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James River Watershed Risk Analysis

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Environmental Stewardship Concepts, LLC

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Written by Environmental Stewardship Concepts, LLC for the James River Association

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1.0 Executive Summary

The James River and its watershed are historically, culturally, ecologically, and economically valuable resources. The James River watershed provides drinking water to 39 counties and 19 cities and provides recreational opportunities for thousands of Virginians.[1] The watershed is home to endangered and threatened species, from the Atlantic sturgeon and freshwater mussels in the river, to bats and birds on land. However, toxic chemicals and other pollutants that are stored, spilled, and discharged into the river and its tributaries threaten the watershed and impact human and ecological health. Three of the most significant sources of risk to the James River watershed are 1) the storage of toxic chemicals within the watershed, 2) coal-fired power plants and their associated coal ash ponds, and 3) crude oil spills during rail transport.

This assessment of risks to the watershed begins with a review of the data on the toxic chemicals stored and released from the three major sources. The contaminants from these sources make their way into the water through a variety of pathways. Permitted releases discharged directly into the river, accidental spills, and seepage onto land and into groundwater all present risks to the resources of the river. This report describes the risks posed to both the environment and the humans living in the watershed by being exposed to these types of contaminants. We also review the toxicological effects of these types of chemicals on key ecological resources, termed assessment endpoints, and on human health.

The results of this watershed assessment indicate that there are significant risks from three major sources of chemical contamination. Many of these large scale events may be infrequent, but they have serious effects. Consistent with national assessments, the dramatic increase in crude oil production and transport can be expected to increase the amount of oil spilled into the environment. The spills and accidental releases do not take place in a vacuum but in a river system that already experiences permitted discharges from hundreds of facilities, the effects of which are not well described or understood.

In compiling data for this report, we found substantial gaps in the information needed to accurately understand the ecological and health risks at the level of the James River watershed. The gaps include the condition of the infrastructure, the status of facilities, and the equipment used to transport toxic chemicals. There is also a lack of basic toxicological data on many chemicals stored in the watershed and released into the river.

2.0 Introduction

Over the past ten years, the number of toxic spills in the Southeast has dramatically increased, namely the following 2014 events: the spill of a coal-wash chemical in Charleston, West Virginia; the coal ash pond rupture in Eden, North Carolina; and the oil train derailment in Lynchburg, Virginia. This last event hit close to home for central Virginia and the James River watershed residents, shedding light on a new risk to the Commonwealth's safety. These recent events have demonstrated the fragility of our natural resources and the instantaneous impact that some human activities can exert on our aquatic resources.

To complete this analysis, we relied to a great extent on the procedures and practices in the field of ecological risk assessment. These methods have been developed over more than two decades by the United States Environmental Protection Agency (EPA) and have been refined and applied by practitioners of all types.[2] EPA and professionals in the field soon recognized the need to apply ecological risk assessment procedures at the level of the watershed. EPA completed several examples of watershed level risk assessments prior to publishing a report specifically addressing watershed ecological risk assessments. Watershed risk assessments in particular are complex, as watersheds span multiple jurisdictions and involve multiple point and nonpoint sources of pollution. Watershed risk assessments are also important because watershed boundaries can define the flow of contaminants through an area. The present analysis draws on the EPA Guidelines[3] and reports on the topic, as well as material on the related topic of cumulative risk assessment.[4] The field of cumulative risk assessment combines approaches from human health, ecological and watershed level risk assessment to address risks at the level of communities.[5]

There are various concerns regarding the wellbeing of the natural resources and the health of the communities in the James River watershed. Agricultural runoff, overharvesting of fishery resources, and invasive species are, among others, all problems for the James River. However, the focus of this report will be the storage, transportation, and release of toxic chemicals and the toll these activities are taking on the watershed.

2.1 Description of the Watershed

As the nation's founding river, the James River plays a vital role for Virginia's citizens and environment. It covers a quarter of the state and flows 340 miles from its headwaters in the Appalachian Mountains to its mouth at the Chesapeake Bay. The James was first inhabited thousands of years ago by Paleo-Indians.[6] Several Native American tribes developed along the James, including the Powhatans and the Monacans.[7] For Native Americans, the James was a source of food, water, and an important cultural icon. After English colonists settled at Jamestown in the early 1600s, the James became an important shipping and navigation route. The floodplains of the lower section of the river served as land for tobacco plantations, and later ironworks and flour and paper mills were developed.[8] Today, the mouth of the river at Norfolk is home to the largest naval station in the world and one of the busiest harbors in the U.S.[9]

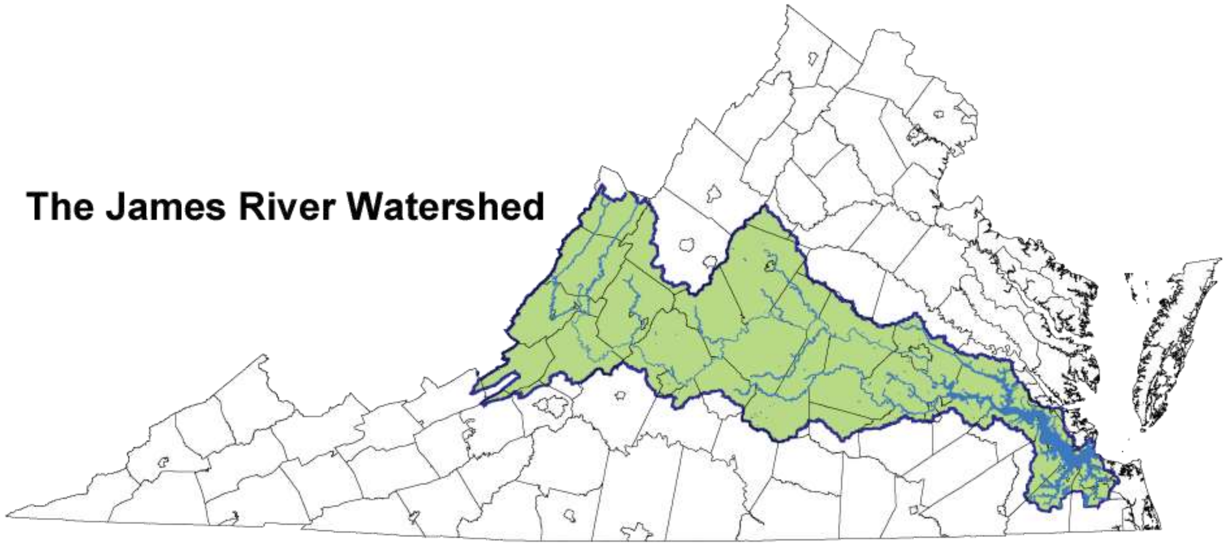

Figure 1: James River Watershed (Image: James River Association)

The James River watershed is defined as the James River itself and all of its tributaries. The watershed encompasses about 10,000 square miles and is home to one-third of all Virginians.[10] The James and its tributaries provide drinking water to millions of Virginians, habitat for native and endangered species, and an abundance of recreational opportunities.

The James River is home to a biologically diverse array of species. Many of these species have suffered from habitat loss and impairment or overharvesting and are now on federal or state endangered species lists. A number of the 58 federally endangered species in Virginia are found in the James River watershed, such as the Atlantic sturgeon and the James spinymussel, to name just a few (see Appendix A: VDGIF list of Virginia "Special Legal Status Faunal Species").

2.2 Toxic chemicals in the Watershed

The James River has a well-publicized sad chapter in its modern history. During and preceding the mid- 1970s, Allied Chemical Co. illegally dumped unknown amounts of the chemical chlordecone into the James from the plant in Hopewell.[11] Located on the banks of the James at the confluence with the Appomatox River, Hopewell is home to a number of industrial facilities, including the former Allied Chemical plant, now Honeywell, Inc. This plant synthesized an insecticide sold under the trade name of Kepone™, spinning off this operation as Life Science International in 1974. In 1975, several events provided the evidence of illegal dumping and careless handling. Kepone was found in fish in the James, workers at Life Sciences went to the hospital with symptoms of nerve damage, the sewage treatment plant failed due to poisoning and a pair of college students was caught dumping bad batches of Kepone into the swamp outside Hopewell.[12]

Kepone was spread through approximately 30 miles of the tidal James River, from Hopewell to the mouth at Newport News. This chlorinated organic insecticide is a potent neurotoxin in mammals, causes sterility (temporary in workers), is an estrogen mimic[13], interferes with molting in blue crabs[14] and is carcinogenic in lab animals.[15]

As a result of the extensive contamination, the river was closed to all recreational and commercial fishing. Kepone accumulated in surface sediments that gradually began to bury beneath new sediments, but slowly. Professor Nichols investigated the natural burial process of the Kepone and concluded would not be isolated by the process because animals living in the sediments above would draw the Kepone up from deeper sediments.[16] The Virginia Department of Environmental Quality (VDEQ) monitored levels of Kepone in fish tissue for a number of years, finding that Kepone levels decreased, but not to zero, through 2009, when the last monitoring was conducted[17]. This incident remains as an example of how persistent toxic chemicals remain available for many decades and contaminated sediments do not readily bury enough to isolate the contamination.

When measured by the amount of toxic chemicals discharged into the water, Virginia's waterways have the second highest total discharge in the nation.[18] The James River is no exception. Over 80% of the toxic chemicals managed in Virginia are present in the James River watershed.[19] The James flows through some of Virginia's most industrial areas, specifically the cities of Richmond and Hopewell. In 2012, the James was ranked as the waterway with the ninth highest in the nation for release of chemicals that interfere with development of fetuses and babies with a total of 7,660 pounds released into the river.[20]

Through examination of Virginia DEQ records, Sachs and Murphy noted that there are 277 facilities with 570 total outfall pipes in Virginia that have legal permits to discharge one or more toxic chemicals into waters of the State.[21] Over 65% of the total toxic chemical emissions in Virginia come from just ten facilities, three of which are in the James River watershed. These facilities are Honeywell Resins and Chemicals, LLC in Hopewell; Babcock and Wilcox Nuclear Operations Group, Inc. in Lynchburg; and Dominion's Chesterfield Power Station in Chesterfield County.[22]

Toxic chemicals discharged into the watershed range from wastewater contaminants to road runoff to chemicals from industrial facilities. Some of the most toxic chemicals in the watershed can persist in soil and sediment and bioaccumulate in plants and animals. Bioaccumulation occurs when chemicals are absorbed at a greater rate than they are lost, leading to a higher concentration of chemicals in the tissues of plants and animals than that of their surrounding medium. Biomagnification occurs as a result of this process, as contaminants are transferred up the food chain in higher concentrations. For animals and plants within the watershed, contamination can lead to disease, decreased reproductive rates, increased mortality rates, loss of threatened and endangered species, and loss of habitat. Bioaccumulation and subsequent biomagnification also have health implications for humans who consume contaminated fish, shellfish, and other animals from the watershed.

Many of the substances that are released into the waters of the James River and its tributaries that may have toxic effects on a multitude of species are not labeled as toxic chemicals, often due to a lack of research. Discharge permits only address those chemicals for which there are legal limits or chemicals that are known to be present in the discharge and are a potential problem in the water. Chemicals present in small amounts, chemicals with little or no toxicological information, and chemicals that have not been measured in the discharge waters are not regulated. Most non-point source chemicals that run off of farms, fields, streets and yards are not monitored either. Chemicals may also seep into groundwater which may then move into streams; this pathway of contamination is also unregulated and unmonitored. Finally, toxics may enter our waterways from atmospheric deposition. Although not the explicit focus of this document, air deposition contributes to the concentrations of toxics in waterways, including the James River.

2.3 Risk Assessment 101

Risk assessment is a formal means of estimating the probability that harm will come from some activity or condition that is ongoing or planned. In this sense, risk assessment is a predictive analysis, rather than an historical analysis. The EPA defines risk as "the chance of harmful effects to human health or to ecological systems resulting from exposure to an environmental stressor."[23] They define risk assessment as a process "to characterize the nature and magnitude of health risks to humans (e.g., residents, workers, recreational visitors) and ecological receptors (e.g., birds, fish, wildlife) from chemical contaminants and other stressors that may be present in the environment."[24] Estimates of probability may be numerical (i.e. a percentage or a ratio) or descriptive, as in "high, medium or low" likelihood.

The basics of ecological risk assessment in the U.S. are similar to human health risk assessment as first described in a National Research Council (NRC) report on the subject in 1983[25] and set out by EPA in the Guidelines for Ecological Risk Assessment[26]. The elements are: 1) determining the nature and purpose of the effort with managers, 2) problem formulation, 3) analysis of sources, exposures, and effects, and 4) characterizing the specific likelihood, nature and magnitude of the risk (or threat). This process is shown in Figure 2 below. The framework that EPA presents for watershed risk assessments, followed here for the James River watershed in Virginia, builds on efforts by the EPA and NRC over the past 25 years.

The initial step in an ecological risk assessment is the Problem Formulation, which determines the scope of the assessment, the understanding of the sources of threats, and the receptors at risk. The tasks involved in the Problem Formulation are:

(1) State a risk hypothesis. In its simplest form, a risk hypothesis describes the potential threats to the resource(s) from the sources of stress.

(2) Create a Conceptual Site Model. The Conceptual Site Model is a graphic display of the components of the system, including the sources of stress and the relationships among the components. The model visually represents the specific risks to the chosen assessment endpoints, including the pathways of exposure.

(3) Determine the assessment endpoint(s). The assessment endpoints are the properties or parts of the system that will be evaluated for ongoing or future harm from the sources of stress. Examples may be an endangered species, or a commercially, ecologically or recreationally important species.

(4) Determine sources, stressors, and pathways. The sources are the actions or entities releasing the contaminants into the watershed. The stressors are the chemical, physical, or biological entities that negatively impact the ecosystem. And the pathways are the ways in which the stressors are transported through the environment.[27]

(5) Formulate a risk analysis plan. The analysis plan describes what information will be obtained, and how it will be used, any new data to be collected, what computations will be completed, and how the information will be used to address the risk hypothesis.

The conceptual site model (shown in Figure 3) provides a graphic and written depiction of the system under investigation.

Especially in ecological systems, it is not practical to address all elements of a system; there are simply too many species and habitats. Additionally, most wildlife species are not sufficiently well understood to predict the responses to specific stresses. Selecting the appropriate endpoints for the focus of the assessment is a critical part of the problem formulation. Assessment endpoints are the actual ecological resources that are at risk and need to be protected. Assessment endpoints are measurable ecological characteristics, such as reproduction rates or mortality rates, which indicate biological responses to stressors. The EPA Guidelines for Ecological Risk Assessment state that three criteria exist for selecting ecological characteristics to target in the risk assessment: 1) responsiveness of the endpoint to ecosystem conditions; 2) the importance of the endpoint in the ecosystem; 3) and the significance or importance of the endpoint to society and managers.[28]

The Problem Formulation also involves determining stressors and exposure pathways. Stressors are defined as chemical, physical, or biological factors that result in deleterious effects to an ecosystem's structure, function, or components.[29] Exposure pathways are the courses a stressor takes to get from the source to the receptor.

Assessing risks at the level of the watershed requires including elements of cumulative risk assessment by determining the condition or status of the system at present. An ecosystem that is degraded, disturbed or recently stressed will be more vulnerable to subsequent stresses, i.e. respond differently to sources of stress, than an otherwise unstressed system.[30]

The analysis consists of estimating the frequency, nature and magnitude of how sources of stress are released and expose some or all parts of the watershed to threats. At the same time, the analysis estimates the types of adverse reactions that might be anticipated, e.g. death, reproductive impairment, disease, dislocation, etc. In watershed assessments, human health effects are considered along with ecological harm to the extent set out in the planning phase at the start of the assessment.

The final step in the risk assessment is estimating the likelihood (probability) that harm will occur and the nature and magnitude of that harm. The assessment must also describe the risk and the confidence or uncertainty around the estimates of risk. Watershed assessments innately offer certain challenges, as watersheds are complex systems with multiple stresses and many unknowns.

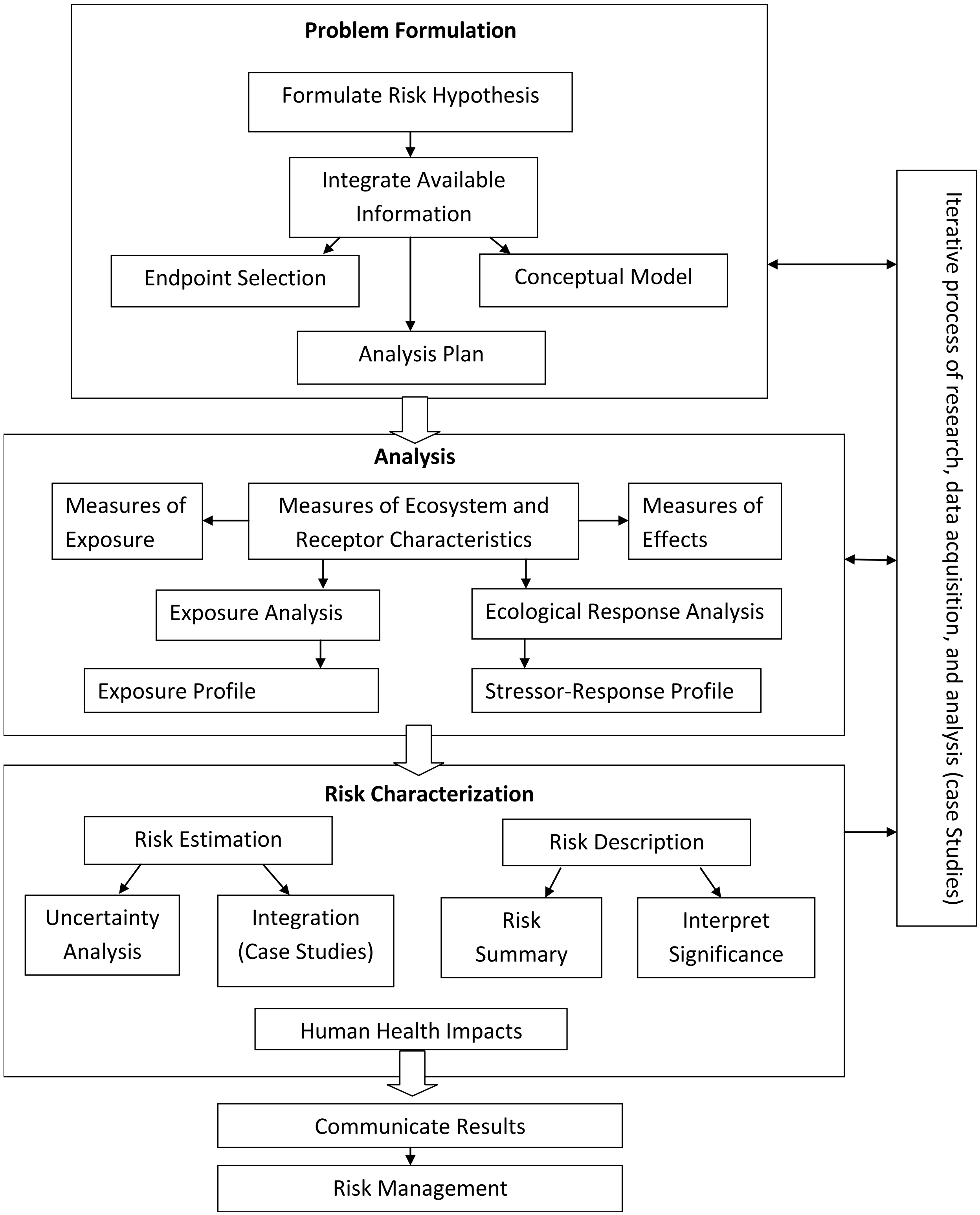

Figure 2: Ecological Risk Assessment watershed framework (adapted from U.S. EPA 2015 Watershed Ecological Risk Assessment[31] and U.S. EPA 1994 Expanded Framework Diagram[32])

3.0 Problem Formulation

3.1 Risk Hypothesis

The Risk Hypothesis can be stated in simplest form as: toxic chemicals in the James River watershed pose avoidable risks to ecological resources and human health. Some of these risks may be considered unacceptable.

3.2 Simplified Conceptual Site Model

A conceptual site model provides information on sources, stressors, receptors, potential exposure, and predicted effects. The purpose of the conceptual site model is to depict the components of the system and the relationships among them. To create this model, we identified critical ecological elements, the three major sources of risk, and assessed the possible effects on specific endpoints of concern within the James River watershed. Consistent with current ecological risk assessment practice, we included loss/protection of threatened and endangered species and their habitats in the James River watershed and human health regarding consumption of contaminated fish and shellfish from the watershed.

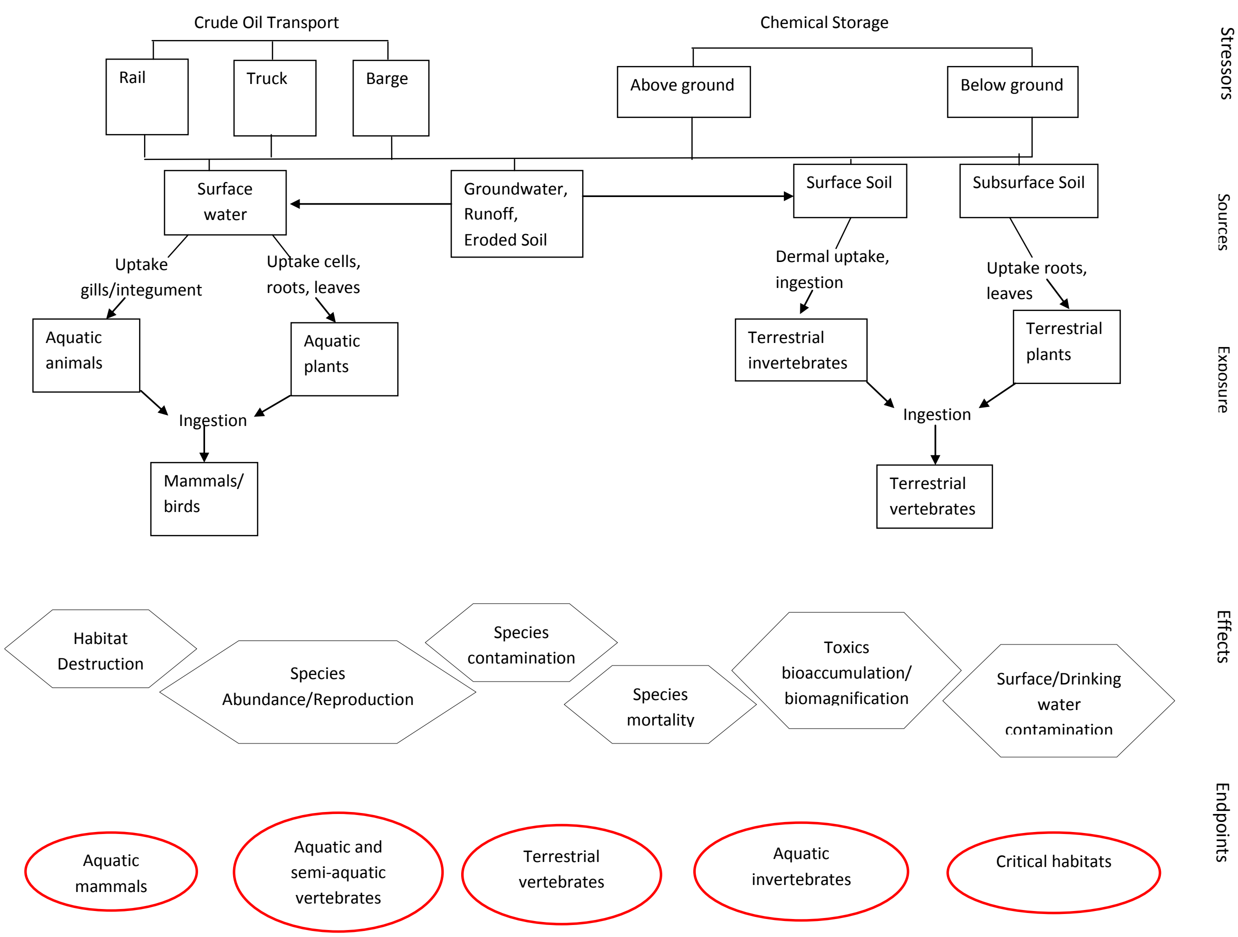

Figure 3: James River watershed Conceptual Site Model

3.3 Assessment Endpoints

To complete an ecosystem-level analysis, the chosen assessment endpoints are representative species from the major trophic levels in the James River watershed. Following the guidance on Ecological Risk Assessment, endpoints were selected with three critical criteria: 1) responsiveness of the endpoint to ecosystem conditions; 2) the importance of the endpoint in the ecosystem; 3) and the significance or importance of the endpoint to society and managers.[33] Rare and endangered species are always considered as potential assessment endpoints for legal protection, and several are included in the analysis below.

3.3.1 Aquatic mammals

Northern River Otter *(Lontra canadensis laxatina)*

The Northern River otter occurs throughout Virginia and has a historical range that includes much of Canada and the United States.[34] The species is classified as semi-aquatic to almost entirely aquatic and is primarily found in coastal areas or lower parts of rivers and streams where food, especially aquatic prey, is plentiful. River otters primarily feed on non-game fish, including slow-moving bottom dwellers. Amphibians, turtles, crabs, and crayfish are also prey, as well as large aquatic insects and some aquatic plants. Birds, bird eggs, or small terrestrial mammals are also occasionally consumed.[35] The species is susceptible to pollution and is scarce where residues of pesticides occur, including dichlorodiphenyltrichloroethane (DDT) and its metabolites and other pollutants, such as mercury and mirex, an insecticide.[36] The river otter is considered a biomonitor for organohalogenated compounds (OHCs), which include polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), and organochlorine pesticides (OCPs).[37] Studies of contaminants in otters suggest that the species is a good predictor of environmental contamination in the area in which it lives; [38] its widespread distribution also makes it a desirable candidate for an accurate assessment endpoint.

Mink *(Mustela vison mink)*

Like otters, mink are semi-aquatic and depend on aquatic animals for the bulk of their food. They are found in most of central and eastern Virginia, always near water. Mink are opportunistic feeders, and tend to eat any animal they can catch and kill. Common prey include crayfish, fish, mice, and muskrats.[39]

Mink are among the most sensitive mammal species to PCBs. As high-trophic-level piscivorous mammals, they bioaccumulate high levels of toxic chemicals and are proven to be sensitive to the effects of numerous poisons, including mercury, DDT, DDE, and dieldrin (an insecticide), among others.[40] Mink are recognized as a sentinel wildlife species due to their chemical sensitivity and their diet of fish that may be contaminated, among other criteria.[41] They are thus commonly selected as an endpoint in risk assessment analyses for areas where PCBs and related compounds are a concern.[42]

3.3.2 Semi-aquatic vertebrates

Semi-aquatic birds

Semi-aquatic birds as a group, which includes ducks, geese, swans, herons, kingfishers, and gulls, are found throughout the James River watershed. They are dependent on the freshwater lakes and ponds found in the watershed, as well as the freshwater and brackish segments of the river.

Preferential absorption of environmental DDT, DDT metabolites, and other organochlorine pesticides in adipose tissue relative to other tissues has been shown in many avian species, including herring gulls (*Larus argentatus*), ringed turtle doves (*Streptopelia risoria*), American kestrels (*Falco sparverius*), and double-crested cormorants (*Phalacrocorax auritus*).[43] After dietary exposure, organochlorine residues were orders of magnitude higher in adipose tissue compared to brain tissue in the above studies.[44] For metals accumulation, feathers have been found to be an effective archive of metal exposure, and breast feathers specifically are considered a better indicator of body burden. For gauging mercury exposure, almost 100% of the mercury found in feathers is methylmercury, the most biologically available form of mercury and the most toxic.[45]

3.3.3 Terrestrial vertebrates

Prothonotary warbler *(Protonotaria citrea)*

The prothonotary warbler nests in tree cavities over water, relying heavily on the food options that the watershed provides. Breeding populations are highly localized because of extreme habitat specificity and are vulnerable to habitat destruction. Prothonotary warblers breed in wooded swamps and other bottomland forests. Characteristic tree species include willows, sweet gum, willow oak, black gum, tupelo, bald cypress, elms, and river birch. Prothonotary warblers feed on butterflies, moths, flies, beetles, mayflies, and spiders throughout the year. They also eat molluscs and isopods outside of the breeding season and may even supplement their diet with seeds, fruit, or nectar.[46]

Because of the warbler's very specific habitat requirements, threats to breeding and wintering populations take the form of wetland losses to logging and development in both the bottomland forests of North America and the mangrove swamps of Central and South America. Data from the North American Breeding Bird Survey show that prothonotary warblers have declined overall at a rate of 1.5% annually since 1966. Steeper declines are evident in some regions where the bird reaches its highest abundances, such as in the lower Mississippi Valley.[47]

Prothonotary warblers are part of the group of birds known as songbirds. Songbirds may be useful sentinels of contamination because they have well-defined, small territories and can integrate pollutant exposure over time.[48] The prothonotary warbler has been shown to be a species sensitive to contaminants, especially mercury. The warbler’s sensitivity was best demonstrated in the relationship between mercury-contaminated soils and kidney tissue body-burden, where soil concentrations accounted for 78% of the variation in kidney samples.[49] Also, in general, concentrations of DDT in soil were effective in describing the variation of contaminants in adipose tissue, or fat, samples.[50]

3.3.4 Aquatic vertebrates

3.3.4.1 Above the fall line

American Shad *(Alosa sapidissima)*
American shad are native to a majority of the Atlantic coast. In spring, shad migrate into freshwater rivers like the James to spawn. After spawning, the shad move back into coastal waters. Since the early 1900s, American shad populations have declined by about 90%.[51] American shad have historically been the dominant commercial fishery for the Chesapeake Bay.[52] To rebuild the stock of American shad, a moratorium was placed on the harvest of shad in 2012, with a limited bycatch allowance during the 2013 to 2017 fishing seasons.[53] Although recent years have seen a rise in populations in the Potomac and Rappahannock Rivers, data shows that abundance has been variable in the lower James and negligible in the upper James.[54]

American shad populations in the James declined drastically due to the construction of five dams around the Richmond area, which blocked the fish from utilizing at least 170 miles of former spawning habitat.[55] By 1998, fish passage was achieved at all five dams, but populations remained low. Since the early 1990s, the U.S. Fish and Wildlife Service has been stocking larval American shad in the James River.[56] Even without the dams as a major obstacle, industrial pollution and sewage effluent have been shown to have negative impacts on American shad populations.[57]

3.3.4.2 Below the fall line

Atlantic Sturgeon *(Acipenser oxyrinchus)*
The historic range for Atlantic sturgeon is along the Atlantic coast, from Labrador, Canada, to Florida, and west to the Mississippi delta. However, centuries of overfishing, habitat alteration, and pollution have caused significant declines in the population. In 2012, NOAA listed the Atlantic sturgeon as an endangered species throughout its range.[58]

Atlantic sturgeon are benthic feeders and require solid substrates upon which to lay eggs, so alteration of riverbeds is particularly detrimental to the species.[59] Since 2006, federal agencies, local advocacy groups, and universities have been working to restore the Atlantic sturgeon to its native range. As of 2009, the Virginia Department of Game and Inland Fisheries (VDGIF) listed several Virginia rivers with known occurrences of Atlantic sturgeon.[60] However, evidence of spawning has been found only in the James and York Rivers, and only within approximately the last decade.[61]

Studies have shown that sturgeon are sensitive to pollution, especially in early life stages.[62] Studies by Chambers et al.[63] and Roy et al.[64] both demonstrated that Atlantic sturgeon are sensitive to PCBs and dioxin and that development was delayed with increasing dose. The Atlantic sturgeon population in the James River watershed and populations all along the east coast are currently in dire need of rehabilitation. Although population decline is due to multiple factors that include historical overfishing and habitat alteration and loss, losing members of the population due to environmental contamination is particularly dangerous for this species, as the number of breeding individuals is already low.

3.3.5 Aquatic invertebrates

3.3.5.1 Above the fall line

Benthic invertebrate: Freshwater mussels

Freshwater mussels play an important role in maintaining water quality by filtering water through their internal filtration systems. Freshwater mussels were once abundant in Virginia, but a combination of water pollution, habitat loss and alteration, and the introduction of exotic species has decimated populations across the state.[65]

Freshwater mussel larvae rely on healthy native fish populations in order to survive. Mussel larvae, known as glochidia, attach themselves to the gills of a fish host, where they receive a constant source of oxygen-rich water and a protected place to develop. When fully developed, the glochidia drop off the fish host and begin their next stage of life on the stream bottom.[66] Freshwater mussels can live up to 100 years depending on the species.[67]

Many freshwater mussel species in the James are threatened or endangered. Out of the 82 mussel species in Virginia, only 30% are considered stable populations.[68] The James River spineymussel (*Pleurobema collina*), which once inhabited much of the James River above the fall line, is now federally endangered and only exists in a few tributaries near the headwaters of the James.[69] Because freshwater mussels take in food by filtering the water around them, they are particularly susceptible to aquatic contamination. It is known that mussels are sensitive to toxic pollutants, particularly copper and ammonia.[70] Freshwater mussels tend to be more sensitive to pollutants than other organisms, and are therefore often used to develop water quality criteria and standards.

3.3.5.2 Below the fall line

Benthic invertebrate: Eastern oyster (*Crassostrea virginica*)

Historically, oysters were abundant throughout the estuaries of the east coast.[71] Today, oyster populations in the Chesapeake Bay are at less than 1% of their historical levels, although aggressive culturing has resulted in increases in Virginia oyster harvests in recent years.[72] The Eastern oyster (*Crassostrea virginica*) plays an essential role in aquatic ecosystems. Like freshwater mussels, oysters are filter feeders. Adult oysters can filter approximately 50 gallons of water per day.[73] Oyster reefs provide essential habitat for fish and crabs, and the rocky nature of the reefs stabilizes bottom areas.

Eastern oyster populations in the Chesapeake Bay have experienced significant declines for decades. The population losses are due to overharvesting, disease, sedimentation, and a general decrease in water quality throughout the bay and its tributaries.[74] In a status review of the Eastern oyster, NOAA states that inadequate enforcement of total maximum daily loads (TMDLs) by responsible agencies is a major threat to water quality.[75] Toxic waste inputs in the James, its tributaries, and the Chesapeake Bay can cause significant detrimental effects to oyster larvae and in later life stage development.[76] Chemicals from in-water infrastructure like treated wood pilings and docks can also introduce metals such as copper and arsenic into the water, which can be toxic to oysters.[77] In addition, the synergistic effects of multiple stressors, which may not be particularly harmful on their own, can accumulate and cause harm to oyster populations.[78]

3.3.5.3 Throughout watershed

Benthic invertebrate: aquatic insects

There are over 10,000 different aquatic insect species in Virginia.[79] Aquatic insects are benthic invertebrates because they spend the first stage of their lives as aquatic larvae, or nymphs, living along the stream or river bottom. When the insects reach their adult stage they become terrestrial. Certain aquatic insects, such as mayflies, stoneflies, and caddisflies, are important indicators of water quality during their larval stages. These organisms are intolerant to the conditions of polluted waters, such as low dissolved oxygen levels and excess sedimentation. Their presence in freshwater systems tends to indicate healthy waters, while their absence usually indicates unhealthy waters. In the James River watershed, there are many different species of mayfly, stonefly, and caddisfly. They are common above the fall line and for a good portion of the river below the fall line, until the river starts becoming tidal and brackish. Virginia's Wildlife Action Plan identifies over 100 species of aquatic insects classified as species of greatest conservation need.[80]

Pollution intolerant aquatic insects like the ones mentioned above are easily affected by sedimentation, excess nutrients, low dissolved oxygen levels, altered pH, and various toxic chemicals. Unlike terrestrial organisms, aquatic insects cannot readily escape pollution. Therefore, they demonstrate the effects of both short-term and long-term pollution.[81]

3.3.6 Critical habitat

It is important to remember that the aforementioned assessment endpoints were chosen as representative species for the major trophic levels in the James River watershed. Risk is assessed on an ecosystem-wide level, not just at the level of individual species or populations. The contaminants of concern in this risk assessment have habitat-wide impacts. By assessing and protecting key organisms from harm, protection is inferred for their respective ecosystems.

3.4 Sources, Stressors and Pathways

This section of the Problem Formulation focuses on the sources, stressors, and pathways for the contaminants of concern. The sources are the actions or entities releasing the contaminants into the watershed. In this assessment, we focus on three types of sources: stored toxic chemicals, coal ash releases, and crude oil spills into the aquatic system. The specific stressors are the chemical, physical, or biological entities that negatively impact the ecosystem and are released by the sources. For example, the train carrying crude oil is the source, and the stressor is the crude oil and its chemical components. The pathways are the ways in which the stressors are transported through the environment.[82] For this report, pathways are noted for each source type but may include releases into surface or groundwater, releases from a pipe, or overland flow.

3.4.1 Storage of toxic chemicals in the watershed

Storage of chemicals in the James River watershed is a major concern. EPA's EnviroMapper tool, which uses data derived from the Resource Conservation and Recovery Act (RCRA), shows that there are approximately 10,001 hazardous and solid waste sites in Virginia. An estimated 35 sites in Virginia are designated Superfund sites, and over 100 are designated as Brownfield sites.[83] In the James River watershed alone, there are over 1,100 unique toxic storage facilities.[84] Figure 4 below shows that toxic storage sites tend to be clumped around city centers, such as Richmond and the Hampton Roads area.

According to VDEQ, many of the storage locations have more than one chemical stored on-site. For purposes of having a consistent method of accurately identifying chemicals, databases typically assign a Chemical Abstracts Service Registry Number (CAS #).[85] This number is assigned in order to eliminate confusion stemming from multiple generic names being given to a chemical in a database. However, some chemicals that are stored in large quantities in the James River watershed are not assigned a CAS #.[86] Chemicals are also given a "storage code" depending on the amount (pounds) of chemical stored in a given location. See Table 1 below.

Table 1: Chemical Storage Codes

Amount (lbs)	Code
0-99	1
100-999	2
1,000-9,999	3
10,000-99,999	4
100,000-999,999	5
1,000,000-9,999,999	6
10,000,000-49,999,999	7
50,000,000-99,999,999	8
100,000,000-499,999,999	9
500,000,000-999,999,999	10
> 1 billion	11

There are over 1400 unique chemicals stored in the watershed, including those with CAS #'s that are blank or "N/A." Those facilities with the highest stored amounts include Chesterfield Power Station in Chester, Virginia, which stores coal ash; Harper and Company, Inc. in Newport News, Virginia, which stores 12.5% sodium hypochlorite, the E.I. Dupont James River Plant in Richmond, which stores calcium carbonate, and Virginia Correctional Enterprises in Richmond, which stores automotive diesel fuel. Of the large cities on the James River, Richmond and Hopewell have the greatest number of unique chemicals stored. Other chemicals stored in large quantities include Marathon Petroleum Corporation (MPC) fuel oil/diesel/kerosene, MPC gasoline, weak wash, white liquor, denatured ethanol, aviation gasoline, coal combustion by-products, hydraulic fluids, various oils, petroleum hydrocarbons (fuel), and others. A table of chemicals and quantities by largest cities in the watershed is included on the following page.

Table 2. Chemical Storage in the James River Watershed

Location	≈ # Chemicals Stored	≈ # of Facilities	Chemicals Stored in Largest Quantities
Watershed-wide	>1400*	>1,100	coal ash (11), 12.5% sodium hypochlorite (10), calcium carbonate (10), automotive diesel fuel (9), MPC fuel oil/diesel/kerosene (7); MPC gasoline (7); aviation gasoline (6), various oils (6), petroleum hydrocarbons (6); others
City of Richmond	>250*	>30	calcium carbonate (10); automotive diesel fuel (9); lead acid batteries (4); diesel fuel, aviation gasoline (6); coal ash (6); plasticizers, motor oils, paint (flammable), natural gas, denatured ethanol (6), "withheld" (6) and (7)
Hopewell	>200*	19	coal, ammonium carbonate/bicarbonate, ammonium sulfate crystals, black liquor, caprolactam (8); #2 diesel fuel, ammonia, green liquor, sulfur (7); ; bottom ash, fly ash/recycle, used oil (5); others
Lynchburg	>80*	>40	#2 diesel fuel, #4 recycled diesel, diesel fuel, fuel oil #2, toluene, brine solution (5); lead acid batteries, locomotive lubricating oil (4); diesel fuel oil (3); others
Hampton	>64*	36	diesel fuel, lead acid batteries, diesel fuel No. 2, nickel, potassium hydroxide, aluminum oxide (5); antifreeze, diesel fuel, automotive gasolines (4); others

Source: VDEQ "Stored Toxics with Lat. Long."

* Includes those not assigned CAS#s and those with "N/A" CAS#s

Types of storage include aboveground and underground storage tanks; these are regulated under the Virginia State Water Control Law.[87] Aboveground storage tanks (ASTs) regulated by VDEQ include those "used to contain an accumulation of oil at atmospheric pressure," where "oil" is defined as, "oil of any kind and in any form, including, but not limited to, petroleum and petroleum by-products, fuel oil, lubricating oils, sludge, oil refuse, oil mixed with other wastes, crude oils, and all other liquid hydrocarbons regardless of specific gravity;" although certain exemptions apply.[88] ASTs must be registered if they are in excess of 660 gallons.[89] Underground storage tanks (USTs) regulated by VDEQ include those that contain petroleum and certain hazardous substances. Specifically, USTs are defined to include those "used to contain an accumulation of regulated substances, and the volume of which (including the volume of underground pipes connected thereto) is 10% or more beneath the surface of the ground," where "regulated substances" include those defined in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, but not those regulated as hazardous wastes under Subtitle C of the Resource Conservation and Recovery Act (RCRA), as well as petroleum.[90] As with ASTs, certain exemptions apply.

Contaminants discharged from both aboveground and underground storage tanks often migrate into subsurface sediments. The fate of subsurface contaminants is determined by a multitude of hydrological, geochemical, and microbial processes. The extent and magnitude of these biogeochemical reactions beneath the surface is dependent upon the media structure, i.e. the type of rock, the size of pores within the rock, and the density of the sediment. For example, water will migrate differently through a substrate with low permeability, like clay, than one with high permeability, like sand. Contaminants that leach into the subsurface can also make their way into groundwater. Unlike organic contaminants, inorganic contaminants, such as metals, do not degrade into innocuous forms. Thus, metal contaminants that are present in groundwater can occur at dangerous concentrations.[91]

3.4.2 Coal ash in the watershed

Coal combustion residues are collectively a variety of materials generated from the combustion of coal; among these are fly ash, bottom ash, boiler slag, flue gas desulfurization residues, and fluidized bed combustion residues.[92] Fly ash is generally what is left behind in air control equipment once it leaves the combustion chamber, while bottom ash is the portion of ash that occurs in pulverized coal furnaces, as it is too large to escape with flue gas.[93] These types of coal ash commonly contain arsenic, boron, cadmium, copper, iron, lead, manganese, mercury, and selenium. Coal ash is commonly stored in three primary ways: dry disposal in landfills, wet disposal in “ponds” or “lagoons,” and surface or underground mine filling. Wet ash disposal in ponds is the least expensive method in terms of delivery costs but leaves a considerable environmental footprint.[94]

Coal ash contaminants are transported through the environment in several different ways. Dellantonio et al. list the following risk pathways for coal combustion residue: [95]

- aerial routes (e.g. dust resuspension)
- emanation of radioactivity
- mercury volatilization
- phytoaccumulation and plant toxicity
- effluent discharge and percolation to groundwater and rivers

Coal ash contaminants can become airborne via dust resuspension. Wind erosion of coal ash is facilitated by the evaporation of moisture from coal ash piles. Fly ash particles, which tend to occur in silt and sand grain sizes, erode more often than bottom ash particles, which tend to occur in sand and gravel sizes.[96] Studies have shown that the air-suspended particles from coal ash are transported at a global scale.[97]

Plants that grow on top of coal ash storage landfills also take in contaminants from the coal ash. For plants growing on coal ash disposal sites, the most frequently reported toxicity problem is excess boron.[98] Most of the boron in coal ash is readily water soluble and phytoavailable. Plants growing on coal ash landfills frequently contain selenium at concentrations potentially toxic to animals.[99]

In a study on coal-fired power plants in North Carolina, Ruhl et al.[100] found that wastewater from coal ash discharge and flue gas desulfurization had significant effects on the water quality of receiving waters. Coal-fired power plants are permitted to discharge coal ash into surrounding waterways by the National Pollution Discharge Elimination System (NPDES). The outflow waters containing coal ash then mix with river or stream waters. While the concentration of contaminants in surface waters may be decreased by mixing outflow waters with river waters, contaminant concentrations in sediments on the river bottom increase.[101] Contaminants from coal ash can also make their way into the surrounding environment by leaching out of storage ponds, many of which are not lined, nor adequately monitored.[102] Leachate from storage ponds can contaminate groundwater as well as surrounding streams and rivers.

Even low concentrations of coal ash contaminants can become problematic as they travel through the environment. Many metals have the potential to transform into more toxic forms. Mercury, which is sometimes captured during air pollution abatement measures at coal-fired power plants, can interact with anaerobic organisms in sediment to form methylmercury, a much more toxic compound.[103] Similarly, arsenic can be transformed or released by microbial activity in sediment or by changes in water conditions, such as a change in temperature or pH. Under hypoxic or anoxic conditions, arsenic may be released as the more toxic arsenite.[104]

Other ecological effects of air pollutants stemming from coal-fired power plants on ecosystem structure and function are acidification of waterways and subsequent responses of aquatic species living in them, soil calcium depletion, alterations to nutrient cycling, pollution resulting from deposition of heavy metals, and decline in growth and productivity of forests.[105] Coal-fired power plants, for instance, contribute greatly to sulfur compound emissions, primarily in the form of sulfur dioxide, which lead to the production of sulfuric acid and acidification of waterways.[106] One of the primary and most studied effects of atmospheric deposition on ecological processes stems from the acidification of terrestrial and aquatic ecosystems due to sulfur dioxides, nitrogen oxides, and ammonia, which react in the atmosphere to produce sulfuric and nitric acid and ammonium.[107] Acidification is not only a concern for sensitive organisms, but has also been shown to cause long-term changes in ecosystem structure and function.[108]

It is important to understand the ways in which transport of contaminants can occur within the environment after a spill, leak, or discharge. For example, in water, a contaminant might initially spread out horizontally, spreading across the water, whereas on land a contaminant is more likely to seep into sediment and/or groundwater. In addition, all toxic substances have the potential to move through the environment through bioaccumulation. Bioaccumulation occurs when organisms absorb or ingest contaminants through food sources, water, air, and/or sediment.

In Virginia, there are three active coal-fired power plants in the James River watershed, the Dominion Chesterfield plant in Chester, Virginia, the Cogentrix Hopewell plant in Hopewell, Virginia, and Chesapeake Energy Center in Chesapeake, Virginia. However, there are at least five facilities in the James River watershed that have one or more storage sites for coal ash or coal pile runoff (both active and inactive). These are described in further detail below and in Table 3 Coal Ash Impoundments and Landfills in the James River Watershed.

Bremo Power Plant

Although Bremo is no longer operated as a coal-fired power plant, it has two coal ash ponds that are still in use, a West Pond and a North Pond. Its East Pond is no longer active, but it is unlined and sits adjacent to the James River.[109]

Chesapeake Energy Center

Chesapeake Energy Center in Chesapeake, Virginia, has a few sites of concern: 1) a bottom ash and sedimentation pond, 2) a dry ash landfill, and 3) a spill retention pond. The spill retention pond, located north of the bottom ash and sedimentation pond, does not receive coal combustion waste; its main purpose is to serve as an oil spill retention basin, although it also receives wastewater from Chesapeake Energy Center.[110]

Chesterfield Power Station

Dominion's Chesterfield Power Station is the largest coal-fueled power plant in the state.[111] Two impoundments are utilized by the Chesterfield Power Station: a Lower Ash Pond and Upper Ash Pond.[112] The Lower Ash Pond dates to 1964, impounds an area of approximately 49 acres, is unlined, and is located on the south side of the power station.[113] It is the main pond used for disposal of approximately 5 million gallons per day of sluiced ash discharge.[114] Materials received by the Lower Ash Pond include "fly ash, bottom ash, boiler slag, coal mill rejects (pyrites), coal fines, coal pile runoff, boiler cleaning wastewater, and water from the station master sump."[115]

The Upper Ash Pond was commissioned in 1983, at one time covered an area of approximately 112 acres; also unlined, it has been used for the storage of "fly ash, bottom ash, boiler slag, flue gas emission control residuals, coal mill rejects, coal fines, and general dredge spoil materials."[116] Materials contained in the Lower Ash Pond were eventually dredged and stored in the Upper Ash Pond.[117]

Hopewell Power Station

Hopewell Power Station in Hopewell, Virginia, now a biomass-fueled power plant, retains an active coal pile runoff pond.[118] The pond is lined, although it is 23 years old and contains fly ash, bottom ash, coal fines, scrubber waste, and ash pile runoff.[119]

Mead Westvaco

Mead Westvaco also owns and operates a bleach board paper mill in the town of Covington, and the discharge into the Jackson River is regulated under DEQ. The Jackson River is a tributary of the James River.[120] Coal ash continues to be produced and stored in one active impoundment on site.[121]

Table 3. Coal Ash Impoundments and Landfills in the James River Watershed

COMPANY	FACILITY	LOCALITY	# UNITS	AREA* (acres)	STATUS*	AGE* (years)
Dominion	Bremo Bluff	Fluvanna	3 ponds	96, 17, unknown	2 active, 1 inactive	32, 37, unknown
Dominion	Chesapeake Energy	Chesapeake	1 pond, 1 landfill	9.7, unknown	active	65, 30
Dominion	Chesterfield	Chesterfield	2 ponds, 1 landfill	49, 112, unknown	2 active, landfill proposed for 2018	51, 32, landfill proposed for 2018
Dominion	Hopewell	Hopewell	1 pond	unknown	closed	23
Mead Westvaco	Covington	Covington	1 pond	unknown**	unknown**	unknown**

ADAPTED FROM: VDEQ, Southeastcoalash.org, EPA
*commas separate respective ponds/landfills
**All “unknowns” provided by Southeastcoalash.org except for these

3.4.3 Rail transport of crude oil in the watershed

Crude oil is a naturally occurring material found beneath the Earth’s surface, the result of heating and compression of organic materials underground over millions of years. Crude oil is unrefined, but when refined can be used to produce gasoline, diesel, alcohols and other petrochemicals. There are different types of crude oil, but the most common type shipped through Virginia is Bakken crude oil from an oil deposit beneath North Dakota, Montana and south-central Canada.[122] Crude oil is typically shipped through Virginia by train in tanker cars, cylindrical tanks that can hold thousands of gallons of oil. Depending on the type of crude oil, a train of 70 to 120 tank cars can carry approximately 50,000 to 90,000 barrels of oil.[123] CSX transports Bakken crude oil in 20 counties of Virginia, and estimates its weekly average for trains carrying 1,000,000 gallons or more of oil to be four to six times per week through each of these counties. The CSX route runs parallel to the James for most of its stretch.[124]

Crude oil transport by rail has increased by over 450% over the last five years.[125] Following the April 30th derailment of a CSX train in Lynchburg, Virginia, which discharged up to 50,000 gallons of crude oil into the James River, Governor Terry McAuliffe convened a Railroad Safety and Security Task Force. The Task Force was created to address rail safety and produce a report on what measures could be taken to improve safety.[126] Senators Kaine and Warner also called for fast implementation of better regulations for oil trains, an enhanced commitment to improved safety efforts on behalf of oil producers and rail companies, and a commitment on behalf of the U.S. Department of Transportation to improve information sharing with local emergency management officials and to make rules to improve safety for cars carrying crude oil.[127]

Because the CSX train route runs parallel to the James River for most of its stretch, crude oil from spills has a high likelihood of going directly into the river or into tributaries of the James. Crude oil is a mixture of many compounds, so a number of chemical, physical, and biological processes can change its composition depending upon where it is spilled. Weathering of crude oil can involve evaporation, volatilization, emulsification, dissolution, and oxidation. Emulsification, for example, can change the viscosity of crude oil, changing the liquid petroleum product into a heavy, semi-solid material. Crude oil from spills in marine environments can turn into tarballs or tar residues that persist in the environment when they become stranded on shorelines.[128]

While rail is the main form of crude oil transport in Virginia, crude oil can also be transported by barge and truck. While important for transporting crude oil involved in the hydraulic fracturing process, trucks are mainly used at drilling sites and not for long distance transport.[129] In Richmond, oil is also transported via ship and barge by a number of operators from the Port of Richmond, which is located along the west bank of the James River on approximately 121 acres.[130] Among the companies that ship and receive are IMTT-Richmond, Koch Industries, Inc., Kinder Morgan Energy Partners, Sims Metal, 64 Express barge service, and CSX railway.[131] Operators vary in the types of materials shipped and received, on-site storage capacity, and the numbers of pipelines that connect storage tanks to the Port of Richmond Terminal Wharf. IMTT-Richmond, for example, primarily receives petroleum products and aviation fuel by barge, and 12 of its storage tanks (total capacity 495,000 barrels of petroleum products) are connected to the wharf by two pipelines.[132] Kinder Morgan Energy Partners also ships and receives petroleum products by barge; their 11 storage tanks have a total capacity of 152,000 barrels that are connected to the wharf by three pipelines.[133]

3.4.4 Other sources

This analysis focuses on the risks from major releases and recognizes that these releases do not occur in isolation. Numerous releases and discharges into the waters of the James River watershed occur on a regular basis, some continuously. These sources include sewage treatment plants or Publicly Owned Treatment Works (POTW), stormwater systems, Combined Sewer Overflows (CSOs), and industrial discharges from permitted facilities. In addition, groundwater flowing into the James and its tributaries brings nutrients and pesticides in some cases. Rainwater flowing overland and running into the rivers, not in stormwater systems, will also pick up various materials and carry them into the rivers. In the interest of presenting a complete picture of the James River watershed risk condition, we note that other sources make a contribution to the total chemical load in the river, and thus that risk is cumulative.

3.5 Risk Analysis Plan

The Risk Analysis Plan consists of two parts: the exposure analysis and the effects analysis. To test the hypothesis that toxic chemicals in the James River watershed pose a risk to human and ecological health in the watershed, we collected information on toxic chemical sources and releases. We examined how the living resources of the James River watershed might be affected by the toxic chemicals released into the James River. The analysis addressed the types and amounts of toxic chemicals entering the watershed and the ecological and human health impacts of short-term and long-term exposure to these toxic chemicals. This entailed studying past and present releases of toxic chemicals into waterways and the ways in which toxic chemicals are transported and stored within the James River watershed.

The focus of the exposure analysis was three source categories that pose risks from large-scale releases: spills and/or releases of stored chemicals, breaches of coal ash storage ponds, and spills of crude oil. To provide context for understanding the whole river system, we included background information on routine discharges. Information on sources and releases was obtained from VDEQ databases or national databases on storage, transportation and spills.

The effects analysis relied on toxicological information on how the chemicals released from the source categories can affect the biological resources represented by the assessment endpoints. The assessment endpoints, described below, were selected on the basis of the criteria indicated above. We examined EPA databases on toxic chemicals and scientific literature to determine the general hazards (mortality, reproductive, developmental, etc.) to living systems. We considered how the assessment endpoints might be affected by the release of chemicals from the three types of sources. The EPA evaluates the effects on most wildlife (non-humans) on the basis of the impact on a population of animals or plants. Thus, if an activity or event is not expected to impair the ability of a population to continue at a sustainable level in the same place for the foreseeable future, then no impact is expected. Not all scientists agree with the strategy of only considering population level effects, and consider an impact serious if it alters the normal biological functions of a species.

4.0 Risk Analysis

The most significant challenge in conducting this risk analysis was the lack of data on spills, discharges, and transportation of toxic chemicals in the James River watershed. A 2015 issue paper from the Natural Resources Defense Council (NRDC) shows that while 36 states in the U.S. have active oil and gas development, only West Virginia, Pennsylvania and Colorado have easily accessible, publicly available data on spills and other violations.[134] NRDC found that not one state grants public access to the basic set of data parameters that NRDC identified as essential: information is available online, information is in an easy to use downloadable format, incident dates and location are included, there is a comment or text description of violation, the operator name is included, and the violated regulation or code is cited. In addition, hardly any oil or gas companies publish information concerning their compliance track record. In fact, many violations aren’t even recorded.[135]

VDEQ does maintain a Pollution Response Program (PREP) database that seeks to track all spills, discharges, or other releases of chemicals in the watershed. This includes aboveground and underground storage tanks, combined sewer overflows, and pollution incidents reported by the public. While the Pollution Response Program database serves as an important source of information, the DEQ “does not certify this data to be all inclusive or complete.”[136] Especially for incidents reported by the general public, the amounts of chemicals and specific types of chemicals for many incidents simply cannot be verified.

In light of these issues with missing, unreported, and/or publicly unavailable data, it should be acknowledged that the exposure assessment is based upon the best available data and that, when needed, national-level data is used for extrapolation purposes.

4.1 Exposure Assessment

The exposure assessment estimates the magnitude, frequency, and duration of exposure to the contaminants of concern. Below we describe the main sources of notable toxic chemical releases in the watershed, listed by the frequency and magnitude of the events.

4.1.1 Toxic storage tank and other spills and releases: low frequency, variable magnitude

As mentioned earlier in the report, Virginia has a large number of storage tanks with chemicals ranging from highly toxic to unknown toxicity, and thousands of these tanks are located in the James River watershed. These storage tanks are both aboveground and underground and associated with a wide range of industrial and municipal facilities. Assessing the risks of releases and spills from such storage facilities poses a challenge because, although the data are publicly available, they are often incomplete or not up-to-date. The experiences in other states indicates that a range of factors affects the likelihood of a spill, including the age and condition of the tanks, inspections, operator behavior and susceptibility to risk factors such as floods, hurricanes and tornadoes.

Spills or leaks from these types of storage tanks have the potential to contaminate surface and groundwater. A 2005 report on leaking underground storage tanks (USTs) in the U.S. estimated that nationally, there were 680,000 USTs, a backlog of 130,000 cleanups from leaks, and 9,000 new leaks discovered annually.[137] The EPA estimates that one gallon of oil has the potential to contaminate one million gallons of water.[138] In the state of Virginia alone, an estimated 2.2 million people depend on groundwater for their domestic water supply.[139] As of December 5, 2014, according to VDEQ's public records for underground storage tanks, there were 6,011 active petroleum UST facilities and 80,354 (active and closed) petroleum USTs in Virginia. Of the total number of petroleum USTs, 18,240 were active. The total number of hazardous substances USTs was 915. Over the reporting period of October 1, 2013 to September 30, 2014, there were 145 confirmed UST releases, 21 of which were not properly equipped to meet spill or overfill protection. Another 55 of the releases were from UST systems that were closed, inactive, or abandoned.[140]

Aside from documented leaks from underground or aboveground storage tanks, other spills of various chemicals occur both sporadically and continuously in the James River watershed. These spills are documented in the VDEQ Pollution Response Program Database (PREP). In the James River watershed in 2014 alone, there were approximately 601 reported spill incidents; of these, 149 were petroleum-related. Diesel and various other types of oils, including fuel oils, engine oils, gasoline, heating oils, lube oils, motor oils, mineral oils, and petroleum were reported. The majority of spills reported were diesel materials (51 incidents) or sewage (40 incidents), sewage being primarily due to sanitary sewer overflows or overflows in general. It is important to note that a number of reported incidents were marked “null” in one or more categories, such as “effect to receptor” or “quantity,” making the true impacts of the incidents on the watershed difficult to gauge and potentially underestimated.[141]

In 2014, approximately 51 incidents occurred that threatened or impacted the James River or the James in combination with another river; 39 of these impacted the river, 4 threatened the river, and 8 were marked as unknown or null. The two largest spills were the crude oil spill in Lynchburg of approximately 29,926 gallons and sewage in the amounts of up to 204,720 gallons.[142]

Approximately 19 incidents occurred in 2014 that directly impacted the James River or the James in combination with another river and that threatened human health in some capacity. Almost all were due to untreated discharge from sanitary sewer overflow; one was due to an aboveground storage tank leak of heating oil of up to 150 gallons that impacted groundwater.[*143]

4.1.2 Coal ash pond spills: low frequency, high magnitude

Over 100 million tons of coal ash is produced in the United States annually, making it one of the largest industrial waste streams in the nation.[144] Often, the ash is contained in ponds and landfills that are proximal to waterways and communities. In the United States, coal combustion residuals are deposited at over 310 active landfills (average size over 120 acres) and over 735 active on-site surface impoundments (average size over 50 acres).[145] Over 200 of these disposal sites have contaminated waterways in 37 states.[146] Of the total number of impoundments, 450 (40%) are located in the Southeast alone. Additionally, 18 of the nation’s 45 “High Hazard” dams, as rated by the EPA, are located in the Southeast.[147]

The most well known coal ash spill (as well as the largest spill in U.S. history) is the 2008 rupture of the coal ash retaining dam at the Kingston Fossil Plant in Kingston, Tennessee. One billion gallons of coal ash slurry spilled into the Emory River, contaminating the water of both the Emory and Clinch Rivers. The most recent coal ash spill on the east coast occurred in February 2014, when a Duke Energy coal ash pond near Eden, North Carolina ruptured, spilling an estimated 140,000 tons of coal ash into the Dan River and causing nearly $70 million dollars in damages.[148]

Virginia’s coal-fired power plants produce about 2.73 million tons of coal ash annually.[149] In Virginia, as in a number of other states, there are minimal regulations regarding the storage of coal ash. Virginia dam safety regulations, enforced by the Virginia Department of Conservation and Recreation (VDCR), do not require stricter safety standards for coal ash ponds than for regular dams, and many of the impoundments are not regulated as dams, meaning that inspections by state personnel do not routinely occur.[150] Also, a number of coal ash ponds are unlined, allowing contaminants to leach into sediment and groundwater. A recent report from the Virginia Conservation Network (VCN) noted that 76% of the coal ash ponds and landfills in

[*] DEQ does not certify this data to be all inclusive or complete. This data is provided to the citizens of the Commonwealth of Virginia free of charge for informational purposes only.

Virginia are in impoverished areas and/or communities of color.[151] Additionally, there are often a number of other industrial facilities in communities that fall below the poverty line, leading to high risk of combined exposure from multiple chemicals.[152]

In 2009, the EPA sent out information requests to electric utilities across the U.S. Of the 240 facilities that responded to the requests, a total of 676 surface impoundments and similar units were reported.[153] A hazard potential rating according to the National Inventory of Dams Criteria was assessed for 214 of the units. Of these, 45 units were rated as High Hazard potential, 84 units were rated as Significant Hazard Potential, 74 were rated as Low Hazard, and 11 were rated as Less Than Low Hazard Potential.[154] The majority (71%) of the 676 units were designed by a professional engineer and varied in height from greater than or equal to 50 feet to no appreciable height.[155] The Hazard Potential classifications refer to potential economic and/or environmental damages or loss of human life due to dam failure or misoperation. High Hazard Potential is defined as dams with the potential to cause serious economic damage or loss of life. Significant Hazard Potential refers to dams with the potential to cause appreciable economic damage or loss of life. Low Hazard Potential is defined as dams with no potential to cause significant economic damage or expected loss of life. Less Than Low Hazard Potential refers to dams which do not pose a high, significant, or low hazard potential.[156]

Bremo Power Plant

Constructed in 1978 to 1979, the West Pond is bordered by the James River to the south and Holman Creek to the east, and was expanded to include a metals pond. Water flows across the West Pond, through a concrete decanting structure, and eventually discharges to the James River (VPDES permit #0004138).[157] Materials from this pond are periodically dredged and transferred to the North Pond for final storage. Design drawings indicative of the design and construction of the West Ash Pond and metals pond are not available. The North Pond was constructed in 1983 and has a 316 acre-feet storage capacity. Hazard potential classification is "significant" for both ponds.[158] The East Pond, which is no longer active, is unlined and located adjacent to the James River. Hazard potential classification is unrated for this pond.[159]

Chesapeake Energy Center

The hazard potential for the bottom ash and sedimentation pond is significant, due to the environmental damage a breach would cause to surrounding waterways and, ultimately, the Chesapeake Bay.[160] The approximately 9.7-acre-pond contains bottom ash and fly ash and receives runoff and leachate from the dry ash landfill, pumped runoff, and wastewater from the plant.[161] The overall condition of the pond was assessed as poor. Because the bottom ash and sedimentation pond is not regulated as a dam by the Virginia Department of Conservation and Recreation (VDCR), state inspections are not routinely performed. The hazard potential for the dry ash landfill on site is not rated.[162]

Chesterfield Power Station

Virginia Pollutant Discharge Elimination System (VPDES) permit #0004146 for the Lower Ash Pond permits the discharge of water from the pond into the James River.[163] The Lower Pond is classified as a significant hazard potential based on the EPA's Coal Combustion Waste checklist. Dam Safety Regulations, established by the Virginia Soil and Water Conservation Board assign a significant hazard potential rating to "dams that upon failure might cause loss of life or appreciable economic damage". Although loss of human life is not likely from the Lower Pond, environmental damage to the James River and surrounding wetlands would be unavoidable.[164] Seepage has been noted a few times from the Lower Ash Pond, once in 1987 and again in 1995. In 2009, a geotechnical engineering study conducted by Schnabel Engineering resulted in recommendations to improve stability to the west dike. Upon visual inspection in 2010, other maintenance deficiencies noted were areas of poor drainage and/or minor seepage and minor corrosion of the metal components of the outlet structure.[165] According to Dominion, these have since been repaired.[166]

The Upper Ash Pond has been in the process of closing since 2002; once the pond is filled, it will be capped with compacted dry-placed ash from the Lower Ash Pond.[167] Another pond, known as the metals pond, also contains materials of concern, including fly ash, scrubber waste, lime, and others. Like the other ponds, it is also unlined.[168] A landfill near Reymet Road in Chesterfield is also in the process of construction. The landfill will accommodate coal ash from the plant once the Upper Ash Pond is closed and is expected to be complete by 2018. The hazard potential for the landfill is unknown.[169]

Hopewell Power Station

The Hopewell Power Station, now a biomass-fueled power plant, retains an active coal pile runoff pond. The pond is lined, although it is 23 years old. This pond is not rated by the EPA Hazard Evaluation.[170]

Mead Westvaco

The paper mill recently reduced its annual coal use by replacing two of its coal-fired units with a biomass boiler[171]; however, coal ash continues to be produced and stored in one active impoundment on site.[172] This impoundment is not rated by the EPA Hazard Evaluation.

Summary

The permits for the Bremo and Chesterfield plants, both of which are in the James River watershed, are up for renewal. As of April 17, 2015, Dominion announced that coal ash ponds at four Virginia power stations (Bremo, Chesapeake, Chesterfield, and Possum Point) would be closed according to the regulations and procedures set out by DEQ and EPA.[173] These types of closures generally use cover materials intended to prevent water from infiltrating into the underlying material. Covers seek to prevent contamination of underlying groundwater or the adjacent or nearby areas, including water bodies. While the EPA chose not to rule that coal ash was a hazardous material in 2014, Virginia can still choose to regulate it as such. As is, there are limited requirements in Virginia for proper closure and post-closure care of coal ash ponds and landfills.[174] See Table 3 for an overview of the major coal ash storage facilities in the James River watershed and see Table 4 below for a summary of the EPA Hazard Evaluation.

Table 4. EPA Hazard Evaluation Summary Table

COMPANY	FACILITY	LOCALITY	# UNITS	EPA HAZARD EVALUATION*
Dominion	Bremo Bluff	Fluvanna	3 ponds	2 significant risk, 1 unrated
Dominion	Chesapeake Energy	Chesapeake	1 pond, 1 landfill	significant risk, not rated
Dominion	Chesterfield	Chesterfield	2 ponds, 1 landfill	significant, low, unknown
Dominion	Hopewell	Hopewell	1 pond	not rated
Mead Westvaco	Covington	Covington	1 pond	not rated

ADAPTED FROM: VDEQ, Southeastcoalash.org, EPA
*commas separate respective ponds/landfills

The EPA national effort to understand the risks from coal ash storage ponds provided some important insight into the risks, indicating that at least two major facilities are significant risks in the James River watershed. As such, the appropriate approach is addressing the deficiencies identified by EPA.[175]

The EPA study[176] was not intended to be a comprehensive evaluation of all coal ash storage facilities in the US, and Virginia has the responsibility to insure the integrity of the state's waters. Not all of the coal ash storage facilities are inspected, meaning the level of risk of a dam breach is unknown for these, and all but one are unlined, presenting at least the potential for groundwater contamination. Virginia should inspect all the facilities across the state and take appropriate action to insure none present a risk to human health and the environment.

4.1.3 Oil train derailment: low frequency, high magnitude

Bakken crude is much more volatile than other types of crude oil.[177] In fact, in 2014, the Pipeline Hazardous Materials Safety Administration (PHMSA) issued a safety alert warning that recent derailments and subsequent fires from trains carrying Bakken crude indicate that it may be more flammable than traditional heavy crude oil.[178] The Center for Disease Control and Prevention lists the following chemicals as chemical constituents commonly found in crude oil[179]:

- benzene
- hydrogen sulfide
- ethyl benzene
- toluene (methylbenzene)
- xylene
- naphthalene and methylnaphthalene
- generic alkanes (including octane, hexane, nonane)

North America is currently experiencing an enormous increase in crude oil supply and shipment. However, there has also been a rapid increase in the number of accidents and spills involving crude oil shipment by rail. According to McClatchy DC, based on data compiled from PHMSA, more crude oil was spilled in 2013 than in the past four decades. In the year 2013 alone, more than 1.15 million gallons of crude oil were spilled.[180] Comparatively, a total of 800,000 gallons was spilled between 1975 and 2012 by trains carrying crude oil. Major incidents in 2013 include a train derailment near Aliceville, Alabama in November, where some 750,000 gallons were spilled, and a December 30th incident in North Dakota where the National Transportation Safety Board (NTSB) estimates that over 400,000 gallons of crude oil were spilled, among others.[181] These data do not include Canadian incidents, the recent event of note occurring in Lac-Megantic, Quebec, which resulted in a spill of 1.5 million gallons and a casualty toll of 47 people. In total, an estimated 11.5 billion gallons of crude oil were shipped in the U.S. last year.[182]

NBC News analyzed PHMSA data and reported that total spills in 2014 amounted to 57,000 gallons, making 2014 the year with the highest frequency of spills yet. In 2014, there were 141 unintentional releases compared to an average of 25 per year from 1975 to 2012.[183] As far as predictions for the future based on recent trends in crude oil transportation, the U.S. Department of Transportation has predicted that fuel-hauling trains could derail at a rate of ten per year over the next two decades, potentially causing over $4 billion in damage. The report also predicts that hundreds of casualties could occur as a result of future derailments, particularly if accidents occur in heavily populated areas.[184]

Aside from spills, explosions due to train derailment are also of grave concern. As mentioned previously, 47 people were killed in a 2014 incident in Lac-Megantic, Quebec. According to Forest Ethics, millions of Americans live within the blast zone that would be affected by an oil train explosion.[185] In Virginia, many city centers and highly populated areas are included within the one mile crude oil train blast zone, including downtown Lynchburg, Richmond, Williamsburg, and Newport News.[186]

According to data derived from the EPA’s Emergency Response Notification System (ERNS) and compiled by The Right to Know Network, a total of 21,632 spill incidents were reported in the U.S. in 2014, resulting in 835 deaths and over $50 million in property damages. Unknown oil was the most frequently reported released substance, with a total of 4,737 reported incidents.[187]

In Virginia in 2014, 629 incidents were reported through the ERNS, resulting in 10 casualties, 12 hospitalizations, and over $1 million in property damages. Numerous types of oil, including unknown, diesel, hydraulic, motor, lubricating, waste oil, various jet fuels, crude oil, transformer, turbine, and other oils accounted for 426 (67.7%) of the 629 reported spills. Mobile vehicles (plane, truck, train ship, etc.) accounted for 296 (47.1%) of the spills; fixed sites, or incidents at buildings, accounted for 213 (33.9%) of the reported incidents. The top city for numbers of incidents was Norfolk, VA, where 134 (21.3%) of the spills were reported.[188]

In 2013 in Virginia, a total of 900 spills were reported, resulting in 12 deaths, 23 hospitalizations and over $1 million in property damage. Numerous types of oil, including unknown, diesel, hydraulic, motor, lubricating, various jet fuels, waste oils, and other miscellaneous oils accounted for 558 (62%) of the reported incidents, with the top substance being unknown oil. Mobile vehicles (plane, truck, train, ship, etc.) accounted for 485 (53.9%) of the total incidents.[189] As in 2014, Norfolk, VA, was the top city for numbers of incidents, with 166 (18.4%) of all reported incidents.[190]

These data reflect only those spills that were reported to the National Response Center (NRC). The Right to Know Network acknowledges that many incidents are never reported, and those that are may not be verified.[191]

In summary, the problem of crude oil spillage in Virginia is a reflection of the national increase in crude oil production and transportation. The total amount of oil shipped by train in the US increased by more than 400% in recent years, with a subsequent increase in the amount of oil spilled. It is not clear if the rate of spillage (spill per amount of oil shipped) has changed, but given the huge increase in total amount shipped, the rate could decrease and we would still see an enormous increase in total spillage. In some respects, the numbers are simply too large and the amount of oil too great to anticipate an improvement. Factors that could affect the situation are likely the condition of the equipment and tracks, experience and training of personnel, inspections, and proximity to resources and risk factors. According to analysts, the nation can expect more oil spills, and there are no reasons to exclude Virginia from that expectation.

4.1.4 Other exposure sources

Wastewater and stormwater discharges: high frequency, low magnitude

VDEQ defines wastewater as "the water supply of a community after it has been soiled by use. It may contain human and household wastes, industrial wastes as well as groundwater and, in many cases, stormwater runoff."[192] While wastewater is treated to remove solids, the treatment process does little to prevent many non-solid contaminants from entering our waterways. To use the city of Richmond as an example, the Richmond wastewater treatment plant treats about 45 million gallons of wastewater per day, and then discharges the treated water into the James River.[193] This wastewater comes from over 1,500 miles of sanitary and combined sewer lines.[194] In 2014, the top pollutants for the Richmond treatment plant were suspended solids, ammonia, and phosphorous.[195]

Wastewater also comes from combined sewer overflows (CSOs). A CSO is a discharge of both domestic wastewater and stormwater from a combined sewer into the environment. CSOs occur during periods of high amounts of rainfall when a sewer system can no longer contain the amount of water input from storm drains and other discharge sources. These overflows are permitted by city governments. The impacts of discharging in populated areas include adverse human health effects, fish contamination and fish consumption advisories, the spread of waterborne disease, and closures of recreational areas along the river. CSOs are listed by the EPA as probable sources contributing to impairments in James River water quality for the Lower James and the Middle James.[196]

Among the many chemicals in wastewater, one of the most dangerous categories is emerging contaminants. While generally defined as any contaminant on which scientific knowledge is insufficient, emerging contaminants often fall into the categories of pharmaceuticals, personal care products, endocrine disruptors, and industrial chemicals for which there may be no published health standards.[197] Emerging contaminants are gaining attention as potential contaminants of concern in streams and rivers, especially those in urban, industrial, agricultural and residential areas. Emerging contaminants pose threats to ecological and human health. Nationally, a sparse amount of research has been conducted. A USGS study from the late 1990s and early 2000s sampled 139 streams throughout the nation, one of which runs through western Virginia.[198] Kolpin et al. found that out of all the streams sampled, 80% contained 31 different emerging contaminants, the most common of which were fecal steroids, plant and animal steroids, insect repellent, caffeine, disinfectants, fire retardants, and detergent components. [199]

In Virginia, this new class of contaminants lacks a statutory and regulatory definition and emerging contaminants are instead termed “microconstituents”. The sparse amount of research that has been conducted was sparked by fish kills and a series of observable problems, such as external lesions and intersex fish in the Shenandoah, Potomac and James River basins. Sampling conducted in 2007 detected polycyclic aromatic hydrocarbons, pesticides, polychlorinated biphenyls, atrazine, fragrance components, caffeine and nicotine metabolites, and natural and synthetic hormones in the Shenandoah and James River basins.[200] Emerging contaminants are often present together in different mixes, which raises concern over the effects of combined toxicity.

Stormwater discharges and their contribution to the toxic contaminant load in the James River are not separately tested for by VDEQ but rather, specific chemicals are measured as part of municipal and industrial permit requirements. These requirements are specific to the operations taking place and are not the same across all permitted dischargers. A repository of all the permitted dischargers, and their separately required discharges, are not compiled and accessible to the public. Additionally, none of the permits require measuring toxic chemicals beyond industry conventionals such as some metals, organics, nitrogen, and phosphorous.

Large-scale natural disturbances: low frequency, high magnitude

Natural disturbances can exacerbate toxic contamination issues. Hurricanes and floods can cause overflow and damage to coal ash ponds and other storage basins. Earthquakes can induce similar damage. These large scale natural disturbances can precipitate “risk cascades” that affect multiple trophic levels. As Foran and Ferenc describe in a publication on multiple stressors in risk assessment, “exposure to stressors...may cause changes in ecological components that in turn become stressors to other components of the ecosystem.”[201] They give the example of nutrient loading in lakes. Nutrient loading can cause algal blooms, which can change the composition of the invertebrate community, which can ultimately alter the composition of the fish community.[202] Similar processes can occur with natural disturbances. What may seem like insignificant stressors may not cause a change in the ecosystem until a driving event like a hurricane or drought perturbs the system.[203] A long term time scale is also an important consideration with natural disturbances. Any type of large scale natural disturbance, such as a flood or fire, could influence ecological systems for anywhere from several weeks to several decades.[204]

4.2 Hazard Identification and Analysis

The Hazard Identification process determines whether exposure to a stressor(s) can lead to an increase in the incidence of specific adverse health effects and whether the adverse health effect is likely to occur in the organisms chosen as assessment endpoints. Exposure to a stressor may generate many different adverse effects in different animals: diseases, formation of tumors, reproductive defects, death, or other effects.[205] In the case of chemical stressors, the process involves examining the available scientific data for a given chemical (or group of chemicals) and developing a weight of evidence to characterize the link between the negative effects and the chemical agent.

4.2.1 Contaminants from stored toxic chemicals and coal ash

4.2.1.1 Aquatic mammals

As apex consumers in aquatic ecosystems, river otters and mink are susceptible to biomagnification of contaminants, making them good biomonitors. Due to the documented PCB contamination in the James River, which has led to fish consumption advisories for a number of species that both mink and river otter typically consume, the survival, growth, and reproduction of these species in the James River watershed is at risk. Among the fish species typically consumed by the Northern river otter are bullheads and catfish, sunfish, perch, suckers, carp, and chubs.[206] River otters in the James River watershed likely feed regularly on these species, which are under fish consumption warnings for PCBs throughout the majority of the James River.[207]

Toxic contaminants have very similar physiological impacts on mink and river otters. Studies have demonstrated that PCBs affect reproductive performance and offspring growth and survivability in mink, as well as organ weight. Skin lesions as a result of exposure have also been noted.[208] Mercury levels as low as 1 part per million (ppm) in aquatic environments can be fatal to mink in two months, and 0.64 ppm PCBs in food sources can cause total reproductive failure.[209]

4.2.1.2 Aquatic vertebrates

Contaminants from industrial activities, agricultural runoff, and sewage effluent can have what is known as “estrogenic effects” on fish in a contaminated waterway. These endocrine disrupting chemicals can alter the reproductive ability of fish and cause male fish to have decreased testosterone concentrations and increased production of vitellogenin. Vitellogenin is a serum egg protein associated with female fish egg production.[210] Gronen et al. looked at the relationship between vitellogenin production in male fish and the potential reproductive impairment it can cause.[211] Adult male medaka fish exposed to a known endocrine disrupting chemical were mated with unexposed females, which resulted in 50% fewer eggs than unexposed males mating with unexposed females. Exposure to the endocrine disrupting chemicals also increased the number of abnormally developing embryos.[212] Dramatic changes in reproductive sex steroids and vitellogenin could have population-level effects on fish in the James River, reducing their overall numbers.

4.2.1.3 Aquatic invertebrates

The effects of metals on aquatic invertebrates have been well studied. One example is the endocrine disruption caused by tributyltin in gastropod mollusks. Tributyltin is associated with the anti-fouling paint on the hulls of ships. In a study by Matthiessen and Gibbs female snails exposed to tributyltin underwent an irreversible sexual abnormality known as imposex.[213] Tributyltin causes masculinization, or the development of male sex organs. Even the production of eggs is stopped and sperm is produced instead in exposed female snails.[214]

Studies have shown that freshwater mussel populations decline with increasing sediment concentrations of lead, cadmium both of which are prevalent contaminants in coal ash.[215] In addition, chronic exposure to urban-derived contaminants in wastewater effluent and road runoff has been shown to cause oxidative stress in freshwater mussels.[216]

Pollution intolerant aquatic insects are particularly sensitive to changes in water chemistry. A study of larvae and nymphs of nine species of common aquatic insects (mayflies, stoneflies, caddisflies, and dragonflies) showed that all nine species were sensitive to low pH levels, which are often caused by sedimentation.[217] Studies on benthic insects in Appalachian streams have shown correlations between the presence of pollutants and a decrease in the local benthic macroinvertebrate assemblage.[218] Lemly found that mayflies, stoneflies, and caddisflies were significantly reduced in zones polluted by sedimentation and excess nutrients.[219] And in a study on acid mine drainage in tributaries of Virginia’s Upper Powell River, Schmidt et al. found that reduced aquatic insect diversity was associated with elevated levels of metals in the water column, paired with habitat impairment.[220]

4.2.1.4 Terrestrial vertebrates

Exposure of birds to industrial chemicals results in adverse effects on reproduction. These effects include direct effects on breeding adults, as well as developmental effects on embryos. The effects on adult birds include mortality, sublethal stress, reduced fertility, suppression of egg formation, eggshell thinning, and impaired incubation and chick rearing behaviors. The effects on embryos include mortality or reduced hatchability, failure of chicks to thrive (wasting syndrome), and developmental effects producing skeletal abnormalities and impaired differentiation of the reproductive and nervous systems through mechanisms of hormonal mimicking of estrogens.[221]

4.2.2 Crude oil contaminants

4.2.2.1 Aquatic mammals

Aquatic mammals, like otters and mink, depend on water-repellent fur to maintain normal body temperatures in water. External oiling reduces the thermal insulation of the fur, and unlike other aquatic mammals, otters and mink do not have a sub-dermal layer of blubber for insulation that guards against heat loss.[222] Oiling of the fur has shown to increase grooming and swimming activities, which are energetically demanding and further exposes them to oil through ingestion.[223]

4.2.2.2 Aquatic vertebrates

Oil is hydrophobic and adheres to sediment rather than staying suspended in water. Because of this attribute of oil, sediment can act as a major sink for spilled oil in the river. Studies have shown long term effects to fish after exposure to oil, which is made up of polycyclic aromatic hydrocarbons (PAHs). Zebrafish, a commonly used fish in laboratory studies, can help indicate the potential exposure effects of contaminants. Several studies have described the effects of PAHs on the developing embryo and larvae, including edema, and altered development of the heart and jaw.[224] In a 2014 study, zebrafish embryos and larvae were exposed for four days to three PAHs (pyrene, phenanthrene, and benzo[α]pyrene) in spiked sediment at concentrations found in contaminated areas (total PAH 4.4 ppm).[225] Reared to adulthood, the zebrafish showed disrupted growth and lower reproductive ability. The adults even displayed lethargic and/or anxiety-like behaviors.[226] All of these outcomes could have population-level effects, potentially reducing the population of fish communities in the James River.

4.2.2.3 Aquatic invertebrates

Many aquatic invertebrates spend considerable amounts of time on, in, and around sediments (a.k.a. benthic organisms). To determine the effects of sediment contaminants on benthic organisms, lab tests can be run to determine the acute toxicity, which is the lethality of a contaminant over a short time. In a study conducted by Verrheist et al. two invertebrates were exposed to sediments spiked with the PAHs phenanthrene, fluoranthene, and benzo(k)-fluoranthene, alone and in combination, at environmentally relevant concentrations.[227] The two invertebrates include an amphipod (*Hyalella azteca*), and what's commonly known as bloodworms (*Chironomus riparius*), which is the larval stage of a non-biting midge. The lethal concentration of each PAH was determined when half of the laboratory organisms died after some amount of exposure had occurred; this is known as the LC50.[228]

The amphipod LC50 occurred after 14 days of exposure to about 20 ppm phenanthrene and after 14 days of exposure to about 5 ppm of fluoranthene. The blood worm LC50 occurred after 10 days exposure to about 15 ppm phenanthrene and after 10 days exposure to about 15 ppm fluoranthene. It took greater than 300 ppm benzo(k)-fluoranthene to make a lethal concentration for both the amphipod and the blood worm, indicating benzo(k)-fluoranthene is not toxic to these organisms. However, in mixing the three PAHs together, after ten days exposure the lethal concentration was lower: about 10 ppm for amphipods and about 11.5 ppm for blood worms. This indicates that the mixture was more lethal than the individual PAHs alone, and more lethal than just their additive toxicity. This phenomenon is called synergy, indicating greater effects than those expected of the additivity hypothesis alone.[229] Lethal effects of oil in the James River, paired with contaminants already present, may cause greater harm to organisms than the individual contaminants alone.

4.2.2.4 Aquatic birds

Oil affects birds' thermal balance by adhering to feathers and causing a reduction in their water repellant properties. Heat loss of oiled birds is greater in water than in air. Mainly-aquatic birds may be forced to stay out in contaminated water to avoid starvation and must increase their energetic expenditure to maintain their normal body temperature. If they are not successful, they may suffer death from hypothermia.[230]

In response to oil adhered to their bodies, birds will preen their feathers, increasing their intake of the oil. Directly ingested oil has been shown to affect reproductive ability, reduce eggshell thickness, and cause anemia. Chicks and sub-adults are more affected by ingesting oil than adults, although both can suffer sublethal physiological effects and even death. Oil coating of eggs leads to a reduction in the gas conductance through the eggshell, slower embryonic growth, and decreased hatchability of the egg.[231]

The birds are also indirectly affected by the consumption of contaminated prey items. Through the process of bioaccumulation, contaminated prey items can increase the bird's exposure to the spilled oil.[232]

Even cleanup of a spill with oil-dispersants can cause similar effects on birds qualitatively identical to that of the oil alone. It is thought that the low tolerance for chemically treated oil due to surfactants makes it more easily adhere to birds' feathers, possibly binding to the hydrophobic waxes in the plumage.[233]

5.0 Risk Characterization

5.1 Example Scenario

As explained in earlier sections, a major goal of risk assessment, including watershed assessments, is to estimate the likelihood, nature and magnitude of harm to the natural resources. The focus for the James River watershed risk assessment is the ecological resources, but human health issues are also considered. In an effort to include cumulative risk issues, this assessment first identifies the three different types of specific exposures: a release (leak or rupture) from a storage tank, the release of coal ash, and a crude oil spill, and then considers the simultaneous occurrence of all three releases. Finally, current conditions that can or may affect the vulnerabilities of human and ecological resources, thereby diminishing the ability to cope with stress.

Three types of chemical releases

The three types of major chemical releases into the watershed considered here are understood differently than the standard releases summarized above for routine activities that contribute to the cumulative risks. In each case, chemical spill from a storage tank, a coal ash spill, or a crude oil spill from a train, the individual events are expected to occur at a low frequency. But when the level of activity, number of storage tanks, amount of oil transported, and the miles over which toxic chemicals are transported increases, even a low frequency of occurrence can substantially impair the living resources. As observed when shipping oil via rail, the dramatic increase in absolute volume (and number of trains, number of tanker cars, number of trips, etc,) will result in an increase in the amount spilled, when the spill rate remains constant. Any or all three events may be precipitated or caused by equipment failure, human error or severe natural disturbances (earthquakes, hurricanes, tornadoes).

Chemical Storage Tanks

Numerous toxic chemicals are stored in aboveground or underground tanks and waste ponds that are not coal ash ponds. According to DEQ, the great majority of these storage units are underground storage tanks, which total over 80,000 (active and inactive).[234] Aboveground tanks currently in use total over 11,000, according to DEQ's tank registration files.[235] Materials that are held in aboveground storage containers include a wide range of toxic chemicals, many of which are stored in high quantities, such as those proximal to the Port of Richmond, as summarized in section 3.4.1. Although data are publicly available on leaks and spills, they may not be up to date, and the condition of each of these units is not made publicly available; therefore the likelihood of a breach, leak or rupture is uncertain, but worthy of consideration. Should a leak in one of these containers occur in close proximity to the river, the contents would certainly reach the river. As with other storage tanks, the design, age and condition of such tanks are determining factors in the likelihood of an accidental release. Operator error is another possible cause of a release.

Coal Ash Pond Releases

Coal ash pond breaches are limited to the few facilities that have such ponds on the facility property: Mead Westvaco in Covington, Bremo, Chesterfield, Hopewell and Chesapeake[236]. The Chesapeake plant is located at the mouth of the James watershed, on the Elizabeth River, whereas the Bremo, Hopewell and Chesterfield plants are located on the middle portions of the river. The Mead Westvaco plant is a pulp and paper mill in Covington on the Jackson River, a tributary to the James. Because of location, the four upriver facilities pose greater risks to the living resources of the James River. The Chesapeake Facility poses a risk to the Chesapeake Bay in addition to the lower James River. Coal ash ponds are susceptible to possible breaches and to leaks into the underlying groundwater and nearby surface water bodies. The earlier section described the hazard ranking by EPA that unfortunately did not include the Bremo plant and its coal ash ponds. As with oil spills, a generic likelihood of a breach is considered a rare event, but the impact would be profound. Coal ash ponds are susceptible to dam failure or infiltration of nearby waters.

Crude Oil Spills

Oil spills from rail transport can occur through much of the length of the James River, and the most upriver point where freight or oil rail lines intersect the James River is in Lynchburg. The rail line used for oil shipments runs along the river, through downtown Richmond and then either into the York River watershed for shipments to Yorktown, or in the James River watershed for shipments to the river mouth. Major spills via train derailments are considered rare events with a large impact due to the toxicity of the oil to living systems (aquatic and terrestrial animals, and people). Because the trains that transport crude oil move on a right of way along the James River from Lynchburg eastward, the likelihood of the oil reaching the aquatic resources is high.

Combined Accidental Release

The simultaneous release from all three sources (chemical storage tank, coal ash pond, crude oil train) is the least likely scenario, but would have the greatest impact. This scenario is not outside the realm of possibility under conditions of extreme weather events or natural disturbances. Virginia has experienced hurricanes, ice storms, tornadoes and major earthquakes all impacting the James River watershed and affecting conditions in the river. Global warming and consequent climate change throughout the East Coast can be expected to continue to bring more extreme and severe weather to all of Virginia, including the James River watershed. With such a change in natural disturbances, an increased likelihood of multiple accidental releases must be considered.

Current baseline contamination

Any discussion of additional inputs of contaminants to the James River must include the baseline contamination already present in the watershed. Water quality in the James River is affected by farm runoff through most of the river's length, by excess sediment in the lower tidal James, by routine discharges from industrial plants along the river and from sewage treatment plants in Lynchburg, Richmond, and Hopewell. Stormwater and combined sewer overflows enter the river from Lynchburg, Richmond and cities downriver. The permitted releases into the James River from the municipal and industrial sources are ongoing and constant or nearly so. Only the stormwater and CSO discharges are sporadic and occur only when storm events produce flows greater than the capacity each specific system can accommodate. Some of the constituents in wastewater effluents are known, such as nitrates, phosphates, bacteria, sugars and starches. Other chemicals are not measured, or detected at such low levels that there might be no permit limit, and these chemicals are the emerging contaminants reported by USGS or, as VDEQ labels them, microconstituents. The categories of chemicals on the emerging contaminant list from 2002 fall into general categories:[237]

Category	Number of Chemicals Found
Prescription drugs	17
Non-prescription drugs	7
Antibiotics	15
Hormones	18
Industrial, etc.	39

The discharges from POTWs are but one type of the numerous routine activities on the James River, and in the adjoining watershed, that affect conditions in the river. This category of threat is known to occur and therefore has the highest likelihood (probability of 1.0) and greatest confidence. There is, however, great uncertainty over what impact these events might be having on the living resources in the watershed. In some cases, the combinations of hormones and hormonally active chemicals can and do alter the biological status of aquatic animals, notably fish.[238]

Summary of Risks to James River Resources

Table 5 below summarizes the risks in terms of high, medium, low or variable for the three types of accidental releases, the combination of all events at once, and on-going cumulative releases.

Table 5. Likelihood of effects on James River resources from toxic chemical releases

	Event		Impact		
Source Type	**Frequency**	**Magnitude**	**Likelihood**	**Magnitude**	**Total Risk**
Storage Tank Release	Low	Variable	High	Variable	Variable
Coal Ash Spill	Low	High	High	Variable	Variable
Oil Spill (Large)	Low	High	High	High	High
All	Low	High	High	High	High
Baseline Contamination	High	Low	Med	Variable	Unknown

The qualitative categories were derived from the information in earlier sections on each source category. Event magnitudes were defined in early sections, basically as the type of events observed in Virginia. Impact magnitudes are taken from information in reports and the literature describing the consequences of release events in terms of damage to ecosystems. Total risk is the product of impact likelihood and magnitude. Events that are infrequent but known to occur, such as oil train spills, are considered high likelihood.

5.2 Sources of Uncertainty

It is important to consider the outstanding data gaps and uncertainties included in the risk analysis. The multiple pathways through which contaminants can enter the watershed and the large size of the watershed lead to some degree of uncertainty in the risk analysis. We are unable to account for all sources of toxic chemicals within the watershed, as there are a number of nonpoint sources and undocumented and unreported spills and discharges, which may occur episodically or continuously. There are many facilities, including homes, within the watershed that may release toxic mixtures into the air, landfills, groundwater, and septic and sewer systems at low intensities and with varying frequencies and durations.[239] Additionally, even accounting for those facilities that do operate with discharge permits does not verify the exact composition of their effluent. It is not uncommon for effluent to contain unexpected chemicals, whether due to faulty equipment or equipment which might contain chemicals, such as PCBs, that have the potential to leach into wastewater.[240]

Aging infrastructure is another component of the problem. For example, according to a recent report from Virginia’s Railroad Safety and Security Task Force, the Virginia State Corporation Commission, the entity responsible for inspecting rail operations across the state, employed only three rail inspectors for the entire state of Virginia as of May 2015[241]. Virginia has 3,394 miles of railroad track.[242] Split between five inspectors, that is over 670 miles of track per an inspector. Many issues with railroad malfunctioning are likely going unnoticed or undocumented. As mentioned earlier, monitoring of power plants, coal ash ponds, and other locations that store toxic chemicals is also lacking.

Ongoing releases of various materials into the James River from the surrounding watershed are contributing nutrients, sediment, and chemicals, both toxic and non-toxic. The sources are known with greater certainty than the identification and characteristics of the chemicals because so many are legally discharged from facilities with a VPDES permit. The problem is that the complete chemical characterization of all effluents into the James River has not yet been conducted, especially for municipal wastewater treatment plants. The uncertainties are the chemicals present in the permitted effluents and how these levels affect biological resources.

A large oil spill, especially the type that occurred in 2014 in Lynchburg, when a train derailed while crossing the James and spilled Bakken crude oil, is a rare event with substantial impacts to the resources and communities. The uncertainties fall into a few categories: where and when the next large spill will occur, the size of the spill and proximity to the river, and long term and downriver impacts. As explained above, this report assumes that accidental releases are a function of the total activity (amount handled, distance travelled, number of transportation events, train length, etc.) and the design and operation of the transporting activity (equipment design, age, operation, etc.).

The uncertainties around a spill of coal ash from one of the facilities in the James River watershed are fewer and less extensive than for other events. The announcement by Dominion on April 17, 2015, that four of its coal ash ponds will be closed according to EPA and DEQ procedures and guidelines may reduce the likelihood for a spill.[243] However, Dominion's proposal remains problematic due to insufficient federal and state requirements for closure of coal ash ponds. For instance, neither EPA nor VDEQ require that old ponds be lined prior to closure, leaving the potential for groundwater infiltration and contamination in place. Additionally, long-term monitoring beyond ten years is not required in Virginia and may be shortened at VDEQ's discretion, and current Virginia regulations do not include certain toxic chemicals, including molybdenum, boron, and sulfate, in the list of those that must be monitored in groundwater.[244]

6.0 Human Health Impacts

6.1 Living in the Vicinity of Toxic Chemicals

6.1.1 Toxic storage sites

Chemicals at the over 1,100 toxic chemical storage sites in the James River span the entire range of toxic chemicals from lead, arsenic, and sulfuric acid to automotive chemicals like diesel fuel and gasoline.[245] Thirty-one sites in Virginia are on the EPA's National Priorities List.[246] The National Priorities List is made up of sites that the EPA has designated as posing the greatest hazard to the public and that require remediation.

Numerous studies have shown that living in the vicinity of toxic waste sites can negatively impact human health. Health impacts from living near toxic waste sites range from respiratory disease to birth defects. In a study in New York State, Kudyakov et al. examined hospitalization rates for respiratory diseases for residents living in zip codes with hazardous waste sites. After eliminating most socioeconomic bias, the researchers found that residents living in zip codes with hazardous waste sites had higher than average rates of chronic bronchitis and chronic airway obstruction.[247]

Scientific studies also suggest that toxic contaminants in the vicinity of pregnant women can contribute to mothers giving birth to low-birth-weight babies. Low birth-weight is an important predictor of infant morbidity and mortality; about 75% of early neonatal mortality in the U.S. and Canada is associated with low birth-weights.[248] Baibergenova et al. tested the hypothesis that PCB waste sites can contribute to resident mothers giving birth to low birth-weight babies. After adjusting for relevant socioeconomic factors, the scientists found that there was still a 6% increased risk for mothers living in zip codes with PCB waste sites to give birth to a male infant of low birth-weight (PCB-induced low birth-weights are more common in male babies than females).[249]

6.1.2 Coal ash

Living near coal-fired power plants and coal ash storage ponds can also do significant damage to human health. The EPA has documented that the toxic contaminants in coal ash can and do escape from disposal sites.[250] Pathways for coal ash exposure include the consumption of contaminated fish, leaching into groundwater, and movement through the air as fine particles that can be inhaled.[251] Gottlieb et al. reported that coal ash contaminants have the potential to damage every major organ system in the human body. Exposure to the contaminants in coal ash can induce a wide arrange of health problems, including heart damage, lung disease, reproductive issues, and cognitive deficits.[252] It is not uncommon for facilities responsible for coal ash pollution to be located in communities where other types of industry are also affecting air and water quality. In fact, 76% of Virginia's coal-fired power plants are located in low-income communities.[253] For individuals living in and around these areas, the cumulative impact of combined chemical exposure increases the risk of contracting cancer, lung, and neurological disease.[254]

6.1.3 Crude oil spills

Oil spills affect human health through exposure to chemicals like benzene, hydrogen sulfide, and other hazardous contaminants.[255] Exposure to these toxic chemicals can cause abnormalities in neurologic, respiratory, renal, hematologic, and hepatic functions.[256] In a study on the effect of oil spills on human health, D'Andrea and Reddy found that workers cleaning up oil from the 2010 Gulf of Mexico oil spill experienced significantly altered blood profiles, liver enzymes, and somatic symptoms.[257]

In a review of scientific studies on the effects of oil exposure on human health, Aguilera et al. looked at several human health studies performed on exposed populations after large oil spills like the Exxon Valdez.[258] In the review, the authors noted that subjects uninformed of proper health protection protocol experienced the highest risks of exposure effects like nausea, vomiting, dizziness, and throat and respiratory problems.[259] Most of the studies in the review provided evidence on the relationship between exposure to spilled oils and the development of "acute physical, psychological, genotoxic and endocrine effects in the exposed individuals."[260]

6.2 Human Consumption of Contaminated Aquatic Life

Fish consumption advisories are in effect for a number of species throughout the James River. Many of these advisories are due to PCB contamination. One such fish consumption advisory begins with one of the James' tributaries, the Maury River. The advisory extends from Buena Vista at Rt. 60 to where it meets the James, and extends to the Hampton Roads Bridge Tunnel and the tidal portion of a number of its other tributaries. A strict "Do Not Eat" advisory is in effect for gizzard shad and carp and for blue and flathead catfish greater than or equal to 32 inches throughout the whole area.[261]

Other species warrant a consumption advisory of no more than two meals per month. Advisories due to Kepone contamination extend from the I-95 James River bridge in Richmond downstream to the Hampton Roads Bridge Tunnel. Although Kepone advisories are less restrictive than PCB advisories, the Virginia Department of Health instructs individuals to follow the same consumption guidelines for PCBs, with the exception of limiting consumption to one meal per day for any species not listed under the PCB advisory.[262]

A 2008 study on fish consumption and PCB-associated health risks in James River fishermen revealed an unacceptable level of risk among those who consumed catfish contaminated with PCBs, although the risk to recreational fishermen on the tidal freshwater James River overall was not significant.[263] In total, 143 individuals were surveyed, of whom 94% were men. 70% of participants were Caucasian and 28% were African American. Overall, 131 individuals identified themselves as fish consumers, while 12 were non-consumers. Caucasians consumed smaller portion sizes (11.7 oz) and had lower annual fish consumption (43 meals per year) than Hispanics, Asians, and African Americans who, on average, consumed a portion size of 15.6 oz and 82 meals per year. Fishermen surveyed at the Jordan Point Marina just outside of Richmond had significantly higher rates of consumption for catfish from the James River as compared to other entry points surveyed. Although 82% of those surveyed had general knowledge of fish consumption advisories in Virginia, those with knowledge of advisories consumed a significantly higher percent of catfish from the James River.[264]

Other studies have demonstrated significant challenges with getting the public to abide by fish consumption advisories. Belton et al. discussed the results of a survey conducted on urban fishermen following the implementation of fish consumption advisories after a New Jersey Department of Environmental Protection study revealed detectable levels of PCB contamination in a number of species.[265] Urban fishermen completed 112 questionnaires, and the behaviors of over 1,900 fishermen were observed and recorded. Out of the 112 who completed the questionnaire, 40% did not eat their catch, 50% knew of the warnings, 20.5% of the sample continued to eat their contaminated catch in spite of their knowledge of consumption warnings. 18.5% knew of the warnings, continued to eat their catch, and contended that their catch was safe. Those who were aware of the advisories were often unaware of who implemented them and why they were implemented. Of those who were aware, 40% also misinterpreted the warnings as fishery management tactics, such as mere restrictions on the size of fish that were kept, rather than problems derived from toxic contamination. Others believed that the general appearance of their catch was enough to indicate that it was safe to eat or that washing the fish and cooking it thoroughly would eliminate the risk of contamination. Overall, the study demonstrated the tendency of humans to resist mandated changes in behavior in instances where the potential for harm might be misunderstood, misinterpreted, or underestimated, often by those who are most at risk for exposure.[266]

6.3 Water Quality

6.3.1 Drinking water

As home to one-third of all Virginians, the James River watershed serves as an important source of drinking water.[267] Any type of spill or massive contamination in the watershed can have widespread and long lasting effects. For example, during the 4-methylcyclohexanemethanol (MCHM) spill in West Virginia’s Elk River last year, residential water supplies were shut down for over 300,000 West Virginians for over a week.[268] According to newspaper reports, up to 20,000 people in the City of Hopewell, Virginia were affected by the approximately 600 gallon diesel oil spill that occurred earlier this year.

6.3.2 Recreational contact with contaminated water

The James provides countless recreational opportunities for its residents; fishing, swimming, boating, and hiking are all common activities throughout the watershed. However, many of these activities involve exposure to contaminated water or sediment along the river. Exposure to contaminants can occur through skin contact, inhalation, or ingestion.

Skin Contact

Dermal exposure can result from skin coming in contact with contaminants via water (e.g., swimming), sediment (e.g., wading or fishing), or soil or dust (e.g., gardening, children playing).[269]

Inhalation

Exposure to contaminants via inhalation can occur through breathing air that is contaminated with particulate matter (such as the pollution from a coal-fired power plant), vapors, or aerosols).[270] Contaminated air can also infiltrate indoor environments.

Ingestion

Exposure to contaminants via ingestion can occur through consumption of contaminated fish or shellfish, which is discussed in the Human Health Impacts section of this report. Accidental ingestion can occur via the deposition of particulate matter on edible produce, or through the non-dietary uptake of contaminated soil or water. This is especially a problem for young children, who tend to have more hand-to-mouth or object-to-mouth activities involved in their daily lives.[271]

The Virginia Department of Health (VDH) can issue recreational advisories, meant to limit human contact with contaminants. In April of 2014 when the train carrying crude oil derailed, spilling thousands of gallons of crude oil into the James, VDH issued a recreational advisory for swimming, kayaking, and other paddling activities on the James River between Lynchburg and Richmond.[272] However, these advisories are typically only issued during large-scale events and do not account for the exposure risks that can occur through coming in contact with low concentrations of contaminants on a day to day basis.

7.0 Conclusions

The ongoing releases of various materials into the James River create cumulative risks that likely increase vulnerability of the living resources and limit the ability of these resources to cope with further exposures from accidental releases. These aggregate exposures may serve to impair normal biological functions, such as immune systems and growth. Such cumulative risk conditions have not been examined outside the context of the Chesapeake Bay, where chronic hypoxia impairs a range of biological functions.[273] The situation raises management implications, including factoring in the economic costs of fishery closures, the protection of native species, and the necessity of collecting more data in order to understand the risks.

A six-month damage cost analysis for the Dan River coal ash spill estimated the total damage cost based on the following: ecological impacts, recreational impacts, human health and consumptive use, and aesthetic values. The grand total was determined to be $295,485,000 with the biggest lost coming from ecological impacts. However, this total is likely to increase substantially as additional information becomes available and long-term impacts on public health, recreational use, and property values are assessed.[274]

Ongoing discharges and releases from pipes, runoff, groundwater and from sediments already expose the ecosystem, both animals and people, to a wide range of chemicals. Examples include PCBs from sediments, bacteria and sediment in stormwater, and various chemicals in permitted discharges.

Not all chemicals are characterized to the extent that the toxicity is understood to the point that management decisions can confidently protect humans and ecological resources. As a result, it is not possible to accurately predict the risks from many chemicals and certainly not from the mixtures.

Cumulative risks from multiple chemicals and multiple types of threats are unknown, recognizing that methods to assess cumulative risks are not well developed.

There is little biological information on the basic condition of the river ecosystem, apart from the list of impaired waters that DEQ submits to EPA.

Not all the releases of chemicals, whether permitted or accidental, are measured, routinely monitored, and reported. As a result, this report was not able to present all of the risks from toxic chemicals in the James River. This gap in data is a substantial impediment to understanding the risks and to informing management actions to control, reduce or eliminate risks.

Metals that are released into any environmental medium, air, surface waters, groundwater, sediment, soil will not break down but will remain present unless removed. Some metals could be chemically transformed, as mercury can be converted to methyl mercury.

The James River watershed is home to a number of rare species of animals, some of which are known to be sensitive to toxic chemicals generally and to some of the specific chemicals present in the James River. Sturgeon and shad are threatened, sensitive to adverse conditions and recovery efforts are in place.

The James River watershed has a large number of chemical storage facilities and some coal ash ponds of unknown condition or even susceptible to breach, according to other analysis. Existing information suggests that small chemical spills occur regularly; the large number of facilities increases the chances that a major accidental spill could threaten the James River.

It is not clear how new regulations for coal ash and storage facilities will affect the operation, maintenance and safety of such facilities that are currently of questionable condition, according to EPA.

Transport of crude oil by rail is increasing in the US and Virginia specific data on total volume moving through the James River watershed was not available for this research. The increasing transport means more oil will be spilled, given the same or even a lower rate of accidental spills. The uncertainties are when, how much and where an oil spill might take place next.

Human health can be threatened by accidental spills from various sources. Research at other locations indicates that people living in the vicinity of contaminated sites do experience adverse health effects; this question has not been addressed outside the context of a few contaminated sites.

7.1 Management Implications

7.1.1 Economic costs of fishery closures

Among implications for management are the economic costs associated with fisheries closures. As a main tributary to the Chesapeake Bay, contamination of the James River could result in fishery closures that could potentially cost the state of Virginia millions, possibly even billions of dollars in lost revenue. In 2014, just the harvest for farm-raised oysters and clams in Virginia was valued at over $55.9 million.[275] A number of studies have assessed fishery closure costs following events such as the James River Kepone spill that occurred from December 1975 to September 1976, or most recently, the Deepwater Horizon Oil Spill of 2010. Considering the number and variety of toxics that are stored or transported throughout the James River watershed, consideration of the economic costs associated with spills, whether incidental or continuous, is warranted.

Swartz et al. examined the effects of imperfect information regarding Kepone in the James River and concluded that seafood demand decreases precipitously as a result of highly publicized contamination of water areas; additionally, news of closures combined with imperfect information may cause demand for seafood outside of the area of contamination to fall.[276] In this case, prohibition of the harvest of James River oysters from December 1975 to September 1976 affected demand for oysters outside of this market and had serious short-term impacts on demand, leading to losses.[277]

Greater New Orleans, Inc. examined the economic impacts of the Deepwater Horizon Oil spill and predicted that the primary effects on the fishing industry in the Gulf would be felt within the first two years of the spill (three years for oysters), but long-term effects are still unknown.[278] They noted that oyster eggs and larvae can be killed with about 0.1 to 1 ppm concentration of oil, and that mature oysters would remain a problem due to bioaccumulation even if they survived the spill. For example, the 1978 Amoco Cadiz spill off the coast of France resulted in the destruction of 6,000 oysters and the avoidance of some reefs for harvest for up to two years after the spill.[279] The authors also mentioned that blue crab larvae would be particularly susceptible. Projected revenue losses in the fisheries were estimated by the authors to be between $59 to $89 million in 2011, $38 to $56 million in 2012, and $18 to $27 million in 2013. Gross losses to the economy were projected to be anywhere from $285 to $428 million, and estimates included losses to industries that feed into the fisheries, as well as the industries in which fishermen spend their money.[280] Considering the overall value of the blue crab and oyster harvest in Virginia, an oil spill event of large magnitude could decimate these populations for years to come.

Lastly, Ofiara and Seneca linked the deleterious biological effects of marine pollution with the economic effects and losses due to marine pollution.[281] They began by assessing ecosystem damage in the forms of biological effects and impairments, such as decreases in the productivity of an ecosystem leading to declines in the distribution of aquatic and terrestrial organisms. For example, Ofiara and Seneca cite the U.S. Atlantic Coast striped bass fishery decline in the 1980s as an example of the effects of degradation of estuary habitats or critical spawning grounds for species. Decreased productivity could, in turn, have economic impacts in the form of human consumptive uses, such as commercial and shellfishing activities, or in the forms of recreational activities and other non-consumptive uses, like bird watching, where the economic effects would be directly related to the severity of damage. Public health damages cited by the authors were extensive. In one instance of harvest closures due to PCB contamination in New Bedford Harbor and Buzzards Bay, Massachusetts, estimated total losses to commercial lobstermen were $89,544/year (2002$) and $3.28 million (2002$) over a 106-year period (damages were expected to last from 1980-2085).[282]

7.1.2 Protection of native species

Environmental managers should seek protection of native species, which often confers protection on the species with which they interact. An example of such cascading benefits is observable with the Eastern oyster, *Crassostrea virginica*. Oysters are a keystone species because of their water filtering capacity and formation of hard substrate, among other attributes. As a result, when oyster beds and reefs regrow, water clarity improves, there is more habitat for reef animals (i.e fish), there is more food for animals that prey on oysters, and oysters add to the flow of energy through the trophic system. [283]

7.1.3 Natural disasters and catastrophic events

As climate change takes its toll on our planet, such large scale natural disturbances are becoming more common. Coastal areas are likely to suffer the most. Scientists predict that events such as hurricanes and high-powered storms will become more common, which will increase rates of flooding. Munich Reinsurance America, a top property and casualty reinsurance provider in the U.S., observed in 2011 that the number of natural disasters had tripled in the 20 years prior.[284] In 2014, there were eight weather and climate disasters in the U.S. alone, costing over $1 billion each in damages. These included a drought, a flood, five severe storms, and a winter storm.[285]

7.1.4 More information to understand the risks

One of the most apparent observations to come from this assessment is the limited information on the current status of contaminants present in the James River watershed. Both VDEQ and JRA have made efforts to understand the “state of the river.” In the case of DEQ, water quality is evaluated via measurements of a limited number of chemical and biological criteria. There is not an effort to understand the scope of the status and condition of the natural resources throughout this watershed, a founding river of the nation.

While there is some information on the sources and types of accidental releases from chemical storage tanks, oil train accidents and coal ash releases, the information is not sufficiently developed to permit an understanding of risks to the James River watershed. In order for managers to make the policy decisions that will protect the James River watershed, information needs to be collected with the express purpose of examining these risks cumulatively.

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9.0 Appendix

Appendix A. Virginia Department of Game and Inland Fisheries: Special Legal Status Faunal Species in Virginia

Virginia Department of Game and Inland Fisheries

Special Legal Status Faunal Species in Virginia

Common Name	Scientific Name	Federal[1]	State	WAP Tier
FRESHWATER FISHES				
Atlantic sturgeon	*Acipenser oxyrinchus*	FE	SE	II
Blackbanded sunfish	*Enneacanthus chaetodon*		SE	I
Blackside dace	*Chrosomus (=Phoxinus) cumberlandensis*	FT	ST	III
Carolina darter	*Etheostoma collis*		ST	II
Duskytail darter	*Etheostoma percnurum*	FE	SE	I
Emerald shiner	*Notropis atherinoides*		ST	III
Golden darter	*Etheostoma denoncourti*	SOC	ST	
Greenfin darter	*Etheostoma chlorobranchium*		ST	II
Orangefin madtom	*Noturus gilberti*	SOC	ST	II
Paddlefish	*Polyodon spathula*		ST	II
Roanoke logperch	*Percina rex*	FE	SE	I
Sharphead darter	*Etheostoma acuticeps*		SE	I
Shortnose sturgeon	*Acipenser brevirostrum*	FE	SE	I
Sickle darter	*Percina williamsi*		ST	II
Slender chub	*Erimystax cahni*	FT	ST	I
Spotfin chub	*Erimonax monachus*	FT	ST	I
Steelcolor shiner	*Cyprinella whipplei*		ST	III
Tennessee dace	*Chrosomus (=Phoxinus) tennesseensis*		SE	I
Variegate darter	*Etheostoma variatum*		SE	II
Western sand darter	*Ammocrypta clara*		ST	II
Whitemouth shiner	*Notropis alborus*		ST	IV
Yellowfin madtom	*Noturus flavipinnis*	FT	ST	I
AMPHIBIANS				
	Frogs			
Barking treefrog	*Hyla gratiosa*		ST	II
	Salamanders			
Eastern tiger salamander	*Ambystoma tigrinum*		SE	II
Mabee's salamander	*Ambystoma mabeei*		ST	II
Shenandoah salamander	*Plethodon shenandoah*	FE	SE	I
REPTILES				
	Lizards			
Eastern glass lizard	*Ophisaurus ventralis*		ST	II
	Snakes			
Canebrake rattlesnake (Coastal Plain population of timber rattlesnake)	*Crotalus horridus*		SE	II
	Turtles			
Bog (= Muhlenberg) turtle	*Glyptemys (=Clemmys) muhlenbergii*	FT(S/A)	SE	I
Eastern chicken turtle	*Deirochelys reticularia reticularia*		SE	I
Green sea turtle	*Chelonia mydas*	FT	ST	
Hawksbill sea turtle	*Eretmochelys imbricata*	FE	SE	

[1] FE=Federal Endangered; FT=Federal Threatened; S/A=Similarity of Appearance; FC=Federal Candidate; FP=Federal Proposed; SOC=Federal Species of Concern (not a legal status; list maintained by USFWS Virginia Field Office); SE=State Endangered; ST=State Threatened; WAP Tier = Virginia Wildlife Action Plan Tiered Species, from the Species of Greatest Conservation Need list that is defined in the plan: Tiers I-IV (not a legal status, Tier levels defined in the Virginia Wildlife Action Plan).

Virginia Department of Game and Inland Fisheries

Special Legal Status Faunal Species in Virginia

Common Name	Scientific Name	Federal[1]	State	WAP Tier
Kemp's ridley sea turtle	*Lepidochelys kempii*	FE	SE	
Leatherback sea turtle	*Dermochelys coriacea*	FE	SE	
Loggerhead sea turtle	*Caretta caretta*	FT	ST	I
Wood turtle	*Glyptemys insculpta*		ST	I
BIRDS				
Bachman's sparrow	*Aimophila aestivalis*		ST	I
Bachman's warbler (=wood)	*Vermivora bachmanii*	FE	SE	
Bewick's wren	*Thryomanes bewickii*		SE	I
Black rail	*Laterallus jamaicensis*		SE	I
Gull-billed tern	*Sterna nilotica*		ST	I
Henslow's sparrow	*Ammodramus henslowii*		ST	I
Kirtland's warbler (=wood)	*Dendroica kirtlandii*	FE	SE	IV
Loggerhead shrike	*Lanius ludovicianus*		ST	I
Peregrine falcon	*Falco peregrinus*		ST	I
Piping plover	*Charadrius melodus*	FT	ST	I
Red-cockaded woodpecker	*Picoides borealis*	FE	SE	I
Red knot	*Calidris canutus*	FP		IV
Roseate tern	*Sterna dougallii dougallii*	FE	SE	IV
Upland sandpiper	*Bartramia longicauda*		ST	I
Wilson's plover	*Charadrius wilsonia*		SE	I
MAMMALS				
American water shrew	*Sorex palustris*		SE	II
Carolina northern flying squirrel	*Glaucomys sabrinus coloratus*	FE	SE	I
Delmarva Peninsula fox squirrel	*Sciurus niger cinereus*	FE	SE	II
Dismal Swamp southeastern shrew	*Sorex longirostris fisheri*		ST	IV
Eastern puma (=cougar)	*Puma (=Felis) concolor cougar*	FE	SE	
Gray bat	*Myotis grisescens*	FE	SE	II
Gray wolf	*Canis lupus*	FE	SE	
Indiana bat	*Myotis sodalis*	FE	SE	I
Northern long-eared bat	*Myotis septentrionalis*	FP		
Rafinesque's eastern big-eared bat	*Corynorhinus rafinesquii macrotis*		SE	I
Rock vole	*Microtus chrotorrhinus*		SE	II
Snowshoe hare	*Lepus americanus*		SE	I
Virginia big-eared bat	*Corynorhinus (=Plecotus) townsendii virginianus*	FE	SE	II
Virginia northern flying squirrel	*Glaucomys sabrinus fuscus*	FE	SE	I
MOLLUSKS				
	Freshwater Mussels			
Appalachian monkeyface (pearlymussel)	*Quadrula sparsa*	FE	SE	I
Atlantic pigtoe	*Fusconaia masoni*	SOC	ST	II
Birdwing pearlymussel	*Lemiox rimosus*	FE	SE	I
Black sandshell	*Ligumia recta*		ST	III
Brook floater	*Alasmidonta varicosa*		SE	II
Cracking pearlymussel	*Hemistena lata*	FE	SE	I
Cumberland bean (pearlymussel)	*Villosa trabalis*	FE	SE	I
Cumberland monkeyface (pearlymussel)	*Quadrula intermedia*	FE	SE	I

[1] FE=Federal Endangered; FT=Federal Threatened; S/A=Similarity of Appearance; FC=Federal Candidate; FP=Federal Proposed; SOC=Federal Species of Concern (not a legal status; list maintained by USFWS Virginia Field Office); SE=State Endangered; ST=State Threatened; WAP Tier = Virginia Wildlife Action Plan Tiered Species, from the Species of Greatest Conservation Need list that is defined in the plan: Tiers I-IV (not a legal status, Tier levels defined in the Virginia Wildlife Action Plan).

Common Name	Scientific Name	Federal[1]	State	WAP Tier
Cumberlandian combshell	*Epioblasma brevidens*	FE	SE	I
Deertoe	*Truncilla truncata*		SE	IV
Dromedary pearlymussel	*Dromus dromas*	FE	SE	I
Dwarf wedgemussel	*Alasmidonta heterodon*	FE	SE	II
Elephantear	*Elliptio crassidens*		SE	IV
Fanshell	*Cyprogenia stegaria*	FE	SE	I
Finerayed pigtoe	*Fusconaia cuneolus*	FE	SE	I
Fluted kidneyshell	*Ptychobranchus subtentum*	FE	SE	II
Fragile papershell	*Leptodea fragilis*		ST	IV
Green blossom (pearlymussel)	*Epioblasma torulosa gubernaculum*	FE	SE	I
Green floater	*Lasmigona subviridis*		ST	II
James spinymussel	*Pleurobema collina*	FE	SE	I
Littlewing pearlymussel	*Pegias fabula*	FE	SE	I
Ohio pigtoe	*Pleurobema cordatum*		SE	III
Oyster mussel	*Epioblasma capsaeformis*	FE	SE	I
Pimpleback	*Quadrula pustulosa pustulosa*		ST	IV
Pink mucket (pearlymussel)	*Lampsilis abrupta*	FE	SE	I
Pistolgrip	*Tritogonia verrucosa*		ST	IV
Purple bean	*Villosa perpurpurea*	FE	SE	I
Purple lilliput	*Toxolasma lividus*	SOC	SE	II
Pyramid pigtoe	*Pleurobema rubrum*	SOC	SE	II
Rayed bean	*Villosa fabalis*	FE	SE	II
Rough pigtoe	*Pleurobema plenum*	FE	SE	I
Rough rabbitsfoot	*Quadrula cylindrica strigillata*	FE	SE	I
Sheepnose	*Plethobasus cyphyus*	FE	SE	II
Shiny pigtoe	*Fusconaia cor*	FE	SE	I
Slabside pearlymussel	*Lexingtonia dolabelloides*	FE	SE	II
Slippershell mussel	*Alasmidonta viridis*		SE	II
Snuffbox	*Epioblasma triquetra*	FE	SE	II
Spectaclecase	*Cumberlandia monodonta*	FE	SE	II
Tan riffleshell	*Epioblasma florentina walkeri* (=*E. walkeri*)	FE	SE	I
Tennessee heelsplitter	*Lasmigona holstonia*		SE	II
	Freshwater & Land Snails			
Appalachian springsnail	*Fontigens bottimeri*	SOC	SE	II
Brown supercoil	*Paravitrea septadens*	SOC	ST	I
Rubble coil	*Helicodiscus lirellus*	SOC	SE	I
Shaggy coil	*Helicodiscus diadema*	SOC	SE	I
Spider elimia	*Elimia arachnoidea*		SE	II
Spiny riversnail	*Io fluvialis*	SOC	ST	III
Spirit supercoil	*Paravitrea hera*	SOC	SE	I
Springsnail (no common name)	*Fontigens morrisoni*	SOC	SE	I
Thankless ghostsnail	*Holsingeria unthanksensis*	SOC	SE	I
Virginia fringed mountain snail	*Polygyriscus virginianus*	FE	SE	I
FRESHWATER CRUSTACEANS				
Big Sandy crayfish	*Cambarus veteranus*	SOC	SE	II
Lee County Cave isopod	*Lirceus usdagalun*	FE	SE	I
Madison Cave amphipod	*Stygobromus stegerorum*	SOC	ST	I
Madison Cave isopod	*Antrolana lira*	FT	ST	II

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MILLIPEDES				
Ellett Valley pseudotremia	*Pseudotremia cavernarum*	SOC	ST	II
Laurel Creek xystodesmid	*Sigmoria whiteheadi*	SOC	ST	I
ARACHNIDS				
Spruce-fir moss spider	*Microhexura montivaga*	FE	SE	
INSECTS[2]				
American burying beetle	*Nicrophorus americanus*	FE		I
Appalachian grizzled skipper	*Pyrgus wyandot (=Pyrgus centaureae wyandot)*	SOC	ST	I
Buffalo Mountain mealybug	*Puto kosztarabi*	SOC	SE	I
Holsinger's cave beetle	*Pseudanophthalmus holsingeri*	SOC	SE	I
Mitchell's satyr butterfly	*Neonympha mitchellii*	FE	SE	I
Northeastern beach tiger beetle	*Cicindela dorsalis dorsalis*	FT	ST	II
Virginia Piedmont water boatman	*Sigara depressa*	SOC	SE	I

[2] all insects listed as federal or state endangered or threatened are protected by regulations that fall under the Virginia Department of Agriculture and Consumer Services' jurisdiction

Common Name	Scientific Name	Federal	State	WAP Tier
MARINE MAMMALS				
Blue whale	*Balaenoptera musculus*	FE	SE	
Finback whale	*Balaenoptera physalus*	FE	SE	
Humpback whale	*Megaptera novaeangliae*	FE	SE	
North Atlantic Right whale	*Eubalaena glacialis*	FE	SE	
Sei whale	*Balaenoptera borealis*	FE	SE	
Sperm whale	*Physeter catodon (= macrocephalus)*	FE	SE	
West Indian manatee	*Trichechus manatus*	FE	SE	

For further information or details regarding this list or any species listed herein, please contact:

Bureau of Wildlife Resources, Statewide Resources
Virginia Department of Game and Inland Fisheries
4010 W. Broad St.
Richmond, Virginia 23230
(804) 367-6913

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