROM OUR "GAPS"??
Information needs and recommendations for future science in urban areas - fate and transport
Others?

Agricultural Areas

Ongoing efforts to monitor toxic contaminants in agricultural areas in 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 Project nested under the purview of the Environmental Health Mission Area has been studying the sources, fate, exposure and effects of EDCs in 5 agricultural watersheds in the Chesapeake Bay from 2013 to present. Kelly Smalling (USGS) highlighted the results of 4 years of intensive contaminant monitoring data with respect to contaminant occurrence and relationships with land-use, select landscape variables and flow. Watersheds studied were a mix of row-crop agriculture, animal feeding operations and urban/suburban development. Over 200 contaminants were measured and of those the chemicals that occurred frequently included herbicides (atrazine, metolachlor), cholesterol and phytoestrogens (naturally occurring estrogens). Flow was a dominant predictor for herbicides, cholesterol and phytoestrogens across sites predominantly in the spring during run-off 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 these preliminary results, management actions designed to reduce run-off could have co-benefits for some EDCs. To adequately answer this question more process-based research is needed focused entirely on the co-benefits of BMP for contaminant reduction.

The number of concentrated animal feeding operations continues to increase in the Chesapeake Bay and Kang Xia (Virginia Tech) highlighted the dominant contaminants associated with this agricultural setting. Antimicrobial compounds used to keep livestock healthy and both natural and synthetic hormones are the dominant contaminants present in manure from animal agriculture. The use of antimicrobial compounds began in the 1950s but has increased substantially due to how we raise animals. Local free-range farming has been converted to large animal operations where disease must be intensely managed. The types of antimicrobial compounds and hormones detected in manure varies by animal type and age which can result in a concentrated source of contaminants to surface and groundwater. The use of antimicrobial compounds has also resulted in increased prevalence of antimicrobial resistant genes which have the potential to occur in local food sources such as vegetables grown in areas where manure is land-applied.

Major findings from Agriculture Breakout Session

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. DDT and Hg 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 Hg 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.

There is less known about the direct and indirect effects of emerging contaminants on aquatic organisms. Estrogens, natural and synthetic, have the potential to induce intersex in fish while other studies have shown that atrazine can modulate the endocrine system as well. Other contaminants considered to adversely affect aquatic organisms include PAHs, pyrethroid insecticides, bifenthrin, neonicotinoid insecticides and metals such as As and Cu. More information on the effects of microplastics, therapeutic drugs and pesticide adjuvants is needed to really assess the effects of chemical mixtures present on agricultural lands that can be transported to waterways. Furthermore, we need to better characterize sediment bound contaminants. As sediment continues to threaten fisheries and their habitats, 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, biosolid application, irrigation of treated wastewater and septic systems (the latter three being human in origin). Commonly applied pesticides include atrazine, neonicotinoid insecticides, copper, bifenthrin (pyrethroid insecticide) as well as the proprietary adjuvants co-applied with the active ingredients. In the Chesapeake Bay Watershed similar to other agricultural watersheds, legacy signatures of DDT and arsenic still persist. Common contaminants present in manure include antibiotics, natural hormones as well as some phytoestrogens. Human influences to the agricultural landscape including biosolid application, septic systems and wastewater reuse and have the potential to be sources of a wide variety of contaminants including but not limited to

PCBs, pharmaceuticals, metals, personal care products, synthetic hormones, PFAS compounds, flame retardants, etc. Other contaminants present in agricultural landscapes include Hg and phytoestrogens (natural estrogens from plants).

Although information is readily available regarding contaminant sources less is known about the effects of these toxic contaminants 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 is currently lacking on septic systems as a source of contaminants to surface 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 biosolid and manure application, irrigation of treated wastewater and septic systems including hydrophobic contaminants bound to sediments and transported off-site.

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

This panel did not have the experience or expertise to conduct and in depth assessment of the fate and transport of many of the chemicals present in agricultural areas. For contaminants like PCBs and DDTs, they are considered ubiquitous in the environment, long-lived 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 can be easily transported to shallow groundwater.

<u>Information needs and recommendations for future science</u>

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

There is a need to study contaminants as part of a multi-stressor system. We also need more studies that adequately identify the mixtures that are most impactful to 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 drivers and stressors in the environment on living resources.

Mitigation and potential interactions with nutrients and sediment

The section summarizes the findings, information needs, and research recommendations from presenters and breakout sessions for sources, fate, and transport of toxic contaminants in urban and agricultural settings. Selected findings from several previous efforts, that were part of the workshop materials, are also summarized in this section.

Selected findings from previous Toxic Contaminant WG efforts (by S. Phillips)

The CBP Toxic Contaminant Workgroup has supported several previous efforts to relate nutrient and sediment practices to also mitigating toxic contaminants.

The Chesapeake Stormwater Network undertook a project to address the potential Benefits of nutrients and sediment practices 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 if sediment BMPs could retain the associated contaminants (Figure4.1/Table E-2).
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
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		

Figure 4.1*: The Chesapeake Stormwater Network report (2016) on agricultural* 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. Below are the report text that summarized each topic.
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 includes 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 -- atrazine and metolachlor -- relying on glyphosate instead. For several years, this 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 as of yet unclear. Glyphosate and its degradate, 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.

<u>Biogenic hormones in animal manure and municipal biosolids</u>: Biogenic hormones are generated by animal feeding operations and are released by wastewater treatment plants. Higher concentration 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 watershed. 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.

<u>Antibiotics</u>: 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 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 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 nutrient and sediment practices on other CBP outcomes. Some of the key findings include

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 urban practices listed included narrow forest buffers, runoff reduction, wet ponds, etc.

Agricultural areas: Agricultural practices listed include forest buffers, streamside forest buffers, and narrow forest buffers.

Workshop Findings: Summary of current 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 contaminants. Largely, across the watershed, this is being approached through the TMDL program. All states have PCB TMDLs in the watershed, which is implemented through the MS4 permits in 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 through the stormwater general permits. Outside of TMDL implementation and WLA permitting, DC implemented a coal tar/high-PAH sealant ban to reduce PAHs. Delaware has targeted contaminated sites in their Delaware River Basin with success and have initiated a similar program to define loads within the Chesapeake Bay drainages. All states, aside from Delaware (through the WATAR program), manage their TMDL programs separate from the land cleanup programs. Delaware has reported considerable efficiencies in combining these efforts.

Most jurisdictions have not implemented BMPs for toxic contaminants to date. Several mention 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 for the use of innovative BMPs (e.g., sedimite in wet ponds) to enhance PCB removal. Many jurisdictions would like guidance to utilize these tools.

Overview of planned nutrient and sediment reductions

Olivia Devereux reviewed the existing qualitative assessments of the BMPs' impact on toxic contaminants. She also showed the BMPs that are 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

There are some BMPs that have negative effects, such as cover crops. This is because cover crops are usually killed in the spring with herbicides. BMPs are classified by function to evaluate the overall impact on the landscape. These classifications include: reduce nutrient application, decrease volatilization, biofiltration and runoff control, and runoff control to a stream.

The effect of BMPs on toxic contaminants be integrated with the CAST model and management tool (CAST@chesapeakebay.net). This 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.

Overview of innovative approaches to mitigate contaminants

Urban Areas:

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. It is suspected that many BMPs designed for sediment trapping would be effective for hydrophobic toxic contaminants (ref here to fact sheet and CSN ref) 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 stormwater and some of this work was highlighted at the workshop.

Pollutants such as PCBs, PAHs, and certain metals are transported into waterways in urban environments through stormwater runoff. As presented by Kjellerup, increases in PCB concentrations 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 concentration 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 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 media for these BMPs to promote biodegradation.

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

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, that are acting as an ongoing “source”. For example, efforts to reduce “clean” sediment transport may negatively affect management of toxic contaminants in contaminated sediment due to slower burial processes. In Lake Onondaga, wastewater nitrification eliminated sulfate-reducing conditions and increase methylmercury levels in water/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 identify the freely dissolved concentration. Ghosh presented advances in the use of in-stream innovative technologies (e.g., bioamended activated carbon) to address hydrophobic toxic contaminants, primarily PCBs. The technology has been proven at the pilot- and full-scale.

<u>Major findings from Urban Breakout session</u>

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. Making decisions about mitigation requires 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 its behavior in water, and the partitioning between water and sediment (both bed and suspended), and its persistence (e.g., potential for transformation and degradation) in the environment. While there is an understanding of the fate and transport in this context primarily for regulated toxic contaminants such as PCBs and PAHs, the site-specific conditions and identification of site-specific sources cannot be overstressed in determining the effectiveness of particular mitigation approaches (wastewater vs. stormwater dominated for example). Additional fate and transport understanding may be needed for many of the unregulated contaminants of emerging concern before their behavior can be assessed in stormwater controls.

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

Many of the chemicals associated with urban land use are regulated in some fashion discussion Fish consumption advisories and TMDLs exist rather widespread in the watershed for PCBs, whereas other contaminants (i.e., mercury and other metals, PAHs, dioxin/furan, and organochlorine pesticides) are less ubiquitous, but are present in urban areas throughout the watershed. Additional state and federal programs (e.g., CERCLA and RCRA, 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 FCA/TMDL programs (aside from Delaware).

Many of the compounds that are suspected to have fish health and other ecological impacts (as described in Table xx) are not currently regulated. Gaps in the understanding of their fate and transport in the environment is needed before BMPs can adequately be assessed in a general sense. 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 ongoing in this area currently (Kjellerup, Davis ref here). Mitigation of toxic contaminants to date has largely fallen under the other federal and state regulatory programs. Delaware has uniquely merged their programs to take advantage of the lessons learned particularly for toxic contaminants.

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 best management practices (BMPs) used in the 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 D.C.(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, (bio) filtering and infiltration practices (include fact sheet and Schuler ref here). The group cautioned that a BMP focus on reducing 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, 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 Califormia, upper mid-west), but have been limited in practice currently for 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 the 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 porewater 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?

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 and is of great interest to the group. It was suggested that this should be evaluated for both wastewater and stormwater flow conveyance to streams. The group also raised concern that operation and maintenance practices of these stormwater control structures may result act as a secondary source of contaminants in the environment if sediments are dredged or land applied and is therefore a critical gap in understanding how to use the BMPs effectively.

<u>**Agricultural areas**</u>

Agricultural areas have a litany of BMPs available and to a great degree BMPs have been installed reducing fate and transport of nutrients and sediment. Sediment reducing BMPs are slowing migration of this pollutant and the contaminants bound to sediment as a result. 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 in most cases, the fate of these contaminants in an alternating oxic-anoxic environment been explored. Source control BMPs like Integrated Pest Management, Nutrient Management and Precision Feeding have an inherent 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 even enhance the release of contaminants are a result of changes in oxidative state. Mitigating these issues would require more research on general fate and transport of contaminants. Emerging research is investigating compost and digestion as reducing sources of pharmaceuticals from manures.

Pesticides 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 run-off 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. Retention ponds on the other hand successfully reduced insecticides and other pesticides up to 100% but did not provide any benefit for toxicity reduction at the outlet. The implementation of BMPs to reduce nutrient, sediments have the potential to reduce pesticides applied in agricultural areas but more detailed studies in the Chesapeake Bay are needed to more adequately address these questions.

Animal production is another source of contaminants to local surface water including hormones and antibiotics. 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 in through the agroecosystem using vegetable production as a case study. A farm to fork conceptual model was designed to track antimicrobials in the environment from the animal to the land application of manure and crop production process. 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 run-off of antibiotics and antibiotic resistance particularly during spring application. 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 run-off potential is lower, subsurface application and finally the addition of buffer strips.

Figure 4.2: 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. (SOURCE?)

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 take away from this breakout session was current management effects are good news for toxic contaminant reductions, generally. 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 expertise and experience available.

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 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 the contaminants not regulated, 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 but more specific research with contaminants is needed to fully answer this question. Wetlands and riparian buffers that reduce surface run-off and increase residence time could be effective in minimizing dissolved and sediment bound contaminants (see Phillips talk). Waste management and proper storage and composting of manure has the potential to reduce contaminants in surface waters (see Kang talk). Planting of post-harvest was designed to reduce erosion, improve soil quality, sequester nutrients and suppress weed growth, however, it is unclear if they have benefits for contaminant removal/reduction. Cover crops are high in phytoestrogens which are released into surface water in the spring during rain events. The effects of these natural estrogens on fish health has yet to be determined but they do have the potential to negatively affect the 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 unlikely first step 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 but in some cases that might not be possible. We must also think about practices that can be implemented to reduce contaminants like integrated pest management and organic farming.

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 the 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 affect the buffer itself reducing its effectiveness. Compositing 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 run-off 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 which contaminants you hope to mitigate and what is considered the ecosystem of concern.

What other innovative approaches should be considered in agricultural areas?
Some of the innovative approaches that were discussed although in not much detail include: 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. For managers, the application of a dashboard or web-based tools to help with BMP implementation guidance and the development of a management reference framework with both nutrients/sediments and contaminants in mind.

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 and included

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

As discussed during Day 1, there is still 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 for many toxic contaminants concentrations and occurrence vary time and space. To better manage the systems we need to determine our end member, when they are most susceptible and how can we better manage these pulses. We need more robust information about the effectiveness of biochar and plastic culture. For biochar, we need to compile information on its effectiveness for sequestering a wide variety 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 (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 areas/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 importance of specific BMPs and their utility for contaminants. Ideally, more research is needed to fully determine the co-benefits to improve water quality, habitat quality and preserve aquatic resources. BMPs are an important tool for reducing contaminants and ideally necessary for keeping the waterways clean.

Findings and Recommendations

Fish health and advisories: major findings, gaps, recommendations:

1. 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.
2. 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.

Understanding of sources fate and transport

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, biosolid 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 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, Per- and polyfluoroalkyl substances (PFAs), flame retardants, microfibers/plastics, and engineered nanomaterials.
3. Fate and transport of emerging toxic contaminants in agricultural watersheds is currently limited and the panel's opinion is that more studies are necessary to really understand BMP effectiveness on contaminant removal and potential improvements in fish health. 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 but we need more information throughout the entire Bay Watershed to understand the implications these may have on the health of aquatic organisms during sensitive life-stages.

Urban settings:

1. In regions outside the Chesapeake Bay, including the Delaware River Basin and Puget Sound, ongoing work demonstrates the value in investing in clearly defining the system and regulatory endpoints prior to taking management actions. For example, in the Hudson River basin, significant loading of PCBs was determined to occur under baseflow conditions, resulting in limited reductions in fish tissue despite the extensive dredging and management efforts. In contrast, regulation and actions taken in New Jersey following detailed investigations by DRBC of PFAS compounds where a decrease has been observed over a 10 year timeframe.
2. The fate and origin of many of the contaminants of emerging concern (e.g., conditions controlling their degradation and predisposition for the aqueous or solid phase and their introduction to the watershed) are still being defined making it difficult to implement management actions such as BMPs. For example, the influence of septic systems on CEC concentrations in Chesapeake Bay tributaries is unknown.
3. The application of high-resolution mass spectroscopy and wastewater-based epidemiology tools may improve the understanding of contaminant sources and loads to the Chesapeake Bay. Use of the source fingerprinting approach may be a way to discern complex mixtures of toxic contaminants under different land use conditions.

<u>Mitigation and potential interactions of contaminants with nutrients and sediment</u>

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 run-off potential is lower, subsurface application and finally the addition of buffer strips. In California reduction in sediment bound insecticides were 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.

Urban settings:

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

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 in 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 the possible co-benefit 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. 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.

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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 risk to fisheries and other aquatic organisms in urban areas? What are the primary sources of chemicals causing fish consumption	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 to fisheries and other aquatic organisms in agricultural areas?

	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?	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 interactions with nutrient and sediment reductions	Which of the chemicals are already regulated in urban areas? 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?	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? 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 for urban areas? What are the remaining science and research needs for more effective mitigation of toxic contaminants in urban 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: Workshop Participants

Name		Affiliation	Email
Allen	Greg	EPA-CBPO	
Arzayus	Felipe	NOAA	
Austin	Doug	EPA-CBP	
Blaney	Lee	UMBC/STAC	
Blazer	Vicki	USGS	
Blomquist	Joel	USGS	
Boomer	Kathy	TNC/STAC	
Brohawn	Kathy	MDE	
Brosch	Chris	DE Dept of Ag/STAC	
Cargill	John	DNREC	
Collins	Loretta	UMD	
Davis-Martin	James	VA DEQ	
Devereux	Olivia	CBP	
Dixon	Rachel	CRC/STAC	
English	Matt	DOEE	
Farley	Kevin	Manhattan College	
Ghosh	Upal	UMBC	
Goulet	Norm	NVRC	
Hain	Ethan	UMBC	
Hanson	Jeremy	VT/CBPO	
Hartwell	Ian	NOAA	
Harvey	Annabelle	CRC/STAC	
Hyer	Ken	USGS	
Islam	Anjuman	DC Water	
James	Andy	UW Tacoma	
Kjellerup	Birthe	UMD	
Leiman	Jonathan	MDE	
MacGillivray	Ron	DRBC	
Majcher	Emily	USGS	
Monroe	Matt	WV Dept of Ag	
Mulkey	Alisha	MDA	
Mullins	Seth	VA DCR	
Phillips	Scott	USGS	
Pinkney	Fred	USFWS	
Richards	Mark	VADEQ	
Robinson	Matt	DOEE	
Schugam	Len	MDE	
Sexton	Tim	VA DCR	
Smalling	Kelly	USGS	
Staver	Ken	UMD	
Thompson	Lindsay	Thompson Ag Consulting	
Uphoff	Jim	MD DNR	
Webber	Jimmy	USGS	
Wertz	Tim	PA DEP	
Whitall	Dave	NOAA	
Whiting	Emily	DelDOT	

Willliams	Michelle	CRC	
Wirts	John	WV DEP	
Xia	Kang	VT	
Yonkos	Lance	UMD	