PRELIMINARY CONCEPTUAL MODEL FOR AN ECOLOGICAL RISK ASSESSMENT FOR MICROPLASTICS ON STRIPED BASS IN THE POTOMAC RIVER ESTUARY

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Table of Contents

List of Figures

List of Tables

1. Introduction

Plastic debris adversely affects aquatic and terrestrial organisms as a physical entanglement hazard, source of gastrointestinal effects, and potential for toxicity/ adverse biological effects following uptake of smaller pieces through oral ingestion, inhalation/gills, or contact with external body surfaces. EPA conceptualized a summary of these pathways and complexities regarding plastic exposure and potential adverse outcomes (Figure 1-1) in their *Microplastics Expert Workshop Report* (USEPA 2017).

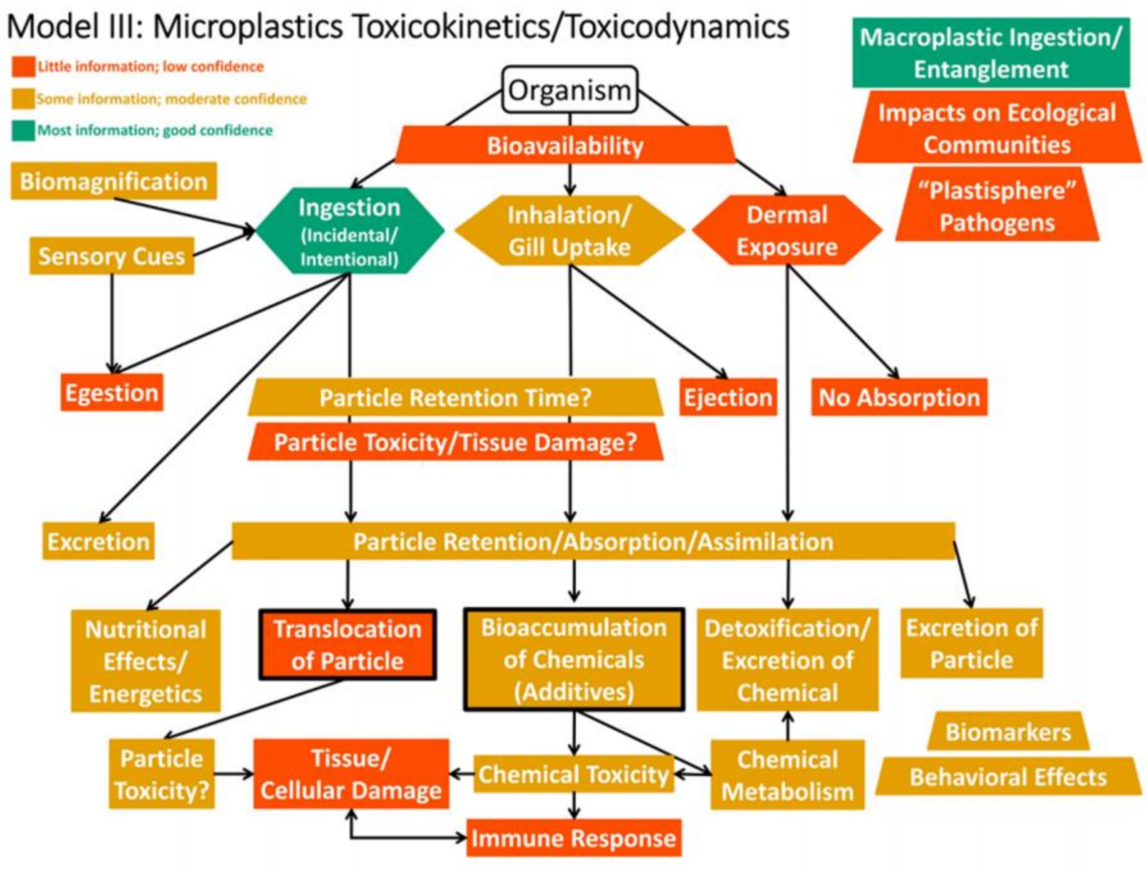


Figure 1-1. Conceptual model describing pathways and complexities regarding plastic exposure and potential outcomes (from EPA 2017)

Plastic trash and its breakdown products are found in many terrestrial and aquatic habitats including fresh, estuarine, and marine waters. These plastics typically occur as the result of two broad sources-- primary and secondary plastics. Primary plastics are intentionally designed as small particles for use in industrial applications (ex.“nurdles”, small plastic pellets used as raw material to produce plastic goods) or consumer product ingredients (ex. abrasives in cosmetics, personal care products, and cleaners). Secondary plastics occur as fragments or fibers from the breakdown of larger debris like water bottles, synthetic fabrics, plastic bags, and single use food packaging.

The ecological risk of these plastics, specifically those in the size range of microplastics (5 mm - 1000 nm [1µm]) and nanoplastics (1 nm - <1000 nm [1µm]) as defined in the companion document *Uniform Size Classification and Concentration Unit Terminology for Broad Application in the Chesapeake Bay Watershed*, is largely unknown. However, these are size ranges known or expected to be ingested or taken in through gills of aquatic organisms. The purpose of this project is to expand upon the needs identified in the *Microplastics Expert Workshop Report* (USEPA 2017) and develop a preliminary conceptual ecological risk assessment model to identify pathways, sources, effects, and unknowns related to environmental plastic debris, specifically microplastics and smaller, in the tidal portion of the Potomac River. The Potomac is a major tributary to the Chesapeake Bay, and this conceptual risk assessment will serve as a starting point for understanding the potential ecological effects of microplastics on the aquatic resources in the larger Bay. This initial effort is expected to inform a science strategy for microplastics in the Potomac River and provide insights regarding restoration efforts around the Chesapeake Bay and contributing watersheds, a need outlined recently by the Chesapeake Bay Program (Murphy et al. 2019).

A variety of individual organisms, species, populations, and/or life stages may be at risk due to microplastic exposures. Multiple species/life stages were considered for inclusion as an ideal biological endpoint for the ERA of microplastics in the Potomac River, with implications for the broader Chesapeake Bay. The first consideration was whether to include a semi-aquatic or aquatic species endpoint. While there are several good candidates for semi-aquatic species, more aquatic species are covered by the 2014 Chesapeake Bay Agreement. In addition, of the few studies carried out in the Chesapeake Bay watershed looking into microplastic occurrence, almost all have assessed the aquatic component. For these reasons, an aquatic species was chosen as the ERA endpoint.

Several fish and shellfish species were initially discussed as candidate endpoints:

1. Blue crabs (*Callinectes sapidus*) are an iconic species for the Bay and evoke strong interest by the general public. In addition, they are a very well-studied species in the Bay and elsewhere. Lastly, the 2014 Agreement established restoration outcomes for blue crabs and thus they should be considered.

2. American Shad (*Alosa sapidissima*). Shad are an abundant group that are regular components of the Potomac River estuary and the state fish of the District of Columbia. A major drawback of using American Shad (or other Alosines) is the nature of their life cycle-- while Alosines are important in the ecosystem, they are transient. Adults enter the system from the ocean to spawn and then leave again. The

young-of-year remain in the estuary, but eventually depart for life primarily in the ocean.

3. Forage fish (e.g. anchovies, silversides, etc) are an integral part of the coastal ecosystem, feeding on zooplankton while serving as primary food for Striped Bass (*Morone saxatilis*), Bluefish (*Pomatomus saltatrix*), and other piscivores. The 2014 Agreement identified the importance of forage fish and recommended further research to better understand their abundance. Research in other parts of the world have demonstrated ingestion of microplastics by forage species. By definition, forage species occur lower on the food chain and therefore might artificially represent a truncated pathway for microplastics.

4. American Eel (*Anguilla rostrata*) is a major component of estuarine and non-tidal ecosystems. However, the American Eel has a very complex life cycle that will make it very difficult to develop a strong risk assessment model. Adults reproduce in the Sargasso Sea, then larval stages are advected and migrate along the east coast of North America before entering estuaries and continuing into non-tidal waters where they develop into mature adults. American Eel then migrate out of the streams and rivers into the estuaries, followed by a long migration back to the Sargasso Sea to spawn and die. This species is not ideal for the current risk assessment because of their extensive movement between different habitats and geographical locations.

5. Eastern oysters (*Crassostrea virginica*) are an iconic species in the Chesapeake Bay and once supported large fishery, including one for the Potomac River. Pollution, overharvesting, and disease have reduced oyster populations to a remnant of their historical abundance. As filter feeders, they are likely to be more exposed to contaminant particles in the water column, such as microplastics. However, oysters are also selective feeders that will egest foreign or non-nutritive material in the form of pseudo-feces. In addition, while well-known and studied, the population resides in a restricted portion of the Potomac River (M. Gary, pers. comm) and lack the distribution within the system to provide a broader picture of the fate of microplastics. Lastly, oysters feed mostly on phytoplankton, thus an ERA model with oysters as the endpoint would miss the flow of microplastics through the larger food chain.

6. White Perch (*Morone americana*) are one of the most common estuarine finfish species in the Chesapeake Bay and Potomac River (Stanley and Danie 1983, Kraus and Secor 2004). They are a well-studied species and are known to the public due to their desirability for human consumption. White Perch remain in the estuary for their entire life cycle feeding on benthic organisms, invertebrates, small fish, and fish eggs. They are prey for larger piscivores such as Weakfish (*Cynoscion regalis*), Bluefish, and Striped Bass.

7. Striped Bass are one of the top-level piscivores found in the Chesapeake Bay and tributaries. The Chesapeake Bay is also a major center of reproduction along the western Atlantic. The species has been recognized as a major success story in terms of aggressive multi-jurisdictional management, when the population crashed in the late 1980's. The species recovered after a fishing moratorium was imposed for several years and is highly managed today. Striped Bass, as one of the highest trophic-level organisms in the Bay, provide a very good model endpoint as they will naturally include blue crabs and forage fish (both having specific outcomes in the 2014 agreement). In addition, there is considerable literature on the trophic dynamics of striped bass (Fay et al. 1983, Hartman and Brandt 1995, Cooper et al. 1998, Secor 2000) along the east coast, including the Chesapeake Bay. While Striped Bass are also migratory, they tend to remain in the estuary the first several years of their life (Fay et al. 1983), thereby providing an organism that can reflect the potential impact of microplastics in a specific location. Lastly, recent research has demonstrated microplastics to be found in Striped Bass, although this work was not from the Chesapeake Bay (Baldwin et al. 2020).

After considering these species or species groups five criteria were considered to select the final ecological endpoint for the preliminary conceptual risk assessment model:

1) Upper trophic level species
    - Incorporation of all trophic ingestion, potentially
    - Includes lower trophic levels of interest
    - Likely to be targeted by humans

2) Represented in Chesapeake Bay Agreement Restoration Goals
    - forage fish
    - blue crabs
    - Striped Bass do not have a specific bay restoration goal, but consume species above

3) Data rich
    - Chesapeake Bay fisheries resources well- surveyed
    - Habitat associations well-known for many species
    - Adequate data to detect population fluctuations

4) Common, including recognition by the general public
    - Eels – fishery species of concern due to declining population bay-wide
    - Blue crab - iconic bay species
    - Oysters - known for water quality benefits as well as habitat and as a direct fishery

- White Perch - ubiquitous
- Striped Bass – prime example for aggressive fisheries management; highly sought-after game fish

5) Wide distribution
    - Eels
    - White Perch
    - Striped Bass
    - Blue crab
    - Forage fish

Striped Bass was selected as the receptor of interest for the initial assessment. It is likely that other species would also serve as excellent potential endpoints but may not fulfill the criteria described above. For example, oysters are an important component of the estuarine ecosystem, provide habitat and are consumed by some fish and humans. However, the population of oysters in the Potomac River is low and would likely not provide as much insight to microplastic movement through trophic pathways (Waite et al. 2018). Additionally, blue crabs and forage fish, both recognized under the 2014 Agreement, are lower trophic level species and would not provide a full picture of potential microplastic vectors. In general, these lower-level species would be included by using Striped Bass as the receptor of interest.

Striped Bass are an apex predator that feed on several important recreational and commercial fishery species in the Chesapeake Bay, which also have goals under the 2014 Chesapeake Bay watershed agreement. Striped Bass have witnessed a decline in abundance recently (M. Gary, Pers. Comm.) and the additional insight provided by the risk assessment will contribute to a better understanding of the suite of stressors facing the population as this species is under increased management scrutiny. Furthermore, The Potomac River and the upper Chesapeake Bay are the two most important nursery areas for Striped Bass. Lastly, by addressing Striped Bass, ecological risk to a myriad of species of interest and lower trophic levels (ex. blue crabs, forage fish, and oysters) can also be addressed by constructing food web models and identify potential trophic transfer.

1.1. Spatial Boundary

The risk assessment conceptual model is focused on the Potomac River estuary, including the tidal portions of any tributaries. Constraining the spatial extent of the assessment is necessary to reduce the amount of uncertainty and variability in the model development. This is particularly critical as data availability and gaps specific to the region are identified. Similarly, Striped Bass demonstrate variability in feeding across latitudes, thereby skewing the accuracy of an assessment for the Potomac using trophic pathways outside the Chesapeake region.

1.2. Temporal Coverage

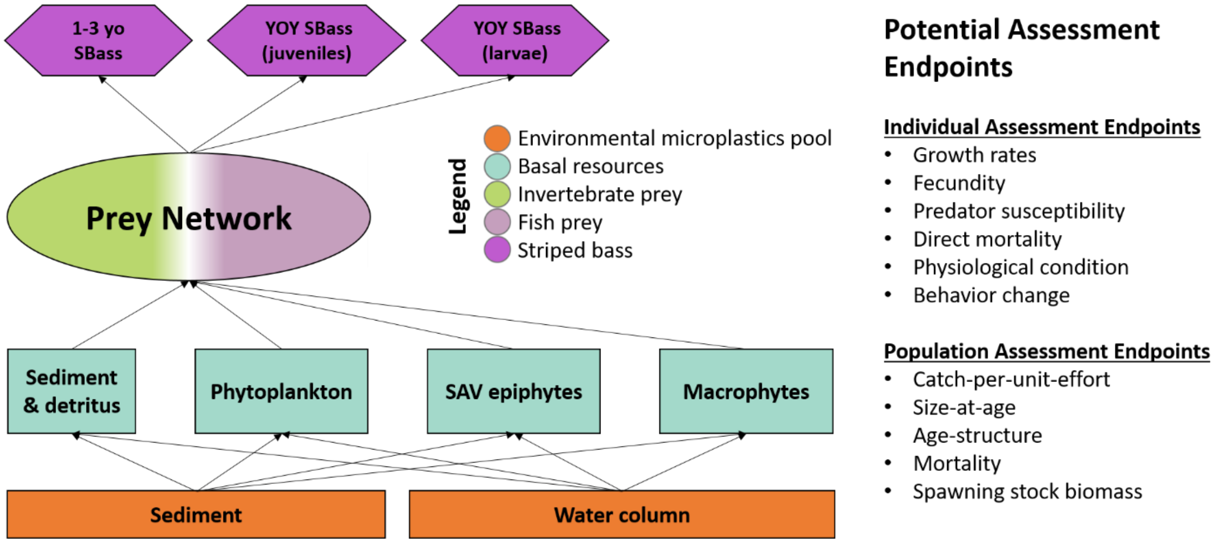
As noted, Chesapeake Bay fisheries, including the Potomac River estuary, has been well-studied for several decades, going back to at least the 1920’s with rigorous population data available. In addition, ecological studies of economically important species (e.g. Striped Bass) span a long timeframe, with relevant studies beginning in the 1960’s and continuing to the present. In light of this, it was decided that all robust and comparative literature be reviewed for relevant trophic data. The studies by Beaven and Mihursky (1980) and Boynton et al (1981), while being older, are still relevant and remain the most comprehensive sources of data on the trophic ecology of Striped Bass in the Potomac River, particularly for the ages of interest. Recent analyses (Ihde et al. 2015) provides more recent analyses of age 1+ Striped Bass from the Chesapeake Bay mainstem that sheds light on other diet trends. We expect the ecological risk assessment to be useful in future years as the understanding of microplastic sources and fates is better understood and quantified within the Potomac River estuary.

1.3. Assessment and Measurement Endpoints

Potential ecological assessment endpoints were identified based on the scope of the ERA. These assessment endpoints build off previously defined generic ecological assessment endpoints (USEPA 2003) which were developed to serve as broadly applicable endpoints for a range of ecological assessments. Specifically, Individual- and Population-level Generic Ecological Assessment Endpoints (GEAEs) (USEPA 2003)were modified to yield potential assessment endpoints identified for the Potomac River Striped Bass population (Figure 1-2). These proposed assessment endpoints reflect the potential individual and population-level effects of microplastics and ultimately reflect an overall assessment of the health of the Potomac River Striped Bass population. This includes recruiting early life stages, resident subadults, and returning adult Striped Bass that use the Potomac River as both spawning and foraging habitat. The strong fisheries management interests focused on Striped Bass support the specification of potential measurement endpoints that are common fisheries population assessment measurements (e.g., age-structure, catch-per-unit-effort, spawning stock biomass). Some of the potential assessment endpoints that are identified will be difficult to measure (e.g., behavior change, changing susceptibility to predation) but could provide useful contextual information for other assessment endpoints such as mortality rates.

Measurement endpoints represent specific measurements required to inform assessment endpoints. Measurement endpoints for some Individual-level assessment endpoints for Striped Bass include data necessary to estimate growth rates, fecundity, mortality and condition. For many of these assessment endpoints, multiple potential empirical measurements are suitable. For example, assessing juvenile growth rates could be accomplished by either collecting weekly-to-monthly cohort length data which would allow the application of modal length progression analysis, or the collection of otoliths from juveniles and the analysis of daily increment widths (assuming proper validation of the approach). Further, experimental options such as in situ caging experiments (to measure differences in body size before and after caged fish are held in the environment) or laboratory-based approaches such as RNA:DNA ratios could be used to help inform estimates of short term growth after appropriate experimental validation. Another example of a single individual assessment endpoint that can be evaluated using multiple measurement endpoints is physiological condition. Fish condition is often evaluated as the ratio of body weight to the cube of body length, a ratio that is sometimes scaled using a constant (i.e., Fulton’s condition factor or *K*). Use of K or any related condition factor based on the relationship between fish weight and body length requires the collection of individual fish length and weight data, preferably at multiple times during the year and for each life-stage of interest. Alternative condition metrics include laboratory-based measurements of percent body (or tissue) lipid composition, energetic content (calorimetry), or stoichiometric ratios such as carbon:nitrogen tissue composition.

Measurements for population assessment endpoints such as population estimates rely on standardized sampling efforts conducted at sufficient spatial and temporal resolution to calculate robust measurements of number of fish caught per unit effort (e.g., square meter, cubic meter, deployment minutes). Age-structure endpoints require measurements that yield data on age distributions of target life stages (days for YOY, years for age-1+), while size-at-age assessment endpoints require that the age data be paired with individual length data. These data needs require a dedicated monitoring survey that collects each life stage at different times of the year, paired with laboratory approaches to determine age of captured individuals (e.g., otolith analysis). Standard fisheries methods are available that provide detailed descriptions of the data needs and associated survey designs for all the assessment endpoints identified here.



Potential Assessment Endpoints

Individual Assessment Endpoints

- Growth rates
- Fecundity
- Predator susceptibility
- Direct mortality
- Physiological condition
- Behavior change

Population Assessment Endpoints

- Catch-per-unit-effort
- Size-at-age
- Age-structure
- Mortality
- Spawning stock biomass

Figure 1-2. This diagram shows a simplified conceptual model of expected environmental pools of microplastics and generalized uptake through the food chain to Striped Bass. The large oval labeled "Prey Network" is further expanded in the next figure. Ecological assessment endpoints quantifiable at the individual (ex. growth, fecundity, etc.) and management-focused population level (ex. catch-per-unit-effort, size at age, etc.) are highlighted as potential endpoints to evaluate the effects of microplastics on the Potomac River population of Striped Bass. In many cases, it is expected that these represent data gaps without a known relationship to microplastic exposure and may not yet be quantifiable.

1.4. Stressors of Concern

Microplastics, both primary and secondary, and consisting of many polymers are the focus of this conceptual model. Microplastics encompass a very diverse group of materials with different physical/chemical properties along with fate, transport, and bioavailability characteristics. It is recognized that nanoplastics likely occur in ecological matrices, and they are acknowledged as a potential stressor, but are not addressed extensively in the current effort due to lack of data. It is also acknowledged that other co-occurring stressors in the Potomac are very important and result in ecological effects, including changes related to the assessment endpoint, growth and survival of striped bass. Such stressors include toxic chemicals, dissolved oxygen, parasites, temperature, and changing hydrological conditions.

Future efforts may focus on specific microplastics, but the initial conceptual model generally acknowledges the contributions of all microplastics. Inclusion of new studies will allow subsequent iterations to tailor the established framework to specific shapes, sizes, and polymers. For example, two initial studies show potential differences in the prevalence of particular microplastics in different portions of the Chesapeake Bay and its tributaries. A recent report of microplastic abundance in submerged aquatic vegetation in the Anacostia River showed that almost 75% of the identified particles were fibers, followed by a smaller percentage of fragments, and beads (Murphy 2020). Another recent study (Bikker et al. 2020) identified morphology of plastic particles from water samples around the Chesapeake Bay and showed that the greatest abundance of particles were fragments, followed by film, and fibers.

It is noteworthy that the proportion of abundances in Bikker et al. (2020) were different than those found by Murphy (2020). This observation could be related to several factors. First, physical and chemical characteristics of plastics govern where they are found in the water column and how far they travel from their source. Currently, little is known about the quantitative transport of different types of plastic between the Potomac River and larger Chesapeake Bay, but differences could be due to distance from source and transport dynamics. Another potential explanation for the differing observation is that sampling methods used to capture plastics were not the same. Bikker et al. (2020) collected plastics from surface water using a manta trawl while Murphy (2020) collected grab sample cores from submerged aquatic vegetation beds. Due to the mesh size (i.e. typically > 300um) of netting used, surveys conducted with manta trawls could miss smaller particles like fibers.

While other types of microplastics might be more prevalent in the main portion of the Chesapeake Bay, preliminary evidence suggests that fibers could be more abundant in river systems. Additionally, field studies evaluating incidental microplastic consumption suggested that the majority of ingested microplastics were fibers (Baldwin et al. 2020, Desforges et al. 2015, Peters et al. 2017). These and future pieces of evidence will allow new iterations of the conceptual model to focus on risk associated with microplastics that may be associated with the greatest risk.

2. Methods

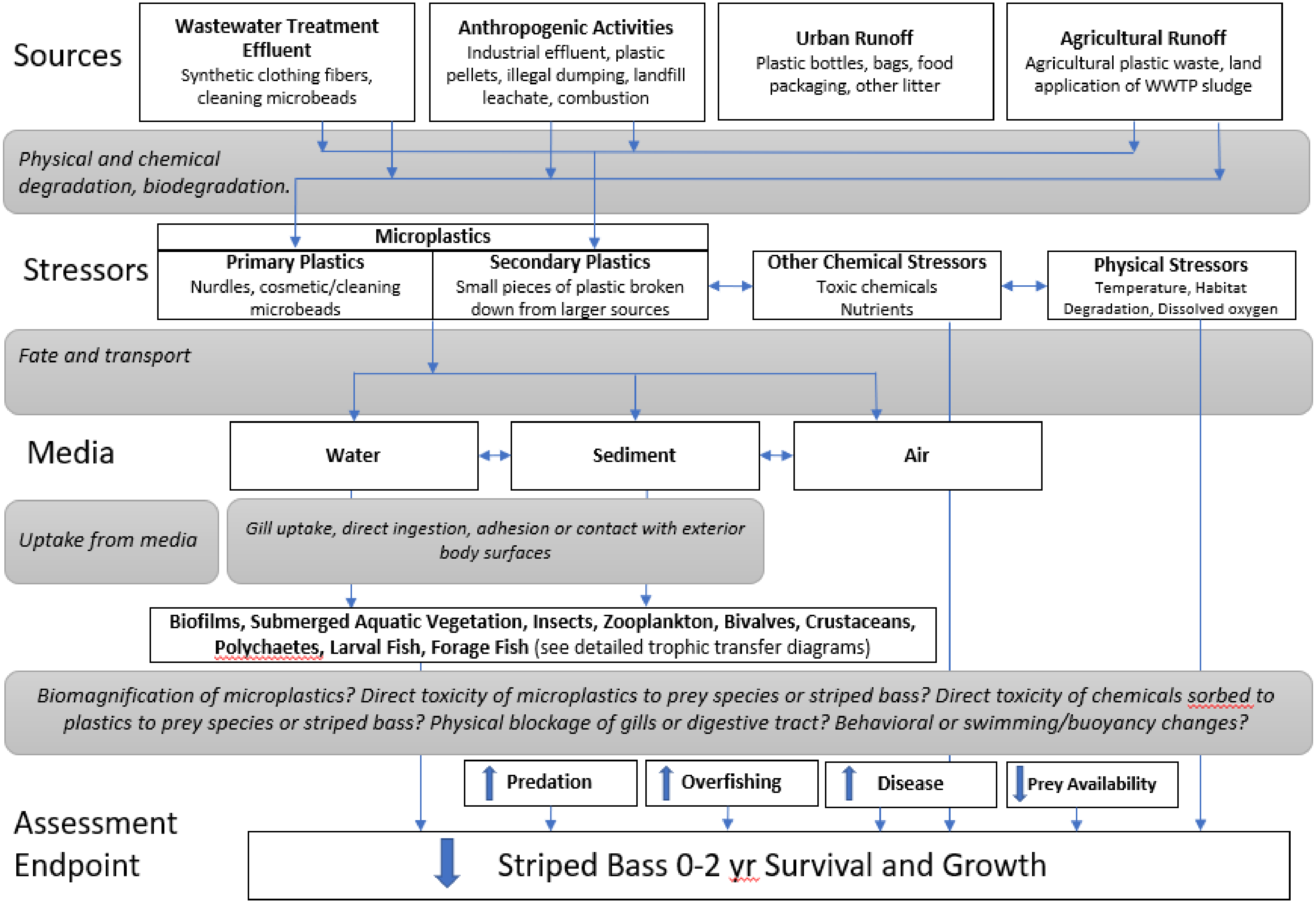
2.1. Literature review

A literature search was completed following the methodology approved under the quality assurance project plan (QAPP—see Appendix 1 for full discussion) developed using EPA guidance. The search of primary and gray literature was conducted to identify prey items consumed by Striped Bass, with an emphasis on data collected from the tidal Potomac River and Chesapeake Bay, and supplemented with information from east coast estuaries and other geographical locations, as appropriate. Prey items for the 0-2 year age class were emphasized in the draft diagrams, but information related to older age classes (and prey organisms) not resident in the Chesapeake Bay were retained for future reference. Relative contribution of prey items to Striped Bass diet was quantified where possible. Additional literature searches reviewed the current understanding of the sources for many microplastics in coastal regions that would subsequently affect the construction of the conceptual model.

2.2. R Script

Trophic networks were constructed using the *igraph* package in the *R* environment. The igraph package is a specialized network visualization package (Csárdi and Nepusz 2006). Trophic networks are graphical representations of static prey composition matrices; therefore, the network structure is not determined by statistical fitting. These network figures provide a reader-friendly representation of complex diet data and have been designed to emphasize important prey for each life-stage or habitat type.

3. Conceptual model



Sources

Wastewater Treatment Effluent
Synthetic clothing fibers, cleaning microbeads

Anthropogenic Activities
Industrial effluent, plastic pellets, illegal dumping, landfill leachate, combustion

Urban Runoff
Plastic bottles, bags, food packaging, other litter

Agricultural Runoff
Agricultural plastic waste, land application of WWTP sludge

Physical and chemical degradation, biodegradation.

Stressors

Microplastics

Primary Plastics
Nurdles, cosmetic/cleaning microbeads

Secondary Plastics
Small pieces of plastic broken down from larger sources

Other Chemical Stressors
Toxic chemicals
Nutrients

Physical Stressors
Temperature, Habitat Degradation, Dissolved oxygen

Fate and transport

Media

Water

Sediment

Air

Uptake from media

Gill uptake, direct ingestion, adhesion or contact with exterior body surfaces

Biofilms, Submerged Aquatic Vegetation, Insects, Zooplankton, Bivalves, Crustaceans, Polychaetes, Larval Fish, Forage Fish (see detailed trophic transfer diagrams)

Biomagnification of microplastics? Direct toxicity of microplastics to prey species or striped bass? Direct toxicity of chemicals sorbed to plastics to prey species or striped bass? Physical blockage of gills or digestive tract? Behavioral or swimming/buoyancy changes?

↑ Predation

↑ Overfishing

↑ Disease

↓ Prey Availability

Assessment Endpoint

↓ Striped Bass 0-2 yr Survival and Growth

3.1. Sources of Microplastics

Sources of plastics considered microplastic size or smaller include wastewater treatment plant effluents (e.g. synthetic clothing fibers, cleaning microbeads); anthropogenic activities (e.g. industrial effluent, plastic pellets, illegal dumping of garbage, landfill leachate, combustion); urban runoff (e.g. plastic bottles, bags, single use food packaging/utensils, and litter); agricultural runoff (e.g. agricultural plastics, land application of sludge from wastewater treatment plants). Primary plastics are most often associated with treated wastewater or industrial processes while secondary plastics are associated with sources of large plastics that break down into smaller pieces in the environment. Both primary and secondary plastics are subject to degradation, creating smaller fragments by physical, chemical, and biological factors. Such processes include ultraviolet radiation, abrasion due to movement of wind or water, and degradation by microbes.

3.2. Media

Primary pools of bioavailable microplastics were identified in different media including settled (sediment) and suspended particles (water column). Atmospheric deposition (air) is expected to contribute microplastics to aquatic systems, but striped bass and other aquatic organisms do not directly interface with air.

3.3. Stressors

Both primary and secondary microplastics are the stressor of concern. It is also acknowledged that other co-occurring stressors in the Potomac are very important and result in ecological effects, including changes related to growth and survival in striped bass. Such stressors include toxic chemicals, dissolved oxygen, disease, predation, prey availability, temperature, and changing hydrological conditions.

3.4. Development of trophic transfer pathways

Lower level trophic organisms and Striped Bass are exposed to microplastics via gills, direct ingestion, or surface/skin contact, potentially causing toxicity or behavioral changes. Understanding the trophic pathways contributing to Striped Bass diets are important to identify the most important dietary microplastic exposure routes. Thus additional, detailed trophic transfer models were developed to better understand potential microplastic transfer within the food web.

The compiled literature was examined for Potomac River relevant data on resident age-classes of Striped Bass, including food web interactions and potential assessment endpoints. Resident age-classes were defined as including: all young-of-the-year (YOY) stages (both larval and post-metamorphosis juvenile), and ages 1 through 3 fish. Though the 0-2 age class was the original focus, age-3 fish were included in the analysis because evidence suggests the majority of age-3 males remain resident in Chesapeake Bay (Secor and Piccoli 2007), indicating that primary exposure to microplastics for males of that age class is still limited to the geographic area of interest. Diet data for age 0-3 Striped Bass reported in several key studies were used to develop an unweighted, qualitative prey network (multigraph) linking dominant primary producers at the base of the food web, prey taxa, and Striped Bass: Markle and Grant (1970), Beaven and Mihursky (1980), Boynton et al. (1981), Walter III and Austin (2003, 458-710 mm size classes only), Muffelman (2006), Martino (2008), Shideler and Houde (2014), and Ihde et al. (2015). These regional studies were conducted in the Potomac River (Beaven and Mihursky 1980, Boynton et al. 1981), adjacent Virginia tributaries (Markle and Grant 1970, Muffelman 2006), and the Chesapeake Bay mainstem (Walter III and Austin 2003, Martino 2008, Shideler and Houde 2014). One study did note the direct consumption of microplastics by older Striped Bass, although it was in a reservoir system outside of the Chesapeake Bay region (Baldwin et al. 2020).

For each focal age-class, quantitative diet data were used to create positive (weighted) network diagrams. These positive networks have edges (lines between nodes) and nodes that vary in thickness as a function of the amount of each prey type consumed by the focal age-class, however, predator-prey linkages for non-focal age-classes or between prey nodes were not weighted. Prey importance for each positive network diagram was determined using % diet composition by biomass or, if biomass was not reported, volume or number. Dominant prey species were assigned individual categories (e.g., Bay Anchovy *Anchoa mitchilli*, Atlantic Menhaden *Brevoortia tyrannus*). Where prey groups were reported as lower taxonomic resolution aggregates, these aggregate prey taxa were maintained (e.g., polychaetes, insects) or were further aggregated to reflect diverse functional groups of taxonomically similar prey that contributed relatively little to diet individually but could be important together (e.g., other crustaceans, other fish, Table 3-1). Among sub-adult age-classes, data for age 3 males were not available at sufficient resolution to develop a positive network diagram; therefore, age-specific positive network diagrams were only developed for age 1 and 2 fish. Multigraph and positive networks linking prey groups to lower trophic position prey and, ultimately, to primary producers were based on compiled literature (Baird and Ulanowicz 1989) and professional knowledge of the project PIs.

Table 3-1. Aggregated Striped Bass prey table identifying specific taxa included in aggregate groups and associated references.

Aggregate group	Included taxa	Reference
Other fish	Teleostei *(Morone americana, Leiostomus xanthurus, Micropogonias undulatus, Urophycis regia, Notropis hudsonius, Lepomis gibbosus, Cynoscion regalis, Gobiosoma bosci)*	(Markle and Grant 1970, Walter III and Austin 2003, Ihde et al. 2015)
Insects (larvae and pupae)	Diptera (e.g., Muscidae, *Chironomus* sp., *Chaoborus* sp.), Hemiptera, Ephemeroptera	(Markle and Grant 1970, Boynton et al. 1981, Muffelman 2006)
Larval zooplankton	Cirripedia (barnacle larvae cirri), copepodites*, copepod nauplii*	(Markle and Grant 1970)
Other crustaceans	Mud crab, Palaemonidae (*Palaemonetes* sp.), sand shrimp (*Crangon septemspinosa*), mantis shrimp, isopods, xanthids*, Ovalipes ocellatus*	(Markle and Grant 1970, Walter III and Austin 2003, Muffelman 2006, Ihde et al. 2015, Lehtiniemi et al. 2018)

**based on literature from other estuaries ((Hjorth 1988, Limburg et al. 1997) - Hudson River)*

Very little data exist on microplastics loads in prey taxa in the Chesapeake Bay region, particularly for the Potomac River basin. Therefore, an initial evaluation of the relative importance of each prey category across Striped Bass age-classes was used to identify key data gaps for the species' forage base. A 'priority level' was assigned to each prey category based on the following criteria:

- High priority (> 5% diet composition across multiple life-stages)
- Moderate priority (> 10% diet comp within one life stage)
- Lower priority (< 10% diet comp within one life stage)

Due to differences in the way that the diet data were reported (i.e., % biomass, % number) and the subjective nature of the threshold values, these priority rankings are only intended to provide a summary of the available data. A life stage-specific breakdown of larval diet data is available in Beaven and Mihursky (1980), reported as % occurrence of each prey taxon in the stomachs of yolk-sac, finfold, and post-finfold larvae. Due to this method of reporting, these stage-specific data were not used to develop positive network diagrams but the data were used to create a prey priority ranking table for Striped Bass larvae in the Potomac River.

- High priority (> 5% frequency of occurrence across multiple larval-stages)
- Moderate priority (> 10% frequency of occurrence within one larval-stage)
- Lower priority (< 10% frequency of occurrence within one larval-stage)

These priority-level rankings are meant to provide guidance for future research priorities for trophic studies of Striped Bass microplastics exposure in the Potomac River.

4. Results

Trophic network supporting Striped Bass in the Potomac River

This series of diagrams is based on the dietary studies described above. The initial multigraph is a complete compilation of the available regional literature and highlights the number of potential trophic pathways through which microplastics could be ingested by different age-classes of Striped Bass (Figure 4-1). These diagrams do not explicitly include other potential microplastics exposure mechanisms such as directed consumption (i.e. mistaking microplastics for prey), passive uptake during feeding, uptake through the mouth during non-feeding activities, or exposure via other surfaces such as gills (Roch et al. 2020). Despite this, these diagrams can be used to infer the potential of such pathways. For example, microplastics in the surface sediments may be passively ingested by Striped Bass feeding on benthic polychaetes. The potential sediment-Striped Bass pathway is not specifically identified as an edge in either the multigraph or the positive network diagrams because there are not sufficient data on microplastics presence or concentration associated with the basal resources in the Potomac River or the amount of basal resource material typically ingested during Striped Bass feeding. The relative importance of trophic versus passive uptake of microplastics is unknown; however, several recent studies have documented the importance of trophic transfer as a major mechanism for microplastics exposure(Nelms et al. 2018, Hasegawa and Nakaoka 2021) Hasegawa and Nakaoka (2021) showed that trophic transfer of microplastics to fish via predation on mysid shrimp was 3–11 times greater than passive uptake from the water column. For Striped Bass in the Potomac River and the broader Chesapeake Bay, the relative importance of these potential exposure routes remain as critical data gaps but the structure of the trophic network(s) provided here can be used to identify where some of these passive pathways could exist.

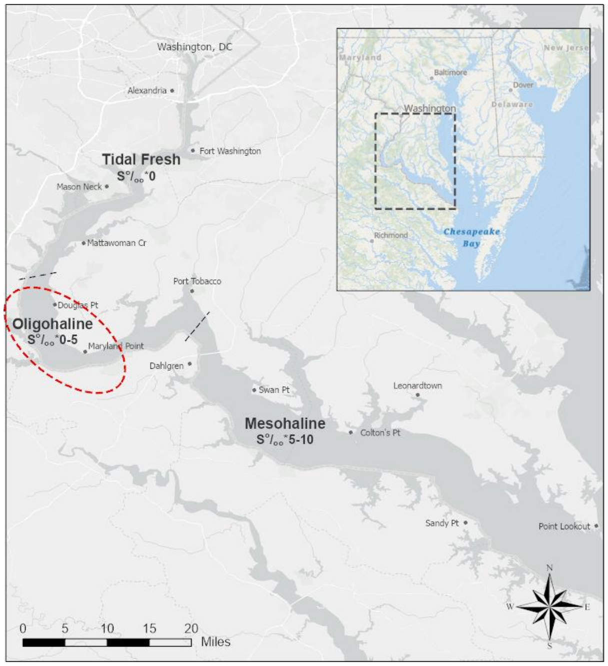


Figure 4-1. Potomac River showing the general extent of the salinity regimes used in this analysis, in addition to the estuarine turbidity maximum (red oval)

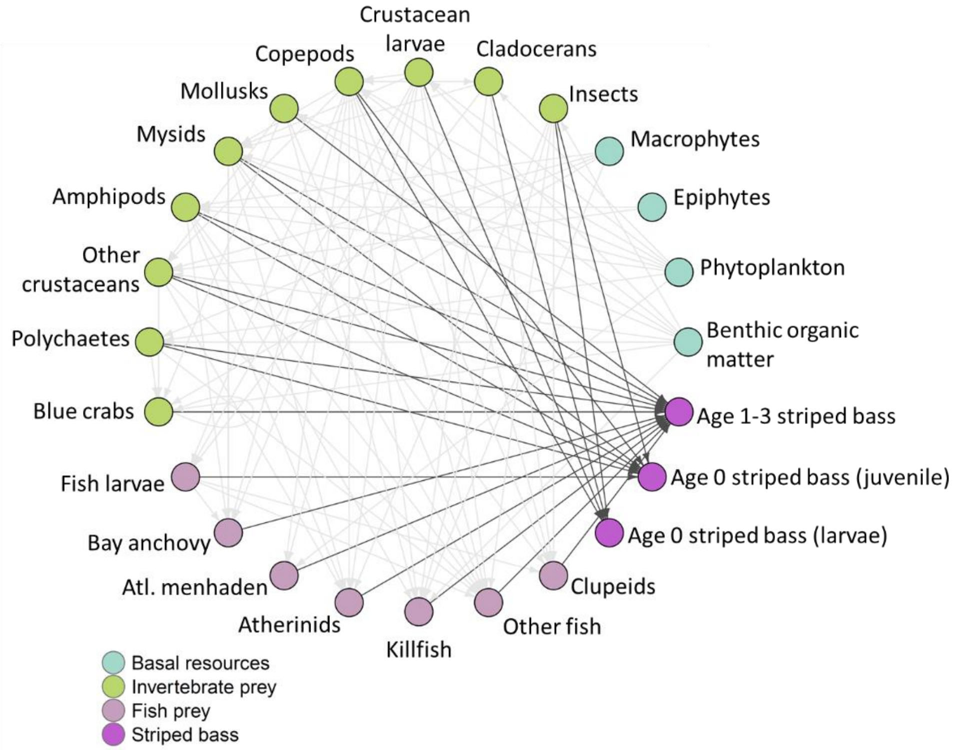


Figure 4-2. This diagram shows basal trophic resources that are also potential pools of microplastics in the environment and a generalized food web of prey items consumed by Striped Bass and organisms consumed by those prey items. Three age classes of Striped Bass (young of year [YOY] larvae, YOY juveniles, and 1-3-year-old) are shown with connections to their known prey items.

The reticulated structure of the Striped Bass food web indicates that microplastics exposure could follow a range of different trophic pathways. Many of the prey consumed directly by Striped Bass also contribute to diets indirectly (separated by at least one trophic transfer). For example, mysid shrimp are depredated by multiple age-classes of Striped Bass as well as by many of the forage fish that are directly consumed by Striped Bass such as bay anchovy, clupeids, and other small or juvenile fishes. If microplastics accumulate in prey, either in the gut or in body tissues following assimilation of very small fragments across the gut wall, indirect trophic transfers may represent an important ‘source’ of microplastics trophic exposure (Setälä et al. 2014). Finally, many of the prey taxa identified here rely on multiple basal resources (e.g., phytoplankton and benthic organic matter). By linking multiple basal resources, individual prey taxa will potentially be exposed to different pools of microplastics available in the environment.

Diet of larval Striped Bass in the Potomac River is dominated by small zoofauna (Beaven and Mihursky 1980). Dominant prey taxa include cladocerans such as *Bosmina longirostris*, copepods such as the calanoids *Eurytemora affinis* and *Acartia tonsa*, and rotifers such as *Brachionus calyciflorus* (Figure 4-2). Data from other salinity zones in the Potomac River for larval Striped Bass are not available but olighaline reaches in the vicinity of the estuarine turbidity maximum (ETM) are known to be important reaches for the concentration, growth and survival of this life stage. Therefore, diet composition of larval Striped Bass from this salinity zone is likely to be a good representation of diet for this life-stage. Due to differences in the reporting of diet composition by larval stage, there is not a stage-specific positive network diagram for yolk-sac, finfold, and post-finfold larvae, but the % frequency of occurrence of each prey type by larval stage is provided (Figure 4-3). Figure 4-3 shows that diet composition changes across these three different larval stages, with yolk-sac larvae feeding primarily on rotifers and cladocerans. Diet of finfold larvae demonstrates a reduced contribution of rotifers and increasing importance of cladocerans and copepods, while diet of post-finfold larvae of dominated by copepods and cladocerns. Among the copepods identified, *E. affinis* occurred much more frequently than *A. tonsa*. Many of these same zooplankton taxa were identified as dominant prey in the stomachs of larval Striped Bass in the oligohaline region of the Chesapeake Bay mainstem (Martino 2008, Shideler and Houde 2014).

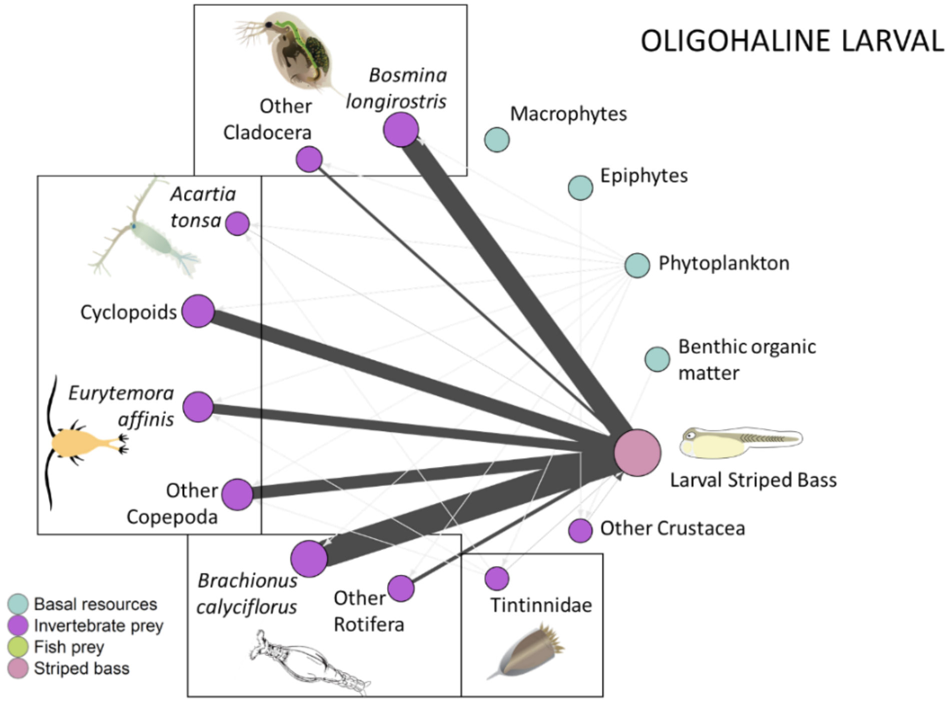


Figure 4-3. Larval Striped Bass food web from oligohaline portion of Potomac River estuary (adapted from Beaven and Mihursky 1980). Dark vectors connecting prey through direct consumption provides biomass-weighted percent contribution to diet for each prey category. Copepods are primarily adult-stages. Boxes around prey group taxonomically similar prey: Cladocera, Copepoda, Rotifera, Tintinnidae.

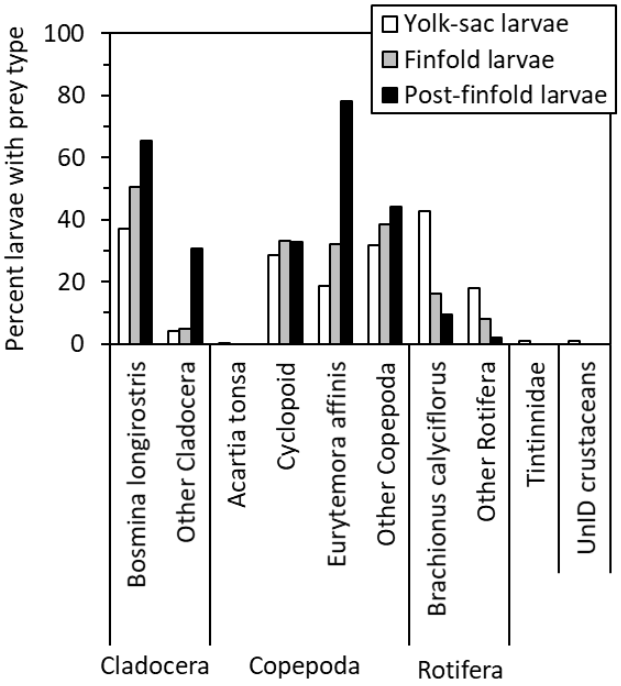
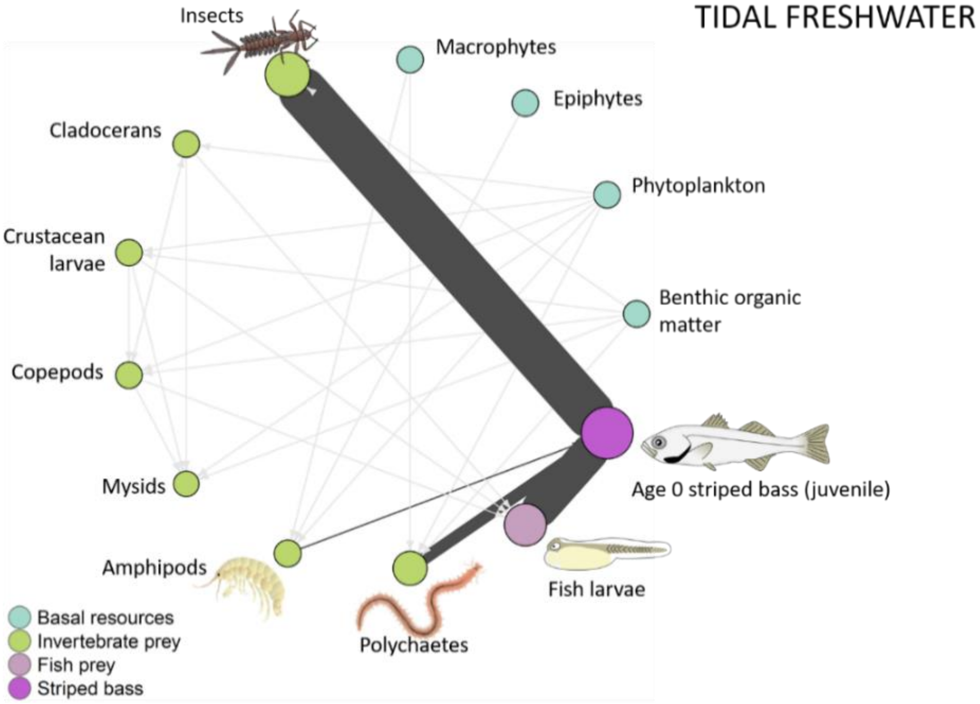


Figure 4-4. Larval Striped Bass diet composition as % frequency of occurrence of prey in fish with material in their stomachs from the oligohaline portion of Potomac River estuary (adapted from Beaven and Mihursky 1980).

Research conducted by Boynton et al. (1981) described quantitative dietary preferences of YOY Striped Bass (25-99 mm) foraging in three Potomac River salinity regimes—mesohaline, oligohaline, and tidal freshwater Figure 4-4, Figure 4-5, Figure 4-6). In these positive networks diagrams, dashed lines connecting the Striped Bass node to a prey item indicate the prevalence of that organism as a food item, with thicker lines and larger nodes indicating a greater contribution than thinner lines. These diagrams demonstrate that the diet of YOY Striped Bass varies in composition depending on salinity zone. For example, mysids and polychaetes make up most of the diet in mesohaline areas while fish larvae and insects are the most dominant dietary components in tidal freshwater areas. Diet composition in oligohaline areas were intermediate between the mesohaline and tidal freshwater with declining importance of insect larvae, increased importance of amphipods and polychaetes and the appearance of mysids. In addition to diet differences across salinity zones, Boynton et al. (1981) also found inshore-offshore differences in diet composition within each salinity zone (Figure 4-7). These differences are likely related to local prey availability, with insect larvae a larger component of the diet in juvenile Striped Bass collected in shallow inshore habitats and mysids a larger component in fish collected offshore (up to 5m depth).

The differing dietary preferences associated with salinity-based and inshore-offshore habitats are potentially important given ongoing research on the fate and transport of microplastics within the

Potomac River. Boyton et al (1981) defined nearshore as the As data gaps close for fate and transport and uptake by prey items, an ecological risk assessment can be tailored to specific habitats that might be disproportionately affected by different varieties or concentrations of microplastics.



*Consumed prey categories identified by weighted, dark lines, icons and group name.

Figure 4-5. Juvenile Striped Bass food web from tidal fresh portion of Potomac River estuary (adapted from Boynton et al. (1981)). Dark vectors connecting prey through direct consumption provides biomass-weighted percent contribution to diet for each prey category. Insects are primarily Diptera larvae (e.g., Muscidae).

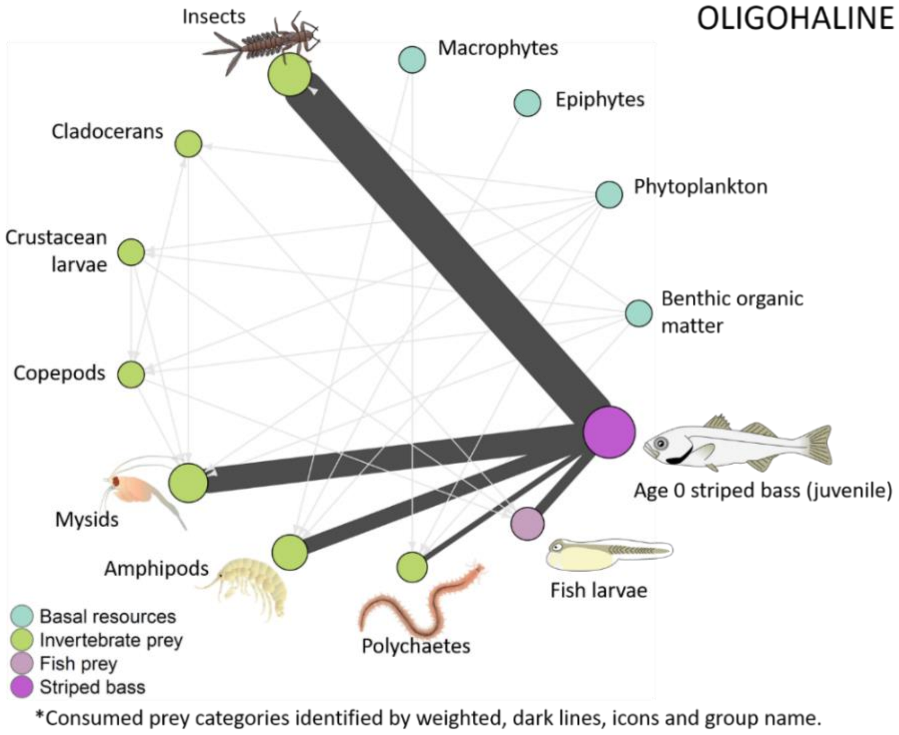


Figure 4-6. Juvenile Striped Bass food web from oligohaline portion of Potomac River estuary (adapted from Boynton et al. (1981)). Dark vectors connecting prey through direct consumption provides biomass-weighted percent contribution to diet for each prey category.

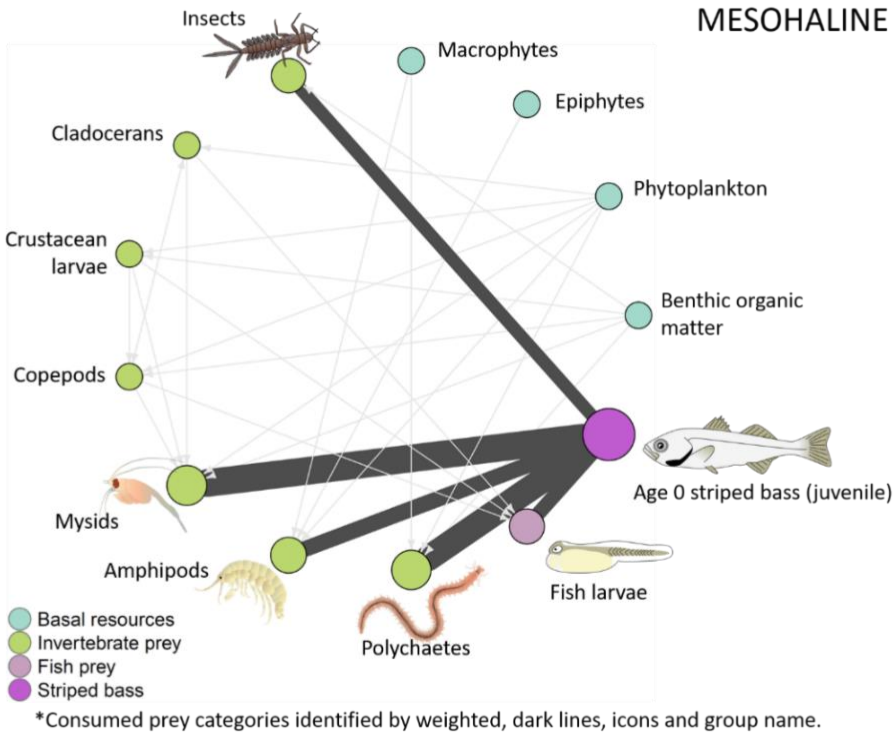


Figure 4-7. Juvenile Striped Bass food web from mesohaline portion of Potomac River estuary (adapted from Boynton et al. (1981)). Dark vectors connecting prey through direct consumption provides biomass-weighted percent contribution to diet for each prey category.

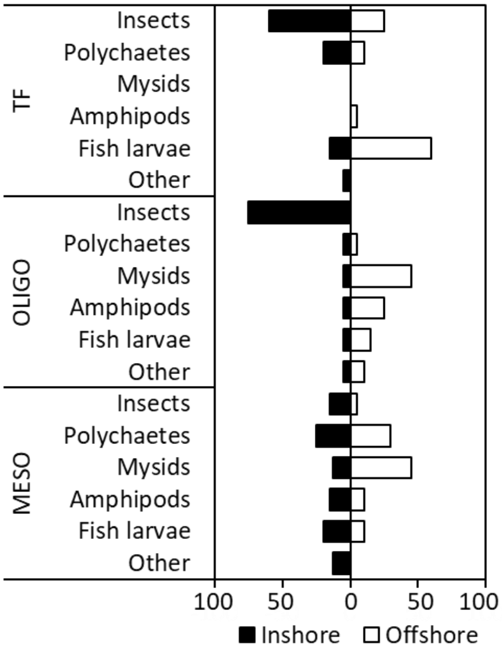
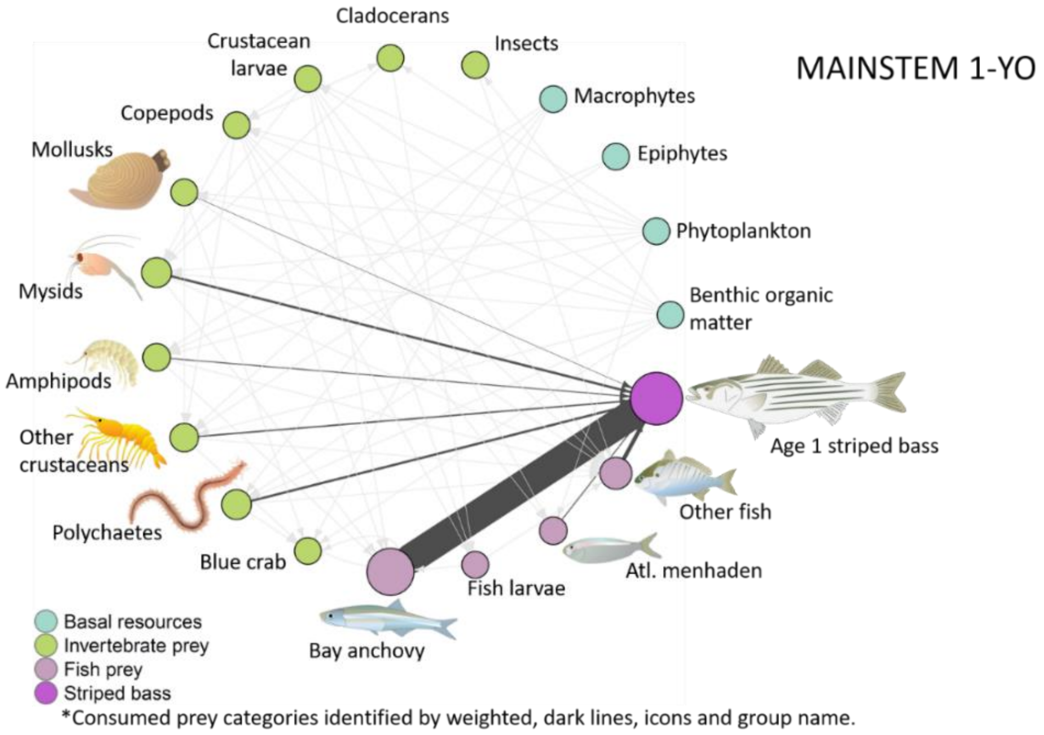


Figure 4-8. Juvenile Striped Bass % diet composition from fish collected at inshore and offshore locations in the tidal fresh (TF), oligohaline (OLIGO), and mesohaline (MESO) portion of Potomac River estuary (adapted from Boynton et al. (1981)).

As previously noted, the literature review evaluated a number of studies on Striped Bass diets and those that focused on Potomac River populations (Beaven and Mihursky 1980, Boynton et al. 1981) were used to develop the YOY positive network diagrams. However, few to no studies were found for older fish (1YO-2YO) from the Potomac River. Ihde et al. (2015) reviewed Striped Bass diets along the entire mainstem of the Chesapeake Bay, from tidal fresh to polyhaline regions, that can be utilized as a proxy for the Potomac River estuary. Those findings were used to develop positive network diagrams for ages 1 and 2 (Figure 4-8, .Figure 4-9). Identities of dominant prey taxa were very similar between the two age classes, with the inclusion of a relatively small amount of blue crab in the diet of age-2 Striped Bass being the major difference (Figure 4-10) (Ihde et al. 2015). Despite these close similarities in prey identity, there were substantial differences in the relative contribution of different prey to each age-class. Some key differences were an increased importance of benthic and invertebrate prey for the age-2 Striped Bass. Mysids, amphipods, and polychaetes all contributed more to the diet of age-2 Striped Bass. Atlantic Menhaden (*Brevoortia tyrannus*) also became more important to the diet of age-2 Striped Bass while Bay Anchovy (*Anchoa micthilli*) declined in importance relative to the age-1 diet.



.Figure 4-9. Food web with Striped Bass 1YO endpoint. Dark vectors connecting prey through direct consumption provides biomass-weighted percent contribution to diet for each prey category as found in Ihde et al. (2015).

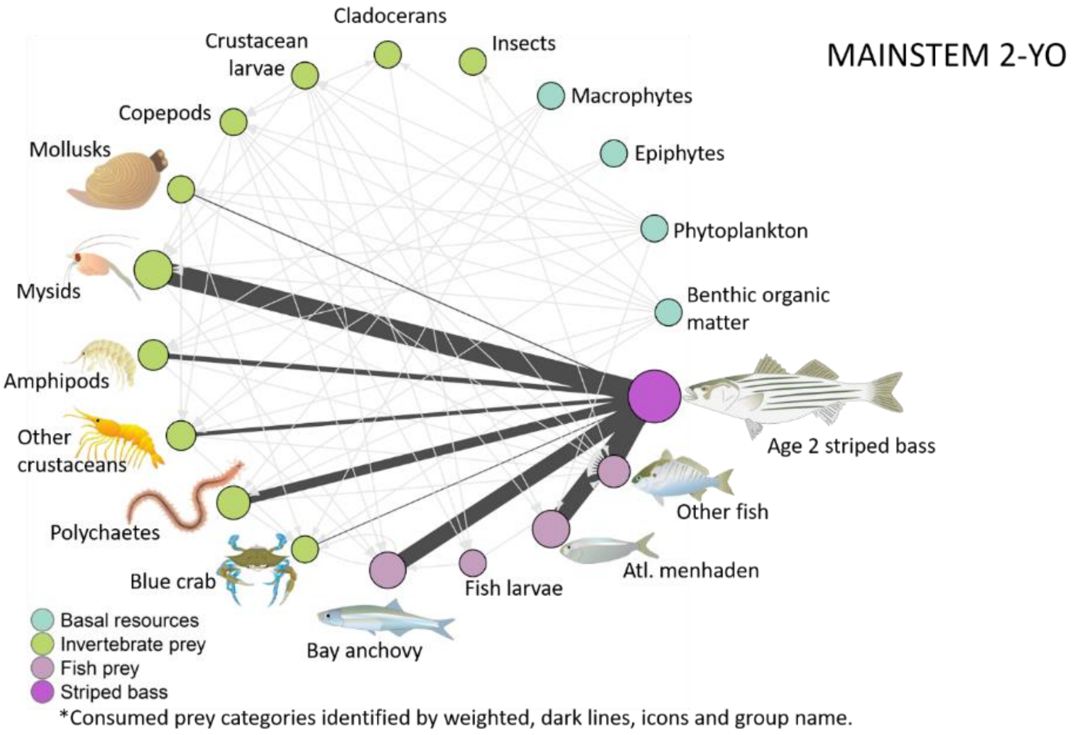


Figure 4-10. Food web with Striped Bass 2YO endpoint. Dark vectors connecting prey through direct consumption provides biomass-weighted percent contribution to diet for each prey category as found in Ihde et al. (2015). Note the change in dominant dietary components from 1YO.

An evaluation of diet composition data revealed several prey taxa that were important across multiple life-stages and age-classes of Striped Bass (Table 4-1Three prey taxa – mysids, amphipods, and polychaetes – were ranked as High priority taxa for future research on potential microplastics exposure of Potomac River Striped Bass through trophic transfer. These three prey taxa were important during the YOY juvenile and ages 1 and 2 subadult age-classes. Six prey taxa were identified as Moderate priority taxa because they were a dominant prey for at least one age-class of Striped Bass. These moderate priority prey included invertebrates (aquatic insect larvae, cladocerans, copepods) and fishes (fish larvae, Bay Anchovy, Atlantic Menhaden). Low priority prey contributed relatively little to diet and were only associated with one life stage (larval zooplankton, bivalves, other crustaceans, other fish).

Table 4-1. Percent diet composition by major prey category for each life-stage of Striped Bass (larval [inclusive of yolk-sac, finfold, post-finfold larvae], age-0 juvenile, age-1 and age-2 subadults [SA]). Salinity zone within the Potomac River is provided for age-0 life-stage diet data (Tidal fresh – TF, Oligohaline – OLIGO, Mesohaline – MESO) but not for age-1 or age-2 Striped Bass diet data originating from the mainstem of Chesapeake Bay (MAIN). Priority-level reflects proposed priority need for empirical measurement of microplastics loading in each prey category (High priority – red, Moderate priority – orange, Lower priority – yellow; classification levels described further in the text).

	Age-0				**Age-1**	**Age-2**	
	Larval	**Juvenile**			**SA**	**SA**	
Prey category	**OLIGO**	**TF**	**OLIGO**	**MESO**	**MAIN**	**MAIN**	**Priority-level**
Insects		47.5	40	12.5			🟧
Cladocerans	26.2						🟧
Larval zooplankton	1						🟨
Adult copepods	40.3						🟧
Bivalves					0.9	1.2	🟨
Mysids		0	24.5	27	4.5	21	🟥
Amphipods		1.5	15	15.5	1.9	5	🟥
Other crustaceans					2.8	4	🟨
Polychaetes		12	5.5	25	4.4	9.4	🟥
Bay Anchovy					57.8	15.6	🟧
Fish larvae		35.5	10	14			🟧
Atl. Menhaden					1.9	17.9	🟧
Other fish					7.6	8	🟨

A separate evaluation of diet percent frequency of occurrence data for each larval stage of Striped Bass was conducted to provide higher resolution of dominant prey for this critical life-stage (Table 4-2). Four zooplankton prey taxa, including *B. longirostris*, *E. affinis*, Cyclopoid copepods, and other copepods, were ranked as High priority taxa for future research. These four prey taxa were important during the yolk-sac, finfold, and post-finfold larval stages. Other cladocerans and rotifers, including *B. calyciflorus*, were identified as Moderate priority taxa because they were a dominant prey for at least one larval stage of Striped Bass. Tintinnids, *A. tonsa*, and other (unidentified) crustaceans were classified as Low priority prey because they contributed relatively little to diet during one larval stage.

Table 4-2. Percent frequency of occurrence by major prey category in the diet of each larval-stage of Striped Bass (yolk-sac, finfold, post-finfold). Larval data are from the oligohaline zone within the Potomac River. Priority-level reflects proposed priority need for empirical measurement of microplastics loading in each prey category (High priority – red, Moderate priority – orange, Lower priority – yellow; classification levels described further in the text).

		Age 0 (OLIGOHALINE)			
Taxonomic group	**Prey taxon**	**Yolk-sac**	**Finfold**	**Post-finfold**	**Priority-level**
Cladocera	*Bosmina longirostris*	36.9	50.5	65.4	🟥
	Other Cladocera	4	5	30.7	🟧
Copepoda	*Acartia tonsa*	0.4			🟨
	Cyclopoid	28.5	33.3	32.8	🟥
	Eurytemora affinis	18.8	32.2	78.1	🟥
	Other Copepoda	31.7	38.4	44.2	🟥
Rotifera	*Brachionus calyciflorus*	42.6	16.2	9.6	🟧
	Other Rotifera	17.8	8.1	1.9	🟧
Ciliophora	Tintinnidae	0.8			🟨
UnID crustaceans	UnID crustaceans	0.8			🟨

4.1. Assessment Endpoint and Potential Effects of Microplastics

It is hypothesized that microplastics may contribute to decreased growth and survival of striped bass by several mechanisms. First, microplastics are known to cause physical blockage of the gut resulting in blockage or potentially reduced feeding due to a full gut. Microplastics could also cause behavioral changes in small organisms if the physical presence of microplastics changes buoyancy or swimming behavior, leading to increased susceptibility to predicators. Additionally, toxicity to striped bass could occur because of organic contaminants like PCBs, PCDEs, or other organic contaminants that strongly partition to plastics.

4.2. Analysis Plan

The conceptual model for microplastic risk assessment on Striped Bass demonstrates wide-ranging data gaps in our understanding of current microplastic abundance, distribution, and biological interactions. The model highlights potential pathways for microplastics to impact Striped Bass and which endpoints are potentially impacted. However, there is no data on the basic uptake of microplastics within the trophic ecology of Striped Bass in the Potomac River. Recent research, on the other hand, has evaluated the uptake of microplastics in species of the same genera seen in the Potomac River Striped Bass diets, although these studies were done elsewhere. These values begin to shed light on some aspects of how microplastics may enter the food chain, eventually reaching Striped Bass (Table 4-3).

Table 4-3. Studies on microplastic ingestion for taxa identified in the Potomac River estuary trophic pathways for Striped Bass, ages 0-2 YO.

Major Taxa	**Confirmed MP presence or consumption? (Y/N)**	**Location**	**Citation**	**Notes**
Habitat				
Macrophytes (includes SAV and wetlands)	Y	(SAV) Caribbean; UK, Korea; Washington, DC; (wetlands)South Africa; multiple	(Goss et al. 2018, Reynolds and Ryan 2018, Murphy 2019, Townsend et al. 2019, Cozzolino et al. 2020, Huang et al. 2020, Jones et al. 2020)	Macrophytes include a compilation of SAV and wetlands given similar roles for microplastic adherence
Epiphytes	Y	Caribbean;	(Goss et al. 2018, Seng et al. 2020)	Found in epiphytes on seagrass
Benthic organic matter	Y	St. Lawrence River; Washington DC;	(Castaneda et al. 2014, Murphy 2020)	
Phytoplankton	Y	Laboratory;	(Long et al. 2015, Shiu et al. 2020)	Diatoms; aggregation of cells on MPs
Invertebrate Prey				
Insects	Y	Germany	(Ehlers et al. 2019)	Field collected caddisfly cases
Crustacean larvae	Y	Laboratory	(Jemec et al. 2016, Gambardella et al. 2017, Woods et al. 2020)	Lobsters; barnacle nauplii;

Table 4-3. Studies on microplastic ingestion for taxa identified in the Potomac River estuary trophic pathways for Striped Bass, ages 0-2 YO.

Major Taxa	Confirmed MP presence or consumption? (Y/N)	Location	Citation	Notes
Cladocerans	Y	Laboratory	(Martins and Guilhermino 2018, Jaikumar et al. 2019, Woods et al. 2020)	Freshwater regions
Copepods	Y	Laboratory; Pacific Ocean	(Cole et al. 2015, Desforges et al. 2015)	
Amphipods	Y	Laboratory	(Jeong et al. 2017, Mateos Cárdenas et al. 2019)	Jeong et al proposed an adverse outcome pathway for microplastic exposure that covers molecular and individual levels.
Mysids	Y	Laboratory	(Setälä et al. 2014, Lehtiniemi et al. 2018, Wang et al. 2020)	Hasegawa et al (2021) demonstrated trophic transfer of microplastics between mysids and fish predator
Polychaetes	Y	Newfoundland; laboratory; Norway	(Mathalon and Hill 2014, Setälä et al. 2014, Knutsen et al. 2020)	

Table 4-3. Studies on microplastic ingestion for taxa identified in the Potomac River estuary trophic pathways for Striped Bass, ages 0-2 YO.

Major Taxa	**Confirmed MP presence or consumption? (Y/N)**	**Location**	**Citation**	**Notes**
Blue crab	Y	Murderkill and St. Jones Rivers, DE; Texas;	(Santana et al. 2017, Cohen 2020, Waddell et al. 2020)	Santana et al found little trophic cascade; Cohen’s work in similar systems to tidal Potomac;
Crustacea (other)	Y	Florida; North Sea	(Devriese et al. 2015, Waite et al. 2018)	Waite et al found MPs in *Panopeus*, a known prey item for striped bass; Devriese looked at *Crangon* shrimp, known prey ofr striped bass.
Molluscs	Y	Laboratory;	(Avio et al. 2015, Gutow et al. 2016)	Gutow looked at *Littorina*; Avio looked at mussels
Fish				
Bay anchovy	Y	South Carolina;	(Gray et al. 2018, Parker et al. 2020)	Other literature available for proxies to bay anchovy

Table 4-3. Studies on microplastic ingestion for taxa identified in the Potomac River estuary trophic pathways for Striped Bass, ages 0-2 YO.

Major Taxa	**Confirmed MP presence or consumption? (Y/N)**	**Location**	**Citation**	**Notes**
Atlantic menhaden	Y	South Carolina	(Parker et al. 2020)	
Fish larvae	Y	Laboratory; Portugal	(Lonnstedt and Eklov 2016, Rodrigues et al. 2019)	Rodrigues looked at urbanized estuaries, multiple fish species;
Striped Bass				
Striped Bass	Y	Lake Meade	(Baldwin et al. 2020)	Freshwater impoundment

Applying the trophic pathways for Striped Bass risk assessment endpoints allows us to identify gaps in data, but more importantly, the ability to prioritize the particular taxa that overlap salinity regimes. For example, mysid shrimp are a priority taxon in Striped Bass diets throughout the Potomac River estuary, but we have no data on microplastic uptake by mysids within the Potomac. Recent research (Lehtiniemi et al. 2018, Hasegawa and Nakaoka 2021) has shown that mysids not only ingest microplastics, but that consumption by fish results in bioaccumulation since the microplastic particles are transferred to fish tissue. This implies the same mechanism can take place in the Potomac and therefore this pathway requires further investigation.

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Appendix 1: Microplastics QAPP

GROUP A: PROJECT MANAGEMENT

A1 TITLE AND APPROVAL PAGE

Quality Assurance Project Plan

for

Developing a Preliminary Conceptual Ecological Risk Assessment Model and Science Strategy for Microplastics in the Potomac River

Contract Number EP-C-17-031
Task Order 68HERC20F0213

Prepared for:

U.S. Environmental Protection Agency
Region 3
1650 Arch Street
Philadelphia, PA 19103-2029

Prepared by:

Tetra Tech
10711 Red Run Blvd. Ste. 105
Owings Mills, MD 21117

July 10, 2020
QAPP 537, Revision 0

This quality assurance project plan (QAPP) has been prepared according to guidance provided in *EPA Requirements for Quality Assurance Project Plans* (EPA QA/R-5); EPA Office of Research and Development's *Quality Assurance/Quality Control Approaches For Existing Scientific Data and Technical Information*; and EPA's *Guidance for Evaluating and Documenting the Quality of Existing Scientific and Technical Information Addendum to: A Summary of General Assessment Factors for Evaluating the Quality of Scientific and Technical Information* to ensure that environmental and related data collected, compiled, and/or generated for this project are complete, accurate, and of the type, quantity, and quality required for their intended use. Tetra Tech will conduct work in conformance with the quality assurance program described in Tetra Tech's *Quality Management Plan* for EPA Contract EP-C-17-031 (Tetra Tech, March 2017) and the procedures detailed in this QAPP.

Approvals:

07/16/20
Robert F. Murphy — Date
Task Order Leader, Quality Control Officer
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07/20/20
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Document Revision History

QAPP Submittal	Summary of Edits Received/Changes Made
Draft QAPP Revision 0 submitted on 05/26/20	Addressed comments received from EPA on 07/01/20.
QAPP Revision 0 submitted on 07/10/20	

A2 TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

LIST OF ACRONYMS AND ABBREVIATIONS

CBP	Chesapeake Bay Program
DQI	data quality indicators
EPA	Environmental Protection Agency
ERA	ecological risk assessment
PDF	portable document format
PPAT	Plastic Pollution Action Team
QA	quality assurance
QC	quality control
QAPP	quality assurance project plan
SOP	standard operating procedure
STAC	Science and Technical Advisory Committee
STAR	Scientific, Technical Assessment and Reporting
TOCOR	Task Order Contracting Officer’s Representative
TOL	Task Order Leader

A3 DISTRIBUTION

The Environmental Protection Agency (EPA) Task Order Contracting Officer's Representative (TOCOR) will distribute this Quality Assurance Project Plan (QAPP) to the EPA staff members listed below, and any other Agency staff participating in the development or review of the plan or deliverables prepared under the performance work statement of Task Order 68HERC20F0213. The Tetra Tech Task Order Leader (TOL) will distribute the approved document to all Tetra Tech staff members involved in the project.

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A4 PROJECT/TASK ORGANIZATION

This quality assurance project plan (QAPP) describes the quality system that Tetra Tech will implement to ensure the quality of results generated, distributed, or used to formulate a preliminary ecological risk assessment (ERA) conceptual model and science strategy for microplastics in the Potomac River. Tetra Tech will compile the best available science through stakeholder engagement, as well as data and literature review to develop a preliminary ERA using the U.S. Environmental Protection Agency's (EPA's) *Framework for Ecological Risk Assessment* (EPA/630/R-92-001). Tetra Tech will analyze relevant data as described in the subject Task Order. The plan follows an abbreviated format that has been recommended by other EPA programs and offices to address projects that have a relatively narrow scope and do not require sampling or data collection. As EPA and Tetra Tech make decisions on the type, quantity, and quality of data needed to execute specific tasks in the Task Order, Tetra Tech will submit a revised QAPP for approval, or, amendments to this QAPP, if requested by EPA and if resources are available. Funding for this project is provided by EPA under Contract Number EP-C-17-031, Task Order 68HERC20F0213.

The project organization chart, presented as Figure 1, includes relationships and lines of communication among all participants and data users. The responsibilities of those persons are described below.

The EPA Task Order Contracting Officer's Representative (TOCOR), Ms. Patricia Gleason, and Alternate TOCOR, Ms. Lydia Bailey, of EPA's Region 3 Water Division, will provide overall project and program oversight for this Task Order. They will review and approve the QAPP, and other materials developed to support the project. The EPA TOCOR and Alternate TOCOR will coordinate with contractors, reviewers, and others to ensure technical quality in all deliverables and adherence to the contract, as appropriate throughout the period of performance.

The EPA Region 3 Quality Assurance (QA) Coordinator is Jillian Adair. Her responsibilities include reviewing and approving the project QAPP and participating in any Agency quality reviews of the project.

The Tetra Tech Task Order Leader (TOL), Mr. Robert Murphy, will supervise the overall project. The specific responsibilities of the TOL include coordinating project assignments; establishing priorities and schedules; ensuring completion of high-quality projects within established budgets and schedules; providing guidance and technical advice and evaluating the performance of those assigned to the project; implementing corrective actions; preparing or reviewing preparation of project deliverables, responses to EPA, action memos, and any other materials developed to support the project; and providing support to EPA in interacting with the project team, technical reviewers, and others to ensure that technical quality requirements are met in accordance with EPA's objectives.

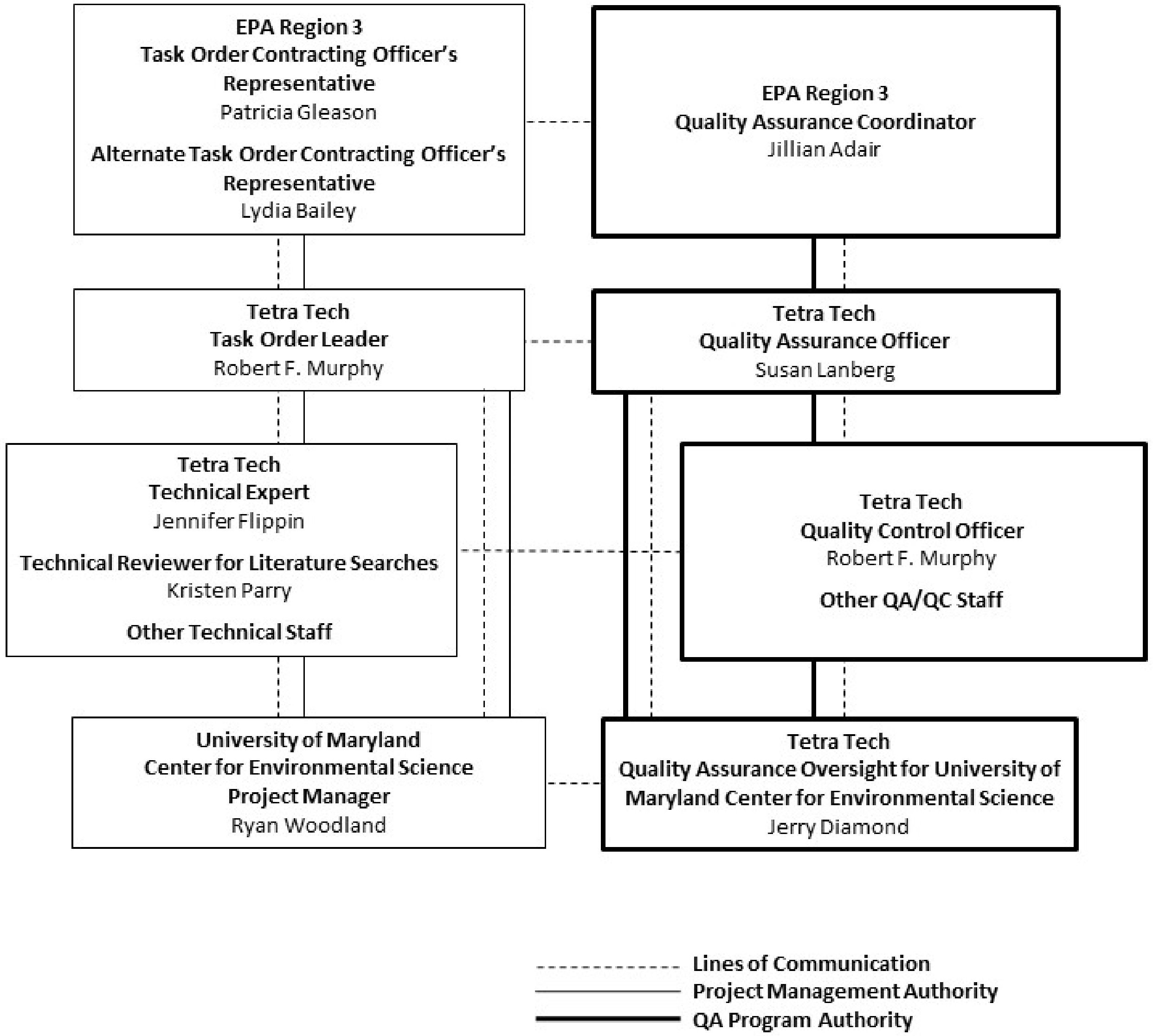


Figure 1. Project Organization

The Tetra Tech Technical Expert, Ms. Jennifer Flippin, will provide support to the Tetra Tech TOL in developing the ERA conceptual model. The Tetra Tech Technical Reviewer for Literature Searches, Ms. Kristen Parry, will oversee the literature search, review, and extraction to support the development of the ERA conceptual model and identification of data gaps. Other Tetra Tech technical staff will assist in secondary data compilation and review, and aid in completing data analyses. Technical staff will implement the QA/quality control (QC) program, complete assigned work on schedule and with strict adherence to the established procedures, and complete required documentation.

The Tetra Tech QA Officer is Ms. Susan Lanberg. Her primary responsibilities are the following: providing support to the Tetra Tech TOL in preparing the QAPP, reviewing and approving the

QAPP, and assisting with monitoring QC activities to determine conformance with QA/QC requirements.

The University of Maryland Center for Environmental Science (UMCES) Project Manager, Dr. Ryan Woodland, will provide support for the development of a conceptual model for the ecological risk assessment of microplastics in the Potomac River. He will work with the Tetra Tech TOL to share the latest research and provide analytical skills to support developing the scientific basis for the development of a uniform microplastics size classification and concentration unit terminology. The UCMES Project Manager will apply modeling experience to provide support for identifying and describing probable pathways to biological endpoints potentially impacted by microplastic occurrence in the Potomac River. He will also provide informed advice in the development of a Chesapeake Bay-wide science strategy to address the issue of microplastics, largely based on other coastal regions both nationally and internationally.

In his role as QC Officer, Mr. Murphy, will provide primary daily oversight. A QC Officer is a technical staff member familiar with the project who has not done the original work. The QC Officer will be responsible for evaluating and reviewing project deliverables. UMCES is a small institution that does not have in-house QA staff. Dr. Jerry Diamond will provide QA oversight of work performed by UMCES to ensure it meets the quality requirements described in this QAPP. Other QA/QC staff, including technical reviewers and technical editors selected as needed, will provide review oversight on the content of the work products and ensure that the work products comply with EPA's specifications. In this light, when the Tetra Tech TOL/QC Officer works directly on technical aspects of this project, an appropriate Tetra Tech technical staff member would be the QC Officer overseeing and reviewing that work.

A5 PROBLEM DEFINITION/BACKGROUND

Microplastics are an emerging contaminant of concern worldwide, particularly in aquatic ecosystems. Microplastics are generally defined as polymer particles 0.1 - 5 mm long. The potential human health and environmental impacts of plastic pollution is an active area of scientific research. The potential impacts on aquatic resources and the food chain could have wide-ranging impacts, from a decline in fish populations to economic impacts. The Chesapeake Bay's Science and Technical Advisory Committee (STAC) recognized this growing threat and hosted a two-day workshop in the Spring of 2019, "Microplastics in the Chesapeake Bay and its Watershed: State of the Knowledge, Data Gaps, and Relationship to Management Goals" (Murphy et al. 2019). Over 50 participants from government, academia, consulting, and non-governmental organizations met to present current research and policy initiatives, followed by facilitated discussion on data gaps and needs.

The workshop was designed within the framework of an ERA, treating microplastics in the environment similarly to other pollutants (Gorycka and De Noordzee 2009; Peng et al. 2017). Participants noted that while our understanding has progressed in recent years, there is still incomplete understanding of the magnitude and distribution of microplastics within the watershed (Yonkos et al. 2014; Parks et al. 2019), much less the potential impact microplastic pollution may be having on living resources (Ling et al. 2017; de Sa et al. 2018). Workshop participants concluded that microplastics pose a potential serious risk to successful restoration of the Chesapeake Bay watershed.

As a result, the following recommendations were presented to the Chesapeake Bay Program (CBP) as urgent and immediate needs:

1. The CBP should create a Plastic Pollution Action Team (PPAT) to address the growing threat of plastic pollution to the Bay and watershed.
2. The Scientific, Technical Assessment and Reporting (STAR) Team should incorporate development of ERAs of microplastics into the CBP strategic science and research framework, and the PPAT should oversee the development of the ERAs focused on assessment of microplastic pollution on multiple living resource endpoints.
3. STAC should undertake a technical review of terminology used in microplastic research, specifically size classification and concentration units, and recommend uniform technology for the CBP partners to utilize in monitoring and studies focused on plastic pollution in the Bay and watershed.
4. The CBP should develop a source reduction strategy to assess and address plastic pollution emanating from point sources, non-point sources, and human behavior.
5. The CBP should direct the PPAT and STAR Tea to collaborate on utilizing Bay and watershed monitoring networks to monitor for microplastic pollution.

Tetra Tech, in partnership with stakeholders, will formulate an ERA conceptual model looking at the effects of microplastics on an ecological endpoint (e.g., American shad) in the Potomac River. The project will entail compiling the best available science to develop a preliminary ERA using the ERA framework (EPA 630/R-92/001). Tetra Tech anticipates that a large number (>100) of defensible existing sources (i.e., peer-reviewed journal articles and assessments prepared by EPA, other federal entities, or states for which project-specific QAPPs or similar documentation describing site-specific sampling and analyses) are available to support the development of an ERA conceptual model for evaluating the effects of microplastics on the ecology of the Potomac River. Tetra Tech anticipates collecting information from literature search engines, general internet searches, and PPAT members who are microplastic or Potomac ecology experts. The depth of relevant literature includes topics such as ecosystem health in the Potomac River, how human activities could act as a source of microplastics to the Potomac River ecosystem, pathways by which a key assessment endpoint could be exposed to microplastics, and the means by which microplastics could impact an assessment endpoint. Because of the availability of existing information and need for a diverse body of information, Tetra Tech expects that using existing data will be more efficient and provide more detailed information than collecting primary data under an individual study for this project (USEPA 2002). The deliverables for this project will include a final report describing the data gathering process, the ERA conceptual model, description of uniform scientific terminology, and science strategy.

A6 PROJECT/TASK DESCRIPTION

Tetra Tech's work plan was developed to provide the TOCOR with detailed information on the approach to be taken by Tetra Tech in accomplishing the objectives of Task Order 68HERC20F0213. The text below from the work plan presents Tetra Tech's approach. Following the text descriptions of tasks, subtasks and deliverables, a table of milestones and communication deliverables are presented as Table 1.

Task 1. Establish Communication and Prepare Project Deliverables

Subtask 1.1 Communication/Kickoff Call

Tetra Tech will participate by conference call in a kickoff meeting as determined by the EPA TOCOR to discuss the following: points of contact, roles and responsibilities, timelines, the schedule of benchmarks, milestones and deliverables, and to establish dates and times for monthly calls, monthly technical progress reports, and general Task Order administrative information. Tetra Tech will provide meeting notes from these calls in the form of technical progress reports by email which will include status updates of all of the tasks of this project.

> *Deliverable 1.1*: Brief progress reports as email to the EPA TOCOR. Due monthly or as agreed upon with the TOCOR for the duration of this Task Order.

Subtask 1.2 Communication and Regular Reporting

The EPA TOCOR will coordinate and set-up monthly conference calls between EPA staff and Tetra Tech's TOL to discuss the status and progress of the work under this Task Order. Tetra Tech will participate in these monthly calls. The EPA TOCOR may modify the frequency of conference calls based on project progress. From time to time, researchers from other federal agencies may be invited by the TOCOR to provide perspectives and information.

> *Deliverable 1.2:* Project meetings and other communications, such as conference calls. Due monthly or as assigned by TOCOR for the duration of this Task Order.

Subtask 1.3 Coordination and Notification with TOCOR

Tetra Tech will notify the TOCOR of any problems, delays or questions as soon as they arise, including immediate written notification of any Task Order delays.

> *Deliverable 1.3:* Brief, written reports as emails to the TOCOR detailing problems, delays, or questions. Due immediately upon problem identification or as needed by TOCOR.

Subtask 1.4 Coordination and Notification Issues with External Parties

This task requires coordination with other stakeholders and therefore it is particularly important that Tetra Tech notifies the TOCOR of issues, problems, questions, or delays as soon as they become apparent or if they are anticipated. Tetra Tech will use webinar systems such as Skype, Teams, Adobe Connect, and Go To Meetings as communication tools under this Task Order.

> *Deliverable 1.4:* Brief, written reports as emails to TOCOR detailing problems, delays, or questions working with stakeholders. Due immediately as questions/problems are presented or as needed to TOCOR.

Subtask 1.5 Reporting and Meeting Minutes

In general, written materials including meeting summaries will be furnished by Tetra Tech within five business days after each conference call for the TOCOR to review; a final written deliverable will be delivered within five business days after receipt of written technical exchange from the TOCOR, including the TOCOR's comments and edits to the draft deliverable.

> *Deliverable 1.5:* Meeting notes and summaries detailing topics discussed and discussion among parties, delivered as memos/emails to TOCOR. Due within 5 business days of call or discussion.

Task 2. Prepare and Implement QAPP

Subtask 2.1 Draft QAPP

Tetra Tech has developed this draft QAPP for review and approval by the EPA TOCOR and the EPA QA Manager. Tetra Tech will not proceed with tasks needing QA review under this Task Order until the EPA TOCOR provides written notice to Tetra Tech that any additions to the QAPP have been accepted by EPA.

> *Deliverable 2.1*: A draft QAPP for EPA review, due four weeks after the Kickoff call.

Subtask 2.2 Final QAPP

Tetra Tech will develop a final QAPP that incorporates comments or concerns identified by EPA.

> *Deliverable 2.2*: A final QAPP including EPA comments, due 5 business days after Tetra Tech receives EPA's review comments.

Subtask 2.3 QA Processes and Changes

All QA activities will be in conformance with EPA's *Requirements for Quality Assurance Project Plans* (EPA QA/R-5) and will demonstrate a clear understanding of the project's goals/objectives/questions and issues. Documentation of all analyses will also indicate how types, quantity, and quality of data have been quality assured and maintained. All deliverables will be prepared so that the decisions and analysis are transparent to a third party. Tetra Tech will alert the TOCOR regarding any quality issues should they arise.

> *Deliverable 2.3*: Final documentation of all analyses that indicate how types, quantity, and quality of data have been quality assured and maintained. Due within 11 months of the task award to the TOCOR.

Task 3. Develop a Uniform Size Classification and Concentration Unit Terminology for Broad Application

EPA's Chesapeake Bay Program Management Board approved the formation of a PPAT to address the emerging and growing concerns of microplastics in the watershed. Tetra Tech will work with the CBP PPAT, the CBP STAC and other stakeholders to develop a uniform size classification and concentration unit terminology for microplastics. This task will be completed by performing a review of primary and gray literature including reports, dissertations, and theses. Size classification and concentration units used or recommended by peer reviewed or reputable scientific literature will be compiled into a report for review and will receive further input by the PPAT. Neither size classification nor concentration units are clearly defined by regulatory agencies or otherwise, and terms are not always used consistently. Thus, a list of terminology will be developed for this task to ensure clear communication for products developed under Task 4.

Tetra Tech assumes there will be one review draft each from the PPAT and STAC over the course of this task. All comments will be addressed/incorporated into the final deliverable document.

> *Deliverable 3:* Final uniform size classification and concentration unit document reviewed and approved by the PPAT and STAC, due within 6 months of Task Order award to TOCOR.

Task 4. Formulate a Preliminary Ecological Risk Assessment Model

Tetra Tech will formulate a preliminary ERA model examining the effects of microplastics on an ecosystem endpoint (e.g., fish species) in the Potomac River. Tetra Tech will follow EPA's Ecological Risk Assessment Framework "Framework for Ecological Risk Assessment" (EPA/630/R-92-001) as discussed in Murphy et al. (2019). Standardized terminology developed in Task 3 will be used in development of the ERA model to ensure that microplastics are addressed consistently and clearly defined, rather than using variable terminology used by different authors.

Tetra Tech will use existing microplastics and targeted aquatic life data collected in the Chesapeake Bay and the Potomac River, as well as relevant data from similar estuaries to develop a preliminary conceptual model illustrating potential ecological risk of microplastics. Tetra Tech will engage the PPAT for input on all model components (see Subtasks 4.1 – 4.4), which will include one or two specific attributes of ecosystem health or key assessment endpoints in the ERA. This conceptual model will describe pathways illustrating how human activities could act as a source of microplastics, potential pathways by which a key assessment endpoint may be exposed to microplastics, and the means by which microplastics could impact an assessment endpoint.

Subtask 4.1: Planning and Problem Formulation

This subtask refers to the first phase of ERA and establishes the goals, breadth, and focus of the assessment. It is a systematic planning step that identifies the major factors to be considered. Tetra Tech will draft the planning and problem formulation which will include subtasks 4.1.1 – 4.1.2.

Subtask 4.1.1 Communication with Stakeholders

Tetra Tech will use the PPAT as a conduit to glean necessary input and preliminary data for the planning phase of the ERA. Tetra Tech will gather information from the PPAT to ensure multi-stakeholder input.

> *Deliverable 4.1.1*: Report out via email detailing the process to plan and engage the PPAT and other stakeholders for input. This deliverable will be submitted to the TOCOR within 14 business days after the initial PPAT meeting.

Subtask 4.1.2 Draft Preliminary Conceptual ERA

Using information collected from the PPAT and other sources, Tetra Tech will formulate a draft preliminary ERA conceptual model illustrating potential sources, pathways, and an endpoint. Tetra Tech anticipates one review draft from the PPAT/TOCOR prior to the submitting the draft deliverable.

> *Deliverable 4.1.2*: Draft preliminary ERA conceptual model illustrating sources, pathways, and an endpoint reviewed by the PPAT. Draft will be submitted to the TOCOR within three months after initial PPAT consultation.

Subtask 4.2: Analysis: Identify Testable Linkages between Sources, Stressors and an Assessment Endpoint

This task refers to the next phase in conducting the ERA, risk analysis, which is designed to compile and analyze existing available information and determine relationships between sources, microplastic effects, and linkages with an assessment endpoint where possible. In this subtask, Tetra Tech, with the support of the PPAT, will identify risk hypotheses or testable linkages between sources, microplastics, and potential effects on an assessment endpoint. Tetra Tech will conduct a review of relevant scientific literature and existing data collected in the Chesapeake Bay and the Potomac River to develop hypothesized linkages and identify critical data gaps in the conceptual model. Identification of data and information sources, as well as uncertainties and confounding factors, may be done in consultation with the PPAT. This draft preliminary conceptual risk analysis will use the updated uniform size classification from Task 3. Once the information is compiled and linkages have been refined, Tetra Tech will develop a second and more detailed preliminary ERA conceptual model and present it to the PPAT for their review and input. Tetra Tech anticipates one additional review draft from the PPAT/TOCOR prior to submitting the updated draft conceptual model.

> *Deliverable 4.2:* Second draft of the preliminary ERA conceptual model, which includes information on linkages between sources, microplastics, and an assessment endpoint. This draft will be submitted to the TOCOR within six months after the initial consultation with TOCOR and PPAT, and within three months after TOCOR/PPAT review.

Subtask 4.3: Risk Characterization: What are the risks and effects?

Subtask 4.3.1: Final Preliminary Conceptual ERA

The final step of the ERA is the risk characterization which strives to integrate exposure and effects. Microplastics may differ from traditional chemical stressors in that typical effect endpoints such as toxicity thresholds may not be known or relevant. The linkages and hypothesized effects of microplastics on the assessment endpoint in Task 4.2 will inform this step. The focus of this subtask will be organismal and population effects of microplastics on an assessment endpoint species or other relevant species where it has been documented either in the Chesapeake Bay watershed or other estuaries in the United States and elsewhere. Based on the information and analyses in this subtask, Tetra Tech will develop a third iteration of the preliminary ERA conceptual model and present it to the PPAT for feedback. Tetra Tech anticipates one round of review from all stakeholders and the TOCOR before the ERA will be considered finalized.

> *Deliverable 4.3.1:* Final draft of the preliminary ERA conceptual model which includes a preliminary risk characterization of the endpoint identified under Task 4.1. This will be submitted to the TOCOR within nine months after initial consultation, and within three months after PPAT/TOCOR review.

Subtask 4.3.2: Report on Methods Used for Preliminary Conceptual ERA

Tetra Tech will submit a report that describes the process used for the Planning and Problem Formulation developed in previous tasks, including the preliminary ERA conceptual model. The report will include the information and data used to inform the model, as well as information needed to complete a preliminary risk analysis and risk characterization of microplastic risk in the Chesapeake Bay watershed. The report will also identify critical information gaps that could be addressed through future research. Tetra Tech anticipates one draft review from the PPAT/STAC/TOCOR to address comments before the report is finalized.

> *Deliverable 4.3.2:* Final report describing the process for compiling the preliminary ERA conceptual model. Final report will be submitted to TOCOR for approval within nine months after initial consultation, and within three months after PPAT/TOCOR review.

As described in Section A7.2 of this QAPP, Tetra Tech will develop a literature review search and screening strategy for EPA TOCOR comment and approval. Tetra Tech anticipates using search tools (e.g., Web of Science, Google Scholar) to identify defensible existing sources (i.e., peer-reviewed journal articles and assessments prepared by EPA, other federal entities, or states for which project-specific QAPPs or similar documentation describing site-specific sampling and analyses) for this project. To support Task 4, Tetra Tech anticipates collecting information from literature search engines, general internet searches, and PPAT members who are microplastic or Potomac ecology experts on attributes of ecosystem health in the Potomac River, how human activities could act as a source of microplastics to the Potomac River ecosystem, pathways by which a key assessment endpoint could be exposed to microplastics, and the means by which microplastics could impact an assessment endpoint. Tetra Tech will evaluate the data sources it collects using a screening strategy to determine whether they are relevant and of adequate quality for use in developing a preliminary conceptual ERA model for microplastics in the Potomac River, as further described in Section A7.2 of this QAPP. Literature will be stored and organized using citation management software such as EndNote to organize papers by topic and relevancy.

As described in Section A8 of this QAPP, all relevant project personnel will have experience and expertise in the effects of microplastics on estuarine ecosystems, the physical properties of microplastics in estuarine systems, and ERA conceptual models, as well as knowledge of the quality system for this project. In addition, relevant personnel will have the ability to search, read, understand, and effectively summarize scientific literature, and the ability to gather and analyze data.

As described in Section B10 of this QAPP, the Tetra Tech TOL, or designee, identifies and obtains the most appropriate hardware or software for project needs commensurate with the complexity of the project. Tetra Tech anticipates that most of the sources gathered for this project will be portable document format (PDF) and Microsoft Excel files to which all relevant Tetra Tech personnel will have the capability to access.

Task 5: Develop a Science Strategy to Address Microplastics

This task will help guide future research on the impacts of microplastic pollution in the Potomac River, Chesapeake Bay, and contributing watersheds. Using the information gaps identified in the development of the preliminary ERA conceptual model (SubTask 4.3.2), Tetra Tech will draft a white paper that outlines the necessary research needed to address these gaps. Tetra Tech will consult with the PPAT/STAC on the finalization of this document. Tetra Tech will refer to the San Francisco Estuary Institute Microplastic Monitoring and Science Strategy for San Francisco Bay and other relevant documents with which Tetra Tech is aware. Tetra Tech assumes one set of draft comments from the PPAT/STAC before finalizing the white paper.

> *Deliverable 5:* Final strategy which outlines the necessary research needed to address information gaps identified during the preliminary ERA conceptual model development (Task 4.3.2). The white paper will be submitted to the TOCOR within eleven months after initial consultation, and within three months after PPAT/TOCOR review.

As described in Task 4 above, as well as in Section A7.2 of this QAPP, Tetra Tech will develop a literature review search and screening strategy for EPA TOCOR comment and approval to support developing the conceptual ERA. Tetra Tech will use the data gathered under Task 4, including information gaps identified in developing the conceptual ERA, to support the development of the Task 5 deliverable.

Task 6: Additional Research to Fill in Gaps Identified in Science Strategy (Option 1)

Subtask 6.1: Communication with Stakeholders and Prioritize Information Gaps

Additional research will be needed to address information gaps identified in the science strategy (Task 5). Tetra Tech will work with the PPAT to identify priority information gaps to address these research needs.

> *Deliverable 6.1:* Detailed memo on identification of priority information gaps and research conducted during the option period. The detailed memo will be submitted to the TOCOR within six months from the Option Period start date.

Subtask 6.2 Research Information Gaps Identified in Science Strategy

Tetra Tech will conduct research to address at least one of the information gaps identified in Task 5 and prepare a PowerPoint presentation.

> *Deliverable 6.2:* Presentation to TOCOR on research conducted during the option period to the TOCOR and PPAT. The presentation will be delivered to the TOCOR within six months from the Option Period start date.

Subtask 6.3 Updated Preliminary Conceptual ERA

Tetra Tech will update the ERA conceptual model and linkages based on updated information obtained in tasks 6.2. Tetra Tech will present its findings and new iterations of the model in the form of a PowerPoint presentation to the PPAT for review before finalizing.

> *Deliverable 6.3:* Updated presentation of the conceptual ERA that includes information collected during the Option Period. The updated conceptual ERA will be submitted to the TOCOR within ten months from the start of the Option Period.

Table 1. Schedule of Deliverables

Task	Sub-task	Communication Deliverables	Due Date	Milestone
1	1.1	Brief, written progress reports as email to the TOCOR	Due monthly or upon request by the TOCOR for the duration of this Task Order	Submission of monthly report

Task	Sub-task	Communication Deliverables	Due Date	Milestone
1	1.2	Project meetings and other communications, such as conference calls	Due monthly or upon request by the TOCOR for the duration of this Task Order	Monthly calls
1	1.3	Brief, written reports as emails to TOCOR detailing problems, delays or questions	Due immediately and as needed to TOCOR	Submission of report
1	1.4	Brief, written reports as emails to TOCOR detailing problems, delays or questions working with stakeholders	Due immediately and as needed to TOCOR	Submission of report
1	1.5	Meeting Notes and summaries detailing topics discussed and discussion among parties	Due within 5 business days of a meeting to TOCOR.	Submission of notes
2	2.1	A Draft QAPP for EPA 45-day review	Due within 4 weeks after receipt of EPA's final review.	Draft QAPP
2	2.2	A Final QAPP including EPA comments	Due within 2 weeks of EPA QA Memo	Final QAPP
2	2.3	Documentation of all analyses that indicate how types, quantity, and quality of data have been quality assured and maintained	Due within 11 months after Task Order award to TOCOR.	Final QA document
3	NA	A Uniform Size Classification and Concentration Unit Document reviewed and approved by the PPAT and STAC	Due within 6 months of Task Order award to TOCOR.	Final report
4	4.1.1	A report out via email to the TOCOR detailing the process to plan and engage PPAT and other stakeholders for input.	Due 2 weeks after Task Order award to TOCOR.	Emailed process plan
4	4.1.2	A draft preliminary ERA Conceptual Model illustrating sources, pathways, and endpoint reviewed by the PPAT	Due 3 months after Task Order award to TOCOR	Draft preliminary conceptual model
4	4.2	A second draft of the preliminary ERA conceptual model reviewed by the PPAT and STAC which includes information on linkages between sources, stressors, and assessment endpoint. This draft shall use the updated uniform size classification	Due 6 months after Task Order award to TOCOR (3 months after initial TOCOR/PPAT review)	Second draft of preliminary conceptual model

Task	Sub-task	Communication Deliverables	Due Date	Milestone
		from Task 3.		
4	4.3.1	A final draft of the preliminary ERA conceptual model approved by PPAT and STAC which includes information on linkages between sources, stressors, and assessment endpoint.	Due 9 months after Task Order award (3 months after initial TOCOR/PPAT review) to TOCOR	
4	4.3.2	Final report submitted to TOCOR for approval describing the process for compiling the preliminary ERA conceptual model. The report must include the information and data used to inform the model, as well as identification of information gaps that could be addressed through future study.	Due 9 months after Task Order award to TOCOR.	Final report
5	NA	A final strategy reviewed and approved by the PPAT and STAC which outlines the necessary research that is needed to address these information gaps identified during the development of the preliminary ERA conceptual model (Task 4.3.3).	Due 11 months after Task Order award to TOCOR.	Final strategy
6	6.1	Memo detailing research conducted during the option period in the form of one or more presentations to the TOCOR and PPAT.	Due 6 months from the initiation of Option Period.	Detailed memo
6	6.2	Report out on research conducted during the option period in the form of one or more presentations to the TOCOR and PPAT.	Due 6 months from the initiation of Option Period.	Presentation
6	6.3	New iteration of the ERA conceptual model reviewed and approved by the PPAT that includes information collected during from research conducted during the option period.	Due 10 months from initiation of Option Period to TOCOR.	Conceptual model

A7 QUALITY OBJECTIVES AND CRITERIA

Information of known and documented quality is essential to the success of any project that involves preparing technical support materials that utilize existing information for EPA. For Task Order 68HERC20F0213, information from other studies will be used to develop a preliminary conceptual ERA model and science strategy for microplastics in the Potomac River. This Task Order will help to inform restoration efforts in the Chesapeake Bay and watershed by helping to drive research on how microplastics affect restoration goals for fishery species such as American shad and striped bass. Tetra Tech will work with the CBP PPAT, the CBP STAC, and other stakeholders to develop a uniform size classification and concentration unit terminology for microplastics; formulate a preliminary ERA model examining the effects of microplastics on an ecosystem endpoint (e.g., fish species) in the Potomac River; develop a science strategy to address microplastics; and during Option Period 1 of this Task Order, perform additional research to develop a uniform size classification and concentration unit terminology for microplastics. Tetra Tech will assess the quality and relevance of the existing information for use in supporting this project as described below.

A7.1 Project Quality Objectives

The basic requirements of this project are that Tetra Tech must ensure that the statistical analyses performed and subsequent interpretations under Task Order 68HERC20F0213 are quality products that are based on sound scientific principles, and that any revisions and updates are reproducible and transparent. Documentation of all analyses will indicate how types, quantity, and quality of data have been quality assured and maintained. Tetra Tech will ensure that metadata are compiled in an easy to use format. Tetra Tech will ensure that all products will be detailed so that the decisions and analyses are completely transparent to a third party. The analyses provided will be logical, consistent, and defensible. All calculations performed on the data must be correct and reported accurately in the evaluation.

Tetra Tech anticipates collecting information for Task Order 68HERC20F0213 from peer reviewed journals, accessed through Web of Science and Google Scholar and other available technical literature databases..

A7.2 Evaluation of Existing Information

Tetra Tech will assess the quality and relevance of the existing information for use in supporting this project using the factors described in EPA's *Guidance for Evaluating and Documenting the Quality of Existing Scientific and Technical Information Addendum to: A Summary of General Assessment Factors for Evaluating the Quality of Scientific and Technical Information* (Table 2) and additional factors relevant to this project.

In consultation with the EPA TOCOR, Tetra Tech will develop a literature review search and screening strategy (including evaluation of the factors in Table 2 and those described in greater detail in this section of the QAPP) for EPA TOCOR comment and approval.

Tetra Tech will gather and identify relevant papers for each of the factors, pathways, and endpoint indicated in conceptual models. Once papers have been identified, they will be subject to extraction. As information to be extracted is collected and evaluated by Tetra Tech for Task Order 68HERC20F0213, Tetra Tech will evaluate it using the factors described below.

Relevance to the study—Tetra Tech is primarily concerned with information that can be used to develop a uniform size classification and unit terminology for microplastics, examine the effects of microplastics on an ecosystem endpoint (e.g., fish species) in the Potomac River, and develop a science strategy to address microplastics.

Table 2. Evaluation Factors Used in Evaluating Existing Information

Factor	Criteria
EPA (2012) Guidance Factors	
Applicability and utility	Is a document returned in the literature search relevant to the project?
Soundness	Are scientific and technical procedures sound?
Clarity and completeness	Are data clearly and completely documented?
Evaluation and review	Has the information been reviewed?
Uncertainty and variability	Has variability and uncertainty been characterized?

Representative of the areas and times of study—Both recent and long-term microplastics data collected from the Chesapeake Bay and similar estuarine systems will be considered.

Tetra Tech will use, extract, and cite existing information that meets the criteria presented in Table 2. Based on Tetra Tech's previous experience with performing existing information searches, Tetra Tech realizes that available literature for some subjects will not fully meet all of the criteria. For example, information on whether a source has been reviewed might not be well-documented for white papers that provide technical information or in trade journal articles that provide information on a specific technology. If Tetra Tech uses literature sources that provide useful information but do not fully meet all of the criteria, Tetra Tech will cite these sources and fully document the limitations in their use or interpretation in the corresponding project deliverable.

If information from a source meeting the criteria in Table 2 and Task 3 in Section A6 appears to be inconsistent with information from another source that also meets these criteria, Tetra Tech will consult with the EPA TOCOR to determine what additional verification is needed. If the information cannot be verified, but the EPA TOCOR approves of citing the source, Tetra Tech will include a footnote or include a statement in the appropriate document indicating that the information comes from a source that has not been verified.

The Tetra Tech TOL will evaluate data collected from literature sources collected under Task Order 68HERC20F0213 following the decision tree presented in Figures 2 and 3. The data requirements for this project encompass aspects of data management to reduce the sources of errors and uncertainty in using the data. Tetra Tech, in consultation with the EPA TOCOR, will determine whether factors in addition to those presented in Table 2 should be evaluated to determine whether the data provided in an existing data source are acceptable for use in performing that task. It should be noted that selection of secondary data sources for a data analysis task might require using techniques for estimation of missing or out-of-range parameters. This would require Tetra Tech to collect data from additional secondary data sources to obtain estimates or replacement data, if this is deemed necessary and appropriate in consultation with the EPA TOCOR.

Existing data selected for use, as described above, will be summarized in the final deliverables. Information from studies that are found to be of unacceptable quality will not be used to develop the final deliverables for this project. Tetra Tech will document in the final deliverables the

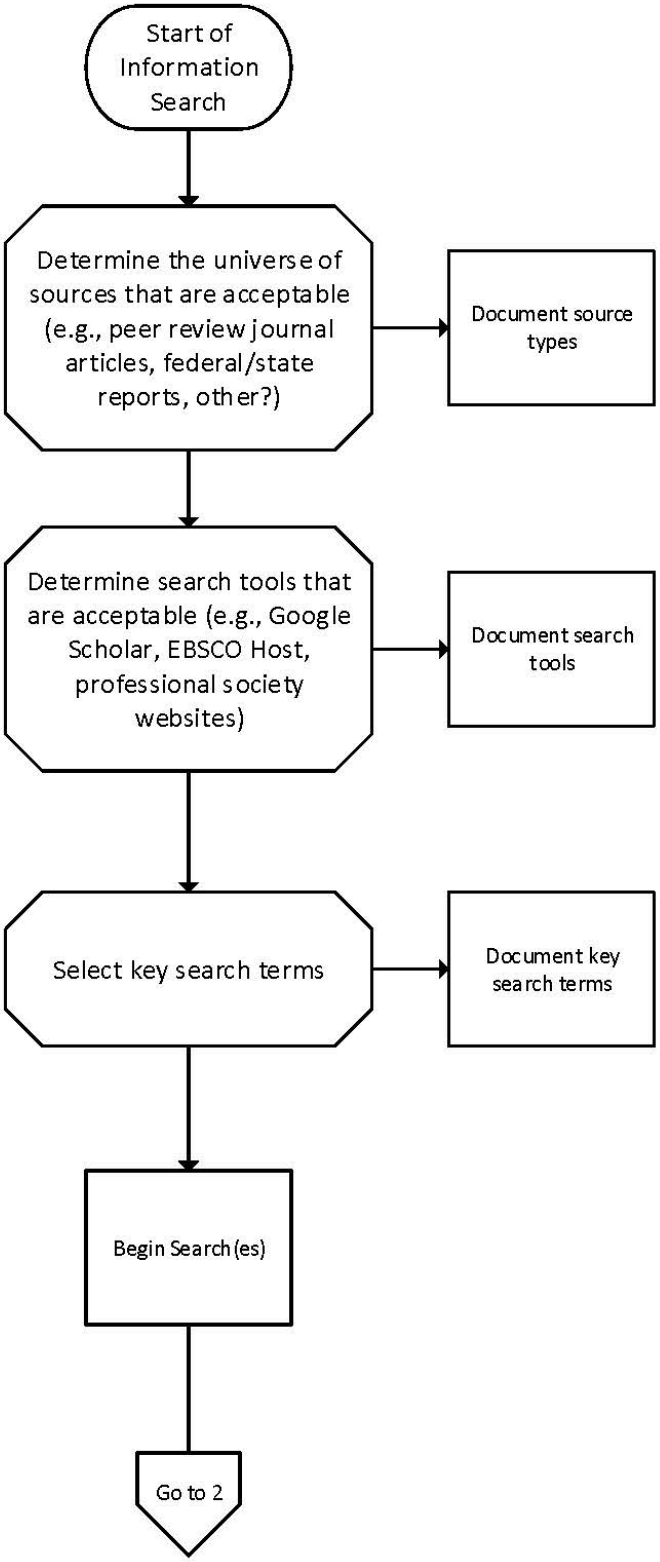


Figure 2. Process for Evaluating Existing Literature Sources, Start of Information Search

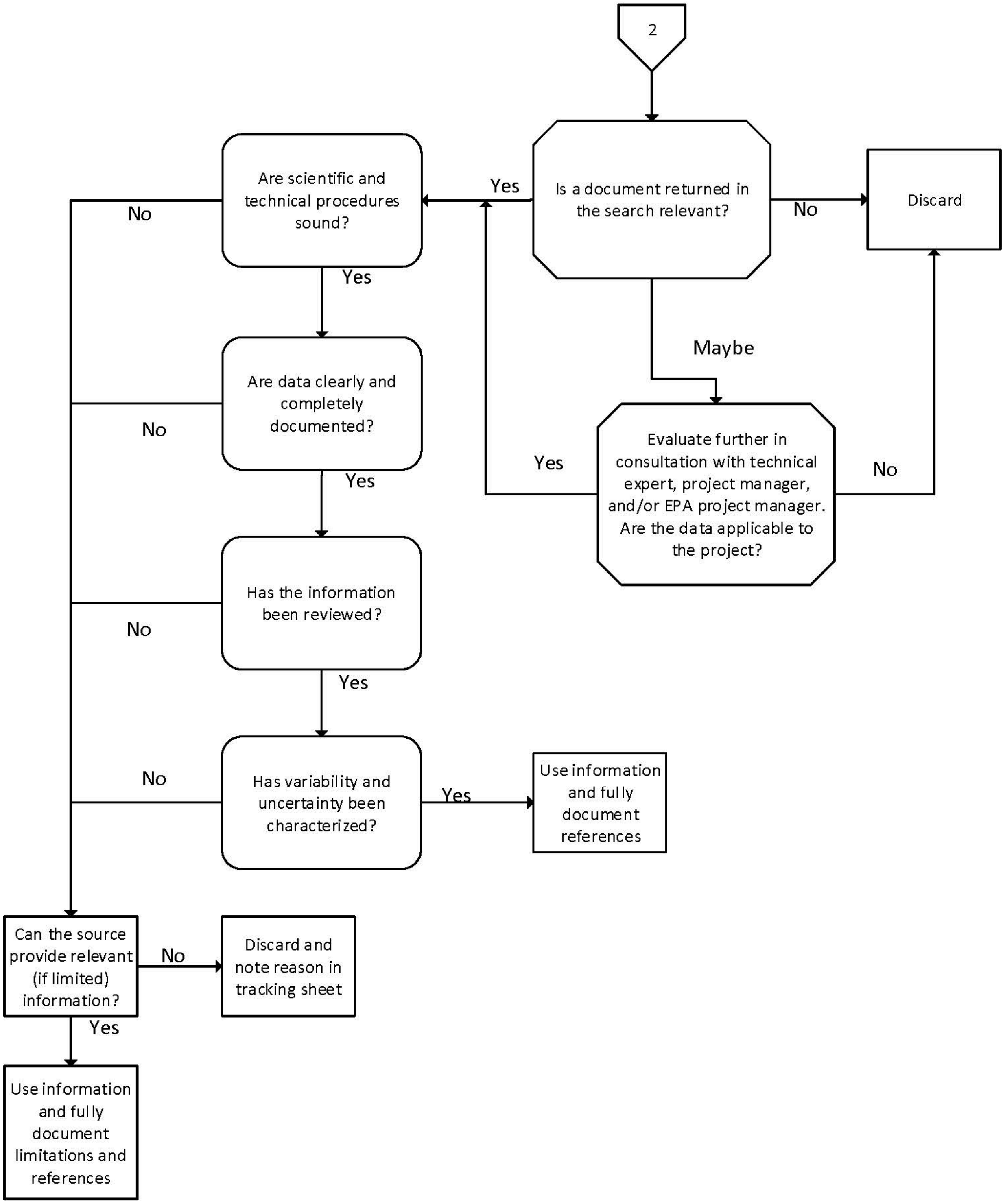


Figure 3. Process for Evaluating Existing Literature Sources, Evaluation of Sources

quality requirements for data collection and how Tetra Tech ensured that information collected for this project was as inclusive and comprehensive as possible. Tetra Tech will describe QA compliance in the final deliverables.

Criteria for Selecting Data Sources

In consultation with the EPA TOCOR, Tetra Tech will complete the search criteria fields shown in Table 3 for this project. Tetra Tech anticipates collecting information on attributes of ecosystem health in the Potomac River, how human activities could act as a source of microplastics to the Potomac River ecosystem, pathways by which a key assessment endpoint could be exposed to microplastics, and the means by which microplastics could impact an assessment endpoint.

Table 3. Example Search Criteria

Project Title	Developing a Preliminary Conceptual Ecological Risk Assessment Model and Science Strategy for Microplastics in the Potomac River
Task Order Number:	68HERC20F0213
Universe of sources to be used:	
Search tools:	Web of Science, Google Scholar
Selected key search terms:	microplastics, Chesapeake Bay, fish, American shad, striped bass, blue crab, plankton,
Additional search criteria (if applicable):	Marine, coastal, estuarine
Search exclusions (if applicable):	

Depending on the types of information found using these search criteria, Tetra Tech might need to update them throughout the project (e.g., key search terms might need to be added, additional source types might need to be searched). The search criteria would be documented and updated in a tracking spreadsheet throughout the project. Tetra Tech will use a tracking spreadsheet to document the evaluation of existing information described in Table 2 and illustrated in Figure 3 of this QAPP.

Selecting data and scientific literature that are representative and comparable is important. Tetra Tech will follow EPA’s Ecological Risk Assessment Framework “Framework for Ecological Risk Assessment” (EPA/630/R-92-001) as discussed in Murphy et al. (2019) to support development of the conceptual ERA model and science strategy for microplastics in the Potomac River. Tetra Tech will work with the EPA TOCOR to develop and document a hierarchy for use of data sources. A preliminary screening hierarchy that might be used to support this project is provided below.

1. Initial Data Screening

After collecting journal articles, peer-reviewed databases, and federal and state documents, Tetra Tech will screen the sources to determine whether they are relevant and of adequate quality for use in developing the conceptual ERA model and science strategy for microplastics in the Potomac River. As a preliminary screen, Tetra Tech anticipates evaluating whether the study provides the following information:

- Units for water or tissue microplastics concentrations
- Organism(s) sampled/tested
- Waterbody type sampled
- Location of study
- Microplastic polymer type/shape

Tetra Tech will use this preliminary screening information to determine from what studies additional information should be collected for the purposes of supporting development the conceptual ERA model and science strategy for microplastics in the Potomac River.

2. Further Data Screening

Additional data screening will be performed for studies that meet the initial data evaluation, as described below.

- Only data from waterbodies similar to the Chesapeake Bay will be used;
- Only studies in which water samples and organisms were collected within the same year will used;
- Only studies with specific details on types of fish data will be used (e.g. specific taxa listed; abundances or other quantitative metric of prey);
- Others

Tetra Tech will evaluate these studies using the process described above. Tetra Tech expects that project-specific QAPPs or similar documentation describing the performance criteria evaluated and met will be available for federal and state sources. If this documentation is not readily available, Tetra Tech in consultation with the EPA TOCOR will determine how much effort should be expended to find reports or metadata that might contain that information.

Tetra Tech will determine in consultation with the EPA TOCOR whether additional acceptance criteria will apply to existing data sources. Additional acceptance criteria for information in these sources could include spatial requirements to provide consistency in the evaluation. For example, information from monitoring studies might be acceptable if collected from a particular geographic location.

Acceptance criteria used for a deliverable will depend on what is important to know about the data or information to be able to judge its utility to the project and confidence in its accuracy. During screening, Tetra Tech will evaluate duplication of references. For various reasons (e.g., data missing units), not all secondary data evaluated for potential use/analyses in supporting this project will be judged acceptable. The data requirements for this project encompass aspects of data management to reduce the sources of errors and uncertainty in using the data. As information from the open literature is evaluated, Tetra Tech, in consultation with the EPA TOCOR, will determine what additional factors will be evaluated (e.g., age of source, study duration) to determine whether the data provided in a secondary data source are acceptable, and based on what criteria, for use/analysis in this project. The Tetra Tech TOL will provide a description of data evaluation (data selection, uses, and analyses) of selected data and methodology followed to the EPA TOCOR in the project deliverables.

If additional information is needed for a particular deliverable, Tetra Tech will include a copy of the search strategy, as well as a printout of the literature search annotated to indicate what was considered retrieved, and not retrieved, and the reasons why.

A7.2 Measurement Performance Criteria

Measurement performance criteria are quantitative statistics used to interpret the degree of acceptability or utility of the data to the user. These criteria, also known as data quality indicators (DQIs) (USEPA 2006), include the following:

- Precision
- Accuracy
- Representativeness
- Completeness
- Comparability

DQIs that cannot be expressed in the above terms will be reported by fully describing the specified method.

This section addresses accuracy, precision, representativeness, completeness, and comparability of the data, and their applicability to this project.

Precision—Precision affects estimates of variance, and poor precision can limit confidence in results from small data sets. The national, regional, and state monitoring data sets planned for use in this study are large enough that precision is not a major issue. Therefore, in general, precision will be assessed on the basis of quantity of available data and information, and on the quality of the information sources. However, provided the basic methods and techniques of sampling, measurement, and other observations and information collection and documentation yield information and data that do not fail screening for outliers, they will be assumed to be of acceptable precision in the context of the technical tasks for Task Order 68HERC20F0213. Exploratory data analysis techniques (e.g., correlation analysis, scatter plots, histograms) will be used to identify potential outliers or other data quality issues. Available supplemental data such as inspection of site setting using Google Earth Pro may be used to validate, correct, or reject data flagged as questionable during QA review. Where results may approach a limit of acceptance or there are other indicators of potential information or data quality limitations, Tetra Tech will consult with the EPA TOCOR regarding the impact of the use of the data in project deliverables.

Accuracy—Accuracy of secondary data sets is generally both unknown and unknowable. Unless there is compelling evidence that the data were collected incorrectly and are inaccurate, Tetra Tech assumes that accuracy was sufficient for this study.

Representativeness—See the discussion of representativeness in A.7.1 above.

Completeness—Completeness is not relevant to secondary data. It is a measure of how well a study was designed and executed, and compares the amount of valid data or information collected to the amount of information planned. Data included in existing collections are accepted with or without consideration of the completeness performance of the original study design.

Comparability— For this project, information from various studies will be synthesized, making sure that different values are expressed in comparable units and that differences among values are clearly tied to how those values were developed. Tetra Tech will evaluate comparability of microplastic size classifications and concentrations, as well as the comparability of information for effects of microplastics on an ecosystem endpoint in the Potomac River. Tetra Tech will make recommendations when there are discrepancies in reported units and densities.

Measurement performance criteria that will be used for data handling for this project will include accuracy and completeness. Measurement performance criteria for various data handling parameters are presented in Table 4 and are discussed in more detail in this section. Of the types of tasks provided in Table 4, Tetra Tech expects that extractions and interpretations of data from journal articles will be most relevant to this project. The data entry task and associated measurement criteria were included in Table 4 in case Tetra Tech needs to enter data by hand from data sheets or forms; however, Tetra Tech does not currently anticipate needing to perform data entries by hand for this project. In addition, Tetra Tech does not anticipate performing many data transfers (from one data set to another) or calculations for this project.

Table 4. Measurement Performance Criteria[a]

Measurement parameter	Accuracy	Description
Data entry	$\leq$ 5% incorrectly entered data	20 percent of manual data entries will be checked. All errors will be corrected.
Data transfers	$\leq$ 10% incorrectly transferred data	10 percent of data transfers of pertinent data from existing sources for use in deliverables will be checked. All errors will be corrected.
Data calculations	$\leq$ 10% incorrect calculations	10 percent of all data calculations will be checked. All errors will be corrected.
Extraction/interpretation of pertinent data from existing sources for use in deliverables	$\leq$1% incorrectly extracted/interpreted data of reviewed extractions	Initially 50 percent of extraction/interpretations of pertinent data from existing sources for use in deliverables will be checked. After this initial phase, 10 percent of extraction/interpretations of pertinent data from existing sources for use in deliverables will be checked. All errors will be corrected.

[a] Analytical truth is unknown for precision. Measurement performance criteria for completeness for all measurement parameters is 100 percent.

It is assumed that data used by or obtained from government agencies have been screened and have met specified measurement performance criteria. No unpublished data will be cited or included in the final deliverables, with the exception of such data that are recommended by EPA for inclusion in the report. In the rare case that a paper or study represents a technical landmark and is considered seminal within a topic/subtopic but has not been peer reviewed or some aspect of study design, methods, or support of results or conclusions is reviewed and found to be poor, that will be documented and discussed (as a caveat) in the draft deliverables when the associated results are presented.

Whenever possible, data will be downloaded electronically from various electronic sources to reduce scanning of hard copy documents. Tetra Tech technical staff will develop dedicated hard copy and electronic files.

Minimizing errors by using QC protocols is of the highest priority for this project. The following steps for assigning staff and general project procedures will be used to ensure the completeness and correctness of data used in the deliverables:

- All original work performed by any member of the technical staff will be subject to QC checks by a different member of the technical staff who is capable of performing the QC checks.
- All QC reviews will be documented.
- Use of data evaluation factors and limits.
- Members of the Tetra Tech staff are capable of collecting technical data and managing data sources.
- The Tetra Tech TOL will maintain a continuing dialog with the EPA TOCOR on technical issues, including discussions regarding the inclusiveness and comprehensiveness of the data sources collected for the project.
- The Tetra Tech TOL will provide answers to specific management questions.

Data Entries

If any raw data are received in hard-copy format (not expected for this project), they will be entered into a spreadsheet and the Tetra Tech QC Officer or his designee will compare 20 percent of data entries to the original hard-copy data sheets. If the percentage of incorrect data entries exceeds 1 percent for a staff member, the Tetra Tech QC Officer or his designee will review an additional 20 percent of the data entries performed by that staff member to determine whether the staff member is performing acceptable data entries. If the percentage of incorrect data entries for the additional sources evaluated exceeds 1 percent, the Tetra Tech QC Officer or his designee will evaluate 100 percent of the data entries performed by that staff member to ensure the accuracy of the information provided in databases or documents prepared to support the project's deliverables. Any discrepancies in data entries discovered by the Tetra Tech QC Officer or his designee will be resolved with the technical staff member who originally performed the data entry during the review process to ensure 100 percent agreement in data entries from the sources.

Data Transfers

The Tetra Tech QC Officer or his designee will independently check transferred data using a standard level review. This standard review consists of independently checking each different file type (i.e., a file with different structure or legacy), confirming the first, last, and a selected middle portion of the data were transferred correctly. Evaluating the first and last portions of data helps confirm that no records were accidentally dropped. Selection of the middle portion of the data to check will be done by targeting unique and unusual record types that might stress the transfer process. More files (up to 10 percent) will be reviewed if files are processed individually while fewer checks (no less than 2 data files of each type) will be used for automated to semi-automated procedures. All identified data transfer errors will be corrected and the Tetra Tech QC Officer or his designee will perform a follow-up review of the corrected components to ensure that the errors have been corrected. Refer to Tetra Tech's standard operating procedure (SOP) on Secondary Data Management (Appendix A) for additional information.

Data Calculations

The Tetra Tech QC Officer or his designee will perform standard-level reviews of data calculations (including conversions) for Task Order 68HERC20F0213. A standard-level of review consists of up to 10 percent independent recalculations of computations and graphs, but no less than 2 examples of each type of computation and 2 examples of each graphic type. More calculations (up to 10 percent) will be reviewed if data sets or points are processed individually while fewer checks (no less than 2 examples of each type of computation and 2 examples of each graphic type) are appropriate for automated to semi-automated procedures. Selection of which calculation types and graphs to check will include targeting unique and unusual record types that might stress the calculation and graphing process. All identified data calculation errors will be corrected and the Tetra Tech QC Officer or his designee will perform a follow-up review of the corrected components to ensure that the errors have been corrected. Refer to Tetra Tech's SOP on Statistical Analyses (Appendix B) for additional information.

Data Extractions

The Tetra Tech QC Officer or designee will compare approximately 10 percent of all extracted/interpreted data to the data in the original sources. A greater percentage (i.e., approximately 50 percent) of extracted data will be reviewed by the Tetra Tech QC Officer at the beginning of the data extraction tasks under Tasks 3 and 4 of this project to ensure that the correct information is being collected. During the middle and later portions of the data extraction tasks, the Tetra Tech QC Officer will review a lower percentage (i.e., approximately 10 percent) of extracted data; if the percentage of incorrectly extracted/interpreted data exceeds 1 percent for a staff member, the Tetra Tech QC Officer or designee will review an additional 20 percent of extracted/interpreted data. If, after reviewing 20 percent of extracted data, the percentage of incorrectly extracted/interpreted data continues to exceed 1 percent for a staff member, the Tetra Tech QC Officer or designee will review 100 percent of extracted/interpreted data for that staff member. Any errors in data extractions/interpretations will be resolved with the technical staff member who originally performed the data extractions/interpretations.

A8 SPECIAL TRAINING REQUIREMENTS/CERTIFICATION

All relevant project personnel will have experience and expertise in the effects of microplastics on estuarine ecosystems; the physical properties of microplastics in estuarine systems; ERA conceptual models, as well as knowledge of the quality system for this project. In addition, relevant personnel will have the ability to search, read, understand, and effectively summarize scientific literature, and the ability to gather and statistically analyze data. The relevant project staff members have an outstanding professional record as demonstrated by peer reviewed publications, awards, and service to relevant professional societies.

This Task Order will help to inform restoration efforts in the Chesapeake Bay and watershed by helping to drive research on how microplastics affect restoration goals for fishery species such as American shad and striped bass. Tetra Tech will work with the CBP PPAT, the CBP STAC, and other stakeholders to develop a uniform size classification and concentration unit terminology for microplastics; formulate a preliminary ERA model examining the effects of microplastics on an ecosystem endpoint (e.g., fish species) in the Potomac River; develop a science strategy to address microplastics; and during Option Period 1 of this Task Order, perform additional research to develop a uniform size classification and concentration unit terminology for microplastics.

The Tetra Tech TOL, Mr. Robert F. Murphy, is an aquatic ecologist who specializes in fish ecology and habitat assessment and restoration with extensive experience in freshwater and coastal systems, especially in the Chesapeake Bay watershed. His work has focused on examining how aquatic habitat alteration affects changes in biological communities, and fish populations in particular. He has worked closely with state and federal government resource managers in the Chesapeake Bay region and elsewhere, in addition to academia, to develop new approaches to habitat assessment and restoration in coastal watersheds. Mr. Murphy has led Essential Fish Habitat Assessments, the Biological Resources section of Environmental Impact Statements (EIS), authoring technical reports, conducting data analyses, and conducting broad, watershed scale monitoring and assessments. He recently co-chaired the CBP's workshop on microplastics in the Chesapeake Bay and was the lead author on the workshop report. He is a recognized expert in both aquatic biology and marine biology and has provided expert witness testimony concerning environmental impacts.

Dr. Jerry Diamond will be providing QA oversight of the work performed by UMCES for this Task Order. He is the Director of Risk Assessment and Ecotoxicology at Tetra Tech. Dr. Diamond has designed and directed site-based, watershed-level, and regional risk assessments for EPA, Navy, Army Corps, state and tribe agencies, and local municipalities. He supported EPA in their ecological risk assessment forum and watershed ecological risk assessment methodologies. He participated as an invited speaker on risk assessment for the "*Microplastics in the Chesapeake Bay and its Watershed: State of the Knowledge, Data Gaps, and Relationship to Management Goals*" workshop referred to previously (Murphy et al 2019). Dr. Diamond is an Editor of risk assessment and toxicology for the international journal *Environmental Toxicology and Chemistry* and frequently serves as a peer reviewer for other journals.

The UMCES Project Manager, Dr. Ryan Woodland, is an ecologist whose research focuses on trophic interactions in coastal food webs and how environmental factors (often human-induced) influence species communities and their dynamics in coastal ecosystems. He has a unique combination of skills, including expertise in trophic pathways in estuarine systems, Chesapeake Bay and Potomac River systems ecology, and past experience working with the Tetra Tech TOL. Dr. Woodland has previous experience as a leading scientific advisor to Chesapeake Bay science plans.

The Tetra Tech Technical Expert, Ms. Jennifer Flippin, is a Senior Environmental Toxicologist for Tetra Tech. She has fourteen years of experience in toxicology, aquatic biology, and environmental science fields, and provides technical assistance and management for numerous, diverse projects on the local, state, and federal levels. She has extensive experience relating to water quality standards and criteria, ecological and human health toxicology, field work, and technical writing.

The Tetra Tech Technical Reviewer for Literature Searches, Ms. Kristen Parry, has extensive experience in literature searches and screening and has most recently been conducting similar tasks for EPA Office of Research and Development using EndNote and SWIFT-AS. She also has coordinated the National Water Quality Monitoring Council Conference, working with a wide variety of federal, state, university, and nonprofit agencies and stakeholders.

A9 DOCUMENTATION AND RECORDS

The EPA TOCOR and Tetra Tech TOL will distribute the QAPP to their respective staff members working on this project. If any changes in the QAPP are required during the project, they must be described in a memorandum and approved by the signatories to this QAPP and attached to the QAPP. The Tetra Tech TOL will maintain a central project file in Tetra Tech's Owings Mills, Maryland, office to contain all related documents, reports, communications, data compilations, checklists or other records, and deliverables (electronic files and hard copies); the TOL will submit draft and final deliverables to the EPA TOCOR. The Tetra Tech TOL will copy the files to disk for archive for 5 years subsequent to project completion (unless otherwise directed by EPA).

GROUP B: DATA GENERATION AND ACQUISITION

B1 SAMPLING PROCESS DESIGN

B2 SAMPLING METHODS

B3 SAMPLE HANDLING AND CUSTODY

B4 ANALYTICAL METHODS

Sections B1 through B4 are not applicable because no primary data will be collected.

B5 QUALITY CONTROL

At the direction of the EPA TOCOR, the interim, draft, and draft final reports will be written in plain English appropriate for their intended audience, and all reports will be reviewed by a technical editor to ensure that the information is understandable to managers and non-statisticians.

B6 INSTRUMENT/EQUIPMENT TESTING, INSPECTION, AND MAINTENANCE

B7 INSTRUMENT/EQUIPMENT CALIBRATION AND FREQUENCY

B8 INSPECTION/ACCEPTANCE OF SUPPLIES AND CONSUMABLES

Sections B6 through B8 are not applicable because no primary data will be collected.

B9 NONDIRECT MEASUREMENTS

Nondirect measurements (also referred to as secondary data) are data that were previously collected under many different efforts outside this project. Tetra Tech will collect relevant information sources for Task Order 68HERC20F0213 as described in Section A6 of this QAPP. All numeric data will be downloaded in electronic format, which Tetra Tech will directly download and use. Such an approach will minimize manual entry of data and associated errors that might arise because of data input. Tetra Tech will perform general quality checks of the transfer of data from any source databases to another database, spreadsheet, or document. Because Tetra Tech was not involved in the original data collection, its ability to detect errors will necessarily be limited to inconsistencies within the databases.

Tetra Tech will perform basic quality assessment on numeric data, including checks for anomalous values, extreme outliers, reported units, and excessive numbers of missing values (occasional missing values are not a concern for the large, long-term databases used in this project). Tetra Tech will examine the performance criteria and quality objectives of the numeric data, if available, but those are often not reported, especially for older data. The data quality objectives are discussed in Section A7 of this document.

This project will also evaluate and extract scientific data from peer-reviewed writings. Information from those writings will be assessed for usefulness and suitability as discussed above, but data quality can generally not be determined from published journal articles.

B10 DATA MANAGEMENT

The Tetra Tech TOL will distribute the QAPP to the technical staff working on this project. If any changes in the QAPP are required during the project as determined through discussions with the EPA TOCOR, they must be described in a memorandum, approved by the signatories to this QAPP, and attached to the QAPP. The Tetra Tech TOL will maintain a central project file in the Owings Mills, Maryland, office to contain all related documents, reports, communications, data compilations, checklists or other records, the various assumptions employed, and deliverables (electronic files); the Tetra Tech TOL will submit draft and final deliverables to the EPA TOCOR. Tetra Tech will store all computer files associated with the project in a project subdirectory (subject to regular system backups). Tetra Tech will store the raw project data files, files documenting the steps used to format the data (including QC checks performed) to develop the final project files from the raw data files, and the final project files. The project subdirectory will be clearly named to indicate that it contains files for Task Order 68HERC20F0213. Tetra Tech will maintain version control of draft and final deliverables by indicating the preparation date or revision number in the file name.

The Tetra Tech TOL will maintain original sources of data not otherwise publicly available as part of the project file in the Owings Mills, Maryland, office, for up to 5 years after the contract under which this work was performed has ended, and the original material and a copy of these files will be provided to EPA for back-up storage. Tetra Tech will contact the EPA TOCOR within this 5-year time frame to determine how he would like to proceed.

Computers are either covered by on-site service agreements or serviced by in-house specialists. All routine maintenance on microcomputers is performed by in-house computer specialists. Electric power to each microcomputer flows through a surge suppressor to protect electronic components from potentially damaging voltage spikes. The Tetra Tech TOL will store all computer files associated with the project in a project subdirectory (subject to regular system backups) and will copy the files to disk for archive for 5 years subsequent to project completion (unless otherwise directed by EPA).

The Tetra Tech TOL, or designee, identifies and obtains the most appropriate hardware or software for project needs commensurate with the complexity of the project. Tetra Tech is familiar with EPA's *Information Resources Management Policies, Standards, and Procedures* (http://www.epa.gov/irmpoli8). The Tetra Tech TOL reviews these policies and standards to determine their applicability to the project, and they are followed as appropriate.

GROUP C: ASSESSMENT AND OVERSIGHT

C1 ASSESSMENT AND RESPONSE ACTIONS

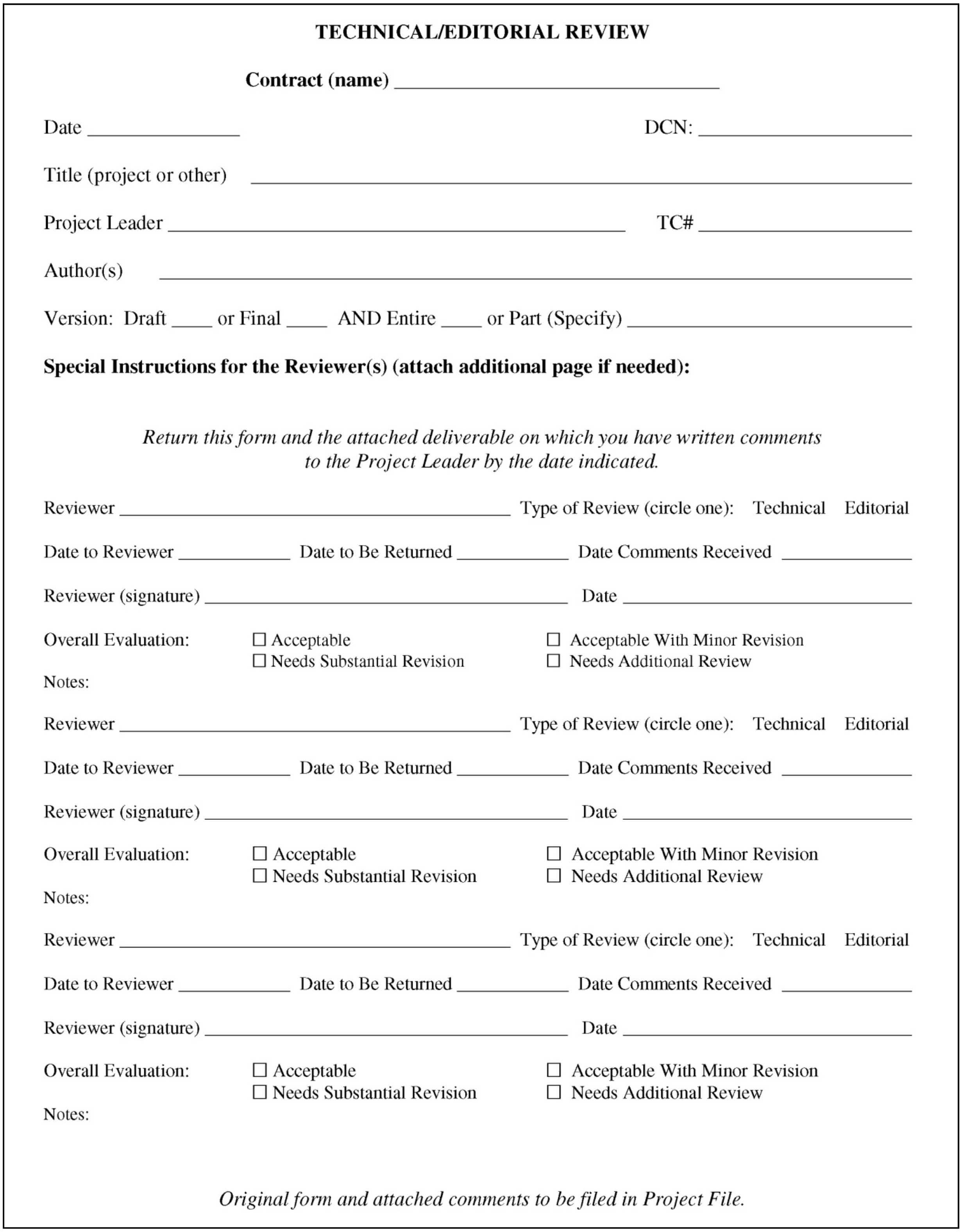
The QA program for Task Order 68HERC20F0213 includes surveillance, with independent checks of calculations and deliverables. Final versions of any deliverable that is to be published or widely distributed by EPA must be reviewed by the Tetra Tech TOL or authorized designee and a qualified editor or authorized designee to ensure that all revisions have been properly made and that the deliverable is consistent with overall contract goals and requirements and does not contain information that could expose EPA to liability.

The Tetra Tech QC Officer will assist the Tetra Tech TOL in conducting internal reviews of the deliverables prepared for this project. They will identify and document all issues that could affect quality and make recommendations for improving the deliverables. When internal reviews have been completed, the Tetra Tech TOL will submit written deliverables to a qualified technical editor for editorial review to ensure that the writing is clear and concise; that the written material conforms to predetermined requirements for format, style, and usage; and that the terms, resources, and format are used consistently throughout the document. The technical editor will sign and date the Technical/Editorial Review form (Figure 4) or equivalent documentation and return it with the marked-up report to the Tetra Tech TOL. The original form(s) or equivalent documentation signed by the internal technical and editorial reviewers will be attached to the marked-up page(s) and filed in the project file.

The essential corrective action steps in the QA program for addressing any problems that could occur during the project (as presented in Figure 5) are as follows:

- Identify and define the problem.
- Assign responsibility for investigating the problem.
- Investigate and determine the cause of the problem.
- Identify the corrective action.
- Assign and accept responsibility for implementing appropriate corrective action.
- Establish the effectiveness of and implement the corrective action.
- Verify that the corrective action has eliminated the problem.

Many of the technical problems that might occur can be solved on the spot by the staff members involved; for example, by modifying the technical approach or correcting errors or deficiencies in documentation.



TECHNICAL/EDITORIAL REVIEW

Contract (name) ________________________

Date ____________ DCN: ________________

Title (project or other) ____

Project Leader ______________________________ TC# ________________

Author(s) ____

Version: Draft ____ or Final ____ AND Entire ____ or Part (Specify) ____________________

Special Instructions for the Reviewer(s) (attach additional page if needed):

Return this form and the attached deliverable on which you have written comments to the Project Leader by the date indicated.

Reviewer ______________________________ Type of Review (circle one): Technical Editorial

Date to Reviewer __________ Date to Be Returned __________ Date Comments Received __________

Reviewer (signature) ____________________________ Date ____________________

Overall Evaluation: ☐ Acceptable ☐ Acceptable With Minor Revision
☐ Needs Substantial Revision ☐ Needs Additional Review

Notes:

Reviewer ______________________________ Type of Review (circle one): Technical Editorial

Date to Reviewer __________ Date to Be Returned __________ Date Comments Received __________

Reviewer (signature) ____________________________ Date ____________________

Overall Evaluation: ☐ Acceptable ☐ Acceptable With Minor Revision
☐ Needs Substantial Revision ☐ Needs Additional Review

Notes:

Reviewer ______________________________ Type of Review (circle one): Technical Editorial

Date to Reviewer __________ Date to Be Returned __________ Date Comments Received __________

Reviewer (signature) ____________________________ Date ____________________

Overall Evaluation: ☐ Acceptable ☐ Acceptable With Minor Revision
☐ Needs Substantial Revision ☐ Needs Additional Review

Notes:

Original form and attached comments to be filed in Project File.

Figure 4. Example Technical/Editorial Review form

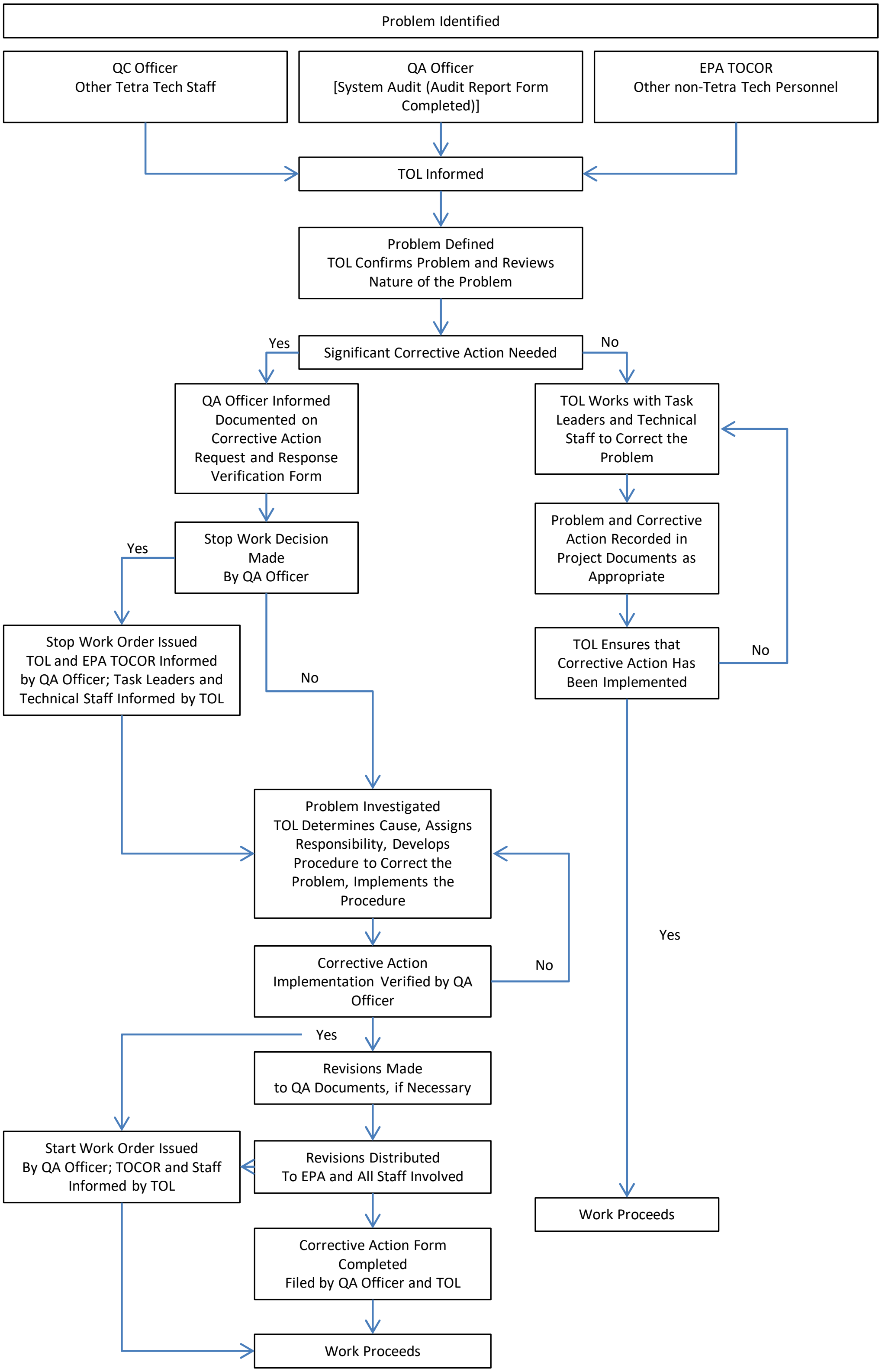


Figure 5. Corrective Action Process

Immediate corrective actions form part of normal operating procedures and are noted in records for the project. Problems not solved this way require more formalized, long-term corrective action. If quality problems that require attention are identified, the project team will determine whether attaining acceptable quality requires short- or long-term actions. If a failure in an analytical system occurs (e.g., performance requirements are not met), the Tetra Tech QC Officer will be responsible for corrective action and will immediately inform the Tetra Tech TOL. Subsequent steps taken will depend on the nature and significance of the problem, as illustrated in Figure 5.

The Tetra Tech TOL has primary responsibility for monitoring the activities of this project and identifying or verifying correction of any quality problems. These problems will also be brought to the attention of the Tetra Tech QA Officer, who will either initiate or verify the corrective action system components described above, document the nature of the problem (using a form such as that shown in Figure 6), and ensure that the recommended corrective action is carried out. The Tetra Tech QA Officer has the authority to stop work on the project if problems that affect data quality and require extensive effort to resolve are identified. The Tetra Tech TOL and the EPA TOCOR will be notified of major corrective actions and stop work orders. The Tetra Tech TOL has primary responsibility for monitoring the activities of this project and identifying and verifying that any quality problems are sufficiently investigated, that appropriate solutions are evaluated, and that corrective actions are implemented, verified to be adequate to address the problem(s), and documented in project reports.

Failure to meet any QC requirements requires that appropriate corrective actions be taken. All major QC failures and associated corrective actions (and their effectiveness) will be documented on a Corrective Action Request and Response Verification form and submitted to the EPA TOCOR. Data associated with QC problems will be clearly identified, along with an assessment as to the potential effects(s) of the QC failure on data quality. The Tetra Tech TOL or QA Officer will notify the EPA TOCOR of such problems/corrective actions as soon as possible after the actual occurrence.

Tetra Tech will provide to the EPA TOCOR and Alternate TOCOR any written reports generated on routine surveillance.

C2 REPORTS TO MANAGEMENT

The Tetra Tech TOL will submit a monthly report to the EPA TOCOR describing the status of the project and deliverables, including a discussion of QA/QC activities, the status of data evaluation efforts, and any significant quality problems encountered and how they were addressed. If requested by EPA in technical directives, and if resources are provided, Tetra Tech will also submit other appendices to this QAPP as secondary data quality objectives are developed and numerical analyses are determined.

CORRECTIVE ACTION REQUEST AND RESPONSE VERIFICATION

Contract (name) ____________________________

Date of Assessment __________________ Request No. __________________

Title (of project or other) ____

Project Leader ____ TC# ________________________

Other Responsible Personnel ____

Auditor or Initiator of This Corrective Action Request _____________________________________

Problem Description:

Recommended Action: **Date to Be Completed:**

_________________________________ ___________________________
Quality Assurance Officer Date

_________________________________ ___________________________
Principal-in-Charge or Program Manager Date

Action Taken: **Date:**

Verification of Completion of Corrective Action:

_________________________________ ___________________________
Quality Assurance Officer Date

_________________________________ ___________________________
Principal-in-Charge or Program Manager Date

Original form to be filed in QAO File; one copy to be filed in Project File and one copy in Contract File (if corrective action pertains to a project), or one copy to be filed in Contract File (if corrective action pertains to a contract).

Figure 6. Corrective Action Request and Response Verification Form

GROUP D: DATA VALIDATION AND USABILITY

D1 DATA REVIEW, VERIFICATION, AND VALIDATION

Data review, verification, and validation processes help determine the usability and limitations of data and provide a standardized data quality assessment. No primary data will be collected for this task; therefore, Tetra Tech cannot validate data against original lab sheets, and so on. As secondary data are gathered as part of Task Order 68HERC20F0213, Tetra Tech will document the source(s) of data and how, when, and why the data were originally collected, to the extent possible, to evaluate the usability and limitations of the data for this project. Tetra Tech will verify the accuracy of data transfers from databases into analysis software, and the correctness of calculations performed in the statistical analyses of the data. As specified in Section B9, Tetra Tech will perform basic quality assessment on secondary numeric data. Data requirements will be determined as the data are reviewed and presented in the final report.

D2 REVIEW AND VERIFICATION METHODS

Tetra Tech staff will obtain secondary data or technical information required to perform evaluations from the TOCOR and from other secondary sources. Tetra Tech will consult with the TOCOR if there are any questions about data acceptability. The TOCOR will provide written technical direction if additional work should be performed to verify values and extract statements of data quality from the raw data, metadata, or original owners of the data. If, in consultation with the TOCOR (who has considered the use of the data and the importance of the decision to be made), it is determined that such searches are not necessary and the data must be used in the project, a disclaimer will be added to the deliverable indicating that the quality of the secondary data is assumed to be satisfactory for these analyses.

As values are transferred to a database (data entry) or into a deliverable (word processing), the person performing this action will review the transfer for accuracy and write the complete citation for the source of the data, following the appropriate style guide format, with the short citation entered in the database, text, or footnote, as appropriate (e.g., author and year). All data must have the source identified during deliverable preparation. All data provided by EPA will be electronic; Tetra Tech does not anticipate extracting data from hard-copy sources.

D3 RECONCILIATION WITH USER REQUIREMENTS

The Tetra Tech TOL will perform the final technical review of materials. Appropriate senior level staff may also review these documents. The Tetra Tech TOL will ensure that data transfers and statistical analyses are checked and that any data quality limitations or uncertainties are clearly identified in the deliverables.

REFERENCES

de Sa, L.C., M. Oliveira, F. Ribeiro, T.L. Rocha, and M.N. Futter. 2018. Studies of the effects of microplastics on aquatic organisms: What do we know and where should we focus our efforts in the future? *Science of the Total Environment* 645: 1029-1039.

Gorycka, M., and S. De Noordzee. 2009. *Environmental Risks of Microplastics.* Investigation Project, 468017. Vrije Universiteit, Aard-en Levenswetenschappen, Amsterdam. .

Ling, S.D., M. Sinclair, C.J. Levi, S.E. Reeves, and G.J. Edgar. 2017. Ubiquity of microplastics in coastal seafloor sediments. *Marine Pollution Bulletin* 121: 104-110.

Murphy, R., M. Robinson, B. Landry, D. Wardrop, M. Luckenbach, K. Grubert, K. Somers, G. Allen, P. Trieu, and L.T. Yonkos. 2019. *Microplastics in the Chesapeake Bay: State of the knowledge, data gaps and relationship to management goals*. STAC Publication Number 19-006. Chesapeake Bay Program, Scientific and Technical Advisory Committee, Edgewater, MD. 51 pp.

Parks, T.B., Bluj, T. and Niles, J. 2019. Diet analysis and presence of microplastics in smallmouth bass of the Susquehanna River watershed. In *Susquehanna River Symposium*, Susquehanna University, Department of Ecology, Selinsgrove, PA.

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Tetra Tech. 2017. *Quality Management Plan for Technical Support for EPA ORD/NCEA's Ecological Assessment Programs*, EPA Contract Number EP-C-17-031. Prepared for U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, Washington, DC.

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USEPA (U.S. Environmental Protection Agency). 2012. *Guidance for Evaluating and Documenting the Quality of Existing Scientific and Technical Information Addendum to: A Summary of General Assessment Factors for Evaluating the Quality of Scientific and Technical Information*. Prepared for the U.S. Environmental Protection Agency, Science and Technology Policy Council, Washington, DC. http://www2.epa.gov/sites/production/files/2015-05/documents/assess3.pdf

Yonkos, L.T., E.A. Friedel, A.C. Perez-Reyes, S. Ghosal, and C.D. Arthur. 2014. Microplastics in four estuarine rivers in the Chesapeake Bay, USA. *Environmental Science and Technology* 48: 14195-14202.

Appendix A.

Tetra Tech's Standard Operating Procedure on Secondary Data Management

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Standard Operating Procedure TT-FFX-SOP-O-001

Secondary Data Management

Prepared by: Name Alex DeWire Title Environmental Scientist

Signature Date 3/9/17

Approved by: Name John Hochheimer, Ph.D. Title Technical Monitor

Signature Date 3/9/17

Approved by: Name Susan Lanberg Title QA Officer

Signature Susan Lanberg Date 3/9/17

Scope and Applicability: This procedure provides an overview of secondary data processing and management techniques. Secondary data are data that were collected under a separate effort for some other purpose, whereas primary data are original data collected for a specific project. Secondary data analyses are becoming increasingly common because technological advances have made it possible to store and remotely access large amounts of data. Secondary data processing can be used to further refine and process data compiled from existing data sources. Information on evaluating secondary data sources for quality is provided in the quality assurance project plan (QAPP) or equivalent documentation prepared for a particular project.

This procedure acknowledges that standard practices and protocols vary temporally and differ among various monitoring groups, states, and agencies. Secondary data processing techniques aim to detect and account for inconsistency in a data set compiled from multiple sources. The goal is to improve the comparability and consistency of secondary environmental monitoring data used for a particular project.

This document describes the following topics as related to ensuring the quality of Tetra Tech's secondary data management: data acquisition and documentation, data quality considerations, data organization, and data transformation. A quick reference list of common steps used for data management and processing developed specifically for water quality data, is also included as Attachment 1.

Responsibility and Personnel Qualifications: The Tetra Tech Project Manager, Data Manager, Quality Assurance (QA) Officer, and Quality Control (QC) Officer should refer to this procedure to ensure that the QA/QC requirements set by the client are met. The Tetra Tech Project Manager supervises the overall project and is responsible for coordinating project assignments; establishing priorities and schedules; ensuring completion of high-quality projects within established budgets and schedules; providing guidance, technical advice, and evaluating the performance of those assigned to the project; implementing corrective actions; preparing or overseeing preparation and review of project deliverables; and providing support to the client in interacting with the project team, technical reviewers, and others to ensure that technical quality requirements are met in accordance with the client's objectives. The Tetra Tech Data Manager is responsible for performing the data processing and management activities and the Tetra Tech QC Officer is responsible for checking those activities. A QC Officer is a technical staff member who is familiar with the project tasks but does not participate in the task or subtask that he or she checks. The Tetra Tech QA Officer, with the assistance of the assigned QC Officer, will monitor QC activities to determine conformance with project QA/QC requirements. The Tetra Tech Project Manager and QA Officer will communicate to the Tetra Tech Data Manager whether specific documentation of QC reviews is required for a particular task.

References:

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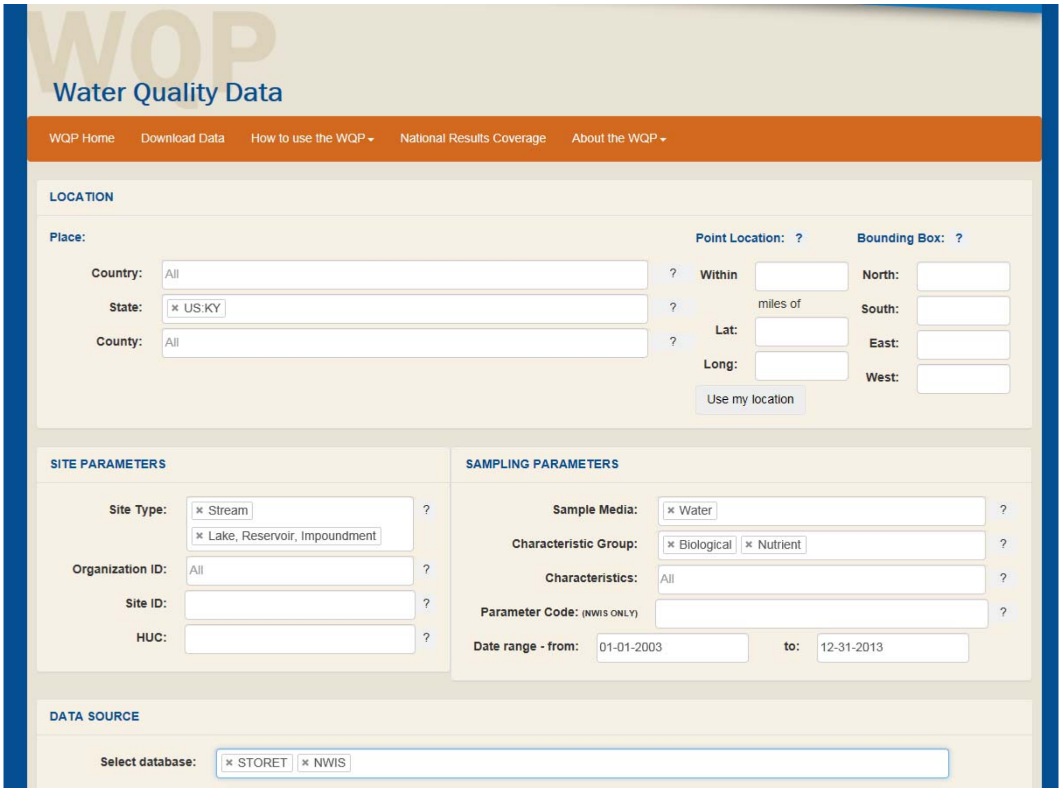
Procedures

1. Data Acquisition and Documentation: Data acquisition involves the process of obtaining and documenting data of various types (e.g., water quality sampling data, spatial data, remote sensing imagery, survey results, 303(d) impairment or 305(b) assessment data, TMDLs, discharger data) using search criteria for the project determined in consultation with the client. Data acquisition must be a repeatable and transparent process. At the beginning of a project, the Tetra Tech Project Manager will consult with the Tetra Tech QA Officer to determine applicable documentation requirements. Data Managers must automate and document each aspect of data acquisition. Data Managers should avoid manual transcription (non-automated data processing) because of the potential to introduce error into the data set. However, automated processes must be properly checked and verified to ensure error-free results.

   The important aspects of data documentation include keeping records of the data source (e.g., URL, agency providing the data, version), the access date, and the access procedure. At the beginning of the project, the Tetra Tech Project Manager will consult with the Tetra Tech QA Officer to determine applicable documentation requirements. Screen captures of search results (refer to Figure 1) can be a quick and effective way to document aspects of the download procedure. Figure 1 is an example of a screen capture of selection criteria entered in the Water Quality Portal: State = “Kentucky”; Site Type = “Stream” and “Lake, Reservoir, Impoundment”; Sample Media = “Water”; Characteristic Group = “Biological” and “Nutrient”; Date Range = “01-01-2003” to “12-31-2013”; and Database = “STORET” and “NWIS”. Alternatively a README text file or word document can be saved with the original data to document this information. If data are acquired via e-mail or file transfer protocol (FTP), save a copy of the original e-mail or FTP access instructions.

2. Data Quality Considerations: At the beginning of a project, the Tetra Tech Data Manager will consult with the Tetra Tech Project Manager and QA Officer for applicable data quality considerations. The advantages of using secondary data include cost and time savings, more extensive data availability, and the potential for analysis by experts not available at smaller scales. However, secondary data have inherent disadvantages because the data were not



LOCATION

Place:

Country: All

State: × US:KY

County: All

SITE PARAMETERS

Site Type: × Stream × Lake, Reservoir, Impoundment

Organization ID: All

Site ID:

HUC:

SAMPLING PARAMETERS

Sample Media: × Water

Characteristic Group: × Biological × Nutrient

Characteristics: All

Parameter Code: (NWIS ONLY)

Date range - from: 01-01-2003 to: 12-31-2013

DATA SOURCE

Select database: × STORET × NWIS

Figure 1. Example screen capture of search criteria selections in the Water Quality Portal[1]

collected by those conducting the analysis and were often not collected to answer the specific question(s) of the current analysis.

For example, data might have been collected for different variables, geographic regions, or sampling frequencies. In addition, because the analyst did not participate in the sampling design or sampling process, the methods and quality of analysis might be unknown. Data might have been collected using different sampling techniques (grab sampling versus composite sampling or random sampling versus targeted sampling). The laboratory or sampling processing methods might also have differed. Differences in technique or documentation can contribute to variability in the data set when multiple secondary data sources are combined for an analysis. Errors in spatial position and taxonomic identification are particularly common in environmental data (Chapman 2005).

The amount of documentation associated with a particular source often varies widely. Documentation of the source, including metadata documented in project reports, validation reports, and any database information, should be maintained along with the data. Research into the origin and documentation of a data source might be necessary to properly evaluate the data source. Potential sources for this documentation might include the website for the agency or group that collected the data, published reports, research articles, and personal communication with the original researcher or monitoring group staff.

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[1] http://www.waterqualitydata.us/portal.jsp

Consider this series of general questions when evaluating the quality of any secondary data source and the applicability of the data to the current project (Boslaugh 2007):

- What was the original purpose for which the data were collected?
- What kind of data are they, and when and how were the data collected?
- What data processing and/or recording procedures have been applied to the data?

Also consider the following questions, which are more specific to water quality data, when evaluating a water quality data source (USEPA 2009):

- Were the data generated under an approved QAPP or other documented sampling procedure?
- If multiple data sets are being combined, were the data sets generated using comparable sampling and analytical methods?
- Were the analytical methods sensitive enough (detection limits) to meet project needs?
- Is the sampling method indicated (e.g., grab, composite, calculated)?
- Was the sampling effort representative of the waterbodies of interest in a random way, or could bias have been introduced by targeted sampling?
- Are the data qualified? Are sampling and laboratory qualification codes or comments included? Are the qualification codes defined?
- Is sufficient metadata available about variables like sampling station location, date, time, depth, rainfall, or other confounding variables?

Specific evaluation criteria for each parameter being considered should also be applied across all sources. Although many water quality data sets include QC samples labeled as duplicate, split, spiked, blank, and so forth; re-checking QC samples is beyond normal practices for secondary data analyses. Rather, it is expected that project-specific QAPPs or similar documentation describing the performance criteria evaluated and met are available for data obtained from peer reviewed sources or from federal, state, or local government reports or data compilations. If this documentation is not readily available, Tetra Tech will consult with the client to determine how much effort should be expended to find reports or metadata that might contain that information. Nevertheless, establishing minimum data requirements for secondary data analyses is often valuable. For example, water chemistry data might require locational information, date, time (optional), depth (optional), chemical name, units, numerical result, and data qualifiers. Specific requirements would depend on project specific needs. For example, it might be necessary to identify outliers or changes in analytical methods. In those cases where requested by the client, QC samples can be used to double-check sample accuracy (e.g., whether duplicate samples are within 15 percent of the corresponding sample).

The National Environmental Methods Index (NEMI)[2] provides a searchable compendium of environmental methods. Different scientific methods can be compared using the method summaries, which also include literature citations. Generally, parameters monitored using different methods should not be combined unless the techniques are documented to be scientifically comparable. EPA also has compiled training materials to detect improper laboratory practices when working with monitoring data.[3]

3. Data Organization: After acquisition, data should be organized and stored. The original unaltered data and "as analyzed" data files should be archived to ensure replicability of the work. Data sets are constantly being updated, so without the original data, replicating an analysis is often impossible. If you are combining data from multiple sources, include information documenting the source of the data in spreadsheets or databases. For water quality data, generally seek to organize data into one of the following hierarchical structures: (1) *source* → *station* → *sample* or (2) *source* → *station* → *sample* → *result* so the data are ready for a variety of analyses.

A relational database, such as Microsoft Access or an Oracle-based system, is an efficient method used to organize multiple related tables. For water quality data, these tables can include station-level tables, sample-level tables, and lookup tables. A primary key or unique identifier, such as a numerical field or a composite primary key made up of multiple fields (e.g., station-sample-date-time-depth), should be assigned to each record. Each table should have a primary key. Foreign keys are fields in one table that uniquely identify a row in another table, often called a lookup table. Figure 2 provides an example of sample-level and lookup relational tables with the primary keys and foreign keys identified. Referential integrity should be maintained such that each foreign key corresponds to the value of a primary key or a null value in a lookup table.

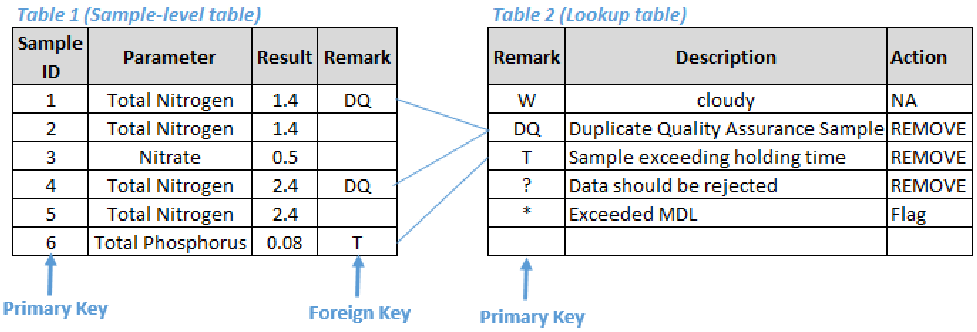

Table 1 (Sample-level table)

Sample ID	Parameter	Result	Remark
1	Total Nitrogen	1.4	DQ
2	Total Nitrogen	1.4	
3	Nitrate	0.5	
4	Total Nitrogen	2.4	DQ
5	Total Nitrogen	2.4	
6	Total Phosphorus	0.08	T

Table 2 (Lookup table)

Remark	Description	Action
W	cloudy	NA
DQ	Duplicate Quality Assurance Sample	REMOVE
T	Sample exceeding holding time	REMOVE
?	Data should be rejected	REMOVE
*	Exceeded MDL	Flag

Figure 2. Example of relational tables with primary and foreign keys

A disciplined file structure and file naming convention can improve version control management. Label files with unique identifiers such as dates or other indicators of version control. Include a documentation table that identifies the database objects (tables, queries,

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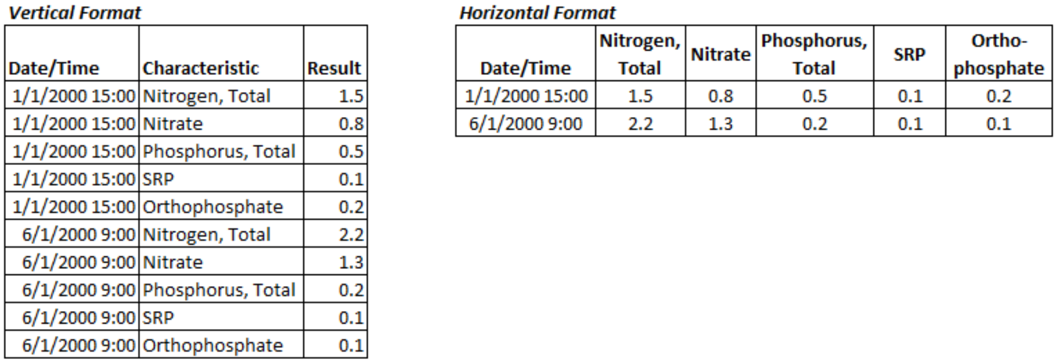
[2] www.nemi.gov

[3] http://www.epa.gov/quality/trcourse.html#monitoring

reports, etc.). Maintain the original data in a read-only database and 'link in' to the analysis database to prevent accidental changes to original data.

Large (e.g., multiple-gigabyte) files sizes are increasingly common, especially with remote sensing imagery, spatial data, or large databases. Consider the storage and backup requirements of these large files. For example, you might need a separate server to accommodate the data needs for a project. If you are working with multiple people, consider the implications of file storage choices for file transfer. Spatial data management has some unique considerations discussed in a separate Geospatial and Data Management QA/QC Procedures document.

Sample-level water quality data are often stored in a vertical format with a column for parameter or characteristic name and a column for result values, as shown in Figure 3. After data transformations, but before statistical analyses, it is often more convenient and space-efficient to convert the data to a horizontal format, in which each parameter of interest has its own column and results for that parameter are reported in the parameter column. This approach allows for simpler identification of paired sampling data (samples taken from the same station-date-time) for multiple parameters, which in turn makes identifying relationships among parameters possible.



Vertical Format

Date/Time	Characteristic	Result
1/1/2000 15:00	Nitrogen, Total	1.5
1/1/2000 15:00	Nitrate	0.8
1/1/2000 15:00	Phosphorus, Total	0.5
1/1/2000 15:00	SRP	0.1
1/1/2000 15:00	Orthophosphate	0.2
6/1/2000 9:00	Nitrogen, Total	2.2
6/1/2000 9:00	Nitrate	1.3
6/1/2000 9:00	Phosphorus, Total	0.2
6/1/2000 9:00	SRP	0.1
6/1/2000 9:00	Orthophosphate	0.1

Horizontal Format

Date/Time	Nitrogen, Total	Nitrate	Phosphorus, Total	SRP	Ortho-phosphate
1/1/2000 15:00	1.5	0.8	0.5	0.1	0.2
6/1/2000 9:00	2.2	1.3	0.2	0.1	0.1

Figure 3. Example of water quality data in vertical (left) and horizontal (right) format

Effective data organization can improve the efficiency with which data can be checked for errors, processed, transformed, and documented. Sorting by location, source, parameter, or other column allows error-checking and transformation to be automated, which improves not only efficiency but also QA.

Aligning matching records can be arduous if not already performed. For example, StationID might differ among sampling visits and would need to be checked using latitude/longitude information (which should be associated with each station). When combining data sets, checks of additional records for near-concurrently collected samples should be performed. These additional records could include chemical species, taxonomic names, and dates. For example, if habitat data were collected on one day and fish were collected 2 days later, there should be an indicator that those data are (or are not) comparable for analysis.

4. Data Transformation: After acquiring the data, archiving the original unaltered data, performing QC checks, and organizing the data, the data often need to be transformed or processed to put them in a comparable format. Data transformation should be organized, systematic, repeatable, and automated as much as possible to reduce the chance of error and minimize the level of effort common to manual transformation.

   This task often involves manipulating the data from the original data source to a 'ready-to-analyze' data set. The original data source can be one to multiple files with the same or different data structure.

Pertinent QA and QC Procedures

1. Relevant QA/QC practices for secondary data management include ensuring that the data processing steps are correct, documented, well organized, reproducible, and transparent. To ensure that we meet the QA/QC requirements set by our clients, data processing steps must undergo QC reviews and those reviews must be documented in the project files. The Tetra Tech Project Manager and QA Officer will communicate to the Data Manager whether specific documentation of QC reviews is required for a particular task.

2. The appropriate level of secondary data management and corresponding level of QC review will vary with project goals, available data, resources, and the decisions to be made. At the beginning of a particular project, the Data Manager will provide recommendations to the Tetra Tech Project Manager regarding methods to be used for processing and managing the data. At this time, the Data Manager and Project Manager should discuss the approximate level of effort needed for the various processing steps and corresponding level of QC review required. Follow-up discussions should be held throughout the duration of the project, as needed, to clarify the analyses to be performed, level of QC review needed, and level-of-effort required.

   - It should be noted that cursory level compilations of data that are used to inform whether more robust data compilations can be prepared can be developed with minimum QC review so long as intermediate work products are identified as such in their transmittal to the client and in progress reports.
   - Data compilations that directly inform decisions/actions (e.g., remediation, compliance decisions, regulatory action, source control, capital investment) require a higher level of QC review.

3. For replicability and QA, maintain a copy of the raw, unaltered downloaded data and related metadata, including variable names/definitions. These raw data can also be important in troubleshooting processing errors introduced during the analysis and in maintaining version control. Data are increasingly dynamic with real-time data uploads and can be updated by data owners at any time. Also, maintain the 'ready-to-analyze' data sets. A 'ready-to-analyze' data set refers to the data set after all processing and transformations have been completed, prior to analysis. At a minimum, the original data, the 'ready-to-analyze' data, and all project deliverables should be electronically stored where automated backups are made on at least a daily basis for the purposes of catastrophic recovery. This can include

office servers or cloud-based solutions. Test analyses and temporary files do not require this type of storage or backup.

4. Other QC checks could leverage the spatial aspect of the data. Stations should be mapped to verify that the data fall in the correct political boundary, ecoregion, waterbody type, or other descriptive spatial factor. Data that reportedly reflect sampling of a lake in Kansas but have coordinates in the Pacific Ocean should call the accuracy of the data and/or the coordinates into question, as should the occurrence of a fish species in a lake in Kansas, not found in inland lakes. Continuous data have a different set of quality concerns such as time stamps, drift in measurements over time, and trimming of the period of record to eliminate records that are out of water, choked in sediment, or exhibiting drift. These concerns are not addressed in this Tetra Tech QA/QC document. For further information on continuous data quality concerns, refer to draft guidance from USEPA and USGS on this topic (USEPA 2014; Wagner et al. 2006).

5. Different data sets can have different naming conventions, units, etc., that need to be unified. The principal QC questions include the following:
   - Was the process documented?
   - Were all data files processed?
   - Were all data records processed (e.g., no dropped records)? If not, were excluded data justified?
   - Were transformation and reshaping steps implemented correctly?

6. As described earlier in this document, cursory level compilations of data that are used to inform whether more robust data compilations can be prepared can be developed with a cursory-level QC review so long as work products are identified as such in their transmittal to the client and in progress reports. With the exception of these cursory-level data compilations, independent checks of data compilations should be performed to ensure we meet the client's QA requirements. Applicable QC checks for data reshaping and transformations tasks are summarized in Table 1.

Table 1. Applicable QC checks for data reshaping and transformations

QC #	Description	Cursory Level Review	Standard Level Review
1.1	Confirm that the reshaping and transformation steps are documented with the data.	X	X
1.2	Confirm that the files processed and record counts of the end product meet expectations.	X	X
1.3	Review meta information prepared by the original analyst that documents transformations and reshaping.	X	X
1.4	For each different file type (i.e., a file with different structure or legacy), confirm the first, last, and a selected middle portion of the data were transformed and reshaped correctly.*		Up to 10% of processed data files, but no less than two data files of each type**

<table>
<tr><th>QC #</th><th>Description</th><th>Cursory Level Review</th><th>Standard Level Review</th></tr>
<tr><td colspan="4">*Evaluating the first and last portions of data helps confirm that no records were accidentally dropped during processing. Selection of the middle portion of the data to check should be done by targeting unique and unusual record types that might stress the transformation and reshaping processing.
** More files should be reviewed (up to 10%) if files are processed individually while fewer files are appropriate for automated to semi-automated procedures.</td></tr>
</table>

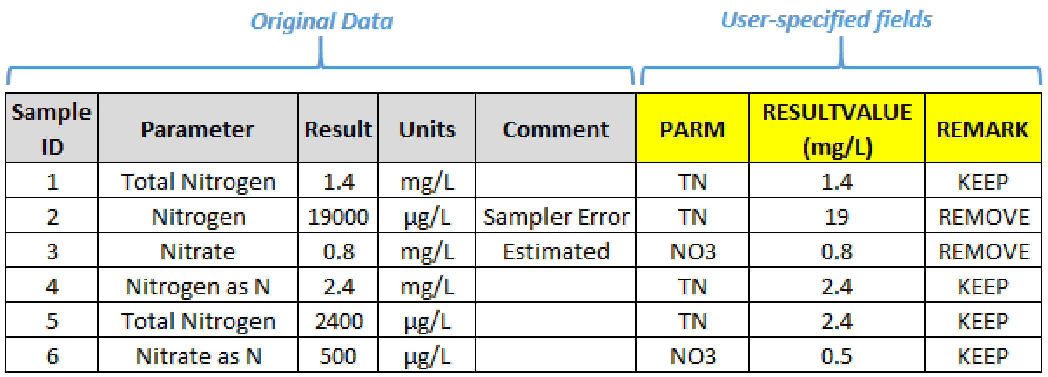
This section describes cursory- and standard-level QC checks that should be performed. Some projects might specify complete independent checking of an entire data compilation. This specification or even standard-level QC could cause a significant and, perhaps unnecessary, resource burden in projects that involve multiple iterations and modifications; thus the Data Manager should confer with the Project Manager to confirm the most cost-effective and efficient process for QC checks.

For data compilations that will be used to directly inform decisions/actions (e.g., remediation, compliance decisions, regulatory action, source control, capital investment), processed data will be independently checked using a standard level review. This standard review consists of independently checking each different file type (i.e., a file with different structure or legacy) and confirming the first, last, and a selected middle portion of the data were transformed and reshaped correctly. Evaluating the first and last portions of data helps confirm that no records were accidentally dropped during processing. Selection of the middle portion of the data to check should be done by targeting unique and unusual record types that might stress the transformation and reshaping processing. More files (up to 10 percent) should be reviewed if files are processed individually while fewer checks (no less than two data files of each type) are appropriate for automated to semi-automated procedures.

All identified data processing errors will be corrected and the Tetra Tech QC Officer will perform a follow-up review of the corrected components to ensure that the errors have been corrected. Where changes are made to previously checked compilation or changes are made to address the results of QC checks, it is normally expected that only the changed/corrected components of the compilation and the dependent, follow-on components would be subject to checking/re-checking. For example, if a change or correction is made to an analysis (e.g., substituting a maximum likelihood technique for a least squares estimation method) then it would not be normally expected that data transformation steps that led to creating the ‘ready-to-analyze’ data set would need to be re-checked.

Frequently, data column names as well as values (e.g., parameter names, comment fields, and result values) are not consistent between different data sources or even within a single source. A more detailed description of data source fields common to water quality data is provided in Attachment 2. To combine data while maintaining the original data, it is good practice to create additional user-specified fields to represent common parameters, standardized comments, and comparable values. Creating user-specified fields allows for correcting errors and performing transformation while retaining the original data in separate fields. Thus, the opportunity to go back to the original data is maintained. Maintaining documentation of data transformation and error correction is especially important when the processes are being performed by people other than the primary data collector.

Creating user-specified fields provides an opportunity to convert units to like units, standardize parameter names, interpret comment fields, convert non-detect values, or institute other data transformations. For instance, a user-specified data qualifier field might be used to flag or exclude blank samples or samples with non-numeric characters in the value field. Figure 4 provides an example of how user-specified fields might be used to convert field names and units and interpret comment fields. Another important use for user-specified fields is creating a column that documents the original source and the row ID of the original source when merging data, so that if systemic issues are found in a source, they can be resolved and processed more effectively. A quick reference guide of procedures to process water quality data is provided in Attachment 1.



Sample ID	Parameter	Result	Units	Comment	PARM	RESULTVALUE (mg/L)	REMARK
1	Total Nitrogen	1.4	mg/L		TN	1.4	KEEP
2	Nitrogen	19000	µg/L	Sampler Error	TN	19	REMOVE
3	Nitrate	0.8	mg/L	Estimated	NO3	0.8	REMOVE
4	Nitrogen as N	2.4	mg/L		TN	2.4	KEEP
5	Total Nitrogen	2400	µg/L		TN	2.4	KEEP
6	Nitrate as N	500	µg/L		NO3	0.5	KEEP

Figure 4. Example user-specified fields

Unintended data duplication is frequently present in water quality data sets. It might be the result of obtaining the same data from different sources, or simply data entry error. This phenomena, should not be confused with field or laboratory duplicate samples which are commonly performed for QA/QC purposes, including evaluating data precision. Unintended duplication can be present within a single data source or among different data sources. Merging two data sets sometimes creates new inconsistencies and duplication. Unintended duplication can skew and bias data. Duplicate values should be flagged and screened from the analysis as much as possible.

Some samples might resemble duplicate entries but actually have different depths, times, or other distinguishing features. If the only fields that are different are descriptive fields, such as comment fields, that might be an indicator of duplication. The organization ID and sampling name can be good indicators that duplication is present, but also look for duplicate values in the data over the same time frame. For example, several identical numerical values on the same day might indicate duplicate data. Sorting the data chronologically and looking for duplicate sample results is one way to begin to identify duplication. Excel has features to identify and highlight duplicate values in a field; when the data are sorted chronologically, Excel can identify potential duplicates. Duplicate records should be flagged using a user-specified field but generally not deleted. Simply deleting unintended duplicate data (i.e., not field or laboratory duplicate samples), rather than flagging and excluding the data, creates a potential for error and data loss that is difficult to identify.

Attachment 1. Quick Reference Guide of Procedures to Process Water Quality Data

These procedures include examples of the types of checks that are performed—not every check to possibly perform. Site-specific steps will apply to many data sets. These steps do not necessarily need to be performed in sequential order and may be iterative.

✓	**Data Acquisition/Organization**
	Acquire data and companion metadata. Maintain a copy of all original files. Document the data source, access date, and the download procedure.
	Start a recording sheet to record decisions and selections to review for quality control and data archive.
	Organize data in a spreadsheet or relational database. Organize data using a hierarchical structure (e.g., source→station→sample or source→station→sample→result).
	Data formatting • Convert “as text” values to numbers. Check for non-numeric characters in numeric fields. • Label all blank cells as blanks to avoid conversion to zero, remove all inappropriate zeros (e.g., chemistry methods rarely measure a true 0, if they have an MDL).
	Review data dictionaries and field names before combining data from multiple sources into a spreadsheet or database format—do not assume that field names are equivalent.
	Utilize exploratory data analysis techniques such as summary statistics or graphical techniques.
	Data Processing
	Generally – do not delete data. Add a screening column to track decision-making and remove records. Maintain removed records in separate file with justification.
	Compare the geographic/temporal scope of the data to the project objectives—it might not be necessary to process all data from a given data set. Map stations in GIS to further refine and select data based on analysis selection criteria. Conduct quality assurance checks based on spatial location.
	Check for unintended duplicate entries (i.e., not field or laboratory duplicate samples). Identify and screen those samples that are duplicates. Check for samples or results that do not have stations.
	Interpret data qualifiers and comments (e.g., spikes, blanks, duplicates, holding time, errors). Screen samples based on an interpretation of the data qualifier remark codes.
	Check each field for inconsistencies. Screen undesired components. Examples include: • Coordinates – Are lat/long coordinates in comparable form? Negative values? • Date/Time – standard format should be used (MM-DD-YYYY). All in same time zone. • Depth – filled out and in the same units? • Sample Media/Type – water, groundwater, air, effluent, stormwater, process water
	Add user-specified fields to interpret, standardize, and clean up existing fields: • Waterbody types – interpret and simplify • Analytes/taxonomy – consistent use of analyte and taxa names • Analytical method/sample fraction – consider accuracy and comparability of methods • Units – standardize units and convert values as appropriate
	Censored Data – Data that are reported as not detected or below detection limit should be utilized but accounted for statistically. Several methods are available to interpret censored data depending on the analysis. At this stage, maintaining MDLs and PQLs is likely appropriate to provide later analysis flexibility.
	Data Transformation
	Calculate metrics or new parameters based on the data available. For example: • Calculate parameter sums or products (e.g., TN as sum of nitrate+nitrite and TKN). • Calculate TSI, M-IBI, F-IBI, other biological indices.
	Outliers – Analyze the data for potential outliers and consider screening those data that are clearly outliers and may introduce bias or error into the data set.
	Document the process to ensure quality assurance and reproducibility.

Attachment 2. Data Source Field-specific Water Quality Data Tips

Several fields that provide more information about the sampling process or sampling location are often included with water quality data. These fields might include sample media, sample type, sampling type or location, and waterbody type. These fields might need to be interpreted or transformed to select the data that are of interest to the analysis. Descriptions of common fields and transformations that should be considered include the following:

- **Sample media:** A field or two for sample media (e.g., water, soil, groundwater) are sometimes included. They can be used to verify that the correct query selections were made for the sample media of interest. Sometimes sample subdivisions identify distinctions that should not be included in an ambient analysis (e.g., effluent, process water).
- **Sample type:** A field is sometimes included that identifies routine samples versus duplicate or quality control samples (spike samples, field replicates, laboratory replicates, or other duplicates). Checking routine values against duplicate values can be a valuable quality control check, but also ensure that duplicate values are not included in the data set used for analysis.
- **Sampling type or location:** Fields indicating the type of sampling, such as effluent, ambient, stormwater, baseflow, pipes, finished water, or process water, are sometimes available. Consider the location of the sampling effort. Sampling focused on effluent outfalls or on pristine waters could introduce bias into an analysis, depending on what the purpose of the project is. Sampling type or location can be an important indicator of sampling bias or spatial bias inherent in the data set resulting from opportunistic sampling rather than random sampling.
- **Waterbody type:** An indication of the type of waterbody where the sampling occurred might be included (e.g., stream/river, lake/reservoir, estuary, ocean, wetland, canal, stormwater). This field can be used to further subset sampling data to the data of interest.

Descriptive fields such as temporal indicators (e.g., date, year, time), sample depth, latitude/longitude, or units are often included in varying formats. A description of common fields and transformations that should be considered is provided below:

- **Temporal:** Ensure all date and time fields are in the same format (e.g., MM-DD-YYYY, YYYY-MM-DD). It is recommended that you use military time and account for time zones. It might be helpful to have one field with “Date” and separate fields for “Year,” “Month,” “Day,” and “Time.” If a measurement of diurnal fluctuations is not needed in a parameter, averaging data by day might remove some inconsistencies resulting from data without time information or with slightly different times due to different processing labs or data entry error. Searching for dates outside the range of interest or outside reasonable date or time values (e.g., month <1 or >12, day <1 or >31, year <1900, time <0 or >24) can be a helpful screening tool. Having a sampling date is a reasonable minimum requirement for data.

- **Depth:** Depth should generally be a numeric field. Sometimes a surface or bottom indicator is included as well as a numeric depth field (e.g., S, B). It can be helpful, especially in lakes and estuaries, to add a separate text depth column for profile data that indicate surface, depth, or bottom measurements for some parameters (e.g., dissolved oxygen). Depth units should be standardized to a consistent format (feet or meters).
- **Latitude/Longitude:** Ensure that latitude and longitude are reported in a consistent format. Latitude and longitude units are most often reported in degrees, minutes, and seconds (DMS) (e.g., 39°59’56.055”N, 102°3’5.452”W), decimal degrees (DD) (e.g., 39.999012, -102.052062), or sometimes Universal Transverse Mercator (UTM) coordinates (e.g., 13N 751705 4431801). The examples provided are all roughly from the same point on the border of Kansas, Nebraska, and Colorado. To convert from DMS to DD, use the formula: (degrees) + (minutes/60) + (seconds/3600) = decimal degrees. If values are missing, consider digitizing from GIS or geocoding from an address if provided. One of the most frequent errors is omitting the negative sign (-) in decimal degree coordinates from the southern or eastern hemispheres. If all the records are from North America, all the longitude values should include a negative sign. Consider spatial accuracy. With today’s standards, be wary of decimal degree data with less than six digits of precision accuracy or seconds reported with less than two digits of precision (although for larger waterbodies less precision might be acceptable). A typical minimum data requirement for station-level data is that the station must have a latitude and longitude measurement as well as the reported datum. Look for extreme values: Latitude should never be outside the range of 90 to -90 degrees; longtiude, 180 to -180.
- **Units:** Standardize units by parameter and among parameters. Check for systematic incorrect reporting of units when converting all values for a parameter to one unit of measurement. Note that laboratories often report results on a weight-per-weight basis, such as parts per million (ppm) or part per billion (ppb). In water samples, 1 ppm is essentially equivalent to 1 mg/L and 1 ppb is equivalent to 1 µg/L unless concentrations are very high (>7,000 mg/L) (Edwards 1986). In addition, µg/L and mg/m^3 can be considered identical in most cases in water samples. Outliers for a parameter might be an indication that data are reported in varying units.

Appendix B.

Tetra Tech's Standard Operating Procedure on Statistical Analyses

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Standard Operating Procedure TT-FFX-SOP-O-002

Statistical Analyses

Prepared by: Name Jon Harcum, Ph.D. Title Environmental Engineer

Signature Jon Harcum Date 3/9/17

Approved by: Name John Hochheimer, Ph.D. Title Technical Monitor

Signature Date 3/9/17

Approved by: Name Susan Lanberg Title QA Officer

Signature Susan Lanberg Date 3/9/17

Scope and Applicability: The Tetra Tech Project Manager, Statistical Analyst, QA Officer, and QC Officer should refer to this procedure to ensure that the quality assurance/quality control (QA/QC) requirements set by our clients are met. Statistical analysis of data covers a wide range of calculations and graphical visualization techniques. Relevant QA/QC practices for statistical analyses include ensuring that the analyses are correct, reproducible, and transparent. To ensure that we meet the QA/QC requirements set by our clients, statistical calculations must undergo QC reviews and those reviews must be documented in the project files. The Tetra Tech Project Manager and QA Officer will communicate to the Statistical Analyst whether specific documentation of QC reviews is required for a particular task.

The appropriate level of statistical analysis and corresponding level of QC review will vary with project goals, available data, resources, and the decisions to be made. At the beginning of a particular project, the Statistical Analyst will provide recommendations to the Tetra Tech Project Manager regarding statistical methods to be used for analyzing the data. At this time, the Statistical Analyst and Project Manager should discuss the approximate level of effort needed for the various analyses and corresponding level of QC review required. Follow-up discussions should be held throughout the duration of the project, as needed, to clarify the analyses to be performed, level of QC review needed, and level-of-effort required.

- It should be noted that analyses that are expected to be used to inform future, more detailed analyses can be performed with a cursory-level QC review so long as work products are identified as such in their transmittal to the client and in progress reports.
- Analyses that directly inform decisions/actions (e.g., remediation, compliance decisions, regulatory action, source control, capital investment) require a higher, standard-level QC review.

This document describes the following topics as related to ensuring the quality of Tetra Tech's statistical analyses: method selection, best practices, and QC.

Responsibility and Personnel Qualifications: The Tetra Tech Project Manager supervises the overall project and is responsible for coordinating project assignments; establishing priorities and schedules; ensuring completion of high-quality projects within established budgets and schedules; providing guidance, technical advice, and evaluating the performance of those assigned to the project; implementing corrective actions; preparing or overseeing preparation and review of project deliverables; and providing support to the client in interacting with the project team, technical reviewers, and others to ensure that technical quality requirements are met in accordance with the client's objectives. The Statistical Analyst is responsible for performing the statistical calculations and analyses and the QC Officer is responsible for checking those activities. A QC Officer is a technical staff member who is familiar with the project tasks but does not participate in the task or subtask that he or she checks. The QA Officer with assistance from the assigned QC Officer, will monitor QC activities to determine conformance with project QA/QC requirements. The Tetra Tech Project Manager and QA Officer will communicate to the Statistical Analyst whether specific documentation of QC reviews is required for a particular task.

Procedures

1. <u>Method Selection</u>: Based on the characteristics of available data and the project's needs, the Tetra Tech Project Manager, in consultation with the client and the Statistical Analyst, will determine whether common exploratory summary statistics and/or standard graphical presentations will be needed for a particular project, or whether more advanced predictive procedures (e.g., applying a range of hypothesis tests, applying multivariate tools, developing empirical models) will be required. Some examples of various procedures are listed below.
    - Common summary statistics include counts of observations and distribution characteristics (e.g., mean, standard deviation, coefficient of variation, variance, median, percentiles).
    - Standard graphical presentations (e.g., distribution plots, scatter plots, boxplots, time series).
    - Parametric and non-parametric hypothesis tests (e.g., t-test, analysis of variance, Kruskall-Wallis).

- Multivariate tools (e.g., principal components analysis, clustering analysis, canonical correspondence analysis, discriminant analysis, non-metric mulitdimensional scaling).
- Models (e.g., linear and non-linear regression, general additive models, general linear models, Bayesian hierarchical models).

When deciding which statistical procedure to apply to any data set, it is essential to consider the characteristics of the data, which will help determine the appropriate statistical analysis. Some common characteristics of data include one or more of the following:

- Presence of outliers, extreme low or high values that occur infrequently, but usually somewhere in the data set (outliers on the high side are common) resulting in skewed distributions.
- Variance heterogeneity.
- Non-normal distribution.
- Small sample size.
- Censored data – concentration data reported above or below one or multiple detection limits or reporting values.
- A lower bound of zero (e.g., no negative concentrations are possible).
- Missing values.
- Irregular sampling.
- Strong seasonal patterns.
- Autocorrelation – consecutive observations strongly correlated with each other.
- Dependence on other uncontrolled or unmeasured variables – values strongly co-vary with such variables as streamflow, precipitation, or sediment grain size.
- Measurement uncertainty.

Common Tools/Software: There are a wide variety of computer tools/software available to support statistical analyses including spreadsheets (e.g., Excel), databases (e.g., Access, SQL), commercial statistical packages (e.g., SAS, Minitab, Systat), customized software (software created by a state/federal agency or a third party vendor designed for a particular analysis, e.g., ProUCL, EPIWEB), and programming code (e.g., FORTRAN, C++, Python, R). Hand calculations can also be used.

The functionality of these tools overlaps, yet different numerical results are sometimes computed when using different tools. For example, a key part in estimating percentiles is to assign ranks to the observed data. Some spreadsheet software programs assign the minimum rank to tied values rather than assigning a rank that is equal to the median of the ranks if the observations had not been tied. Other commercial software may include multiple formulas for computing percentiles, which the user can select. The outcome is that different percentiles might be computed among different software packages. Similarly, different analysts can compute different numerical results when applying similar steps, but simply in a different order (e.g., the logarithm of the average is not equal to the average of the logarithms). It is important that the original analyst and person performing QC checks be aware of these potential differences and their impact on the analyses and independent checking of results. *Overall Justification and Documentation of Methods Used*: Common summary statistics and standard graphical presentations that follow normal practices for the type of data being evaluated require little or no justification for their usage. Method selection for hypothesis testing, multivariate procedures, model development, or more advanced procedures should be made by an experienced analyst with justification included in the corresponding report. Citing similar analyses available from applicable guidance/methods documents or peer-reviewed literature is sufficient. Methods selected from the Internet, gray literature, software literature, or presentations require additional narrative to document why a particular method is, or might be expected to be, appropriate.

2. Best Practices: This section provides a list of best practices that can be implemented to reduce errors in statistical analyses and improve the overall work product. It is the responsibility of the Tetra Tech Project Manager and delegated Statistical Analyst to identify which practices are appropriate for a particular task.

- *Overall*:
    - Maintain original copies of source data, related metadata, and the ‘ready-to-analyze’ data sets. See the Secondary Data Management SOP for more information on data organization and management. Use a naming convention for files that is understandable to you and others, and is designed in way that helps ensure that version control is maintained throughout the project (e.g., use of dates, version numbers, draft, final).
    - Develop a written technical description of the analysis. This description can be written before beginning analyses and/or developed as a living document throughout the course of the project.
    - Identify analysis milestones where data should be exported/saved to improve transparency and reproducibility, as well as for QC analyses and record keeping.
    - Perform statistical analyses in a similar fashion throughout the project. Document deviations in the technical description of the analyses.
    - Document the name, version, and, where applicable, the source code of the software used to perform analyses. This is applicable for commercial and open source software.
    - Give titles to objects in the spreadsheet, database, or software that lend an understanding to the purpose of the object. For example, a database query entitled ‘selectData_v02’ might be a useful object title for the second version of a query that selects data from a primary source table.

- *Hand Calculations*:
  - Hand calculations should be legible and document their purpose.
  - Scan hand calculations so they can be maintained as electronic documents with other documentation.
- *Spreadsheets*:
  - Include a documentation tab that includes information about the spreadsheet as a whole and a description of the other tabs.
  - Organize tabs from left to right in the same order as the analysis steps.
  - Organize calculations within a tab from left to right and/or top to bottom.
  - Make judicious use of named cells and relative/absolute cell addresses to allow maximum use of ‘fill-down’ and ‘fill-right’ options.
  - Limit cell and font styles for highlighting information that could be derived from examining the data. For example, it is an acceptable practice to set a cell color to “yellow” to help visualize all p-values less than 0.05. It is not a typically accepted practice to highlight statistically significant regression slopes but not show/include the actual p-values.
- *Commercial Statistical Packages*:
  - Document the name and versions of the software used.
  - Document the steps and settings used to implement calculations that are menu/interactively implemented.
  - Develop macros to implement repeated tasks.
- *Customized Software*:
  - Document the name and versions of the software used.
  - Document the steps and settings used to implement calculations that are menu/interactively implemented. (Note that it is a common practice for software packages to be developed by a third party on behalf of a state or federal agency to perform a very specific set of analyses that are not directly available in commercial software. While these software packages may be well tested for the primary work flow, they may not be as well tested or error proof, if used in a non-conventional manner. Therefore it important that the analyst have an understanding of the basic work flow of the software package and document its usage.)
- *Programming Code (e.g., FORTRAN, C++, Python, R)*
  - Maintain all source code, and if applicable compiled code, used to perform all analyses for documentation and future use. This allows for transparency and repeatability of the analysis.
  - Where practicable, repeat the analyses with a separate tool to verify the results or code and/or independently unit test the source code.

Pertinent QA and QC Procedures

1. The appropriate level of QC will vary with project goals, available data, resources, technical approach, and the decisions to be made. The principal QC questions include the following:

    - Was an appropriate method chosen and applied?
    - Were the statistics computed and graphics created correctly?
    - Were the statistics and graphics representative of the data?
    - Were method assumptions met?
    - Were the results presented correctly?

2. Selection of a particular method depends on the data and the analysis objectives. Calculating summary statistics and developing basic graphics can normally be performed by any basic environmental consultant/staff member. Exceptions might include calculations with censored data or other non-standard data. Advanced statistical calculations and related output (tabular, graphic, etc.), including, but not limited to, hypothesis testing, multivariate tools, empirical models, and statistical simulations will generally benefit from oversight by an experienced analyst. However, it should be noted that multiple methods might be applicable for a given project and set of data (see Overall Justification and Documentation of Methods Used section above).

3. As described in the introductory section of this document, analyses that are expected to be used to inform future, more detailed analyses can be performed with a cursory-level QC review so long as work products are identified as such in their transmittal to the client and in progress reports. While a cursory-level QC review could include some independent checking of calculations, a cursory-level review may also be limited to reviewing selected sections of a technical report that focus on the data summary, technical approach, and results sections.

4. For statistical calculations performed using analysis software for which the results will be used to directly inform decisions/actions (e.g., remediation, compliance decisions, regulatory action, source control, capital investment), calculations will be independently checked using a standard-level review. As used here, independent calculations can refer to a different analyst performing the same analysis, or they may refer to the same analyst performing the same analysis using a different software tool. Some projects might require complete independent checking of all calculations. This requirement, or even standard-level QC, could cause a significant resource burden in projects that involve multiple iterations and modifications. Thus, the Statistical Analysts should confer with the Project Manager to confirm the best timing for QC checks to best use the available budget.

5. With today’s computer technologies, it is more appropriate in some instances to perform targeted checking rather than rely on a fixed “10 percent of all calculations” rule when performing independent calculations. A standard-level review consists of up to 10 percent independent recalculations of computations and graphs, but no less than two examples of each computed statistic and two examples of each graphic type. More calculations (up to 10 percent) should be reviewed if data sets or points are processed individually while fewer

checks (no less than two examples of each computed statistic and two examples of each graphic type) are appropriate for automated to semi-automated procedures. Selection of which statistics and graphs to check should include targeting unique and unusual record types that might stress the calculation and graphing process. All identified calculation errors will be corrected and the Tetra Tech QC Officer will perform a follow-up review of the corrected components to ensure that the errors have been corrected. Where changes are made to previously checked analyses or changes are made to address the results of QC checks, it is normally expected that only the changed/corrected components of the analysis and the dependent, follow-on components would be subject to checking/re-checking. For example, if a change or correction is made to an analysis (e.g., substituting a maximum likelihood technique for a least squares estimation method) then it would not be normally expected to re-check data transformation steps the led to creating the ‘ready-to-analyze’ data set. In cases where codes are developed to perform statistical calculations, codes and changes to codes should be checked and tested for reproducibility by a qualified QC Officer, and if possible, run on independent software.

6. In the majority of instances, statistical calculations will be performed using analysis software. In (relatively uncommon) circumstances where statistical calculations are primarily performed by-hand, a Tetra Tech QC Officer will independently recalculate 10 percent of these calculations to ensure they were performed correctly. If more than 1 percent of the data calculations are incorrect, the Tetra Tech QC Officer will independently check the remaining calculations to ensure they are correct. All identified errors will be corrected.