



Vicki Blazer of the U.S. Geological Survey leads a field survey of smallmouth bass from the Shenandoah River. Her team has observed the effects of pesticides, pharmaceuticals and other chemicals that disrupt the hormonal systems of smallmouth bass and lead to the presence of eggs in male specimen's gonads.

I. Introduction

The Chesapeake Bay Agreement has a goal to ensure that the Bay and its rivers are free of effects of toxic contaminants on living resources and human health. The two associated outcomes are (1) research and (2) policy and prevention. The research strategy will provide information about the occurrence, concentrations, sources and effects of toxic contaminants on fish and wildlife. The information will be used by the Toxic Contaminant Workgroup (TCW) to consider policy and prevention approaches to reduce the effects of contaminants on living resources in the Bay watershed and make them safer for human consumption. The five issues being addressed in the research strategy (in order of priority) are:

- Supply information to make fish and shellfish safer for human consumption;
- Understand the influence of contaminants degrading the health, and contributing to mortality, of fish and wildlife;
- Document the occurrence, concentrations and sources of contaminants causing fish and wildlife degradation;
- Assess relative risk of contaminants, and options for mitigation, to inform policy and prevention strategies,
- Gather information on issues of emerging concern (including microplastics).

II. Goal, Outcome and Baseline

This management strategy identifies approaches for achieving the following goal and outcome:



Toxic Contaminants Goal

Ensure that the Bay and its rivers are free of effects of toxic contaminants on living resources and human health.

Research Outcome

Continually increase our understanding of the impacts and mitigation options for toxic contaminants. Develop a research agenda and further characterize the occurrence, concentrations, sources and effects of mercury, PCBs and other contaminants of emerging and widespread concern. In addition, identify which best management practices might provide multiple benefits of reducing nutrient and sediment pollution as well as toxic contaminants in waterways.

Baseline and Current Condition

The TCW worked with stakeholders to develop the issues to be addressed for this research strategy. These issues are listed in order of priority and are discussed in each of the appropriate sections of the research strategy. The issues are:

- Supply information to make fish and shellfish safe for human consumption.
- Understand the influence of contaminants degrading the health, and contributing to mortality, of fish and wildlife.
- Document the occurrence, concentrations, and sources of contaminants causing fish and wildlife degradation.
- Assess relative risk of contaminants, and options for mitigation, to inform policy and prevention strategies. Provide implications to consider in management approaches.
- Gather information on issues of emerging concern.

Much of the current baseline information for these issues comes from the report “Extent and Severity of Toxic Contaminants in the Chesapeake Bay Watershed” (Chesapeake Bay Program, 2013). Information from this report and more recent findings were used to discuss the current understanding for each issue in the research strategy.

Issue: Supply information to make fish and shellfish safe for human consumption

Polychlorinated biphenyls (PCBs) and mercury are the primary causes of fish consumption advisories that have been issued in the Chesapeake Bay and its watershed. PCBs are suspected human carcinogens whereas methyl mercury (the dominant and toxic form of mercury that accumulates in fish) is known to cause impaired neurological development. In addition, both of these pollutants have adverse ecological impacts. The sources of these pollutants to fish and wildlife can be a combination of exposure to legacy deposits in sediments, ongoing inputs to the watershed from secondary sources (e.g., PCB contaminated terrestrial sites, previously contaminated stormwater pipes), and ongoing releases (e.g., wastewater and stormwater releases and atmospheric deposition, especially for mercury). Given these concerns, PCBs are the focus on the initial management strategy for Toxic Contaminant Policy and Prevention. Mercury

is being addressed through new national air emission controls and will be considered for a future strategy if levels are not reduced through these efforts.

There is a much broader set of issues related to the effects of toxic contaminants on human health. However, these issues are beyond the scope of the Chesapeake Bay Watershed Agreement so they are not included in this Toxic Contaminants Research Management Strategy. Many of the human health issues, such as occupational exposure or exposure in residential setting (i.e., lead paint), are being addressed by other government agencies and research organizations and may be incorporated in future efforts if needed to meet the outcome.

Issue: Understand the influence of contaminants degrading the health, and contributing to mortality, of fish and wildlife

There are numerous indications of reduced general and reproductive health of fish populations throughout the watershed. Research findings to date strongly suggest the influence of toxic contaminants. Observed conditions include widespread occurrence of intersex and other gonadal abnormalities, reduced reproductive success of semi-anadromous fishes, occurrence of skin and liver tumors, skin lesions, high parasite loads and opportunistic infectious disease. The impact of endocrine-disrupting chemicals (EDCs) on reproductive systems of fish and wildlife has been documented by the U.S. Geological Survey (USGS), the U.S. Fish and Wildlife Service (FWS), and the National Oceanographic and Atmospheric Administration (NOAA). Chemical contaminants, including legacy and chemicals of emerging concern, particularly EDCs have had effects on fish (reproductive systems in several species) and selected waterbirds in the Bay ecosystem.

Toxic contaminants may also contribute to fish and wildlife kills, in addition to degrading health, in the Bay and its watershed. Kills are generally defined as large numbers of fish or wildlife dying within a relatively short period of time. Some of the known fish and wildlife kills and their causes include:

- Acute kills of fish and wildlife due to hydrocarbon spills. Fish and wildlife species have been killed by oil spills such as the Colonial Pipeline Spill in a Potomac River tributary and the Chalk Point Oil Spill on the Patuxent River. Localized kills have been linked to a sequence of events resulting in algal blooms and die-off of the algae depleting available oxygen. Algal blooms of toxin-producing species have occurred in several years at Poplar Island, resulting in the deaths of hundreds of waterbirds. These are linked to *Microcystis* and possibly with avian botulism.
- Fish kills in the Chesapeake Bay watershed have also been associated with one or more pathogens and include the kills of menhaden with ulcerative mycosis in estuarine tributaries. In the case of the menhaden lesions and kills, one pathogen *Aphanomyces invadans*, was consistently observed in the ulcerative lesions. However, the role of toxic contaminants or algal toxins in susceptibility to the pathogens is unknown.

Fish kills have been associated with immunosuppression influenced by the presence of toxic contaminants. Kills of adult bass and sunfish in the Potomac basin and young-of-the-year smallmouth bass in the Susquehanna basin have occurred in multiple years and multiple sub-watersheds. These kills are associated with multiple pathogens and parasites. These observations together with the concurrent observations of intersex and other indicators of contaminant exposure suggest a role in toxic

contaminants in immunosuppression. However, the role of toxic contaminants in relation to smallmouth die offs is only one of several potential causes under investigation.

The role of contaminants in the health of numerous wildlife species, including birds, amphibians and reptiles is not as well documented. Results from the 2013 federal report (Chesapeake Bay Program, 2013) reveal the indications of responses to contaminant exposure have also been found among wildlife in the Chesapeake Bay watershed, primarily wild birds. In a few locations, eggshell thinning associated with *p,p'*-DDE is apparent, and reproduction may be impaired. In some cases, organochlorine pesticides are found in eggs of predatory birds at concentrations associated with embryo lethality. Several studies are cited in which PCB concentrations in addled bald eagle eggs may have been high enough to contribute to the failure to hatch. Detectable concentrations of PBDEs have been found in eggs of predatory birds that approach the lowest-observed-adverse-effect level for pipping and hatching success.

There is less evidence linking contaminants to reduced health and impacts on lower trophic levels of the Chesapeake food web, including stream invertebrates and submerged aquatic vegetation (SAV).

Issue: Document the occurrence, concentrations, and sources of contaminants causing fish and wildlife degradation

The current understanding of extent, severity, and sources of ten groups of toxic contaminants in the Bay watershed were summarized from existing information (Chesapeake Bay Program, 2013) and are listed in Table 1. Contaminant groups, including PCBs, mercury, polycyclic aromatic hydrocarbons (PAHs), and some pesticides have widespread extent, while the remainder of the groups had local extent. The findings for severity were based on impairments developed by watershed jurisdictions, which rely on the monitoring of select contaminants in water, sediment and fish tissue. Impairments included human health concerns (e.g., fish consumption advisors), or potential harm to aquatic organisms.

Table 1: Extent and Severity of Contaminant Groups (from Chesapeake Bay Program, 2013)

Contaminant Group	Extent, Severity and Sources
Polychlorinated biphenyls (PCBs)	PCBs have widespread extent and severity. The severity was based on risk to human health through consumption of contaminated fish with impairments identified in all of the watershed jurisdictions. Some primary sources are contaminated soils, leaks from transformers, and atmospheric deposition.
Mercury	Mercury had both widespread extent and severity. The severity was based on risk to human health through consumption of contaminated fish. The primary source is air emissions from coal-fired power plants.
Polycyclic aromatic hydrocarbons (PAHs)	Widespread extent throughout the Bay watershed. The severity was localized based on impairments for risk to aquatic organisms in a limited number of areas in the watershed. The primary sources are contaminated soils, road sealants, atmospheric deposition, and combustion.
Pesticides	Widespread extent of selected herbicides (primarily atrazine, simazine, metochlor, and their degradation products) and localized extent for some chlorinated insecticides (aldrin, chlordane, dieldrin, DDT/DDE, heptachlor epoxide, mirex). The chlorinated insecticides have localized severity based on risk to aquatic organisms. For many pesticides that had widespread occurrence, water-quality standards were not available to determine impairments. Research shows sublethal effects for some compounds at environmentally relevant concentrations. Primary sources are applications on agricultural and urban lands and legacy residue in soils.
Petroleum hydrocarbons	Localized extent and severity (to aquatic organisms) in a limited number of areas in the watershed.

Dioxins and Furans	Localized extent and severity (to aquatic organisms) in a limited number of areas in the watershed. The primary sources are spills, contaminated soils, and atmospheric deposition.
Metals and Metalloids	Localized extent and severity (to aquatic organisms) of some metals (aluminum, chromium, iron, lead, manganese, zinc) in a limited number of areas in the watershed. The primary sources are spills, industrial processes, and atmospheric deposition.
Pharmaceuticals, Household and Personal Care Products, Flame Retardants, Biogenic Hormones	Information was not adequate to determine extent or severity. However, their use in the watershed suggests widespread extent is possible. Severity was not assessed but research shows sublethal effects to selected aquatic organisms for some compounds at environmentally relevant concentrations. Range of sources from wastewater treatment and septic tanks to animal feeding operations. Biogenic hormones assessment was focused on naturally occurring compounds from human or animals.

Issue: Assess relative risk of contaminants, and options for mitigation, to inform policy and prevention

There is no organized information on the relative risk of different contaminant groups (listed in Table 1) to the Bay ecosystem to help determine future management strategies. Information on the extent and severity of contaminant groups could be considered for an initial approach to assess the relative risk of contaminant groups. This is discussed further in the management approach section of this strategy. Based on the report findings, both PCBs and mercury had widespread extent and severity (Table 1) and also contributed to fish consumption advisories. Given this information, PCBs are the focus of the policy and prevention strategy. Mercury will likely be the next pollutant addressed through a prevention strategy, and that strategy will likely rely strongly on air emission controls currently being required across the Nation. Given the effort to reduce nutrients and sediment in the watershed as part of the Bay TMDL, the research outcome also will focus on providing a better understanding of the potential benefit of nutrient and/or sediment practices for toxic contaminant reduction.

Issue: Gather information on issues of emerging concern

Issues of emerging concerns are (1) contaminant toxicity to pollinators (including neonicotinoids), (2) microplastics, and unconventional oil and gas drilling (known as “fracking”). The baseline information on each of these is very limited. Colony Collapse Disorder (CCD) has taken a significant toll on honey bee hives in much of the US. CCD and declines in other pollinators are topics of growing concern. Multiple factors, including pesticides (e.g., neonicotinoids and pyrethroids) acting singly or in mixtures are suspected to contribute acute and/or chronic toxicity to honey bees and other pollinators and potentially aquatic organisms. Routes of exposure are generally terrestrial and may be through intentional application within hives (e.g., fungicides and miticides) or through dermal contact or ingestion of herbicide or insecticide treated crops. These pesticides are then returned to the hive where they may poison queens or developing larvae. Other effects may include inhibiting bees from returning to the hives. Effects may be aggravated by other stressors including travel strain, climate change, and abundant parasites and pathogens.

Microplastics are small plastic particles in the environment and have become a paramount issue especially in the marine environment. Microplastic debris, including microbeads is now found across all aquatic habitats, including estuaries and shorelines, freshwater lakes, rivers, the deep sea and even Arctic Sea ice. They have been ingested by hundreds of species and have been documented at many trophic levels. They are persistent, bioaccumulative and can be toxic upon ingestion. How much

contamination is caused by microplastics is not known. It can be assumed that with litter as an end-of-life outcome, microplastics have the potential of becoming a large source of pollution, both globally and locally.

Toxic contaminants from unconventional oil and gas (UOG) activities and their effects on fish and wildlife are not well understood. There are national, regional, and jurisdictional efforts to better define the potential impacts of UOG activities, and the CBP will depend on results from those efforts to assess relative risk to the Chesapeake ecosystem. The potential effects of land disturbance on streams and fisheries are being considered as part of the Brook Trout management strategy.

III. Participating Partners

The following partners have participated in the development of this strategy. A workplan to accompany this management strategy will be completed six months after this document is finalized. It will identify specific partner commitments for implementing the strategy.

Chesapeake Bay Watershed Agreement Signatories

- Maryland Department of the Environment
- Maryland Department of Natural Resources
- Virginia Department of Environmental Quality
- DC Department of the Environment
- Pennsylvania Department of Environmental Protection
- Delaware Department of Natural Resources and Environmental Control
- New York Department of Environmental Conservation
- West Virginia Department of Environmental Protection
- Chesapeake Bay Commission (CBC)
- U.S. Environmental Protection Agency
- U.S. Geological Survey
- U.S. Fish and Wildlife Service
- U.S. Department of Homeland Security
- National Oceanic and Atmospheric Administration

Other Key Participants

- Non-Governmental Organizations
 - Bluewater Baltimore
 - Metropolitan Washington Council of Governments
 - MD Pesticide Network
- Private sector organizations
- University of Maryland, Baltimore County
- Virginia Polytechnic Institute and State University
- Virginia Institute of Marine Science
- CBP Local Government Advisory Committee
- CBP Water Quality Goal Implementation Team Workgroups

Local Engagement

Most of the actions to plan and complete the actual research are expected to be the responsibility of federal, state and academic entities. Local governments and NGOs have been helpful in identifying priorities within the research strategy, including NGOs from Baltimore Harbor, the Elizabeth River, and the Anacostia River. Increasing the awareness of the impacts of toxic contaminants, especially safe consumption of fish and shellfish, will be carried out with local governments and organizations and will be targeted towards areas with diverse and underrepresented populations in the bay watershed.

IV. Factors Influencing Success

There are several cross-cutting factors that may influence our ability to meet the outcome: (1) resource constraints, (2) lack of consolidated information system of existing data, (3) different monitoring and analytical approaches that limit comparability of information. The primary factors influencing each major issue are presented below (and listed in priority order).

- 1. Consumption advisories:** The jurisdictions have different assumptions about human exposure through fish consumption, which can limit comparability across the watershed. There are also resource constraints to collect and analyze fish and associated samples every year.
- 2. Fish and wildlife health:** Ability to determine which pollutants and additional factors are causing the degradation (and mortality) of fish and wildlife due to their exposure to varying mixtures of compounds. There is no watershed-wide monitoring program on the condition of fish and wildlife that is integrated with water and sediment sampling.
- 3. Occurrence of contaminants:** Lack of consistent information (both spatial and temporal) on the occurrence and concentrations of toxic contaminants. Some of this is due to the high cost of generating new data on toxic contaminants. Additionally, there are few laboratories that have the capabilities to conduct analysis for all of the contaminant groups.
- 4. Relative risk and management strategies:** Development of strategies can be hindered by lack of toxicity thresholds for many pollutants to allow assessment of their effects on fish and wildlife. A companion factor is the difficulties in assessing the relative risk groups of contaminants and their mixtures.
- 5. Emerging issues:** Limited knowledge to assess importance and implications of emerging issues.

V. Current Efforts and Gaps

There are ongoing efforts, by multiple organizations in the Bay watershed, to assess toxic contaminants and their effects on fish and wildlife. The types of studies and monitoring include:

- Monitoring to assess water-quality impairments and issue fish consumption advisories in state waters.

- Documenting the extent of degraded fish conditions and wildlife conditions and relation to toxic contaminants and endocrine-disrupting compounds. Specific examples include monitoring the prevalence of liver tumors in fish and the linkage with sediment contamination.
- Understanding the role of toxic contaminants and other factors in fish and wildlife mortality.
- Monitoring programs for occurrence and concentrations of selected contaminant groups (such as pesticides).

A brief description of the current efforts and associated research gaps for the five issues in this strategy are discussed. Efforts to address the research gaps are presented in the management approaches (next section).

Issue: Supply information to make fish and shellfish safe for human consumption

- **Current Efforts:** All states and DC, in cooperation with USEPA, have existing monitoring programs to ensure there are guidelines for safe fish and shellfish consumption through yearly fish monitoring programs. The primary focus of PCB monitoring in the Bay watershed has been measuring fish and shellfish concentrations for setting consumption advisories. Information is available from NOAA through their previous monitoring in the Bioeffects project and “Mussel Watch”, and several ongoing studies in localized areas.
- **Research Gaps:** Research is needed to support the policy and prevention management strategy for PCBs. Research is needed improve information on the sources of PCBs that are contaminating fish and making them unsafe for human consumption. This information is critical to the development of appropriate and prioritized mitigation efforts. The policy and presentation management strategy for PCBs has identified the following research needs related to sources of PCBs.
 - **Stormwater:** Enhanced information is needed to investigate whether the following are source of PCBs in unregulated and NPDES regulated stormwater:
 - construction activities associated with the demolition/remodeling of buildings with PCB containing materials and disturbance of contaminated soils
 - land application of biosolids in commercial and agricultural practices
 - land application of dredged material from the maintenance of stormwater BMPs.Also improved information on PCB removal effectiveness of BMPs that are designed to remove sediments and nutrients with emphasis on stormwater BMPs.
 - **Wastewater:** Enhance information on cost-effective tools for track-down studies (source identification) and provide a mechanism for municipalities to share information on lessons learned from pollution minimization plan (PMP) development and implementation strategies including through a track-down methods workshop.
 - **Atmospheric:** Improve information on the atmospheric sources of PCBs, PCB concentrations in atmospheric deposition to the watershed and Bay, and the significance of these sources for bioaccumulation in fish.

To support these research needs for PCB source identification, PCB data are needed on the various environmental media that lead to PCB exposure to fish. Past approaches for PCB source identification has involved spatial sampling of air, water, and sediments combined with mass balance modeling to

delineate sources, such as the ones carried out in the Great Lakes (e.g., Lake Michigan mass balance study). Such studies can help identify relative loads of PCBs and other pollutants of concern in the watershed from rivers, air deposition and contaminated sediment re-suspension. While air and water sampling have been previously performed in the watershed, there is lack of current data that will be necessary to adequately identify sources at the present time.

More specific monitoring and modeling needs to help relate sources to effects on fish include:

- Synthesis of existing information to consider enhanced modeling that could link PCB sources, transport pathways, and effects on fish. There has been some monitoring of PCBs in air, water, and sediments by the different agencies involved in the watershed, but there is a lack of a coordinated Bay-wide synthesis of the data for PCBs.
- Development and implementation of a coordinated monitoring effort to measure atmospheric and water-borne sources of PCBs to the Bay along with measurements of levels in surface sediments. This would include spatially explicit measurements where data are lacking of air, water and sediment samples using latest techniques that allow very low detection limits. For PCBs, the required water quality goals for the protection of human health from fish consumption can be very low (e.g. 0.059 ng/L BAF-based, Target Water Concentration for the tidal Potomac in DC), making it necessary to adopt emerging analytical techniques such as passive sampling (Guidelines for Using Passive Samplers to Monitor Organic Contaminants at Superfund Sediment Sites OSWER Directive 9200.1-110 FS December 2012)
- Enhance tools to relate sources to occurrence and potential effects of management practices. Currently there are some localized models of PCB occurrence which can help determine the degree of reduction needed to decrease their occurrence in water and sediment. As more information is gathered, additional areas should be considered for models to inform identification and relative importance of PCB toxicity.

Issue: Understand the influence of contaminants degrading the health, and contributing to mortality, of fish and wildlife

- **Current efforts:** Research is ongoing between jurisdictions, federal, and academic partners to better understand the influence of toxic contaminants on the health of fish and wildlife as well as confounding factors that may make them more susceptible to these contaminants. In the Potomac and Susquehanna basins, studies are also addressing the complex interactions of chemical and algal toxins, pathogens and parasites and water quality on contributing to fish mortalities. Some selected studies are described below.

In 2012, Pennsylvania initiated a large scale study of the Susquehanna River drainage in response to the decline of the smallmouth bass population that continues to this day. In addition to toxic contaminants, the study is looking at other water quality variables and assessing the overall health of several aquatic communities. This will help put the toxic contaminate issues in context with other water quality variables and the overall aquatic community.

The National Aquatic Resource Survey (NARS)/National Coastal Condition Assessment (NCCA) evaluates a selection of metals, PCB congeners, PAHs, and pesticides in surficial sediment and in fish tissues on a five-year recurrent schedule. A number of sites in the national survey routinely fall within the tidal

portions of the Chesapeake Bay watershed. The Virginia DEQ Estuarine Probabilistic Monitoring Program routinely analyzes the same group of sediment analytes at approximately 30 sites per year within the tidal portion of the CB watershed. Sediment toxicity and benthic community health (CBP B-IBI) are concurrently evaluated at each site. Efforts are currently underway to recalibrate the CBP B-IBI using sediment chemistry, sediment toxicity, and benthic community data from probabilistic monitoring sites. The effects of EDCs on fish and wildlife have been documented in the Bay watershed (see baseline section of this document). The USGS initiated in 2014 a five-year plan to better understand the effects of known EDCs and chemicals of emerging concern on fish and wildlife within the Chesapeake watershed. The plan includes assessing adverse effects in wild fishes, experimental exposures of key species to mixtures, based on chemical concentrations measured in affected areas, assessing the role of mercury as an endocrine disruptor, monitoring amphibian populations of adverse effects, as well as exploring the potential for EDCs to be affecting avian and reptile populations. State agencies usually have the lead to respond to fish and wildlife kills and determine if the likely cause is a spill or accidental release of petroleum, toxic contaminants, or low dissolved oxygen conditions. Additionally, the NOAA Office of Response and Restoration assesses fish kills due to chemical spills in coordination with the US Coast Guard and state agencies.

- **Research gaps:** Research is needed to determine the primary contaminants (and mixtures) adversely affecting general, as well as reproductive, health of fish and wildlife populations within the watershed. A better understanding is needed for which contaminants (and mixtures) contribute to 1) causing the greatest degree degradation of the health and reproductive systems of fish and wildlife, (2) compromising the immune systems of fish and making them more susceptible to other environmental stresses, such as pathogens, parasites; and the effects of hypoxia; 3) prevalence of for tumors; and 4) in embryo and larval survival.

Understanding the sublethal, cumulative effects of complex mixtures of EDCs and toxic chemicals on reproductive success and general health and survival is necessary in developing management strategies. Identifying factors that influence species' susceptibility to toxic chemicals and EDC-related effects will identify the most at-risk fish and wildlife populations, as well as guide mitigation efforts to reduce potential impacts on sensitive populations. Integral to mitigation efforts will be identification of sources and transport mechanisms for EDCs.

A better understanding is needed about the role of contaminants in mortality of fish or wildlife. Contaminants can be directly or indirectly involved in large-scale mortalities. Oil and chemical spills can lead to acute mortalities. More commonly, contaminants may have an indirect effect on mortalities (acute and chronic) through numerous pathways such as alteration of the immune response and disease resistance, tumor induction or promotion, metabolic and endocrine effects. Additionally, there are complex interactions of contaminants (particularly herbicides), nutrients and algal populations that can lead to mortality by algal/cyanobacterial toxins.

Some of the more specific fish health research needs include:

- Skin lesions of adult fishes and young of year bass, co-occurring with a high prevalence of intersex. The role of contaminants in production of these lesions needs to be better understood. Questions that need to be addressed: 1) do certain contaminants accumulate in the skin, 2) is suspended sediment a source of these contaminants, 3) are the bacteria observed in some

lesions associated with nutrient or other water-quality parameters and 4) are other factors, such as algal and cyanobacterial toxins, involved.

- Skin and internal infections from multiple *Mycobacteria* species have been identified in striped bass as well as some other species. While considerable research has been directed at identifying the bacterial species, the extent of the problem and the progression of the lesions, studies directed at better understanding the predisposing factors, including exposure to immunosuppressive contaminants are needed.
- A high prevalence of skin and liver tumors in brown bullhead catfish and liver tumors in mummichogs has been documented. While there is evidence for the role of PAHs in liver carcinogenesis, other factors acting as both promoters and initiators are not well studied. Research is needed on risk factors associated with these tumors.
- The complex interactions between contaminants and infectious disease need to be understood. While contaminants can adversely affect the ability of an organism to resist infectious diseases and parasites, the presence of these biological agents can also affect the ability of an organism to metabolize and otherwise deal with exposure to chemical contaminants.
- Better understand the extent, causes and adverse effects of intersex (testicular oocytes) in bass and potentially other fishes. Considerable research has been directed toward this issue in the Chesapeake watershed. Estrogenic contaminants have been associated with prevalence and severity of intersex in many fish species. However, associations have also been documented in the Potomac drainage with herbicides. The complex interactions of herbicides, phytoestrogens, algal toxins/products and intersex need to be addressed.
- Lack of reproductive success of yellow perch and other anadromous fishes has been documented in certain urban tributaries. A clear relationship between percentage of impervious surface and declining recruitment of yellow perch and river herring has been demonstrated. In yellow perch, effects on egg quality (abnormal yolk, thin chorions) have been observed. A better understanding of the multiple stressors including contaminants, hypoxia, sediment and nutrient loading and changes in salinity is necessary to prevent further declines.
- Having a bay-wide network of control sites where toxic contaminants are present at appreciable levels in the water column or sediment but the fish community has no or low incidence of disease. Comparison to controls is an essential step for eliminating contaminants that are not contributing to the disease pathways because they are present in appreciable amounts at both diseased and un-diseased sites.

Issue: Document the occurrence, concentrations, and sources of contaminants causing fish and wildlife degradation

- **Current efforts:** The Toxic Summary Report (Chesapeake Bay Program, 2013) provided the most current understanding of 10 contaminant groups within the Bay watershed. Some of these contaminant groups have jurisdictional monitoring programs but many of those of emerging concern do not have any systematic monitoring besides individual studies by some individual federal and academic monitoring efforts.
- **Research gaps:** The Toxic Summary Report identified monitoring gaps for: dioxins and furans, petroleum hydrocarbons, some pesticides currently in use (e.g., insecticides and fungicides), pharmaceuticals, household and personal-care products, flame retardants, and biogenic

hormones. The information was used to prepare an initial assessment of the level of uncertainty for ten contaminant groups (Figure 1) with regard to the occurrence, concentrations, sources and effects on fish and wildlife. Monitoring for the presence and adverse effects of compounds needs to be implemented.

Concept for Determining Highest Priorities for Research to Increase Understanding Impacts and Mitigation Options for Toxic Contaminants (Color codes are examples)

Contaminant Groups	Occurrence	Concentrations	Sources	Effects	Uncertainty
PCBs	Small	Medium	Medium	Small	
Dioxins/Furans	Small	Medium	Small	Small	
PAHs	Small	Small	Small	Small	
Petroleum Hydrocarbons	Medium	Medium	Small	Small	
Pesticides	Large	Large	Medium	Medium	Priorities for an agenda to increase certainty?
Bio. Hormones	Large	Large	Medium	Large	
Pharms.	Large	Large	Medium	Large	
HPCP	Large	Large	Medium	Large	
PBDEs	Large	Large	Medium	Medium	
Metals	Medium	Medium	Medium	Small	
Mixtures	Large	Large	Large	Large	

Figure 1: Level of uncertainty for ten contaminant groups with regard to the occurrence, concentrations, sources and effects on fish and wildlife.

Issue: Assess relative risk of contaminants, and options for mitigation, to inform policy and prevention

- Current Efforts:** The current policy and prevention management strategy is focused on reducing the effects of PCBs. The information on sources of PCBs will be enhanced through the research strategy, and more in-depth research needs are discussed on pages 8-9 . The new findings will help inform an update to the policy and prevention strategy in 2017 and consider other contaminants to be addressed. The TCW does not have a formal process for determining the relative risk of contaminants for management strategies. Information from the Toxic Contaminant Summary report (CBP, 2013) provides an initial approach to assess relative risk based on the extent and severity of contaminant groups.
- Research gaps:** The policy and prevention strategy needs additional information on the issues listed in research strategy to consider moving beyond PCBs in the next management strategy. The management approach outlined in the next section of this document will provide an improved understanding of the sources, occurrence, concentrations, and effects of toxic contaminants (Figure 1). All of this information will considered to help discern the relative risk of contaminant groups so additional management strategies can be considered to reduce their impacts. The process to assess relative risk of contaminant groups needs to be further developed by the TCW.

Better understanding and identification and quantification of sources, fate, transport, distribution, and exposure of fish and other organisms to contaminants is a key step in identifying the proper management approach. In many cases, current efforts to nutrients and sediment on the landscape will result in added benefits of reducing the release of contaminants into waters where they may adversely affect aquatic biota. However, more detailed information is needed to define which water-quality practices for nutrient and sediment reduction will also reduce contaminants and to what degree.

Issue: Gather information on issues of emerging concern

- **Current Efforts:** There is very little knowledge within the Bay watershed on (1) contaminant toxicity to pollinators (including Neonicotinoid pesticides), and (2) microplastics, and (3) chemicals from UOG activities and their effects on fish and wildlife.
- **Research Gaps:** Research gaps are being developed. There is a critical need for more information about the presence and impacts of microplastics in the Chesapeake Bay, both in the Bay itself and in its tributaries. Recent studies have shown a positive correlation between human population density and concentrations of microplastics in the Chesapeake Bay watershed. However, studies on the impacts are limited because specialized equipment, including very fine mesh nets, is needed. Additionally, more understanding is needed about the multiple factors, including pesticides that are suspected to contribute acute and/or chronic toxicity to honey bees and other pollinators. Neonicotinoid pesticides, which have been implicated in both fish health issues and the decline in pollinators, have received little attention to date. They are currently being measured in water and sediment at a few select sites. Monitoring for the presence and adverse effects of these and other emerging pesticide/herbicides (glyphosate, etc.) needs to be implemented. Very little information exists on the composition of fracking fluid and vulnerability of streams to spills and accidental discharge.

Actions, Tools and Support to Empower Local Government and Others

- **Current Efforts:** The research workgroup has reached out to local organizations within some of the areas of most concern including the Baltimore Harbor and Anacostia watershed. In both the Susquehanna and Shenandoah watersheds, the USGS has been interacting with the respective RiverKeeper organizations.
- **Research Gaps:** There has been limited activity to engage additional local groups about the issues being addressed by the research strategy. Also need to assess where fish consumption advisories are being issued to determine the extent of their occurrence in diverse communities.

VI. Management Approaches

The Partnership will work together to carry out the following actions and strategies to achieve the Toxic Contaminants goal. These approaches seek to address the factors affecting our ability to meet the goal and the gaps identified above.

The management approach addresses each of the major issues identified at the beginning of the strategy. The management approach builds from existing research and monitoring efforts to address the

research gaps and factors influencing our ability to meet the toxic contaminant goal. Since resources are limited, some guiding principles for the management approach are to:

- Focus studies on areas where fish and wildlife have been degraded and/or there are human health concerns.
- Better understand and identify the multiple stressors and mixtures of contaminant groups contributing to degraded fish and wildlife.
- Improve the understanding between sources of these contaminants (and mixtures), their pathways to the environment, and exposures to receptor organisms.

Issue: Supply information to make fish and shellfish safe for human consumption

The current toxic contaminants prevention and policy management strategy is focused on reducing the impacts of PCBs. Additional information will be provided on PCBs sources and transport pathways so the policy and prevention strategy can be improved in 2017. These research efforts are reflected below and additional science support activities are in the Policy and Prevention strategy.

Existing programs, through the states, D.C. and USEPA are addressing human exposure to PCBs primarily through two approaches: 1) monitoring of levels in fish and shellfish and issuing/revising consumption advisories, and 2) moving known contaminated sites towards cleanup both at the State and Federal level. While advisories do not reduce levels of contamination, ongoing cleanup activities should lead to reduction of PCB levels in fish. Better delineation of sources, especially of (1) diffuse sources on land, (2) release from deposits in stormwater pipes, and (3) atmospheric deposition is needed to refine the management approach and prioritize cleanup efforts on sources that can have the biggest impact on overall reductions in PCB loadings. This will be done through more coordinated monitoring where data gaps exist.

The effects of contaminants on shellfish and fisheries will be enhanced by summarizing information from several recent studies by NOAA and partners. The science partners will work with the TCW to consider if development of a PCB mass balance model for the Bay can help delineate and prioritize the current sources that need to be controlled.

Further information will also be generated for mercury to discern if Chesapeake strategies are needed to supplement national efforts to reduce its impact on fish and associated consumption advisories. An existing research group, involving MD DNR, NOAA and SERC, will provide a potential mechanism to consider existing information and coordinate research needs.

The TCW will also work with the CBP Diversity Action Team to explore the extent to which diverse populations are located in areas where fish advisories are being issued, especially where fishing is being done for subsistence purposes. EPA's EJ SCREEN tool will be used to help with the identification of such areas. A joint pilot project will be undertaken to improve outreach and communications tools in these areas of concern.

Issue: Understand the influence of contaminants in degrading the health, and contributing to mortality, of fish and wildlife

The research efforts will provide a better understanding of the factors affecting health of fish, shellfish, and wildlife, with a focus on high value species (for commercial and recreational fishing, and rare and

endangered species). The states in the watershed (as well as DC) have active projects, many in cooperation with USGS, FWS and academic partners, attempting to discern causes of declining fish health, and fish mortality, in their respective drainage areas of the Bay watershed.

The USGS has revised its Chesapeake Bay Science Strategy to better support these efforts and put studies into a regional context. Enhanced USGS activities, working with partners and FWS, include addressing skin lesions, mortalities and reduced reproductive health of adult fishes include identifying the most important causes (pathogens, parasites) and contributing factors (nutrients, toxic compounds contributing to immunosuppression and endocrine disruption), assessing the role of algal/cyanobacteria toxins (microcystin) and other products (phytoestrogens) on general and reproductive health, and developing gene expression markers and molecular pathogen techniques to better understand the mechanisms (disease resistance factors, hormone receptor activation, etc.) of observed effects. The investigations include identifying the factors (climatic, invasive species, nutrients) contributing to the proliferation of parasite and opportunistic pathogens associated with mortality of young of year bass by evaluating the distribution of diseased young bass, toxic contaminants that may be passed from mother (egg) to young bass, the proliferation of the benthic worms and snails that are parasite intermediate hosts, and the role of algal toxins.

To assess the effects of toxic contaminants on wildlife, USGS will work with FWS to summarize existing and work with partners to consider additional research activities.

Issue: Document the occurrence, concentrations, and sources of contaminants causing fish and wildlife degradation

The management approach will better define the sources and occurrence of EDCs and other contaminant groups that are affecting the health of fish and wildlife. The primary activities will focus on contaminants affecting fish health. These activities, done in collaboration with fish investigators, will provide an improved understanding of: (1) the contaminant groups are most likely degrading fish health, (2) their occurrence in the watersheds, and (3) the sources. Sources and occurrence of EDCs and other key contaminant groups that can affect endocrine system and health of fish include pesticides, biogenic and synthetic hormones, and pharmaceuticals. Most of these groups have a large amount of uncertainty about the occurrence and sources (Figure 1). Other contaminants, such as pesticides and pharmaceuticals such as antidepressants and antibiotics, may not affect endocrine systems, but can affect other aspects of fish health, including immunosuppression, increased susceptibility to pathogens, changes in fish behavior, and other outcomes.

Identifying the settings where the inputs of these contaminants are expected to have the maximum impact on fish, amphibian, and other biological resources as well as human health are an important factor to consider in assessing the occurrence of these compounds. Sources of EDCs include agricultural, wastewater, urban, and suburban lands with more information needed on potential relation to animal manure and agricultural runoff, aging sewer infrastructure, septic systems, urban runoff, and biosolids. Important considerations include assessing mixtures of the different type of chemical stressors and

understanding how they interact with fish health issues, including, but not limited to endocrine disruption, reproductive changes, increased susceptibility to pathogens.

To meet the needs of assessing the impacts of EDCs, the USGS has developed a National Research Framework for Evaluation of Endocrine Disrupting Chemicals. Although this framework focuses on EDCs, it also offers a way to assess the impact of other chemical stressors on the health of aquatic communities, and so offers a guide to assessing a broader suite of chemical stressors. The USGS National Research Framework for EDCs have been developed to identify priority effects-directed analysis to research will be undertaken to identify the chemical or chemicals responsible for causing endocrine disruption in fish and wildlife inhabiting the Chesapeake Bay watershed. This will be achieved through a series of specific objectives: 1) develop and validate the appropriate effects measures for direction of the chemical analysis based on the ED concerns; 2) develop and validate a complementary chemical fractionation scheme and strategy for the physical separation and testing of chemicals or chemical classes of suspected EDCs based on land-use practices; and 3) use the methodology to identify chemicals that cause ED in exposed fish consistent. These chemical stressors also include some of the compounds included in the emerging issues such as neonicitoids, which have been identified as causing issues with pollinators in the watershed, and pharmaceuticals, which can affect both fish health and human health. Finally, assessing this broad suite of compounds also helps to meet the need to fill in gaps for assessing mixtures of chemicals. This approach ensures that the appropriate set of sources, chemicals, and effects can be assessed to insure the integrity of biologic resources in the Chesapeake Bay region. The USGS study is funded for 2015-2019 in the Chesapeake Bay watershed.

Issue: Assess relative risk of contaminants, and options for mitigation, to inform policy and prevention

The TCW needs to develop an approach to assess the relative risk of contaminants to help inform policy and prevention strategies. An initial approach could be based on Toxic Contaminant Summary Report (CBP, 2013). The report defined both extent and severity of contaminant groups with three possible classifications: widespread, localized, or uncertain. Extent is characterized as “widespread,” contaminant has been detected throughout the watershed or “localized” if only in a limited number of subwatersheds. Severity was based entirely on the jurisdictions’ impairment determinations as identified in the integrated assessment reports. Contaminants that have caused impairments in many locations are considered to have widespread severity; contaminants associated with impairments in few locations are classified as having localized severity. “Uncertain” was assigned to groups if monitoring information was not adequate to define occurrence or if they did not have water-quality standards to identify impairments,

Using the Summary Report information, both PCBs and mercury have widespread extent and severity and also cause fish consumption advisories, so they could be considered to have the highest relative risk to the Chesapeake ecosystem. Some pesticides and PAHs may have the next greatest risk. Several herbicides (primarily atrazine, simazine, metolachlor, and their degradation products) had widespread extent but information did not exist to assess their severity. PAHs had widespread extent but localized severity. Other contaminants groups had only localized extent and severity so they would potentially have a lower relative risk (Table 1). Finally, contaminant groups that had uncertain extent or severity

cannot be assigned a relative risk. The TCW will consider the information from the Summary report and develop a more defined approach to assess relative risk.

Information generated from the research strategy, including approaches to assess relative risk, will be continuously shared with the TCW so they can consider options for mitigation impacts of toxic contaminants. One of the first activities will be assessing the potential for nutrient and sediment management to provide additional benefits to reduce contaminants. The work will be done during 2015 and results available in early 2016. The results will be shared with the CBP Water-Quality Goal Team so they can consider opportunities to emphasize practices that simultaneously reduce nutrient and/or sediment as well as contaminants. For the contaminants found to have the primary effects on fish and wildlife, implications of the findings will be provided to help inform options for policy and prevention.

Issue: Gather information on issues of emerging concern

Workshops will be proposed to STAC to address (1) contaminant toxicity to pollinators, and (2) microplastics. Each issue will be discussed with the TCW and other stakeholders to assess if more research is needed and a policy/prevention strategy should be considered. There are National, Regional, and jurisdictional efforts to better define the potential impacts of UOG activities, and the TCW will decide in the future whether to assess risk to streams and other surface waters in the Chesapeake watershed. The potential effects of land disturbance on streams and fisheries are being considered as part of the Brook Trout management strategy.

Approaches Targeted to Local Participation

The research team will work with local organizations to inform them of ongoing studies and discuss closer interaction. Potential interactions include having the researchers work with local governments and non-profits to identify target locations in watersheds to demonstrate tracking technologies, resulting in actual source-identification and elimination outcomes in targeted jurisdictions, and, at the same time, help to increase technical capacity of local participants. EJ SCREEN will also be used to target areas in the watershed with diverse populations where fish consumption advisories are being issued.

Collaborating with other Management Strategies

There is potential cross-collaboration working with WQ Goal Team (to reduce nutrients and sediment); Habitats (improve stream health), and Fisheries (making fish and shellfish safer to eat).

VII. Monitoring Progress

Two types of monitoring are being considered: (1) programmatic and (2) environmental. Programmatic monitoring will focus on completion of planned activities for actions in the research strategy and biannual workplan. Environmental monitoring provides several types of information (1) to improve of knowledge of baseline conditions for occurrence, concentrations, sources and effects for the highest priority pollutants and (2) supports the policy and prevention outcome to help assess effects of

management practices. Initial ideas for monitoring to improve information of environmental conditions for five major issues include:

- **Human consumption:** Monitor number and location of fish health consumption advisories in the Bay watershed due to PCBs and mercury. Monitoring of levels of PCBs and mercury at sentinel sites to assess if reduction activities are having desired benefit.
- **Fish and wildlife health:** Develop indicators for fish and wildlife health to better characterize effects of contaminants. Possibilities include indicators of (1) intersex conditions in fish, and/or (2) presence of tumors in fish.
- **Occurrence of contaminants:** Monitoring of the selected compounds listed from the major contaminant groups (Figure 1) to better document their extent and severity.
- **Management approaches:** Monitoring to assess if implications are used in a greatest number opportunities to reduce contaminants. For example, assess if the jurisdictions use results to emphasize nutrient and sediment reduction practices that also provide benefits for lower levels of selected contaminants.
- **Issues of emerging concern:** Monitor to assess if information on issues of emerging concern results in need for them to be included in future research strategies.

VIII. Assessing Progress

Assessing programmatic progress (making sure planned activities are completed) will be at least annual so that adjustments to the biennial workplan can be made to accommodate changing circumstances and availability of resources. Formal review of programmatic progress will be completed through the update of the biennial workplan.

Assessment of environmental conditions and change will be done less frequently (every 2 to 5 years) depending on contaminant monitoring. We will utilize the biannual reporting for impaired waters (305b) done by each state and DC to assess conditions for selected contaminants that monitored for these efforts. Monitoring for additional contaminants will be done less frequently due to efforts needed to collect, compile, and analyze information. The planning, completion and publishing of research is usually a multi-year process which affects the advancement in gaining more knowledge to reduce uncertainty.

IX. Adaptively Manage

The Toxic Contaminants Workgroup will assess the management implications from the research findings and decide on updates (that are required every two years) needed to policy and prevention strategy to address contaminants beyond PCBs. There will be interchange between the research and policy and

prevention teams of the TCW to discuss evolution of research issues every two years to support management needs.

X. Biennial Workplan

Biennial workplans for each management strategy will be developed by September 2018. It will include the following information:

- Each key action
- Timeline for the action
- Expected outcome
- Partners responsible for each action
- Estimated resources