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Community Impact Analysis of Ash Basin Closure Options at the Marshall Steam Station

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Prepared on behalf of Duke Energy Carolinas, LLC

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Acronyms and Abbreviations

AADT	annual average daily traffic
AOW	area of wetness
ASOS	Automated Surface Observing System
BCF	bioconcentration factor
CAMA	North Carolina Coal Ash Management Act
CAP	corrective action plan
CCR	coal combustion residuals
CCR Rule	EPA Coal Combustion Residuals Rule of 2015
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CIP	cap in place
COI	constituent of interest
COPC	chemical of potential concern
CSA	comprehensive site assessment
DPM	diesel particulate matter
Duke Energy	Duke Energy Carolinas, LLC
DSAY	discounted service acre-year
ELCR	excess lifetime cancer risk
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
ERA	ecological risk assessment
FGD	flue gas desulfurization
GIS	geographic information system
HEA	habitat equivalency analysis
HHRA	human health risk assessment
HI	hazard index
HQ	hazard quotient
LOAEL	lowest-observed-adverse-effects level
MOVES	Mobile Vehicle Emissions Simulator
MSS	Marshall Steam Station
NEBA	net environmental benefit analysis
NCDEQ	North Carolina Department of Environmental Quality
NCDOT	North Carolina Department of Transportation
NOAA	National Oceanic and Atmospheric Administration
NOAEL	no-observed-adverse-effects level
NPDES	National Pollutant Discharge Elimination System
NPP	net primary productivity
NRDA	natural resource damage assessment
OSAT-2	Operational Science Advisory Team-2
PBTV	provisional background threshold value
PV	Photovoltaic
RCRA	Resource Conservation and Recovery Act
REL	reference exposure level

RfD	reference dose
SOC	Special Order by Consent
TRV	toxicity references value
TVA	Tennessee Valley Authority

Limitations

This report sets forth my conclusions, which are based on my education, training, and experience; field work; established scientific methods; and information reviewed by me or under my direction and supervision. These conclusions are expressed to a reasonable degree of scientific certainty. The focus of this report is on local community impacts. I have, therefore, not attempted to evaluate broader environmental impacts, such as impacts from greenhouse gas emissions, that would be associated with each closure option.

The conclusions in this report are based on the documents made available to me by Duke Energy or collected as part of my investigation. I reserve the right to supplement my conclusions if new or different information becomes available to me.

Executive Summary[1]

In 2015, the U.S. Environmental Protection Agency (EPA) issued a rule called the "Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals [CCR] from Electric Utilities" (CCR Rule), which, among other things, regulates closure of coal ash impoundments in the United States. Closure of coal ash impoundments in North Carolina is further regulated by the North Carolina Coal Ash Management Act of 2014 (CAMA) as amended by H.B. 630, Sess. L. 2016-95. Under both the North Carolina CAMA and the federal CCR Rule, there are two primary alternatives for closure of an ash impoundment:

- "Cap in place" (CIP) closure involves decanting the impoundment and placing a low-permeability liner topped by appropriate cap material, soil, and grass vegetation over the footprint of the ash to restrict vertical transport of water through the ash, as well as a minimum of 30 years of post-closure care, which requires the implementation of corrective action measures if and as necessary;
- Excavation closure involves decanting the impoundment, excavating all ash in the basin, transporting the ash to an appropriate, permitted, lined landfill, and restoring the site.

Duke Energy Carolinas, LLC's (Duke Energy's) Marshall Steam Station (MSS) has one unlined inactive ash basin. CCR associated areas that lie partially or completely within the ash basin waste boundary include the Dry Ash Landfill (Phase II), the Industrial Landfill No. 1, and the Photovoltaic (PV) Farm Structural Fill. Other landfill areas located beyond the ash basin waste boundary include the Dry Ash Landfill (Phase I), the flue gas desulfurization (FGD) landfill, the demolition landfill, and the asbestos landfill (SynTerra 2018a).

Duke Energy has evaluated three representative types of closure for the ash basin at MSS—CIP, excavation, and hybrid closure—the latter of which involves excavating and consolidating ash

[1] Note that this Executive Summary does not contain all of the technical evaluations and analyses that support the conclusions. Hence, the main body of this report is at all times the controlling document.

within the basin footprint to reduce the spatial area of CIP closure. The administrative process for selecting an appropriate closure plan for the ash basin is ongoing.

The purpose of my report is to examine how the local community's environmental health and environmental services[2] are differently affected by each closure option as currently defined and to evaluate these differences in a structured framework that can support decision-making in this matter.

Environmental Decision-Making

Environmental decision-making involves understanding complex issues that concern multiple stakeholders. Identifying the best management alternative often requires tradeoffs among stakeholder values. These tradeoffs necessitate a transparent and systematic method to compare alternative actions and support the decision-making process. My analyses in this matter have used a net environmental benefit analysis (NEBA) framework (Efroymson et al. 2003, 2004) to compare the relative risks and benefits from CIP closure, excavation closure, or a hybrid CIP and excavation closure of the ash basin at MSS. The NEBA framework relies on scientifically supported estimates of risk to compare the reduction of risk associated with chemicals(s) of potential concern (COPCs)[3] under different remediation and closure alternatives alongside the creation of any risk during the remediation and closure, providing an objective, scientifically structured foundation for weighing the tradeoffs between remedial and closure alternatives.

Despite the scientific basis of the risk characterization process used in NEBA, stakeholders in any environmental decision-making scenario may place different values on different types of risk (i.e., stakeholders may have different priorities for the remediation and closure). NEBA does not, by design, elevate, or increase the value of, any specific risk or benefit in the framework. The purpose of NEBA is to simultaneously and systematically examine all tradeoffs

2 Environmental services, or ecosystem services, are ecological processes and functions that provide value to individuals or society (Efroymson et al. 2003, 2004).

3 COPCs are "any physical, chemical, biological, or radiological substance found in air, water, soil or biological matter that has a harmful effect on plants or animals" (https://ofmpub.epa.gov/sor_internet/registry/termreg/searchandretrieve/glossariesandkeywordlists/search.do?details=&glossaryName=Eco%20Risk%20Assessment%20Glossary).

that affect the services provided to humans and the ecosystem by the environment under remediation and closure, allowing decision-makers to more fully understand all potential benefits and risks of each alternative.

NEBA and similar frameworks have been used extensively by regulatory agencies such as the National Oceanic and Atmospheric Administration (NOAA) and EPA to support evaluating tradeoffs in mitigation (e.g., NOAA 1990), remediation (e.g., U.S. EPA 1988, 1994), and restoration (e.g., NOAA 1996). The National Environmental Policy Act (40 CFR § 1502) relies on a structured framework to conduct environmental assessments and produce environmental impact statements; these analyses evaluate potential adverse effects from development projects and identify alternatives to minimize environmental impacts and/or select mitigation measures. Natural resource damage assessment (NRDA) utilizes a structured process to estimate environmental injury and lost services and identify projects that restore the impacted environment and compensate the public for the lost environmental services (e.g., NOAA 1996). The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remedial investigation/feasibility study process uses a set of evaluation criteria to identify remediation projects for contaminated Superfund sites that meet remediation objectives for effectiveness, implementability, and cost (U.S. EPA 1988). Within the Superfund Program, EPA has also recognized the importance of remediation that comprehensively evaluates cleanup actions "to ensure protection of human health and the environment and to reduce the environmental footprint of cleanup activities to the maximum extent possible" (U.S EPA 2010).

The Tennessee Valley Authority (TVA) recently used a structured framework to compare the impacts and benefits of ash basin closure alternatives at ten of its facilities (TVA 2016). Through a NEBA-like analysis, the TVA identified "issue areas," such as air quality, groundwater, vegetation, wildlife, transportation, and noise and created a summary table that provided a side-by-side comparison of the impacts of "no action," "closure-in-place," and "closure-by-removal" actions. As a result of this analysis, TVA identified "closure-in-place" as "its preferred alternative" for all ten facilities stating, "[t]his alternative would achieve the purpose and need for TVA's proposed actions and compared to Closure-by-Removal with less environmental impact, shorter schedules, and less cost" (TVA 2016). The Marshall ash basin closure presents similar "issue areas" that can benefit from a similar, systematic analysis of net benefits resulting from closure activities.

Linking Stakeholder Concerns to NEBA

To better understand stakeholder concerns related to closure of the ash basin at MSS, I reviewed written communications about ash pond closure plans for MSS submitted to and summarized by the North Carolina Department of Environmental Quality (NCDEQ 2016). From this review, I identified the following categories of stakeholder concerns:

- Drinking water quality
- Groundwater quality
- Surface water quality
- Fish and wildlife
- Maintaining property value
- Preservation of natural beauty
- Recreational value
- Swimming safety
- Failure of the ash impoundment
- Risk created by the closure option outweighing risk from contamination.

The primary concerns expressed in this matter involve perceived risks from exposure to CCR constituents that could negatively affect environmental services that benefit the local community: provision of safe drinking water and food, safe recreational enjoyment (hunting, fishing, swimming), and protection of natural beauty and biodiversity.[4] Potential hazards to the community associated with closure activities include physical disturbance of existing habitats; air pollution from diesel emissions resulting from transportation activities; and traffic, noise, and accidents that could result in property damage, injuries, and fatalities. Table ES-1 links concerns over CCR exposure and potential hazards created by ash basin closure to environmental services that could be affected by closure activities.

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[4] Biodiversity is the variety of plants and animals present at a location. Protection of biodiversity refers to provision of habitat and related functions capable of sustaining biological populations.

Table ES-1. Relationships between environmental services and concerns to the local community associated with CCR and ash basin closure hazards

	Environmental Services							
	Safe drinking water quality	Safe surface water quality	Safe air quality	Safe food quality	Protection of biodiversity	Recreation	Natural beauty	Safe community environment
CCR Concerns								
Drinking water contamination	X	X						X
Groundwater contamination	X	X						X
Surface water contamination	X	X		X	X	X	X	X
Fish/wildlife contamination				X	X	X	X	X
Contamination impacting property value	X	X		X	X	X	X	X
Contamination impacting natural beauty					X		X	X
Contamination impacting recreational enjoyment		X			X	X	X	X
Contamination impacting swimming safety		X				X	X	X
Failure of the ash impoundment	X	X		X	X	X	X	X
Closure Hazards								
Habitat loss		X	X		X	X	X	
Contamination of air			X		X	X		X
Noise, Traffic, Accidents						X		X

In recognition of the potential discrepancy between stakeholder priorities and the broad and balanced treatment of service risks and benefits in NEBA, I organized the NEBA analysis around the following five objectives for ash basin closure that recognize local stakeholder concerns while being consistent with the methods and purpose of NEBA:

1. Protect human health from CCR constituent exposure
2. Protect ecological health from CCR constituent exposure
3. Minimize risk and disturbance to humans from closure
4. Minimize risk and disturbance to the local environment from closure
5. Maximize local environmental services.

In my analysis, I linked environmental services to the local community that could be potentially impacted by ash basin closure and the identified objectives of ash basin closure, and I identified attributes and comparative metrics[5] that characterize the condition of the environmental services (Efroymson et al. 2003, 2004).

I used human health attributes (e.g., risk to onsite construction workers, risk to offsite swimmers) and risk quotients (hazard index [HI], excess lifetime cancer risk [ELCR]) to evaluate whether there would be a potential impact to environmental services related to safe water, air, and food under each ash basin closure option. I also used human health attributes to evaluate whether there would be an impact to air quality during closure activities. I used ecological health attributes (e.g., risk to birds, mammals) and risk quotients (hazard quotients [HQs]) to evaluate whether there would be a potential impact to environmental services related to safe surface water and food and protection of biodiversity and natural beauty under the ash basin closure options. I evaluated risk and disturbance associated with traffic and accidents using transportation metrics and trucking logistics (e.g., number of truck miles driven) associated with each closure option to evaluate potential impacts to community safety. I used net primary productivity (NPP)[6] and discounted service acre-years (DSAYs)[7] to characterize

[5] For purposes of this analysis, an attribute is a feature that characterizes environmental services and may be impacted by a closure option. Comparative metrics are features of the attribute (e.g., risk quotients, acreage of habitat) that can be measured and compared between closure options.

[6] NPP represents the mass of chemically fixed carbon produced by a plant community during a given time interval. It reflects the rate at which different ecosystems are able to sequester carbon, which is related to mitigating climate change (https://earthobservatory.nasa.gov/GlobalMaps/view.php?d1=MOD17A2_M_PSN).

differences in the environmental services that derive from habitats (e.g., protection of biodiversity, natural beauty) and that would be impacted by ash basin closure activities. Finally, I assembled all attributes, services, and objectives within a full NEBA to examine which of the closure options best maximizes environmental services for the local community. The metrics I used are scientifically appropriate and commonly applied metrics to evaluate risk to humans and the environment (U.S. EPA 1989, 1997, 2000b; NHTSA 2016) and to quantitatively measure differences in environmental services associated with impact and restoration (Dunford et al. 2004; Desvousges et al. 2018; Penn undated; Efroymson et al. 2003, 2004).

Of note, my analysis did not consider the risks involved with onsite construction activities. For example, I did not attempt to evaluate occupational accidents created by onsite construction and excavation. Nor did I attempt to evaluate emissions associated with onsite construction activities. Finally, I did not attempt to consider the risk created by disturbing the ash basin and exposing it to the elements during excavation activities.

Some stakeholders also expressed concern over safety of the ash impoundment dam (NCDEQ 2016). The most recent dam safety report produced by Amec Foster Wheeler and submitted to NCDEQ indicates “the construction, design, operation, and maintenance of the CCR surface impoundments have been sufficiently consistent with recognized and generally accepted engineering standards for protection of public safety and the environment” (Browning and Thomas 2018).

Three possible options for closure of the ash basin at Marshall were identified by Duke Energy (2018b) and summarized in (Table ES-2). I used these options in the NEBA to examine how different closure possibilities impact environmental services to the local community.

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[7] DSAYs are derived from habitat equivalency analysis (HEA). HEA is an assessment method that calculates debits based on services lost and credits for services gained from a remediation action (Dunford et al. 2004; Desvousges et al. 2018; Penn undated). A discount rate is used to standardize the different time intervals in which the debits and credits occur, and in doing so, present the service debits and credits at present value. The present value of the services is usually expressed in terms of discounted service acre-years of equivalent habitat, or DSAYs, which provide a means to compare the different service levels of affected habitat acres (Dunford et al. 2004; Desvousges et al. 2018; Penn undated).

Table ES-2. Ash basin closure options provided by Duke Energy (2018b)

Closure Option	Description	Closure Duration (years)[a]	Construction Duration (years)[b]
CIP	CIP	15	13
Excavation	Excavate to current onsite landfill and create new landfill within the excavated basin	32	28
Hybrid	Partially excavate to consolidate ash and CIP consolidated ash	15	12

[a] Includes pre-design investigation, design and permitting, site preparation, construction, and site restoration.
[b] Includes only site preparation, construction, and site restoration.

NEBA Risk Ratings

NEBA organizes environmental hazard and benefit information into a unitless metric that represents the degree and the duration of impact from remediation and closure alternatives. One approach to structure this analysis is to create a risk-ranking matrix that maps the proportional impact of a hazard (i.e., risk) with the duration of the impact, which is directly related to the time to recovery (Robberson 2006). The risk-ranking matrix used for this application of NEBA is provided in Table ES-3. In this application, the matrix uses alphanumeric coding to indicate the severity of an impact: higher numbers and higher letters (e.g., 8F) indicate a greater extent and a longer duration of impact. Shading of cells within the matrix supports visualization of the magnitude of the effect according to the extent and duration of impact.[8] When there is no meaningful risk, the cell is not given an alphanumeric code. Relative risk ratings for each attribute and scenario examined were assembled into objective-specific summaries to compare the net benefits of the closure options. All closure options in the NEBA were evaluated against current conditions as a "baseline" for comparison.

[8] Categories and shading as defined in the risk-ranking matrix are based on best professional judgment and used for discussion of the relative differences in relative risk ratings. Alternative risk matrices and resulting NEBA classifications are explored in Appendix E.

Table ES-3. Risk-ranking matrix for impacts and risk from closure activities. Darker shading and higher codes indicate greater impact.

		Duration of Impact (years)							
		>50 **(8)**	35–50 **(7)**	26–35 **(6)**	16–25 **(5)**	10–15 **(4)**	5–9 **(3)**	1–4 **(2)**	<1 **(1)**
% Impact	No meaningful risk	--	--	--	--	--	--	--	--
	<5 % **(A)**	**8A**	**7A**	**6A**	**5A**	**4A**	**3A**	**2A**	**1A**
	5–19% **(B)**	**8B**	**7B**	**6B**	**5B**	**4B**	**3B**	**2B**	**1B**
	20–39% **(C)**	**8C**	**7C**	**6C**	**5C**	**4C**	**3C**	**2C**	**1C**
	40–59% **(D)**	**8D**	**7D**	**6D**	**5D**	**4D**	**3D**	**2D**	**1D**
	60–79% **(E)**	**8E**	**7E**	**6E**	**5E**	**4E**	**3E**	**2E**	**1E**
	>80% **(F)**	**8F**	**7F**	**6F**	**5F**	**4F**	**3F**	**2F**	**1F**

NEBA analysis of possible closure options for the ash basin at MSS helps both Duke Energy and other stakeholders understand the net environmental benefits from the closure option configurations that were examined. If a closure option that is preferred for reasons not considered in the NEBA does not rate as one of the options that best maximizes environmental services to the local community, closure plans for that option can be re-examined, and opportunities to better maximize environmental benefits can be identified (e.g., including an offsite habitat mitigation project to offset environmental services lost from habitat alteration). The NEBA can then be re-run with the updated plan to compare the revised closure plan with other closure options.

The following is a summary of my conclusions and supporting analyses, which are structured around the five objectives identified above.

Conclusion 1: All closure options for the MSS ash basin are protective of human health.

The first objective for ash basin closure, *to protect human health from CCR constituent exposure*, is represented by environmental services that provide safe drinking water, safe groundwater, safe surface water, safe food consumption, and safe recreation. For purposes of the NEBA, these safety considerations were evaluated based on the following:

1. Provision of permanent alternative drinking water supplies to private well water supply users within a 0.5-mile radius of the MSS ash basin compliance boundary (Holman 2018);
2. Concentrations of CCR constituents of interest (COIs)[9] in drinking water wells that could potentially affect local residents and visitors, as characterized by HDR (2015a, 2016b) and SynTerra (2018a) in the Comprehensive Site Assessment (CSA); and
3. Risk to various human populations from CCR exposure, as characterized in the updated human health and ecological risk assessment conducted by SynTerra (2018b; Appendix B).

Based on these analyses, no CCR impacts to drinking water and no meaningful risk to humans from CCR exposure were found under current conditions[10] or under any closure option. Using the NEBA framework and relative risk ratings, these results are summarized in Table ES-4 within the objective of protecting human health from exposure to CCR constituents.

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[9] COIs are constituents relevant to analysis of potential exposure to CCR constituents but are not necessarily associated with risk to human or ecological receptors.

[10] SynTerra's updated human health risk assessment (HHRA) considered only potential exposure pathways that currently exist and could remain after ash basin closure under any closure option. Any potential risk currently associated with seeps (or areas of wetness [AOWs]) at MSS was not evaluated in the HHRA or considered in this analysis because any risk resulting from seeps will be eliminated, reduced, or mitigated per the court-enforceable Special Order by Consent (SOC) that Duke Energy entered with the North Carolina Environmental Management Commission on April 18, 2018 (EMC SOC WQ S17-009; See Section 4.2). The SOC requires Duke Energy to accelerate the schedule for decanting the ash basin to "substantially reduce or eliminate" seeps that may be affecting state or federal waters; the SOC also requires Duke Energy to take appropriate corrective actions for any seeps remaining after decanting is complete to ensure the remaining seeps are managed "in a manner that will be sufficient to protect public health, safety, and welfare, the environment, and natural resources" (EMC SOC WQ S17-009).

Table ES-4. Summary of relative risk ratings for attributes that characterize potential hazards to humans from CCR exposure in drinking water, surface water, groundwater, food, and recreation

Objective	Protect Human Health from CCR						
Hazard	Exposure to CCR						
Potentially Affected Populations	Local Residents/Visitors	Onsite Construction Workers	Offsite Recreational Swimmers	Offsite Recreational Waders	Offsite Recreational Boaters	Offsite Recreational Fishers	Offsite Subsistence Fishers
Scenario							
Baseline	--	--	--	--	--	--	--
CIP	--	--	--	--	--	--	--
Excavation	--	--	--	--	--	--	--
Hybrid	--	--	--	--	--	--	--

"--" indicates "no meaningful risk."

Current conditions and conditions under all closure options support provision of safe drinking water, safe surface water, safe food, and safe recreation, satisfying the first objective of ash basin closure—*to protect human health from CCR constituent exposure*.

Conclusion 2: All closure options for the MSS ash basin are protective of ecological health.

The second objective for ash basin closure, *to protect ecological health from CCR constituent exposure*, is represented by environmental services that provide safe surface water, safe food consumption, and protection of biodiversity and natural beauty. For purposes of the NEBA, these considerations were evaluated based on the following:

1. Risk to ecological receptors from CCR exposure, as characterized by SynTerra (2018b; Appendix B) in the updated human health and ecological risk assessment; and

2. Aquatic community health in Lake Norman as reported in the Lake Norman Maintenance Monitoring Program summary report for 2016 (Duke Energy 2018a).

From my review of these analyses, no evidence of impacts to ecological receptors from CCR exposure was identified under current conditions[11] or under any closure option, and Lake Norman continues to support a healthy aquatic community (Duke Energy 2018a). Using the NEBA framework and relative risk ratings, these results are summarized in Table ES-5 within the objective of protecting environmental health from exposure to CCR constituents.

Current conditions and conditions under all closure options support provision of safe surface water, safe food consumption, and protection of biodiversity and natural beauty, satisfying the second objective of ash basin closure—*to protect ecological health from CCR constituent exposure*.

[11] SynTerra's updated ecological risk assessment (ERA) considered only potential exposure pathways that currently exist and could remain after ash basin closure under any closure option. Any potential risk currently associated with seeps (or AOWs) at MSS was not evaluated in the ERA or considered in this analysis because any risk resulting from seeps will be eliminated, reduced, or mitigated per the court-enforceable SOC that Duke entered with the North Carolina Environmental Management Commission on April 18, 2018 (EMC SOC WQ S17-009; See Section 4.2). The SOC requires Duke Energy to accelerate the schedule for decanting the ash basin to "substantially reduce or eliminate" seeps that may be affecting state or federal waters; the SOC also requires Duke Energy to take appropriate corrective actions for any seeps remaining after decanting is complete to ensure the remaining seeps are managed "in a manner that will be sufficient to protect public health, safety, and welfare, the environment, and natural resources" (EMC SOC WQ S17-009).

Table ES-5. Summary of relative risk ratings for attributes that characterize potential hazards to ecological resources from CCR exposure in surface water, soil, sediment, and food

Objective	Protect Ecological Health from CCR					
Hazard	Exposure to CCR					
Potentially Affected Populations	Fish Populations	Aquatic Omnivore Birds (mallard)	Aquatic Piscivore Birds (great blue heron)	Aquatic Carnivore Birds (bald eagle)	Aquatic Herbivore Mammals (muskrat)	Aquatic Piscivore Mammals (river otter)
Scenario						
Baseline	--	--	--	--	--	--
CIP	--	--	--	--	--	--
Excavation	--	--	--	--	--	--
Hybrid	--	--	--	--	--	--

"--" indicates "no meaningful risk."

Conclusion 3: CIP and hybrid closure options limit the duration of community disturbance.

The third objective for ash basin closure, *to minimize risk and disturbance to humans from closure*, is represented by environmental services that provide safe air quality and a safe community environment. For purposes of the NEBA, these considerations were evaluated based on the following:

1. Health risks from diesel exhaust emissions to the community living and working along transportation corridors during trucking operations to haul materials to and from the ash basin, as evaluated through the application of diesel truck air emissions modeling and human health risk assessment; and

2. The relative risk for disturbance and accidents resulting from trucking operations affecting residents living and working along transportation corridors during construction operations, as evaluated by comparing the relative differences in trucking operations among the closure options.

From these analyses, no meaningful health risk is expected from diesel exhaust emissions under any closure option, but all the closure options are expected to produce different levels of community disturbance in the form of noise and traffic congestion and risk of traffic accidents.

I used the number of trucks per day passing[12] a receptor along a near-site transportation corridor to examine the differences in noise and traffic congestion under the closure options. I compared the increase in the average number of trucks hauling earthen fill, geosynthetic material, and other materials under the closure options[13] to the current number of truck passes for the same receptor. I specified a baseline level of truck passes[14] on the transportation corridor under current conditions of 153 passes per day. Based on the assumed 153-truck-per-day baseline level and the number of truck trips per day from Duke Energy's projections (Duke Energy 2018b), the closure options would have similar impacts to the communities through which the trucks pass on a daily basis (CIP = 7%, excavation = 4%, hybrid = 7%). I input these percent impacts to the risk-ranking matrix (Table ES-3) along with the total duration of construction activities (13 years CIP; 28 years excavation; 12 years hybrid) to evaluate which of the closure options best minimizes human disturbances.

I also evaluated risk of traffic accidents by comparing the average number of annual offsite road miles driven between closure options relative to an estimate of the current road miles driven in Catawba County, North Carolina. I specified a current, or baseline, level of annual road miles

[12] Truck passes per day resulting from closure activities are calculated as the total number of loads required to transport earthen fill, geosynthetic materials, and other materials multiplied by two to account for return trips. The resulting total number of passes is then divided evenly among the total number of months of construction time multiplied by 26 working days per month.

[13] Truck trips to haul ash were not included in the estimate for MSS ash basin closure because trucks hauling ash would not leave MSS property and would not affect community receptors along the transportation corridors.

[14] A baseline estimate of trucking passes per day for transportation corridors near MSS was derived from North Carolina Department of Transportation (NCDOT) data of annual average daily traffic (AADT) at thousands of locations across the state and the proportion of road miles driven by large trucks in North Carolina (See Appendix E for details).

driven along the transportation corridor near Marshall of 129 million miles,[15] and the road miles driven under the closure options are from the trucking projections provided by Duke Energy (2018b). Using the 129-million-truck-miles baseline assumption, CIP has a 0.04% impact; excavation has a 0.02% impact; and hybrid closure has a 0.04% impact. All closure options have a relative risk rating of <5%. These relative risk ratings appear to be insensitive to lower assumed baseline annual truck miles (Appendix E).

Table ES-6 summarizes the NEBA relative risk ratings based on the trucking projections and implementation schedules provided by Duke Energy (2018b) for the objective of minimizing disturbance to humans during closure. All closure options create a level of risk and disturbance to human populations over baseline conditions. While the excavation closure option produces comparable, if slightly lower, impacts to CIP and hybrid closures on a daily or annual basis (risk rating of A), the impacts occur for more than twice as long as those for CIP or hybrid closure, resulting in a greater cumulative impact (risk rating 6 compared to 4) from excavation closure based on the trucking projections and implementation schedules provided by Duke Energy (2018b).

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[15] To estimate the number of baseline truck miles, I multiplied the number of total vehicle miles traveled in Catawba County (NCDMV 2017) by the Catawba County average 6.6% contribution of trucks to total AADT (NCDOT 2015).

Table ES-6. Summary of relative risk ratings for attributes that characterize potential hazards to communities during closure activities. Darker shading and higher codes indicate greater impact.

Objective	Minimize Human Disturbance		
Hazard	Noise and Traffic Congestion	Traffic Accidents	Air Pollution
Potentially Affected Populations	Local Residents/Visitors	Local Residents/Visitors	Reasonable Maximum Exposure
Scenario			
Baseline	baseline	baseline	baseline
CIP	**4B**	**4A**	**--**
Excavation	**6A**	**6A**	**--**
Hybrid	**4B**	**4A**	**--**

"--" indicates "no meaningful risk."

All closure options support safe air quality from diesel truck emissions along the transportation routes, and each creates comparable levels of disturbance and risk on a daily or annual basis that could adversely impact community safety; however, these impacts occur for a substantially longer period under the excavation closure option (28 years for excavation closure compared to 13 and 12 years for CIP and hybrid closures, respectively). Thus, CIP and hybrid closure options better satisfy the third objective of ash basin closure—*to minimize risk and disturbance to humans from closure*.

Conclusion 4: All closure options for the MSS ash basin create environmental disturbance.

The fourth objective for ash basin closure, *to minimize risk and disturbance to the local environment from closure*, is represented by two environmental services: protection of biodiversity and natural beauty. For purposes of the NEBA, these considerations were evaluated based on differences in the NPP of impacted habitats under the closure options, as estimated by the number of DSAYs calculated by a habitat equivalency analysis (HEA).

The results of the HEA indicate that all closure options will result in a net loss of environmental services due primarily to loss of forest habitat for borrow and landfill areas, reduced NPP services provided by a grass cap (cap and landfill areas),[16] and the long delay for restoration of forested habitat in the ash basin (excavation and hybrid closures) and borrow pit (all options). These factors, collectively, adversely affect environmental services provided by the impacted habitat such that environmental services produced after closure will not compensate for the service losses resulting from the closure, with hybrid closure creating the least NPP service loss. These differences are summarized in Table ES-7. A full description of the methods, assumptions, results, and sensitivity analyses for the HEA are provided in Appendix D and E.

[16] An open field provides a relatively lower NPP service level than forest habitat (40% of forest NPP; Ricklefs 2008), and since a grass cap requires periodic maintenance mowing, for purposes of the HEA it was assumed never to reach a level of NPP service equivalent to an open field. Grass cap was assigned a post-closure service level of 8%, with full service attained in 2 years.

Table ES-7. Summary of NPP DSAYs for closure options

		CIP	Excavation	Hybrid
Ash basin losses	Open Field	−8	−8	−8
	Grass Cap	−324	−306	−324
	Open Water	−253	−239	−253
	Wetland	−89	−84	−89
	Broadleaf Forest	−1,757	−1,645	−1,757
	Needle Leaf Forest	−1	−1	−1
	Scrub/Shrub	−1,542	−1,453	−1,542
	Wetland Forest	−25	−24	−25
	Total losses	−4,002	−3,758	−4,002
Ash basin post-closure gains	Open Field		89	111
	Grass Cap	784	164	495
	Open Water		329	541
	Wetland		12	15
	Broadleaf Forest		1,627	1,033
	Needle Leaf Forest		122	77
	Scrub/Shrub		309	384
	Wetland Forest		49	80
	Total gains	784	2,704	2,737
Landfill/borrow losses	Forest	−1,508	−5,286	−754
	Open Field			
	Grass Cap		−9	
	Total losses	−1,508	−5,295	−754
Landfill/borrow post-closure gains	Forest	823	1,022	424
	Grass cap		126	
	Total gains	823	1,148	424
Net Gain/Loss per Option		**−3,903**	**−5,202**	**−1,594**

Note: DSAYs for specific habitat types are reported here rounded to the nearest whole number. As such, the net gain/loss per option differs slightly from the sum of the individual DSAYs reported in the table.

The impact of the closure options on environmental services was computed as the percentage difference in net DSAYs produced by the closure option and the baseline DSAYs (or the absolute value of the DSAY losses). The DSAY losses represent the NPP services that would have been produced by the ash basin, borrow areas, and landfills but for the project closure. The DSAY gains represent the NPP services restored after project closure plus any future gains realized from existing habitats before remediation begins. The sum of DSAY losses and gains represents the net change of NPP services for the project resulting from closure. Dividing the closure option net DSAYs by the absolute value of the DSAY losses provides a percentage of the impact. From these calculations, CIP closure will have a 71% impact, excavation closure will have a 57% impact, and hybrid closure will have a 34% impact. [17] These percent impacts were input to the risk-ranking matrix (Table ES-3) along with the duration of the closure activities (13 years CIP; 28 years excavation; 12 years hybrid) to visualize, within the NEBA framework, which of the closure options best minimizes environmental disturbances (Table ES-8).

Table ES-8. Summary of relative risk ratings for habitat changes that affect protection of biodiversity and natural beauty. Darker shading and higher codes indicate greater impact.

Objective	**Minimize Environmental Disturbance**
Hazard	Habitat Change
Attribute	DSAYs
Scenario	
Baseline	baseline
CIP	**4E**
Excavation	**6D**
Hybrid	**4C**

Within the objective of minimizing environmental disturbance from closure, my analyses indicate that all closure options adversely impact habitat-derived environmental services; however, hybrid closure best minimizes impacts to the protection of biodiversity and natural beauty, better satisfying the fourth objective of ash basin closure—*to minimize risk and disturbance to the local environment from closure*.

[17] As discussed below, this habitat impact could be offset with an appropriate reforestation project.

Conclusion 5: Hybrid closure maximizes environmental services.

Identifying environmental actions that maximize environmental services (the fifth objective for ash basin closure) is a function of NEBA (Efroymson et al. 2003, 2004) and the overarching objective that encompasses each of the other four objectives and all of the environmental services that have been considered to this point.

I organized my analyses around the following five objectives for ash basin closure, and I found the following:

1. Protect human health from CCR constituent exposure
   All closure options for the MSS ash basin are protective of human health.
2. Protect ecological health from CCR constituent exposure
   All closure options for the MSS ash basin are protective of ecological health.
3. Minimize risk and disturbance to humans from closure
   CIP and hybrid closure options limit the duration of community disturbance.
4. Minimize risk and disturbance to the local environment from closure
   All closure options for the MSS ash basin create environmental disturbance.
5. Maximize environmental local services
   Hybrid closure maximizes environmental services.

Table ES-9 summarizes the relative risk ratings for all attributes and objectives that have been considered. From this analysis, which is based on a scientific definition of risk acceptability and includes no value weighting, the hybrid closure option best maximizes environmental benefits compared to the CIP and excavation closure options because it offers equivalent protection of human and ecological health from CCR exposure, results in less disturbance to the local community over time compared to excavation closure, and produces the least disturbance to the environment. Thus, hybrid closure best satisfies the fifth objective of ash basin closure—*to maximize local environmental services*.

As noted previously, NEBA analysis provides an opportunity to better understand the net environmental benefits of possible closure options. If Duke Energy's preferred closure option for reasons not considered in the NEBA does not best maximize environmental services to the local community as currently defined, the NEBA results provide insight into how environmental services could be improved for that closure option. For instance, if Duke Energy's preferred closure option for MSS is CIP closure but the HEA results for the currently defined CIP closure option estimate a net environmental service loss of 3,903 DSAYs, Duke Energy could consider incorporating into an updated CIP closure plan for MSS a mitigation project that compensates for the net environmental service losses projected from the currently defined CIP closure option. As an example, if Duke Energy started a reforestation project outside of the ash basin in 2022 (when onsite preparation of the ash basin begins), the reforestation project would gain 24.3 DSAYs/acre over the lifetime of the site (150 years in the HEA), requiring an approximate 160 acre project to compensate for the 3,903 DSAY loss projected in the HEA. Re-analysis of the HEA component of the NEBA for the updated possible closure options would then result in no net environmental losses (as NPP services) from habitat alteration of the basin for CIP closure, but net losses would remain under the hybrid and excavation closure options.

By looking at a wide variety of attributes that represent a number of different environmental services that directly link to local stakeholder concerns for the MSS ash basin, I conclude, with a reasonable degree of scientific certainty, that the hybrid closure option for the MSS ash basin provides greater net environmental services and less disturbance to the community and the environment than the excavation and CIP closure options evaluated.

Table ES-9. NEBA for closure of the ash basins at Marshall.
Darker shading and higher alphanumeric codes indicate greater impact.

Objective	**Protect Human Health from CCR**							**Protect Ecological Health from CCR**						**Minimize Human Disturbance**			**Minimize Environmental Disturbance**
Hazard	Exposure to CCR							Exposure to CCR						Noise and Traffic Congestion	Traffic Accidents	Air Pollution	Habitat Change
Potentially Affected Populations	Local Residents/Visitors	Onsite Construction Workers	Offsite Recreational Swimmers	Offsite Recreational Waders	Offsite Recreational Boaters	Offsite Recreational Fishers	Offsite Subsistence Fishers	Fish Populations	Aquatic Omnivore Birds (mallard)	Aquatic Piscivore Birds (great blue heron)	Aquatic Carnivore Bird (bald eagle)	Aquatic Herbivore Mammals (muskrat)	Aquatic Piscivore Mammals (river otter)	Local Residents/Visitors	Local Residents/Visitors	Reasonable Maximum Exposure	DSAYs
Scenario																	
Baseline	--	--	--	--	--	--	--	--	--	--	--	--	--	baseline	baseline	baseline	baseline
CIP	--	--	--	--	--	--	--	--	--	--	--	--	--	**4B**	**4A**	--	**4E**
Excavation	--	--	--	--	--	--	--	--	--	--	--	--	--	**6A**	**6A**	--	**6D**
Hybrid	--	--	--	--	--	--	--	--	--	--	--	--	--	**4B**	**4A**	--	**4C**

"--" indicates "no meaningful risk."

1 Qualifications

I am a senior managing scientist in the Ecological and Biological Sciences Practice at Exponent, a scientific and engineering consulting firm. I am a professional ecologist, toxicologist, and biologist with more than 20 years of experience studying the relationship between human activities and effects on natural resources and people. I have Doctor of Science and Master of Science degrees in environmental health from the Harvard University School of Public Health. I have a Bachelor of Science degree in biology from Rhodes College. My academic and professional training includes a broad background in topics ranging from biology, ecology, toxicology, epidemiology, pollution fate and transport, and statistical analysis. Key areas of my practice involve the use of structured frameworks for evaluating multiple lines of evidence to assess causation of environmental impacts and to weigh the benefits and consequences of decisions that affect ecological and human health.

Decision support projects I have conducted include the following:

- Net environmental benefit analysis (NEBA) to facilitate the selection of a remediation plan for a lead contaminated river and to support closure option analysis of coal ash basins;
- Developing beach management tools to improve public advisories related to elevated fecal bacteria from sewage contamination at recreational beaches;
- Selecting cleanup thresholds for sediment remediation that quantitatively weigh the tradeoff between sensitivity and specificity of potential thresholds to meet cleanup objectives;
- Natural resource damage assessment (NRDA) to support injury quantification and restoration selection; and
- Review and testimony on the sufficiency of environmental impact analysis to support development planning.

Projects I have been involved in have concerned coal ash basin closures, oil spills, sewage releases, heavy metal contamination, development planning, and various industrial and municipal facilities that have generated complex releases to the aquatic environment. A list of my publications, presentations, and cases for which I have written expert reports, been deposed, and/or provided trial testimony is provided in my *curriculum vitae*, included as Appendix A of this report.

2 Assignment and Retention

I was asked to examine how local environmental health and environmental services are differently affected under potential closure options for the coal ash basin at Duke Energy Carolinas, LLC's (Duke Energy's) Marshall Steam Station (MSS) and to evaluate these differences in a structured framework that can support decision-making. My assignment included review of the comprehensive site assessment (CSA) and corrective action plan (CAP) documents for Marshall, as well as documents available through the North Carolina Department of Environmental Quality's (NCDEQ's) website and documents prepared as part of Duke Energy's National Pollutant Discharge Elimination System (NPDES) permitting. I visited MSS on September 5, 2018, and I reviewed expert reports prepared for related matters involving MSS. A list of the primary documents I relied upon is provided in Section 3 of this report.

3 Reliance Materials

In the process of conducting my analyses, I have reviewed many documents. Of those, I have relied most on the following reports and documents. Technical (scientific literature) references are cited in subsequent sections of this report and listed in Section 12.

- Comprehensive Site Assessment (CSA) for the Marshall Steam Station (HDR 2015a, 2016b) and SynTerra (2018a)
- Corrective Action Plan (CAP) for the Marshall Steam Station (HDR 2015b, 016a)
    - Baseline Human Health and Ecological Risk Assessment for the Marshall Steam Station (HDR 2016c [Appendix F of CAP 2])
- Lake Norman Maintenance Monitoring Program summary report for 2016 (Duke Energy 2018a)
- NCDEQ Marshall Meeting Officer Report (NCDEQ 2016)
    - Attachment V. Written Public Comments Received
    - Attachment VIII. Public Comment Summary Spreadsheet
- Updated Baseline Human Health and Ecological Risk Assessment (SynTerra 2018b; Appendix B)
- Closure logistics estimates (Duke Energy 2018b).

4 Introduction

In 2015, the U.S. Environmental Protection Agency (EPA) issued a rule called the "Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals [CCR] from Electric Utilities" (CCR Rule), which, among other things, regulates closure of coal ash impoundments in the United States. Closure of coal ash impoundments in North Carolina is further regulated by the North Carolina Coal Ash Management Act of 2014 (CAMA), as amended by H.B. 630, Sess. L. 2016-95. Under both the North Carolina CAMA and the federal CCR Rule, there are two primary alternatives for closure of an ash impoundment:

- "Cap in place" (CIP) closure involves decanting the impoundment and placing a low permeability liner topped by appropriate cap material, soil, and grass vegetation over the footprint of the ash to restrict vertical transport of water through the ash, as well as a minimum of 30 years of post-closure care, which requires the implementation of corrective action measures if and as necessary;
- Excavation closure involves decanting the impoundment, excavating all ash in the basin, transporting the ash to an appropriate, permitted, lined landfill, and restoring the site.

Duke Energy has evaluated three representative types of closure for the ash basin at MSS—CIP, excavation to a new onsite landfill at MSS, and hybrid closure—the latter of which involves excavating and consolidating ash within the basin footprint to reduce the spatial area of CIP closure. The administrative process for selecting an appropriate closure plan is ongoing.

The purpose of my report is to examine how the local community's environmental health and environmental services[18] are differently affected by each closure option as currently defined and to evaluate these differences in a structured framework that can support decision-making in this matter.

[18] Environmental services, or ecosystem services, are ecological processes and functions that provide value to individuals or society (Efroymson et al. 2003, 2004).

4.1 Site Setting

MSS is a four-unit coal-fired power plant located on the west bank of Lake Norman near Terrell, North Carolina, in Catawba County and is approximately 1,446 acres in area (Figure 4-1; SynTerra 2018a).

Marshall began operations in 1965 with Unit 1; Unit 2 was added in 1966; Unit 3 in 1969; and Unit 4 in 1970 (SynTerra 2018a). Marshall has one unlined active ash basin that is approximately 394 acres in size and was formed by constructing an earthen dike at the confluence of Holdsclaw Creek and Lake Norman (an impounded segment of the Catawba River). The ash basin has "a dendritic shape consisting of coves of deposited ash, dikes that impound ash in portions of the basin, and four main areas of ponded water" (SynTerra 2018a). Historically, fly ash and bottom ash were wet sluiced to the ash basin; however, since 1984, fly ash has been disposed of in the onsite dry ash landfills, and bottom ash is currently wet-sluiced to a concrete pit where the overlying water decants to the ash basin and the remaining ash is excavated and sold for offsite beneficial reuse or used for road maintenance at MSS (SynTerra 2018a). In addition to the overlying water from bottom ash recovery, contact stormwater and leachate from the flue gas desulfurization (FGD) landfill and FGD wastewater treatment system effluent are routed to the ash basin. The active ash basin contains approximately 16.7 million tons of CCR (SynTerra 2018a), and effluent from the ash basin discharges to Lake Norman through National Pollutant Discharge Elimination System (NPDES) Outfall 002 (Figure 4-1).

MSS has two unlined ash landfill units on the eastern edge of the ash basin—Ash Landfill Phase I[19] and Ash Landfill Phase II. The Phase I landfill contains approximately 280,000 tons of fly ash, and the Phase II landfill contains approximately 4.9 million tons of fly ash (SynTerra 2018a).

Other waste management areas at MSS include additional landfills and a structural fill. The FGD landfill is a single-liner system located to the west of the ash basin that is permitted to receive FGD residue (gypsum), clarifier sludge, fly ash, bottom ash, construction and

[19] The ash basin footprint underlies a portion of the Phase I landfill.

demolition waste, asbestos waste, mill rejects (pyrites), waste limestone, land clearing and inert debris, boiler slag, ball mill rejects, sand blast material, and coal waste; however, the FGD landfill is currently in interim closure with a 12 in. soil cover system in place and a geosynthetic clay liner planned to be installed by the end of 2018 (SynTerra 2018a). The Industrial Landfill No. 1,[20] which has been historically permitted to receive the same inputs as the ash landfills noted above, is located along the northern portion of the ash basin and has a three-component liner system and a leachate collection and removal system (SynTerra 2018a). The unlined Photovoltaic (PV) Farm Structural Fill[21] located along the northwestern portion of the ash basin is constructed of fly ash and contains a solar panel field on the south portion of the structural fill unit (see Figure 4-2); the PV Farm Structural Fill was closed with a soil cover in 2013 (SynTerra 2018a). A demolition landfill and asbestos landfill are also located at MSS and were closed with soil caps in 2008 (SynTerra 2018a).

[20] The Industrial Landfill No. 1 is partially located above the ash basin.

[21] The PV Farm Structural Fill is partially located above the ash basin.

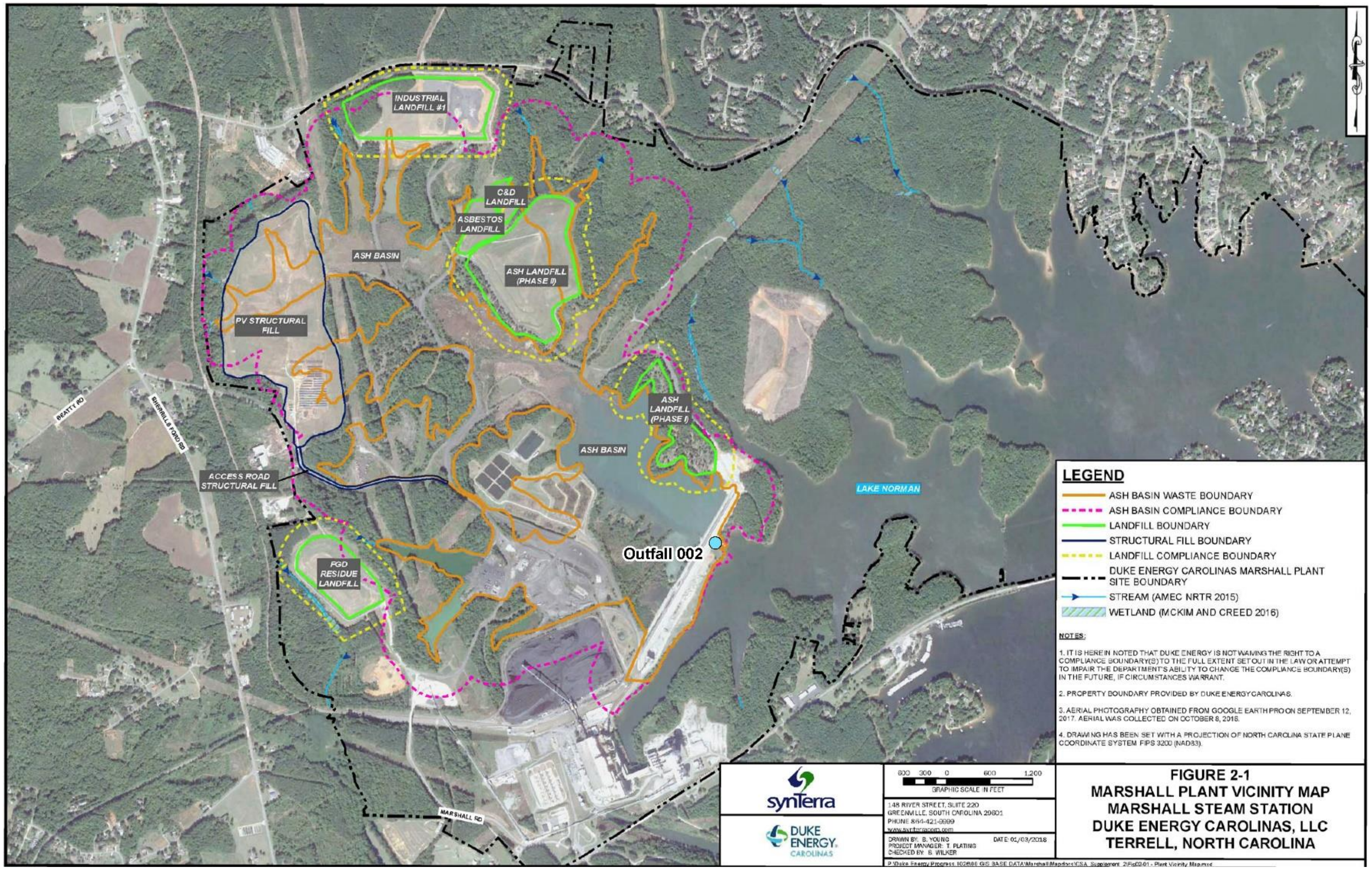

Figure 4-1. Map of MSS. Reproduced and adapted from Figure 2-1 of the 2018 CSA Supplement (SynTerra 2018a). The location of ash basin discharge to Lake Norman was added (NPDES Outfall 002).

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MSS is located in an ecological transitional zone between the Appalachian Mountains and the Atlantic coastal plain.[22] Historically, much of the region was transformed from oak-hickory-pine forests to farmland and more recently from farmland back to woodlands characterized by successional pine and hardwood forest (Griffith et al. 2002). Current aerial imagery and onsite observations show that approximately 68% of MSS property is forested,[23] and I observed forest, scrub/shrub,[24] open water, wetland, and mowed grass habitat areas onsite during my September 5, 2018 visit (Figure 4-2).

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22 Marshall is located in the Southern Outer Piedmont based on EPA's ecoregion classification system. https://www.epa.gov/eco-research/ecoregions

23 Based on interpretation of aerial satellite imagery and geographic information system (GIS) layers provided by Duke Energy for Marshall.

24 Scrub/shrub habitat is characterized by low, woody plants.

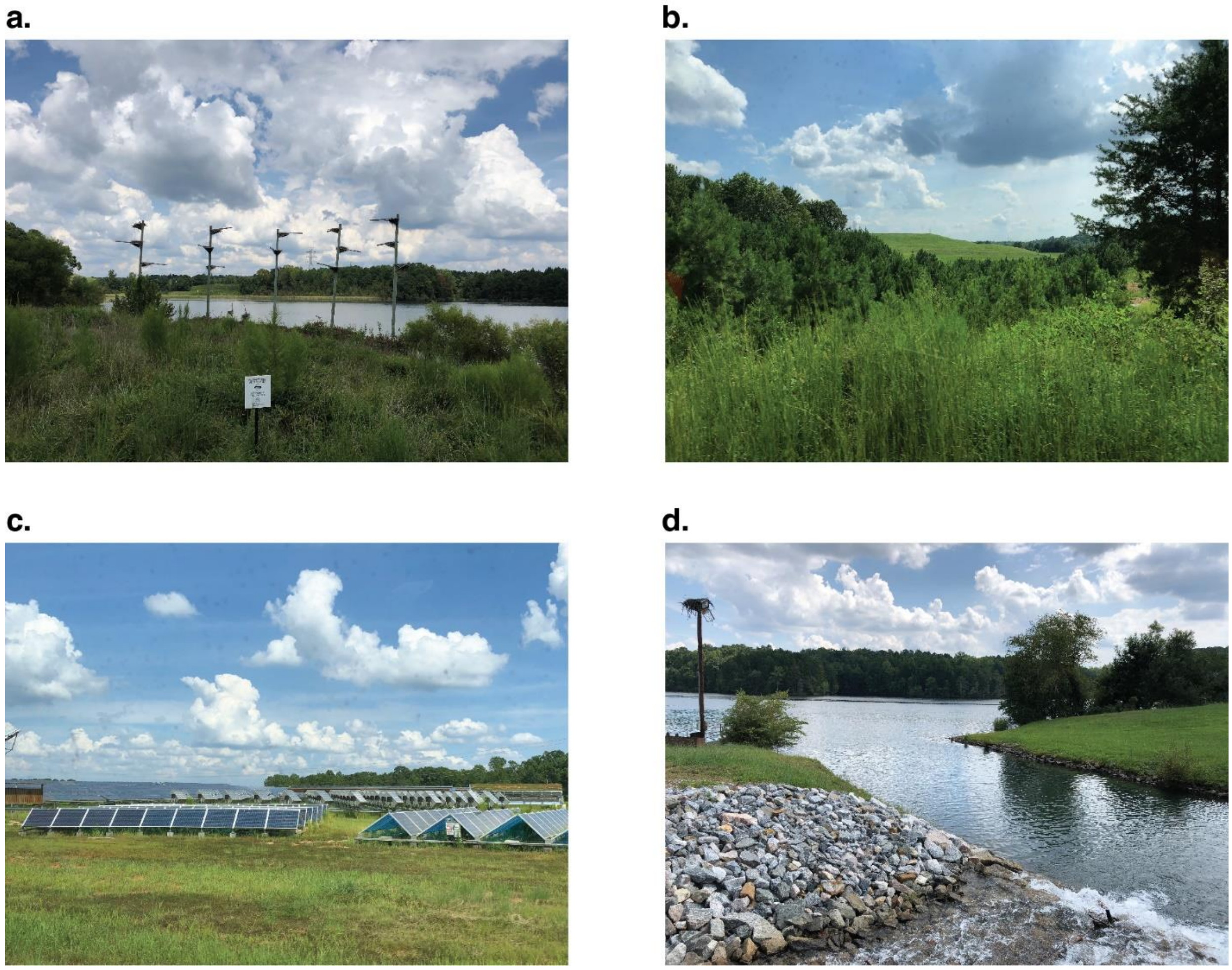

Figure 4-2. Images of various habitat types at MSS, September 5, 2018.
(a) Forest, shrub/scrub, and open water habitat looking north through a heron rookery adjacent to the ash basin. (b) Forest, shrub/scrub, and mowed grass habitat looking north toward the Industrial Landfill No. 1. (c) Forest and mowed grass habitat visible from the PV Farm Structural Fill. (d) Open water and forest around Lake Norman at NPDES Outfall 002 from the ash basin to Lake Norman; N.B., osprey nest can be seen on top of the street light adjacent to the outfall.

The area surrounding MSS generally includes residential properties, undeveloped land, and Lake Norman (SynTerra 2018a). Lake Norman was formed in 1963 when the Catawba River was dammed during construction of Cowan's Ford Hydroelectric Station, creating the largest man-made body of water in the state of North Carolina (Duke Energy 2018a). Lake Norman is a popular recreational destination for fishing, swimming, and boating.[25] Known as a "bass fishing haven," anglers catch channel catfish (*Ictalurus punctatus*), flathead catfish (*Pylodictis olivaris*), blue catfish (*Ictalurus furcatus*), black crappie (*Promoxis nigro-maculatus*), bluegill (*Lepomis*

[25] https://www.visitlakenorman.org/things-to-do/lake-activities/

macrochirus), largemouth bass (*Micropterus salmoides*), striped bass (*Morone saxatilis*), spotted bass (*Micropterus punctulatus*), white bass (*Morone chrysops*), and yellow perch (*Perca* flavescens) from Lake Norman.[26] "Visit Lake Norman" hosts "several national fishing tournaments annually, a testament to the fishing opportunities available here."[27] In addition to the abundant and diverse fish in Lake Norman, a variety of wildlife can be found around the lake, including numerous species of songbirds as well as larger species such as great blue heron (*Ardea herodias*), osprey (*Pandion haliaetus*), bald eagle (*Haliaceetus leucocepbalus*), black vulture (*Coragyps atratus*), turkey vulture (*Catbartes aura*), great egret (*Ardea alba*), red Tail hawk (*Buteo jamaicensis*), mute swan (*Cygnus olor*), and black swan (*Cygnus atratus*);[28] eastern wild turkey (*Meleagris gallopavo silvestris*) are also found in the terrestrial habitat around Lake Norman.[29] A great blue heron rookery is located at MSS adjacent to the ash basin, and osprey nests are also found on site, including one built atop the street lamp next to NPDES Outfall 002 (Figure 4-2).

4.2 Closure of the Ash Impoundments at Marshall

Coal ash, or CCR, includes fly ash, bottom ash, boiler slag, and FGD material (U.S. EPA 2017c). CCR are derived from the inorganic minerals in coal, which include quartz, clays, and metal oxides (EPRI 2009). Fine-grained, amorphous particles that travel upward with flue gas are called fly ash, while the coarser and heavier particles that fall to the bottom of the furnace are called bottom ash (EPRI 2009). The chemical composition of coal ash is similar to natural geologic materials found in the earth's crust, but the physical and chemical properties of coal ash vary depending on the coal source and the conditions of coal combustion and cooling of the flue gas (EPRI 2009). The majority of both fly ash and bottom ash are composed of silicon, aluminum, iron, and calcium, similar to volcanic ash and shale (Figure 4-3). Trace elements such as arsenic, cadmium, lead, mercury, selenium, and chromium generally constitute less than

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26 https://www.aa-fishing.com/nc/nc-fishing-lake-norman.html

27 https://www.visitlakenorman.org/things-to-do/lake-activities/fishing-guides/

28 http://www.bestoflakenorman.com/about_lake_norman/wildlife/birds_waterfowl/index.php

29 http://www.lakenormanpublications.com/herald_weekly/wildlife-of-all-kinds-found-around-lake-norman/article_ac62daf8-1a2e-11e7-8871-c3a109ab9daf.html

1% of total CCR composition (EPRI 2009; USGS 2015). CCR are classified as a non-hazardous solid waste under the Resource Conservation and Recovery Act (RCRA).[30]

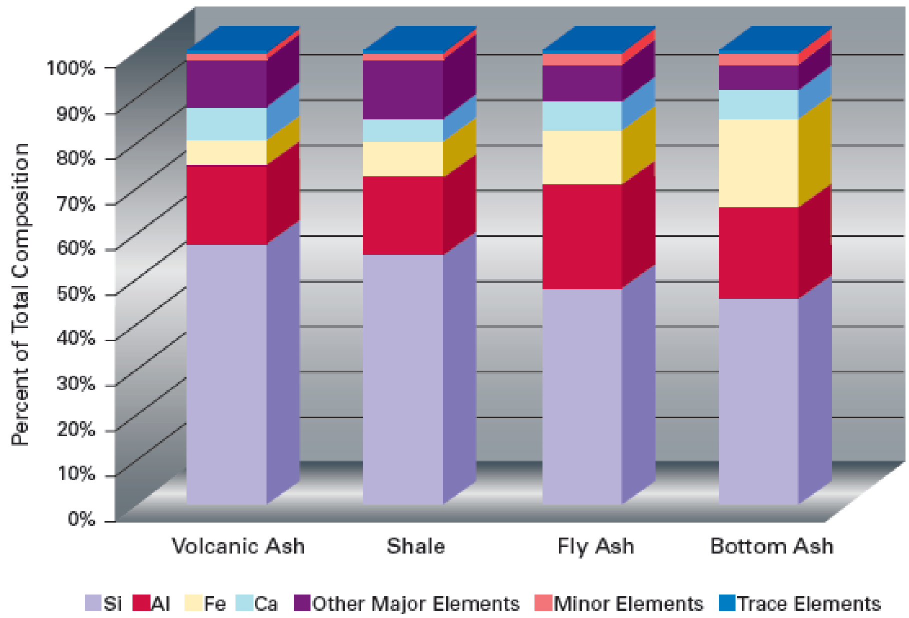

Figure 4-3. Elemental composition of bottom ash, fly ash, shale, and volcanic ash. Excerpt from EPRI (2009).

EPA's 2015 CCR Rule (40 CFR §§ 257 and 261) requires groundwater monitoring[31] of CCR landfills and surface impoundments and for corrective action, including closure, of CCR sites under certain circumstances. Owners and operators of CCR landfills and impoundments that are required to close under the regulation must conduct an analysis of the effectiveness of potential corrective measures (a corrective measures assessment) and select a strategy that involves either excavation or capping the "waste-in-place." Per § 257.97(b), the selected strategy must at a minimum be protective of human health and the environment, attain groundwater protection standards, control the source of releases so as to reduce or eliminate further releases of certain CCR constituents into the environment, remove from the environment as much of the

[30] https://www.epa.gov/coalash/coal-ash-rule

[31] Groundwater must be evaluated for boron, calcium, fluoride, pH, sulfate, and total dissolved solids, which are defined as the constituents for detection monitoring in Appendix III. When a statistically significant increase in Appendix III constituents over background concentrations is detected, monitoring of assessment monitoring constituents (Appendix IV) is required. Assessment monitoring constituents are antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, fluoride, lead, lithium, mercury, molybdenum, selenium, thallium, and radium 226 and 228, combined.

contaminated material that was released from the CCR unit as is feasible, taking into account factors such as avoiding inappropriate disturbance of sensitive ecosystems, and comply with the standards for management of wastes in § 257.98(d).

The CCR Rule does not provide criteria for selecting between these closure alternatives because they are both considered effective closure methods. The CCR Rule states both methods of closure "can be equally protective, provided they are conducted properly." Hence, the final CCR Rule allows the owner or operator to determine whether excavation or closure in place is appropriate for their particular unit (80 FR 21412).

For the last several years, Duke Energy has been evaluating all of its ash impoundments and remains in the midst of further evaluating each one, including at MSS, under the CCR Rule and pursuant to the administrative process set forth in CAMA. Ultimately, a final closure plan will be approved by NCDEQ.

Three possible options for closure of the ash basin at MSS were identified by Duke Energy and are summarized in (Table 4-1). These options were used in the NEBA to examine how different closure possibilities impact environmental services to the local community.

Table 4-1. Ash basin closure options provided by Duke Energy (2018b)

Closure Option	Description	Closure Duration (years)[a]	Construction Duration (years)[b]
CIP	CIP	15	13
Excavation	Excavate into existing and new onsite landfills.	32	28
Hybrid	Partially excavate to consolidate ash and CIP consolidated ash	15	12

[a] Includes pre-design investigation, design and permitting, site preparation, construction, and site restoration.
[b] Includes only site preparation, construction, and site restoration.

Table 4-2 provides a summary of some of the logistical differences between the closure options. Key among these are the following: (1) a substantially longer period is necessary to complete excavation closure and (2) substantially more deforestation is required under an excavation closure for new landfill space and provision of barrow material. Considering logistics alone, however, does not provide a complete understanding of the potential benefits and hazards associated with each closure option, and an integrated analysis is necessary to place stakeholder concerns regarding risk from CCR in the larger context of risks and benefits to environmental services.

Table 4-2. Overview of some key logistical differences between closure options for the MSS ash basin. Data provided by Duke Energy (2018b).

Closure Option	Closure Completion Time (years)[a]	Deforested Acres[b]	Average truck trips/day[c]	Total truck miles[d]
CIP	15	50	5	588,009
Excavation	32	303	3	832,249
Hybrid	15	25	6	535,753

[a] Includes pre-design investigations, design and permitting, site preparation, construction, and site restoration.
[b] Includes areas deforested to create borrow pits and/or landfill.
[c] Includes the total number of offsite roundtrip truck trips to haul earthen and geosynthetic material to and from the ash basin.
[d] Includes the total number of truck miles driven over the duration of construction operations to haul material to and from the ash basin.

Closure of the ash basin at MSS involves decanting any overlying water in the basin and excavating or capping in place the underlying ash, as specified under CAMA and the federal CCR Rule. Additional activities related to, but separate from, closure under CAMA and the CCR Rule concern constructed[32] and non-constructed[33] seeps associated with the ash basin.[34] A Special Order by Consent (SOC; EMC SOC WQ S17-009) was signed by the North Carolina Environmental Management Commission and Duke Energy on April 18, 2018, to "address issues related to the elimination of seeps" from Duke Energy's coal ash basins. The SOC requires Duke Energy to accelerate the schedule for decanting the ash basin to "substantially reduce or eliminate" seeps that may be affecting state or federal waters; the SOC also requires Duke Energy to take appropriate corrective actions for any seeps remaining after decanting is

[32] Constructed seeps are features within the dam structure, such as toe drains or filter blankets, that collect seepage of liquid through the dam and discharge the seepage through a discrete, identifiable point source to a receiving water; there are no constructed seeps at MSS to incorporate into the MSS NPDES permit NC0004987 and managed as part of the wastewater treatment system at MSS (NCDEQ 2018).

[33] Non-constructed seeps are not on or within the dam structure and do not convey liquid through a pipe or constructed channel; non-constructed seeps at MSS that require monitoring (and potentially action if they are not eliminated after ash basin decanting) are listed in the SOC (EMC SOC WQ S17-009).

[34] In 2014, Duke Energy provided a comprehensive evaluation of all areas of wetness (AOWs or seeps) on Duke Energy property and formally applied for NPDES coverage for all seeps (EMC SOC WQ S17-009).

complete to ensure the remaining seeps are managed “in a manner that will be sufficient to protect public health, safety, and welfare, the environment, and natural resources” (EMC SOC WQ S17-009). Given the court-enforceable requirement for Duke Energy to remediate any seeps remaining after decanting the ash basin to meet standards for the protection of public and environmental health, for purposes of my analyses, seeps (or areas of wetness [AOWs]) are assumed to contribute no meaningful risk to humans or the environment following any closure option since all closure options will entail decanting the basins and remediating any risk associated with remaining seeps as required by the SOC (EMC SOC WQ S17-009).

5 Approach to Forming Conclusions

Environmental decision-making involves understanding complex issues that concern multiple stakeholders. Identifying the best management alternative often requires tradeoffs among stakeholder values. For example, remediation management alternatives can decrease potential risks to human health and the environment from contaminants, but such benefits can also have unintended consequences, such as adverse impacts to other functions of the environment (e.g., destruction of habitat) or create other forms of risk (e.g., contamination of other environmental media). These tradeoffs between existing and future environmental services necessitate a transparent and systematic method to compare alternative actions and support the decision-making process.

Structured frameworks or processes are commonly used to weigh evidence and support requirements for environmental decision-making. Examples include:

- Environmental assessment (EA) and environmental impact statement (EIS) process that supports National Environmental Policy Act requirements for evaluating impacts from development projects and selecting mitigation measures (40 CFR § 1502);
- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remedial investigation/feasibility study process that characterizes risk from contaminants at a site and then evaluates remediation alternatives (U.S. EPA 1988);
- RCRA corrective measures study that supports identification, development, and evaluation of potential remedial alternatives for corrective action (U.S. EPA 1994);
- EPA's causal analysis/diagnosis decision information system (CADDIS) that supports stressor identification and selection of appropriate mitigation actions under the Clean Water Act (Cormier et al. 2000);

- NRDA that characterizes injury and lost human services to support selection of restoration projects under a number of environmental laws, including CERCLA and the Oil Pollution Act of 1990 (e.g., NOAA 1996); and
- NEBA that evaluates the tradeoffs in environmental impacts and benefits from remediation alternatives (NOAA 1990; Efroymson et al. 2003, 2004).

These frameworks have different regulatory origins and somewhat different approaches to accomplishing their specific objectives, but they all rely on a common core of analyses, including characterization of exposures, identification of adverse effects, definition of complete pathways between exposures and effects, characterization of risk or impact to exposed receptors (i.e., human and ecological populations), and weight-of-evidence analysis.

My analyses in this matter have used a NEBA framework to compare the relative risks and benefits derived from the closure options under consideration for the ash basin at MSS. NEBA was originally developed to examine impacts and benefits to ecological resources and habitats excluding impacts and risk to humans (Efroymson et al. 2004); however, as noted by EPA (2009), remediation and closure actions can also have both direct and indirect consequences to humans. To support a more thorough analysis of the net benefits of each closure option in this matter, I have included comparative analyses in the NEBA that consider environmental health more broadly, including risks and benefits to both ecological and human populations in the vicinity. My analyses draw on the core principles of the environmental decision support frameworks discussed above and follow a pragmatic and transparent process.

In assembling information for the NEBA and forming my conclusions, I have relied on analyses reported in the CSA and CAP documents, as well as information provided by Duke Energy. Because a NEBA of environmental health necessarily encompasses a variety of scientific disciplines, I assembled a team of professionals within Exponent with expertise in ecological risk assessment (ERA), human health risk assessment (HHRA), contaminant fate and transport, decision support analysis, remediation, and statistics to review documents and, where indicated, conduct analyses at my direction. The results of these efforts are included in this report and have been reviewed by me.

5.1 Net Environmental Benefit Analysis

Net environmental benefits are defined as, "the gains in environmental services or other ecological properties attained by remediation or ecological restoration, minus the environmental injuries caused by those actions" (Efroymson et al. 2003, 2004). Environmental services, or ecosystem services, are ecological processes and functions that produce value to individuals or society. A NEBA, as discussed above, is a structured framework for comparing impacts and benefits to environmental services and support decision-making (Efroymson et al. 2003, 2004). NEBA can be useful in evaluating and communicating the short-term and long-term impacts of remedial alternatives but does not make a determination of which alternative is best; that decision must be made by stakeholders and decision-makers and may ultimately involve weighing or prioritizing some values or objectives over others (Efroymson et al. 2003, 2004).

NEBA relies on scientifically supported estimates of risk to compare the reduction of risk associated with the chemicals of potential concern (COPCs)[35] under different remediation and closure alternatives alongside the creation of any risk during the remediation and closure, providing an objective, scientifically structured foundation for weighing the tradeoffs among remedial and closure alternatives. Despite the scientific basis of the risk characterization process, however, stakeholders in any environmental decision-making scenario may place different values on different types of risk. In other words, stakeholders may have different priorities for the remediation and closure. NEBA does not, by design, elevate, or increase the value of, any specific risk or benefit in the framework. The purpose of NEBA is to simultaneously and systematically examine all tradeoffs that affect the services (e.g., provision of safe drinking water, protection of biodiversity[36]) provided to humans and the ecosystem by the environment under remediation and closure, allowing decision-makers to more fully understand all potential benefits and risks of each alternative.

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[35] COPCs are "any physical, chemical, biological, or radiological substance found in air, water, soil or biological matter that has a harmful effect on plants or animals" (https://ofmpub.epa.gov/sor_internet/registry/termreg/searchandretrieve/glossariesandkeywordlists/search.do?details=&glossaryName=Eco%20Risk%20Assessment%20Glossary).

[36] Biodiversity is the variety of plants and animals present at a location. Protection of biodiversity refers to provision of habitat and related functions capable of sustaining biological populations.

EPA supports the use of NEBA (U.S. EPA 2009) as a means to compare remediation and redevelopment alternatives "based on their contributions to human well-being." EPA and the National Oceanic and Atmospheric Administration (NOAA) also use NEBA to support oil spill response decision-making (Robberson 2006; NOAA 1990). Examples of NEBA in oil-spill decision-making include:

- *Exxon Valdez* Oil Spill: NEBA was first applied to weigh the net environmental benefits of rock-washing to remove beached oil versus leaving the oil in place to naturally degrade (NOAA 1990).
- *Deepwater Horizon* Oil Spill: NEBA was used by the Operational Science Advisory Team-2 (OSAT-2) to "compare the environmental consequences of the defined cleanup endpoints for the oil and beach types considered, and the consequences of cleanup beyond those endpoints," specifically noting, "It is at this juncture that the concept of continued remedial efforts doing 'more harm than good' becomes a concern" (OSAT 2011).

I have personally applied NEBA to evaluate the net environmental benefits associated with two alternative sediment remediation cleanup goals for lead contamination in a tidal river. At that site, the river had been contaminated with lead from a battery manufacturing facility, and the state required removal of contaminated sediment that could potentially pose a health risk to people and the environment. The responsible party conducted human and ecological risk assessments, toxicity tests, and benthic community analyses to support the selection of an appropriate cleanup threshold for lead that would be protective of humans and the natural environment. Uncertainty in the results, however, led to two different remediation threshold concentrations being proposed by the state and by the responsible party. The NEBA was conducted to examine the tradeoffs in environmental impacts associated with the two cleanup thresholds. For one segment of the river, the footprint of remediation, including the size and types of habitat impacted, was substantially different under the alternative cleanup goals. The lower remediation threshold caused much greater impacts to submerged aquatic vegetation and riparian (shoreline) habitat that had cascading consequences to animals that rely on those environments. NEBA was able to demonstrate that remediation to the lower threshold would cause greater ecological harm and disturbance to the local community with little or no decrease in risk to benthic invertebrates (the ecological receptor at issue).[37] Consequently, the higher remediation goal was applied to that segment of the river.

These examples of NEBA are particularly relevant to the issues at Marshall. Remediation and closure of coal ash basins is specifically addressed in CAMA and the CCR Rule, and both CIP and excavation closure satisfy defined cleanup endpoints. At issue is whether removal of the coal ash under an excavation closure crosses the "juncture," as noted by OSAT-2, where the action would do more harm than good (OSAT 2011).

5.2 Linking Stakeholder Concerns to NEBA

To better understand stakeholder concerns related to closure of the ash basin at MSS, I reviewed written communications about ash basin closure plans for MSS submitted to and summarized by NCDEQ (2016). From this review, I identified the following categories of stakeholder concerns:

- Drinking water quality
- Groundwater quality
- Surface water quality
- Fish and wildlife
- Maintaining property value
- Preservation of natural beauty
- Recreational value
- Swimming safety
- Failure of the ash impoundment
- Risk created by the closure option outweighing risk from contamination.

The primary concerns expressed by community stakeholders involve perceived risks from exposure to CCR constituents that could negatively affect environmental services that benefit the community: provision of safe drinking water and food, safe recreational enjoyment (e.g., hunting, fishing, swimming), protection of natural beauty, and biodiversity. Potential hazards to

[37] Both remediation goals were found to be protective of human, fish, bird, and mammal health. Uncertainty in toxicity test results and concern for protection of benthic macroinvertebrates (e.g., insect larvae and crustaceans) led the state to propose a lower remediation threshold for lead.

the community associated with closure activities include physical disturbance of existing habitats; air pollution from diesel emissions; and traffic, noise, and accidents that could result in property damage, injuries, and fatalities. Table 5-1 links concerns over CCR exposure and potential hazards created by ash basin closure to environmental services that could be affected by closure activities.

Table 5-1. Relationships between environmental services and concerns to the local community associated with CCR and ash basin closure hazards

	Environmental Services							
	Safe drinking water quality	Safe surface water quality	Safe air quality	Safe food quality	Protection of biodiversity	Recreation	Natural beauty	Safe community environment
CCR Concerns								
Drinking water contamination	X	X						X
Groundwater contamination	X	X						X
Surface water contamination	X	X		X	X	X	X	X
Fish/wildlife contamination				X	X	X	X	X
Contamination impacting property value	X	X		X	X	X	X	X
Contamination impacting natural beauty					X		X	X
Contamination impacting recreational enjoyment		X			X	X	X	X
Contamination impacting swimming safety		X				X	X	X
Failure of the ash impoundment	X	X		X	X	X	X	X
Closure Hazards								
Habitat alteration		X	X		X	X	X	
Contamination of air			X		X	X		X
Noise, Traffic, Accidents						X		X

In recognition of the potential discrepancy between stakeholder priorities and the broad and balanced treatment of service risks and benefits in NEBA, I organized the NEBA in this matter around the following five objectives for ash basin closure that recognize stakeholder concerns while being consistent with the methods and purpose of NEBA:

1. Protect human health from CCR constituent exposure
2. Protect ecological health from CCR constituent exposure
3. Minimize risk and disturbance to humans from closure
4. Minimize risk and disturbance to the local environment from closure
5. Maximize local environmental services.

Associations between environmental services to the local community that could be potentially impacted by ash basin closure and the identified objectives of ash basin remediation are shown in Table 5-2.

Table 5-2. Associations between objectives for closure and remediation of the Marshall ash basins and environmental services

	Ash Basin Closure Objectives				
Environmental Services	Protect human health from CCR constituent exposure	Protect ecological health from CCR constituent exposure	Minimize risk and disturbance to humans from closure	Minimize risk and disturbance to the local environment from closure	Maximize local environmental services
Safe drinking water quality	X	X			X
Safe surface water quality	X	X			X
Safe air quality			X		X
Safe food quality	X	X			X
Recreation	X				X
Natural beauty		X		X	X
Protection of biodiversity		X		X	X
Safe community environment			X		X

NEBA relies on comparative metrics for specific attributes of the environment to examine the potential impacts and benefits from remediation and closure alternatives (Efroymson et al. 2003, 2004). NEBA methodology is not, however, prescriptive in defining attributes or comparative metrics because each application of NEBA is unique to contaminant exposure, remediation and closure alternatives, available data, and stakeholder concerns. NEBA is an extension of the risk assessment process (Efroymson et al. 2004). As a result, receptors, exposure pathways, and risks identified in a site risk assessment are key inputs to a NEBA. The links between key environmental services, attributes that represent those services, and comparative metrics used in this NEBA are summarized in Table 5-3.

Table 5-3. Matrix of key environmental services, attributes, and comparative metrics applied in the NEBA

	Attributes			
Environmental Services	Human Health Risk	Ecological Health Risk	Net Primary Productivity	Transportation Metrics
Safe ground water quality	HI/ELCR	--	--	
Safe surface water quality	HI/ELCR	HQ		
Safe soil and sediment quality	HI/ELCR	HQ	--	
Safe air quality	HI/ELCR	--	--	
Safe food quality	HI/ELCR	HQ	--	
Protection of biodiversity		HQ	DSAYs	
Recreation	HI/ELCR[a]	--	DSAYs	
Natural beauty		HQ	DSAYs	
Safe community environment		--		Trucking Logistics

Notes:

DSAYs – discounted service acre-years
ELCR – excess lifetime cancer risk
HI – hazard index
HQ – hazard quotient

[a] Estimated from health risks from consumption of fish.

I used human health attributes (e.g., risk to onsite construction workers, risk to offsite swimmers) and risk quotients (hazard index [HI], excess lifetime cancer risk [ELCR]) to evaluate whether there would be a potential impact to environmental services related to safe water, air, and food under the ash basin closure options. I also used human health attributes to evaluate whether there would be an impact to air quality during closure activities. I used ecological health attributes (e.g., risk to birds, mammals) and risk quotients (hazard quotient [HQ]) to evaluate whether there would be a potential impact to environmental services related to safe surface water and food and protection of biodiversity and natural beauty under the ash basin closure options. I evaluated risk and disturbance associated with traffic and accidents using transportation metrics and trucking logistics (e.g., number of truck miles driven) associated with each closure option to evaluate impacts to community safety. I used net primary productivity (NPP)[38] and discounted service acre-years (DSAYs)[39] to characterize differences in the environmental services that derive from habitats (e.g., protection of biodiversity, natural beauty) and that would be impacted by ash basin closure activities. Finally, I assembled all attributes, services, and objectives within a full NEBA to examine which of the closure options best maximizes environmental services to the local community. These metrics represent scientifically appropriate and commonly applied metrics to evaluate risk to humans and the environment (U.S. EPA 1989, 1997, 2000b; NHTSA 2016) and to quantitatively measure differences in environmental services associated with impact and restoration (Dunford et al. 2004; Desvousges et al. 2018; Penn undated; Efroymson et al. 2003, 2004).

Of note, my analysis did not consider the risks involved with on-site construction activities. For example, I did not attempt to evaluate occupational accidents created by on-site construction and excavation. Nor did I attempt to evaluate emissions associated with on-site construction activities. Finally, I did not attempt to consider the risk created by disturbing the ash basin and exposing it to the elements during excavation activities.

Some stakeholders also expressed concern over safety of the ash impoundment dam (NCDEQ 2016). The most recent dam safety report produced by Amec Foster Wheeler and submitted to NCDEQ indicates “the construction, design, operation, and maintenance of the CCR surface

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[38] NPP represents the mass of chemically fixed carbon produced by a plant community during a given time interval. It reflects the rate at which different ecosystems are able to sequester carbon, which is related to mitigating climate change (https://earthobservatory.nasa.gov/GlobalMaps/view.php?d1=MOD17A2_M_PSN).

[39] DSAYs are derived from habitat equivalency analysis (HEA). HEA is an assessment method that calculates debits based on services lost and credits for services gained from a remediation action (Dunford et al. 2004; Desvousges et al. 2018; Penn undated). A discount rate is used to standardize the different time intervals in which the debits and credits occur, and in doing so, present the service debits and credits at present value. The present value of the services is usually expressed in terms of discounted service acre-years of equivalent habitat, or DSAYs, which provide a means to compare the different service levels of affected habitat acres (Dunford et al. 2004; Desvousges et al. 2018; Penn undated).

impoundments have been sufficiently consistent with recognized and generally accepted engineering standards for protection of public safety and the environment" (Browning and Thomas 2018).

5.3 NEBA Risk Ratings

NEBA organizes environmental hazard and benefit information into a unitless metric that represents the degree and the duration of impact from a remediation and closure alternative (Efroymson et al. 2003, 2004). One approach to structure this analysis is to create a risk-ranking matrix that maps the proportional impact of a hazard (i.e., risk) with the duration of the impact (Robberson 2006). The risk-ranking matrix used for this application of NEBA is provided in Table 5-4. The matrix uses alphanumeric coding to indicate the severity of an impact: higher numbers and higher letters (e.g., 8F) indicate a greater extent and a longer duration of impact, respectively. Shading of cells within the matrix supports visualization of the magnitude of the effect according to the extent and duration of an impact.[40] When there is no meaningful risk, the cell is not given an alphanumeric code. Risk ratings generated from the risk-ranking matrix for each attribute and closure option examined were assembled into objective-specific summaries to compare the net benefits of the closure options. All closure options in the NEBA were evaluated against current conditions as a "baseline" for comparison.

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[40] Categories and shading as defined in the risk-ranking matrix are based on best professional judgment and used for discussion of the relative differences in relative risk ratings. Alternative risk matrices and resulting NEBA classifications are explored in Appendix E.

Table 5-4. Risk-ranking matrix for impacts and risk from remediation and closure activities. Darker shading/higher codes indicate greater impact

		Duration of Impact (years)							
		>50 **(8)**	35–50 **(7)**	26–35 **(6)**	16–25 **(5)**	10–15 **(4)**	5–9 **(3)**	1–4 **(2)**	<1 **(1)**
% Impact	No meaningful risk	--	--	--	--	--	--	--	--
	<5 % **(A)**	**8A**	**7A**	**6A**	**5A**	**4A**	**3A**	**2A**	**1A**
	5–19% **(B)**	**8B**	**7B**	**6B**	**5B**	**4B**	**3B**	**2B**	**1B**
	20–39% **(C)**	**8C**	**7C**	**6C**	**5C**	**4C**	**3C**	**2C**	**1C**
	40–59% **(D)**	**8D**	**7D**	**6D**	**5D**	**4D**	**3D**	**2D**	**1D**
	60–79% **(E)**	**8E**	**7E**	**6E**	**5E**	**4E**	**3E**	**2E**	**1E**
	>80% **(F)**	**8F**	**7F**	**6F**	**5F**	**4F**	**3F**	**2F**	**1F**

NEBA analysis of possible closure options for the ash basin at MSS helps both Duke Energy and other stakeholders understand the net environmental benefits from the closure option configurations that were examined. If a closure option that is preferred for reasons not considered in the NEBA does not rate as one of the options that best maximizes environmental services to the local community, closure plans for that option can be re-examined, and opportunities to better maximize environmental benefits can be identified (e.g., including an offsite habitat mitigation project to offset environmental services lost from habitat alteration). The NEBA can then be re-run with the updated plan to compare the revised closure plan with other closure options.

5.4 Risk Acceptability

Selecting any remediation, mitigation, restoration, or closure alternative involves considerations of risk—risk posed by contamination in place, risk created by the action, risk remaining after the action—and all of these risk considerations must be placed in some contextual framework if informed decisions are to be made. Hunter and Fewtrell (2001) state, "The notion that there is some level of risk that everyone will find acceptable is a difficult idea to reconcile and yet, without such a baseline, how can it ever be possible to set guideline values and standards, given that life can never be risk free?"

EPA defines risk as “the chance of harmful effects to human health or to ecological systems resulting from exposure to an environmental stressor” (U.S. EPA 2017a). In accordance with EPA guidance for conducting ERAs (U.S. EPA 1997) and HHRAs (U.S. EPA 1989), risk to a receptor (e.g., person, animal) exists when exposure to a stressor or stressors occur(s) at some level of effect; however, because not all exposures produce *adverse* effects in humans or ecological species, the exposure concentrations need to overlap with adverse effect thresholds for there to be the potential for meaningful risk. The science supporting individual benchmarks or levels of concern differs by the specific exposure at issue and the receptor at risk; however, such benchmarks are considered by regulatory authorities to represent the best scientific information available to create a baseline for risk (U.S. EPA 2017b).

The potential for risk associated with contamination is often evaluated using HQs, HIs, and ELCRs to screen environmental media (e.g., water, soil) and identify the potential risk associated with contamination (U.S. EPA 1989, 1997, 2000b). The HQ is the ratio of an exposure point (EPC) concentration[41] divided by an appropriate toxicity benchmark for the receptor, chemical, and exposure scenario. An HI, which is used in HHRA, is the sum of the HQs for several chemicals that share the same target organ. If the HQ or HI is less than 1, exposure to that chemical (HQ) or group of chemicals (HI) is expected to result in no adverse effects to even the most sensitive receptors. Cancer risk to humans is typically evaluated using a probabilistic approach that considers an acceptable risk benchmark range of 10^{-4} to 10^{-6}, meaning that a person’s ELCR from the exposure being assessed is less than 1 in 10,000 to 1 in 1,000,000 (U.S. EPA 1989, 2000b).

NEBA relies on scientifically supported estimates of risk; however, regardless of the scientific acceptability of the risk characterization process, stakeholders may place different values on different types of risk.

41 A conservative estimate of the chemical concentration available from a particular media and exposure pathway.

6 Summary of Conclusions

Based on my review and analyses, I developed the following conclusions, which are structured around the five objectives identified previously:

Conclusion 1: All closure options for the MSS ash basin are protective of human health. Current conditions and conditions[42] under all closure options support provision of safe drinking water, safe surface water, safe food, and safe recreation, satisfying the first objective of ash basin closure—to protect human health from CCR constituent exposure.

Conclusion 2: All closure options for the MSS ash basin are protective of ecological health. Current conditions[43] and conditions under all closure options support provision of safe surface water, safe food consumption, and protection of biodiversity and natural beauty, satisfying the second objective of ash basin closure—to protect ecological health from CCR constituent exposure.

Conclusion 3: CIP and hybrid closure options limit the duration of community disturbance. All closure options support safe air quality from diesel truck emissions along the transportation routes, and each creates comparable levels of disturbance and risk that could adversely impact community safety on a daily or annual basis; however, these impacts occur for a substantially longer period under the excavation closure option (28 years for excavation closure compared to 13 and 12 years for CIP and hybrid closures, respectively). Thus, CIP and hybrid closure options better satisfy the third objective of ash basin closure—to minimize risk and disturbance to humans from closure.

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[42] SynTerra's updated HHRA considered only potential exposure pathways that currently exist and could remain after ash basin closure under any closure option. Any potential risk currently associated with seeps at MSS was not evaluated in the HHRA or considered in this analysis because any risk resulting from seeps will be eliminated, reduced, or mitigated per the court-enforceable SOC that Duke entered with the North Carolina Environmental Management Commission on April 18, 2018 (EMC SOC WQ S17-009; See Section 4.2).

[43] SynTerra's updated ERA considered only potential exposure pathways that currently exist and could remain after ash basin closure under any closure option. Any potential risk currently associated with seeps at MSS was not evaluated in the ERA or considered in this analysis because any risk resulting from seeps will be eliminated, reduced, or mitigated per the court-enforceable SOC that Duke entered with the North Carolina Environmental Management Commission on April 18, 2018 (EMC SOC WQ S17-009; See Section 4.2).

Conclusion 4: All closure options for the MSS ash basin create environmental disturbance. All closure options adversely impact habitat-derived environmental services, with hybrid closure creating the least NPP service loss and best satisfying the fourth objective of ash basin closure—to minimize risk and disturbance to the local environment from closure.

Conclusion 5: Hybrid closure maximizes environmental services. The hybrid closure option best maximizes environmental benefits compared to the excavation and CIP closure options because it offers equivalent protection of human and ecological health from CCR exposure, results in less disturbance to the community over time compared to excavation closure, and produces the least disturbance to the environment.[44] Thus, hybrid closure best satisfies the fifth objective of ash basin closure—to maximize local environmental services.

Each will be discussed in detail in the following sections.

[44] As noted in Section 5 and further discussed in Section 11, the loss of habitat-derived environmental services could be offset with an appropriate reforestation project.

7 Conclusion 1: All closure options for the MSS ash basin are protective of human health.

The first objective for ash basin closure, to protect human health from CCR constituent exposure, is represented by environmental services that provide safe drinking water, safe groundwater, safe surface water, safe food consumption, and safe recreation. For purposes of the NEBA, these safety considerations were evaluated based on the following:

1. Provision of permanent alternative drinking water supplies to private well water supply users within a 0.5-mile radius of the MSS ash basin compliance boundary (Holman 2018);
2. Concentrations of CCR constituents of interest (COIs) in drinking water wells that could potentially affect local residents and visitors, as characterized by HDR (2015a, 2016b) and SynTerra (2018a) in the Comprehensive Site Assessment (CSA); and
3. Risk to various human populations from CCR exposure, as characterized in the updated human health and ecological risk assessment conducted by SynTerra (2018b; Appendix B).

Through these lines of evidence, I evaluated whether CCR constituents are currently impacting drinking water wells, whether they will in the future, and whether other exposures to CCR constituents pose a risk to human populations now or with ash basin closure.

7.1 Private water supply wells pose no meaningful risk to the community around MSS.

Per H.B. 630, Sess. L. 2016-95, all residents with drinking water supply wells within a 0.5-mile radius of the MSS ash basin compliance boundary have been provided with permanent alternative drinking water supplies (i.e., filter systems or connection to public drinking water supplies; Draovitch 2018),[45] eliminating drinking water as a potential CCR exposure pathway for local residents or visitors

Additionally, the available data indicate that public and private well water conditions are not impacted by CCR constituents and that groundwater flow paths from the ash basin are generally away from residential areas (SynTerra 2018a; HB630 Residential Well Data - Sept 24 2018.xlsx).

According to the 2018 CSA, four public wells are within a 0.5-mile radius of the ash basin, three of which are likely currently in use (SynTerra 2018a). These wells are likely not impacted by CCR COIs as groundwater does not flow from the ash basin toward the wells, and the 2018 CSA found no evidence of risk to users of any of the public wells (SynTerra 2018a).

Fifty-seven private wells have been identified within a 0.5-mile radius of the ash basin compliance boundary, and 17 others were assumed to be present at residences within the same radius (SynTerra 2018a). Based on the available data, groundwater does not generally flow from the ash basin compliance boundary toward the private wells. A few possible exceptions can be found to the southwest of the site's compliance boundary, along Sherrills Ford Road; however, the chemistry data for the two wells sampled in this area showed no evidence of CCR impacts. The only parameters exceeding North Carolina Groundwater Quality Standards (2L)[46] in these wells (MR47 and MR1004) were pH and vanadium, both of which commonly exceeded 2L in the other private wells sampled (see below). Boron, an indicator of CCR impacts, was below the provisional background threshold value (PBTV) in both wells (Marshall_Comprehensive All Media thru 2018-06.xlsx).

Thirty-eight private wells were sampled by the NCDEQ in 2015, and 10 more wells were sampled by Duke Energy in 2016 and 2017. All well concentration data were compared to PBTVs for bedrock, 2L standards, or interim maximum allowable concentrations (IMACs) (SynTerra 2018b). Several COIs exceeded 2L or IMAC levels, including vanadium (39 wells),

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45 NCDEQ determined Duke Energy had satisfactorily completed the permanent alternative water provision under CAMA General Statute (G.S.) 130A-309.21 l(cl) on October 12, 2108 (Holman 2018).

46 North Carolina Administrative code 15A NCAC 02L Groundwater Rules.

pH (33), iron (5), manganese (2), total dissolved solids (1), and zinc (1). Importantly, however, these COIs were generally below their respective PBTVs for bedrock (including vanadium in all samples). Eleven COIs exceeded PBTVs in at least one sample, with the most frequently being chloride (13 wells), cadmium (6 wells), and strontium (6 wells). Other PBTV exceedances were sporadic. Constituents that were not identified as COIs at Marshall also exceeded bedrock PBTVs in some samples. These included aluminum, calcium, hexavalent chromium, copper, lead, sodium, and zinc (SynTerra 2018a). Exceedances of PBTVs do not by themselves constitute evidence of CCR impacts. PBTVs were developed from a limited number of samples at the site and may not provide a complete representation of natural background conditions in the surrounding area encompassing the sampled wells (SynTerra 2018a). The lack of exceedances for indicator COIs like boron supports the conclusion that private wells are not impacted by CCR, and that sporadic PBTV exceedances for other COIs are the result of natural variability or due to components used in well constructions (SynTerra 2018a). Based on comparison to the downgradient groundwater and background conditions, the water in the sampled private wells is consistent with background bedrock wells and reflects natural background conditions (SynTerra 2018a). This conclusion is supported by the fact that groundwater does not generally flow from the ash basin towards the private wells (SynTerra 2018a).

Since the sampling for the 2018 CSA, an additional 11 samples have been collected from 4 private wells not previously sampled (HB630 Residential Well Data - Sept 24 2018.xlsx). 2L exceedances were detected for vanadium (in all 11 samples) and pH (in 2 samples). All samples were below 2L and PBTV levels for both boron and sulfate. The frequency and magnitudes of the exceedances were similar to those in the previous sampling campaigns and lend further support to the conclusion that private well water chemistry is not impacted by CCR.

7.2 CCR constituents from the Marshall ash basin pose no meaningful risk to human populations.

To assess potential risk to humans both onsite and offsite using the most recent and comprehensive data available, SynTerra updated the HHRA (SynTerra 2018b) that was originally conducted by HDR (2016c) as a component of the CAP part 2 (HDR 2016a). The updated HHRA included updates[47] to the conceptual site model, EPCs for human receptors with complete exposure pathways, screening level risk assessments for human receptors with complete exposure pathways, and hazard calculations (HI, ELCR) for receptors and COPCs with plausible complete exposure pathways.

Consistent with the 2016 Baseline Human Health and Ecological Risk Assessment (HDR 2016c), the updated HHRA (SynTerra 2018b) examined CCR constituent exposure to a range of human populations, including construction workers; swimmers; waders; boaters; and recreational and subsistence fishers under different pathways (i.e., exposure to sediment, surface water, groundwater, or fish tissue). HIs and ELCRs were estimated for scenarios with plausible complete exposure pathways.

Complete CCR exposure pathways evaluated in the updated HHRA included the following (SynTerra 2018b):

- Onsite construction workers via groundwater[48]
- Offsite recreational swimmers via offsite surface water and sediment
- Offsite recreational waders via offsite surface water and sediment
- Offsite recreational boaters via offsite surface water
- Offsite recreational fishers via offsite surface water and fish tissue
- Offsite subsistence fishers via fish tissue.

Since all households with drinking water supply wells within a 0.5-mile radius of the MSS ash basin compliance boundary have received permanent alternative water supplies (Holman 2018), and since no potable water wells are located downgradient of MSS, drinking water risks from groundwater were not further evaluated because there is no complete exposure pathway (SynTerra 2018b).

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[47] Updates to risk assessments are a natural part of the risk analysis process. EPA guidance for ecological risk assessment notes, "The [risk assessment] process is more often iterative than linear, since the evaluation of new data or information may require revisiting a part of the process or conducting a new assessment As more information about a site is gained through site investigations, the risk assessment must be updated to reflect the best knowledge of potential risk at a site" (U.S. EPA 1998). EPA similarly describes human health risk characterization as an iterative process (U.S. EPA 2000b).

[48] Groundwater exposure to onsite construction workers was evaluated in the updated HHRA, though a pathway for exposure was considered incomplete by SynTerra (2018b).

A summary of the risk assessment results from the updated HHRA (SynTerra 2018b) is provided in Table 7-1.

Table 7-1. Summary of human health risk assessment hazard index (HI) and excess lifetime cancer risk (ELCR) from SynTerra (2018b)

Media	Receptor	HI	ELCR
Groundwater	Construction Worker	0.001	NC
Sediment	Recreational Swimmer	0.003	NC
Surface Water	Recreational Swimmer	0.04	2.6×10^{-6}
Sediment	Recreational Wader	0.003	NC
Surface Water	Recreational Wader	0.03	6.2×10^{-7}
Surface Water	Recreational Boater	0.002	5.3×10^{-8}
Surface Water	Recreational Fisher	0.002	5.3×10^{-8}
Biota (fish)	Recreational Fisher	2	3.8×10^{-6}
Biota (fish)	Subsistence Fisher	57	2.9×10^{-4}

Notes:

NC – Risk-based concentration based on non-cancer HI.

The majority of exposure scenarios assessed by SynTerra (2018b) indicated that exposure to CCR poses no meaningful risks to humans. The HI associated with recreational fishers and the HI and ELCR associated with subsistence fishers were, however, estimated by SynTerra (2018b) to be greater than 1 and 1×10^{-4}, respectively.

Risk assessment is subject to a number of uncertainties, including the representativeness of sample data, the degree to which exposure assumptions approximate actual exposure, estimation of chemical toxicity, and characterization of background concentrations. Risk assessment typically addresses these uncertainties by including conservative assumptions that tend to overestimate exposure and risk. For example, to evaluate potential risk to subsistence fishers in the MSS HHRA, SynTerra (2018b) used a fish consumption rate of 170 g/day, which represents the highest level of consumption (95th percentile) in a high consuming subsistence Native American population living in an area with plentiful fish resources that can support such high fish consumption (Columbia River Tribes in Oregon) (U.S. EPA 2000a, 2011a).[49] SynTerra (2018b) further assumes this rate of fish consumption would continue for many years using only

[49] In the case of MSS, SynTerra has not identified any populations of subsistence fishers in the area.

fish from a single water body with fish tissue COPC concentrations estimated using a conservative uptake model (bioconcentration factors [BCFs]) from the highest surface water COPC concentrations. Each exposure pathway in the HHRA uses similarly conservative assumptions to address uncertainty. While this serves to ensure a health protective assessment, results that exceed target risk levels should be examined in more depth to understand the context. Therefore, I examined the foundation for each exceedance in more detail.

Risk to fishers was modeled by SynTerra (2018b) by estimating fish tissue concentrations from surface water sample data. The cumulative HIs from these exposures, 2 for recreational fishers and 57 for subsistence fishers, were driven by concentrations of cobalt. Similar risks were noted previously in the baseline HHRA (HDR 2016c), and HDR (2016c) attributed this estimated risk to the use of onsite surface water as a surrogate for offsite conditions as well as conservative uptake assumptions and bioaccumulation models, which likely overestimate metals concentrations in fish tissue. While SynTerra (2018) used offsite water data to update EPCs in the updated HHRA, other conservative assumptions were retained by SynTerra (2018b). The cumulative ELCR of 2.9×10^{-4} for subsistence fishers from these exposures was driven by concentrations of chromium (VI). This risk was not identified in the previous HHRA (HDR 2016c), as more recent samples were included in the 2018 analysis.

Examining these COPCs individually, for cobalt, the EPA provisional oral reference dose (RfD) of 0.3 µg/kg/day may be considered unnecessarily conservative.[50] Other government agencies have derived higher guidance values for cobalt, including the Dutch National Institute of Public Health and the Environment (tolerable daily intake of 98 µg/day, or 1.4 µg/kg/day for a 70 kg adult) and the European Food Safety Authority (EFSA) (600 µg/day, or 8.6 µg/kg/day) (Schoof 2017). A recent reanalysis of relevant human and animal studies involving oral exposure to cobalt proposed a new RfD for cobalt of 30 µg/kg/day, which is 100 times higher than what is currently recommended by EPA (Finley et al. 2012; Schoof 2017). If the recent cobalt RfD reported in Finley et al. (2012) were applied instead of the current EPA RfD for cobalt, the HIs for cobalt exposure to recreational and subsistence fishers would be 0.02 and 0.57, respectively.

[50] The RfD is an estimate of a daily exposure to the human population that is likely to be without an appreciable risk of deleterious effects during a lifetime. The cobalt RfD was developed in 2008 (U.S. EPA 2008).

SynTerra (2018) notes that concentrations of cobalt in background samples were of the same order of magnitude as the EPC used in risk calculations and would predict a comparable background level of risk unassociated with CCR exposure. Given the conservative use of a BCF to estimate fish tissue concentration and the low likelihood that the water body would be used as a sole subsistence fish source, I conclude there is no meaningful risk to recreational or subsistence fishers from exposure to cobalt.

For chromium (VI), the ELCR of $2.9{\times}10^{-4}$ is less than an order of magnitude above the upper end of EPA's target ELCR range of 10^{-6} to 10^{-4} (U.S. EPA 1989, 2000a). This ELCR was determined using a BCF for chromium (VI) of 200, based on a 1996 report from the National Council on Radiation Protection and Management (NCRP 1996). However, a more recent review by the Office of Environmental Health Hazzard Assessment (OEHHA, a part of the California EPA) evaluated chromium uptake in fish and derived a lower BCF for chromium based primarily on studies of chromium (VI). OEHHA (2012) states that chromium (VI) is not well taken up into edible fish tissue and recommends a BCF of 20 (OEHHA 2012). Had a BCF of 20 been used, the resulting ELCR would be $2.9{\times}10^{-5}$, within EPA's range of acceptable risk. Synterra (2018) also notes that concentrations of chromium in background samples were as much as four times higher than the EPC used in risk calculations, and would predict a comparable level of risk unassociated with CCR exposure. Based on the conservative uptake assumptions and bioaccumulation factors used in this model, and the very limited exceedance of acceptable ELCR, I conclude there is no meaningful risk to subsistence fishers from exposure to chromium (VI).

Given the lack of meaningful risk under current conditions,[51] there is also no meaningful risk to humans from CCR exposure under any of the ash basin closure options since all options reduce or eliminate exposure pathways following closure. Thus, all closure options are protective of public health.

[51] SynTerra's updated HHRA considered only potential exposure pathways that currently exist and could remain after ash basin closure under any closure option. Any potential risk currently associated with seeps at MSS was not evaluated in the HHRA or considered in this analysis because any risk resulting from seeps will be eliminated, reduced, or mitigated per the court-enforceable SOC that Duke entered with the North Carolina Environmental Management Commission on April 18, 2018 (EMC SOC WQ S17-009; See Section 4.2).

7.3 NEBA – Protection of Human Health from CCR Exposure

There is no CCR risk from drinking water supplies, no evidence of CCR impacts to drinking water wells, and no meaningful risk to humans from CCR exposure under current conditions or under any closure option. Using the NEBA framework and relative risk ratings, these results are summarized in Table 7-2 within the objective of protecting human health from CCR constituent exposure.

Table 7-2. Summary of relative risk ratings for attributes that characterize potential hazards to humans from CCR exposure in drinking water, surface water, groundwater, soil, sediment, food, and through recreation

Objective	Protect Human Health from CCR						
Hazard	Exposure to CCR						
Potentially Affected Populations	Local Residents/Visitors	Onsite Construction Workers	Offsite Recreational Swimmers	Offsite Recreational Waders	Offsite Recreational Boaters	Offsite Recreational Fishers	Offsite Subsistence Fishers
Scenario							
Baseline	--	--	--	--	--	--	--
CIP	--	--	--	--	--	--	--
Excavation	--	--	--	--	--	--	--
Hybrid	--	--	--	--	--	--	--

"--" indicates "no meaningful risk."

Current conditions and conditions under all closure options support provision of safe drinking water, safe surface water, safe food, and safe recreation, satisfying the first objective of ash basin closure—to protect human health from CCR constituent exposure.

8 Conclusion 2: All closure options for the MSS ash basin are protective of ecological health.

The second objective for ash basin closure, to protect ecological health from CCR constituent exposure, is represented by environmental services that provide safe surface water, safe food consumption, and protection of biodiversity and natural beauty. For purposes of the NEBA, these considerations were evaluated based on the following:

1. Risk to ecological receptors from CCR exposure, as characterized by SynTerra (2018b; Appendix B) in the updated human health and ecological risk assessment; and
2. Aquatic community health in Lake Norman as reported in the Lake Norman Maintenance Monitoring Program summary report for 2016 (Duke Energy 2018a).

Through these two lines of evidence, I evaluated whether CCR constituents pose a risk to ecological populations now or after ash basin closure.

8.1 No meaningful risks to ecological receptors from CCR exposure exist under current conditions or any closure option.

To assess potential risk to ecological receptors both on-site and off-site using the most recent and comprehensive data available, SynTerra (2018b) updated the Baseline Human Health and Ecological Risk Assessment that was originally conducted by HDR (2016c) as a component of the CAP part 2 (HDR 2016a). The updated ERA included updates to the conceptual site model, EPCs for receptors with potentially complete exposure pathways, and screening level risk assessments for ecological receptors with potentially complete exposure pathways. Updated HQs were estimated for ecological receptors with plausible complete exposure pathways to CCR related COPCs (SynTerra 2018b).

The ecological receptors evaluated in the ERA are common representatives of particular groups of organisms inhabiting different habitats and aspects of the food web. Key receptors in

SynTerra's updated ERA (SynTerra 2018b) and their pathways for exposure included the following:

- **Birds:** Avifauna species may be exposed by ingestion of food and surface water and by incidental ingestion of sediment and soil. Aquatic/wetland species included were mallard duck (omnivore) and great blue heron (piscivore), and bald eagle (carnivore).[52]
- **Mammals:** Aquatic/wetland or terrestrial species may be exposed by ingestion of food and surface water and by incidental ingestion of sediment and soil. Aquatic/wetland species included were muskrat (omnivore) and river otter (piscivore).

Ecological risk for these indicator species was characterized by SynTerra (2018b) using a risk-based screening approach that compared exposure levels to toxicity references values (TRVs) to calculate HQs for COPCs. TRVs in the ERA included no-observed-adverse-effects levels (NOAELs)[53] and lowest-observed-adverse-effects levels (LOAELs)[54] derived from the literature for each COPC.

HQ results for the site were evaluated for one exposure area at MSS[55] (Figure 8-1). HQs less than 1 indicate no meaningful risk to an ecological receptor species associated with exposure to the COPCs evaluated.

- **Exposure Area 1:** All HQs <1, indicating no meaningful risk to receptors in this area.

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52 The bald eagle was added to this risk assessment model because the species is federally protected and represents a raptor that preys upon fish, primarily, HQ calculations for the bald eagle include hypothetical consumption of fish and terrestrial vertebrates that inhabit adjacent areas.

53 A NOAEL is a concentration below which no adverse effects have been observed for a specific receptor and pathway of exposure. NOAELs are typically estimated from laboratory toxicity tests.

54 A LOAEL is a concentration associated with the lowest concentration level at which adverse effects have been observed for a specific receptor and pathway of exposure. LOAELs are typically estimated from laboratory toxicity tests.

55 The baseline ecological risk assessment conducted by HDR in 2016 (HDR 2016c) included two exposure areas. Exposure Area 2, which is northwest of the ash basin, was not evaluated for the updated ERA because it was considered representative of background conditions (SynTerra 2018b).

Based on the updated ecological risk assessment (SynTerra 2018b), there are currently no meaningful risks to ecological receptors associated with CCR exposure at MSS.

Additionally, the 2018 Lake Norman Maintenance Monitoring Program[56] summary report for 2016 reported results from biological sampling (phytoplankton,[57] zooplankton,[58] fish) and water chemistry analyses conducted in 2016 (Duke Energy 2018a). The report concluded that phytoplankton and zooplankton density and diversity, and phytoplankton biomass were within historical ranges in 2016 and represent a balanced indigenous community, with no discernable impacts from Duke Energy operations (Duke Energy 2018a). The 2016 fishery data "indicate that the Lake Norman fish community is balanced and is composed mostly of indigenous species expected from a reservoir located in the NC piedmont," with the proportions of pollution tolerant fish species comparable throughout all zones in the lake and no indication of negative effects as a result of Duke Energy operations (Duke Energy 2018).

Given the lack of meaningful ecological risk from CCR exposure under current conditions based on the lines of evidence evaluated, all closure options would be protective of ecological receptors since all closure options reduce or eliminate potential exposure pathways.

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[56] Duke Energy operates two power generation facilities on Lake Norman. MSS is located in the mid-lake region of Lake Norman, and the McGuire Nuclear Station is located on the southern end of Lake Norman. Both facilities have NPDES permitted discharges to the lake, and the Maintenance and Monitoring Program is an annual lake-wide assessment of in-lake productivity, fish populations, and physicochemical characteristics of the lake.

[57] Phytoplankton are microscopic plants that require sunlight to grow and form the base of the aquatic food web.

[58] Zooplankton are microscopic organisms that consume phytoplankton or other zooplankton and are a key component of the aquatic food web,

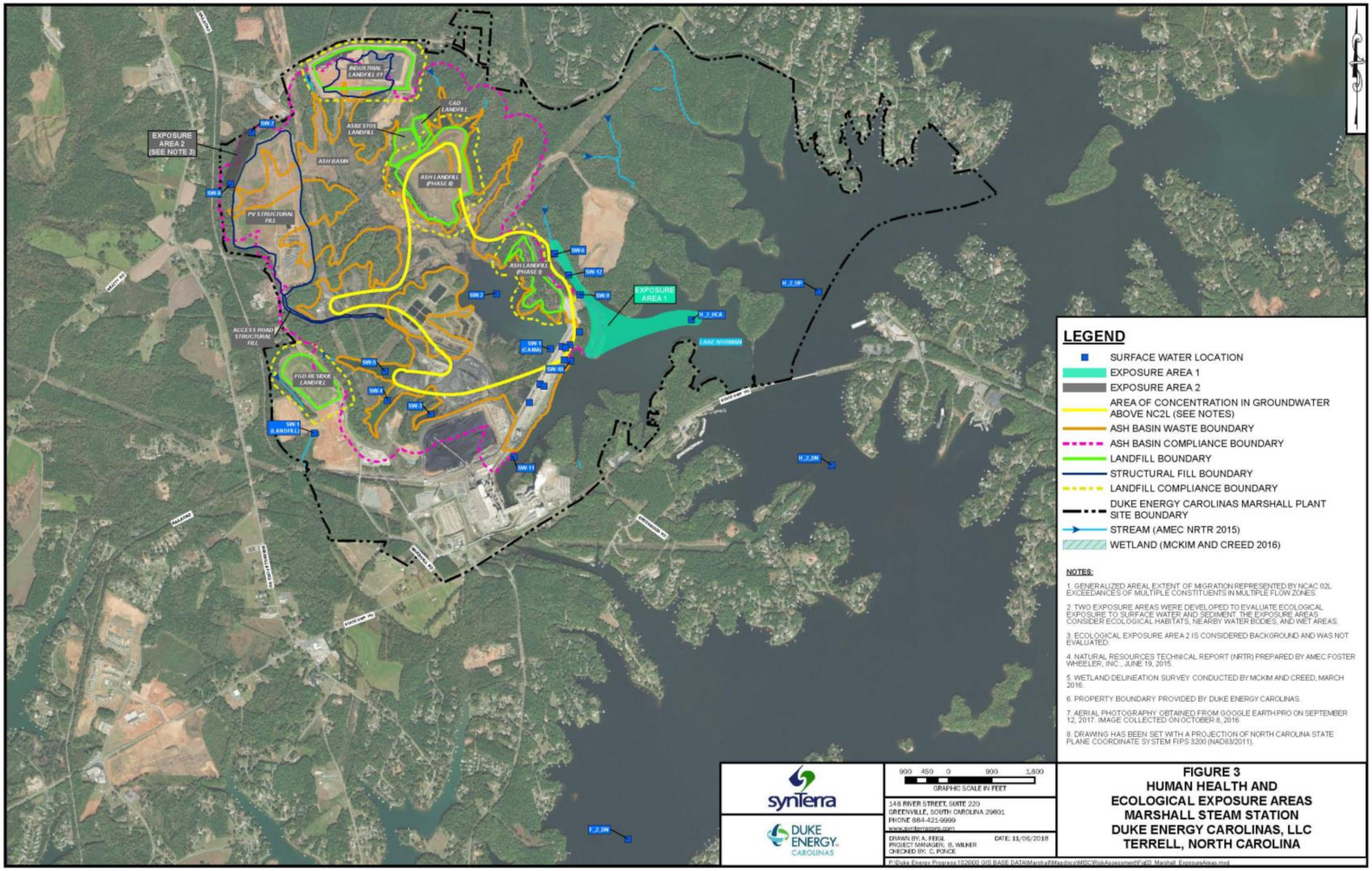

Figure 8-1. Exposure areas evaluated in the 2018 ecological risk assessment update (SynTerra 2018b)

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8.2 NEBA – Protection of Environmental Health from CCR Exposure

Based on these analyses, no meaningful risk to ecological receptors from CCR exposure was found under current conditions[59] or under any closure option. Using the NEBA framework and relative risk ratings, within the objective of protecting ecological health from exposure to CCR constituents, these results are summarized in Table 8-1.

Table 8-1. Summary of relative risk ratings for attributes that characterize potential hazards to ecological resources from CCR exposure in surface water, soil, sediment, and food

Objective	Protect Ecological Health from CCR					
Hazard	Exposure to CCR					
Potentially Affected Populations	Fish Populations	Aquatic Omnivore Birds (mallard)	Aquatic Piscivore Birds (great blue heron)	Aquatic Carnivore Birds (bald eagle)	Aquatic Herbivore Mammals (muskrat)	Aquatic Piscivore Mammals (river otter)
Scenario						
Baseline	--	--	--	--	--	--
CIP	--	--	--	--	--	--
Excavation	--	--	--	--	--	--
Hybrid	--	--	--	--	--	--

"--" indicates "no meaningful risk."

Current conditions and conditions under all closure options support provision of safe surface water, safe food consumption, and protection of biodiversity and natural beauty, satisfying the

[59] SynTerra's updated ERA considered only potential exposure pathways that currently exist and could remain after ash basin closure under any closure option. Any potential risk currently associated with seeps at MSS was not evaluated in the ERA or considered in this analysis because any risk resulting from seeps will be eliminated, reduced, or mitigated per the court-enforceable SOC that Duke entered with the North Carolina Environmental Management Commission on April 18, 2018 (EMC SOC WQ S17-009; See Section 4.2).

second objective of ash basin closure—to protect ecological health from CCR constituent exposure.

9 Conclusion 3: CIP and hybrid closure options limit the duration of community disturbance.

The third objective for ash basin closure, to minimize risk and disturbance to humans from closure, is represented by environmental services that provide safe air quality and a safe community environment. For purposes of the NEBA, these considerations were evaluated based on the following:

1. Health risks from diesel exhaust emissions to the community living and working along transportation corridors during trucking operations to haul materials to and from the ash basin, as evaluated through the application of diesel truck air emissions modeling and HHRA; and
2. The relative risk for disturbance and accidents resulting from trucking operations affecting residents living and working along transportation corridors during construction operations, as evaluated by comparing the relative differences in trucking operations between the closure options.

All closure options require increased trucking activity to haul materials to the site (e.g., transport cap material to the ash basin). These activities involve the use of diesel-powered dump trucks, which increase local diesel exhaust emissions and traffic, both of which present potential hazards to local populations in the form of air pollution and roadway hazards. Table 9-1 summarizes the transportation logistics associated with each of the closure options Duke Energy is considering for MSS (Duke Energy 2018b). From this summary, the amount of offsite trucking involved is comparable between CIP and excavation closures, but excavation closure requires more truckloads of cap and fill material and more miles driven.

Table 9-1. Summary of offsite transportation logistics associated with each closure option (Duke Energy 2018b)

Logistics	CIP	Excavation	Hybrid
Closure Duration (years)[a]	15	32	15
Construction Duration (years)[b]	13	28	12
Offsite truckloads to haul cap & fill material[c]	20,582	29,303	20,459
Offsite miles driven to haul cap & fill material[c]	588,009	832,249	535,753

[a] Includes design and permitting, decanting, site preparation, construction, and site restoration.
[b] Includes site preparation, construction, and site restoration.
[c] Includes cover soil, top soil, and geosynthetic material.

Costs to society associated with trucking include accidents (fatalities, injuries, and property damage), emissions (air pollution and greenhouse gases), noise, and the provision, operation, and maintenance of public roads and bridges (Forkenbrock 1999). Generally, the magnitude of these impacts scales with the frequency, duration, and intensity of trucking operations (Forkenbrock 1999). Figure 9-1 illustrates the normalized differences between offsite transportation activities under the excavation and hybrid options relative to CIP. From these results, it is clear that risk and disturbance associated with transportation activities will be relatively comparable between CIP and hybrid closure options. However, excavation closure has a greater total potential for risk and disturbance from the increased number of offsite truckloads and total miles driven; excavation closure also requires a substantially longer duration for closure activities.

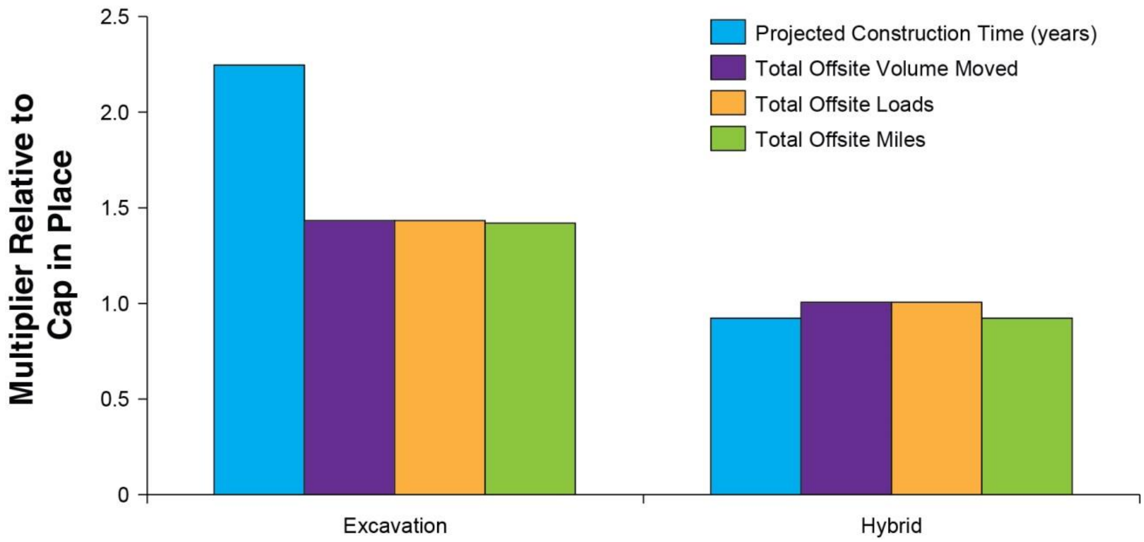

Figure 9-1. Normalized differences between all offsite transportation activities under CIP, excavation, and hybrid closure options. Bars represent the relative activity of each closure option compared to CIP.

9.1 There is no meaningful risk from diesel emissions to people living and working along the transportation corridor.

The types of large dump trucks that will be used in closure activities at MSS are generally diesel powered, and diesel exhaust includes a variety of different particulates and gases, including more than 40 toxic air contaminants.[60] North Carolina does not have a diesel-specific health-based toxicity threshold because diesel exhaust is not currently regulated as a toxic air pollutant. North Carolina also does not regulate $PM_{2.5}$ or PM_{10}[61] as toxic air pollutants. North Carolina defers to EPA's chronic non-cancer reference concentration (RfC) for diesel particulate matter of 5 $\mu g/m^3$ based on diesel engine exhaust to estimate risk from diesel emissions.[62] California is, to my knowledge, the only state that currently regulates diesel as a toxic air contaminant and has identified both an inhalation non-cancer chronic reference exposure level (REL)[63] of 5 $\mu g/m^3$

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60 https://oehha.ca.gov/air/health-effects-diesel-exhaust

61 $PM_{2.5}$ and PM_{10} are airborne particulate matter sizes. $PM_{2.5}$ is particulate matter that is 2.5 µm or less in size; PM_{10} is particulate matter that is 10 µm or less in size.

62 Integrated Risk Information System (IRIS). U.S. EPA. Diesel engine exhaust.

63 A chronic REL is a concentration level (expressed in units of micrograms per cubic meter [$\mu g/m^3$]) for inhalation exposure at or below which no adverse health effects are anticipated following long-term exposure.

and a range of inhalation potency factors indicating that a "reasonable estimate" for the inhalation unit risk is 3.0×10^{-4} $(\mu g/m^3)^{-1}$ "until more definitive mechanisms of toxicity become available" (OEHHA 2015). California bases the non-cancer and cancer health factors on the whole (gas and particulate matter) diesel exhaust and uses PM_{10} as a surrogate measure.

As PM_{10} is the basis for both the non-cancer and inhalation risk factors for diesel exhaust exposure in California, I relied on a PM_{10} exposure model to evaluate potential non-cancer and cancer health risks from diesel exhaust.[64]

A representative segment of road was simulated using EPA's AERMOD model[65] to quantify air concentrations at set distances away from the road (U.S. EPA 2016). Diesel truck emissions were configured in the model in a manner consistent with the recommendations from EPA's Haul Road Working Group (U.S. EPA 2011b). The emission rate for diesel trucks was calculated using the U.S. EPA Mobile Vehicle Emissions Simulator (MOVES) model (U.S. EPA 2015).[66] Emission factors were then applied to the average number of anticipated offsite truck trips each year to define the average annual amount of diesel particulate matter emitted along the representative road segment, and these exposures were then summed over seventy years.[67] AERMOD simulations were run for four transportation orientation directions and used five years of local meteorological data to estimate EPCs at regular intervals from 10 to 150 m perpendicular to either side of the road. The results of the model were translated into average PM_{10} exposure ($\mu g/m^3$) and excess cancer risk over a 70-year period using reasonable maximum

EPA has defined long-term exposure for these purposes as at least 12% of a lifetime, or about eight years for humans.

64 California regulations and guidance indicate that when comparing whole diesel exhaust to speciated components of diesel (e.g., polycyclic aromatic hydrocarbons, metals) the cancer risk from inhalation of whole diesel exhaust will outweigh the multi-pathway analysis for speciated components.

65 AERMOD will calculate both the downwind transport and the dispersion of pollutants emitted from a source. Both transport and dispersion are calculated based on the observed meteorology and characteristics of the surrounding land. AERMOD is maintained by EPA and is the regulatory guideline model for short-range applications (transport within 50 km).

66 The MOVES model allows a user to determine fleet average emission factors (in units of grams of pollutant per mile traveled) for specific classes of vehicles and specific years. In this application, factors defined by MOVES for single-unit short-haul diesel trucks were used.

67 For the cancer risk analysis, emissions were calculated as an average over the regulatory default 70-year residential exposure duration. If the truck activity for a closure option occurs over a shorter period, the duration of the truck activity exposure is factored into the 70-year averaging time (OEHHA 2015).

exposure.[68] Results of the exposure modeling are provided in Table 9-2. Full results and a more detailed description of the model are provided in Appendix C.

Table 9-2. Hazard indices (HI) and excess lifetime cancer risk (ELCR) from exposure to diesel exhaust emissions along transportation corridors in northern North Carolina. Results are for the maximum exposures modeled.

Perpendicular distance to road	CIP		Excavation		Hybrid	
	ELCR	HI	ELCR	HI	ELCR	HI
10 m	4.59E-09	0.0000	3.78E-09	0.0000	4.11E-09	0.0000
20 m	3.95E-09	0.0000	3.25E-09	0.0000	3.54E-09	0.0000
30 m	3.07E-09	0.0000	2.53E-09	0.0000	2.75E-09	0.0000
40 m	2.55E-09	0.0000	2.10E-09	0.0000	2.28E-09	0.0000
50 m	2.17E-09	0.0000	1.78E-09	0.0000	1.94E-09	0.0000
60 m	1.88E-09	0.0000	1.55E-09	0.0000	1.69E-09	0.0000
70 m	1.66E-09	0.0000	1.37E-09	0.0000	1.49E-09	0.0000
80 m	1.49E-09	0.0000	1.22E-09	0.0000	1.33E-09	0.0000
90 m	1.34E-09	0.0000	1.10E-09	0.0000	1.20E-09	0.0000
100 m	1.22E-09	0.0000	1.00E-09	0.0000	1.09E-09	0.0000
110 m	1.12E-09	0.0000	9.19E-10	0.0000	1.00E-09	0.0000
120 m	1.03E-09	0.0000	8.47E-10	0.0000	9.23E-10	0.0000
130 m	9.54E-10	0.0000	7.85E-10	0.0000	8.54E-10	0.0000
140 m	8.87E-10	0.0000	7.30E-10	0.0000	7.95E-10	0.0000
150 m	8.28E-10	0.0000	6.81E-10	0.0000	7.42E-10	0.0000

Based on the assumptions applied in the air model, no meaningful risk from diesel emissions associated with ash basin closure trucking operations was identified for people living and working along the transportation corridor. The exposure model and risk assessment applied here represent a simple approach to estimate risk. A more refined estimate of risk could be computed with a more sophisticated air and risk model; however, it is unlikely to change the conclusion that there is no meaningful risk to people living and working along the transportation corridor from diesel emissions associated with ash basin closure construction operations.

[68] Long-term exposure was incorporated into the air simulation as the average exposure given estimated trucking rates for 12 hours per day—7am to 7 pm—6 days a week for the duration of the project trucking time.

9.2 All closure options produce comparable risk and disturbance from transportation activities on a daily or annual basis, but excavation closure produces these impacts for substantially longer than CIP or hybrid closures.

Increased trucking increases noise and traffic congestion and creates a statistically based risk for increased traffic accidents that could result in fatalities, injuries, and/or property damage (Forkenbrock 1999; NHTSA 2016). MSS is located on a peninsula of Lake Norman and the region consists primarily of sparse lakeside communities and rural forest and farmland. North Carolina Highway 150 transects the peninsula immediately south of MSS providing the only east-west bridge crossing of Lake Norman. There will be an increase in trucking traffic hauling topsoil and/or geosynthetic material under all closure options along this corridor, with a statistically increased likelihood of traffic accidents (NHTSA 2016). These accidents and associated risks to life, health, and property will generally scale with the frequency and duration of trucking in the region, total number of truckloads, number of roundtrip truck trips per day, and duration of the closure.

For purposes of the NEBA, two attributes of offsite truck traffic that create disturbance to local communities were considered: (1) noise and congestion and (2) accidents. Noise and congestion were evaluated by comparing the number of times a construction truck would be expected to pass a given location along the transportation corridor during closure construction activities, and the difference in the likelihood of traffic accidents between the closure options was assumed to be a function of the number of offsite road miles driven by construction trucks (NHTSA 2016).

9.2.1 Noise and Congestion

Regardless of the option, closure of the ash basin at MSS will result in an increased number of large trucks[69] on local roads (Table 9-1). Noise from these trucks includes engine and braking noise, which can be disruptive to the communities through which they are passing,[70] and trucks

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[69] Twenty-ton dump trucks, or similar vehicles for bulk transport, are assumed to be the primary vehicles that will be involved in transporting materials during closure construction activities.

[70] A typical construction dump truck noise level is approximately 88 decibels 50 ft. from the truck. (https://www.fhwa.dot.gov/ENVIRONMENT/noise/construction_noise/handbook/handbook09.cfm)

frequently passing through rural communities may pose additional disturbance from roadway congestion. To compare the disturbance of trucking noise and congestion between closure options, I used the average daily number of truck passes for trucks carrying earthen fill and geosynthetic material to the construction site (Table 9-1). The number of passes of trucks hauling ash from the ash basin to the landfill was not considered because these trucks do not leave MSS. For the CIP option, it is estimated that a total of 41,164 truck passes would occur at locations along the transportation corridor within 11 miles of the facility over the 13-month course of trucking activities, for an average of 11 passes per day, or about one truck every hour, assuming a 10-hour work day[71]. The excavation option has 58,605 total truck passes and averages 7 truck passes per day for 28 months, or one truck every 90 minutes. For the hybrid option, there would be 40,919 total truck passes hauling cover material along the transportation corridor for 12 months for an average of 11 passes per day, or one truck every hour. These results and their relative differences (as the ratio to CIP closure) are summarized in Table 9-3.

9.2.2 Traffic Accidents

Traffic accidents are assumed to be a function of the total number of offsite road miles driven by construction trucks (NHTSA 2016). As with noise and congestion, only the miles driven hauling earthen fill and cap materials were considered because ash-hauling vehicles will not leave MSS. CIP closure requires a total of approximately 588,000 miles of driving; excavation closure requires approximately 832,000 miles of driving; and hybrid closure requires approximately 536,000 miles of driving. The difference in distances driven between the hybrid and excavation option is equivalent to twelve trips around the earth. Table 9-3 summarizes the results for all disturbances considered.

[71] All closure option assume 10-hour work days, 6-day work weeks, and 26 working days per month.

Table 9-3. Comparative metrics for increased noise and congestion and traffic accidents

	Months of trucking	Noise and congestion		Traffic Accidents	
		Average truck passes per day	Ratio to CIP	Total offsite road miles driven	Ratio to CIP
CIP	150	11	1	588,009	1
Excavation	335	7	0.64	832,249	1.4
Hybrid	138	11	1.1	535,753	0.9

9.3 NEBA – Minimize Human Disturbance

From these analyses, no meaningful health risk is expected from diesel exhaust emissions under any closure option, but all the closure options are expected to produce different levels of community disturbance in the form of noise and traffic congestion and risk from traffic accidents.

I used the number of trucks per day passing[72] a receptor along a near-site transportation corridor to examine the differences in noise and traffic congestion under the closure options. I compared the increase in the average number of trucks hauling earthen fill, geosynthetic material, and other materials under the closure options to the current number of truck passes for the same receptor. I specified a baseline, or current, level of truck passes on the transportation corridor, and the number of truck passes per day under the closure options derive directly from the trucking projections and implementation schedules provided by Duke Energy (2018b).

A baseline estimate of trucking passes per day for transportation corridors near MSS was derived from North Carolina Department of Transportation (NCDOT) data of annual average daily traffic (AADT) at thousands of locations across the state[73] and the proportion of road miles

[72] Truck passes per day is calculated as the total number of loads required to transport earthen fill, geosynthetic material, and other materials multiplied by two to account for return trips. The resulting total number of passes is then divided evenly among the total number of months of trucking time multiplied by 26 working days per month.

[73] Annual average daily traffic (AADT) values are derived from counts of axle pairs in every lane travelling in both directions using a pneumatic tube counter. At each monitoring station, raw data are collected for two days, and these raw counts are adjusted using axle and seasonal correction factors to estimate the AADT. AADT

driven by large trucks in Catawba County.[74] Based on the assumed 153-trucks-per-day baseline level and the number of truck trips per day from Duke Energy's projections, all options would have a less than 10% impact (CIP = 7%, excavation = 4%, hybrid = 7%) on noise and congestion. I input these percent impacts to the risk-ranking matrix (Table 5-4) along with the total duration of trucking activities (13 years CIP; 28 years excavation; 12 years hybrid) to evaluate which of the closure options best minimizes human disturbances (Table 9-4).

I evaluated risk from traffic accidents by comparing the average number of annual offsite road miles driven between closure options relative to a baseline estimate of the current road miles driven.[75] I chose a baseline of 129 million annual road miles for Catawba County, North Carolina, based on the reported total vehicle miles traveled in Catawba County (NCDMV 2017) multiplied by the county average 6.6% contribution of trucks to total AADT (NCDOT 2015). I used the increase in truck miles driven over baseline in the closure options as a surrogate for the potential increase in traffic accidents.

Using the 129-million-truck-miles baseline assumption, CIP has a 0.04% impact; excavation has a 0.02% impact; and hybrid closure has a 0.04% impact. All closure options have a relative risk rating of <5%. These relative risk ratings appear to be insensitive to lower assumed baseline annual truck miles (see Appendix E for sensitivity analysis); reducing the baseline assumption to the statewide minimum number of truck miles driven per year (6.2 million miles in Hyde County) does not increase the expected percent impact for any option above 1% or increase the relative risk rating and, by extension, the risk of traffic accidents. Results are summarized in the NEBA framework (Table 9-4) within the objective of minimizing disturbance to humans during closure.

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results are compared to historical values at the same location and values at nearby stations to provide temporal and spatial quality assurance. AADT data and a mapping application user interface are available online (http://ncdot.maps.arcgis.com/apps/webappviewer/index.html?id=5f6fe58c1d90482ab9107ccc03026280)

[74] A value of 2,300 AADT was chosen as a baseline value for all vehicle traffic by identifying potential transportation routes to and from the MSS ash basin and selecting the AADT station along the route that currently has the lowest traffic and would experience the greatest proportional increase in trucking traffic from ash basin closure. The baseline AADT value (2,300) was then multiplied by the county average of large truck traffic volume (6.6%) to derive an estimated 153 passes per day along the most sensitive portion of the transportation corridor to and from MSS (Appendix E).

[75] The difference of baseline miles and closure option miles was divided by the baseline miles and multiplied by 100 to get a percent impact.

Table 9-4. Summary of relative risk ratings for attributes that characterize potential hazards to communities during remediation activities. Darker shading and higher codes indicate greater impact.

Objective	Minimize Human Disturbance		
Hazard	Noise and Traffic Congestion	Traffic Accidents	Air Pollution
Potentially Affected Populations	Local Residents/Visitors	Local Residents/Visitors	Reasonable Maximum Exposure
Scenario			
Baseline	baseline	baseline	baseline
CIP	**4B**	**4A**	**--**
Excavation	**6A**	**6A**	**--**
Hybrid	**4B**	**4A**	

"--" indicates "no meaningful risk."

All closure options create some level of risk and disturbance to human populations. While the excavation closure option produces comparable impacts to CIP and hybrid closures on a daily or annual basis (risk rating of A)[76], the impacts occur for more than twice as long as those for CIP or hybrid closure, resulting in a greater cumulative impact (risk rating 6 compared to 4) from

[76] The "A" risk rating for excavation closure is based on an estimated <5% impact on noise and congestion, as calculated from the estimated increase in the number of truck passes per day over baseline conditions. 5% is the upper limit of the "A" risk rating category (see Table 5-3). CIP and hybrid closures are estimated to have a 7% impact on noise and congestion, which is very close to the low limit of the "B" risk rating category (see Table 5-3) and functionally similar to the 4% risk for excavation closure for noise and traffic congestion on a daily basis. Therefore, while the risk ratings and shading in Table 9-4 suggest differences between the closure options in terms of magnitude of impact (alphabetic rating), these ratings are sensitive to the category ranges defined in the matrix because excavation closure rates at the upper limit of the "A" risk rating category and CIP and hybrid closures rate at the low limit of the "B" risk rating category. The numeric rating, which corresponds to the duration of impact, is the distinguishing factor between the impacts to noise and congestion under the closure options.

excavation closure based on the trucking projections and implementation schedules provided by Duke Energy (2018b).[77]

All closure options support safe air quality from diesel truck emissions along the transportation routes, and each creates comparable levels of disturbance and risk that could adversely impact community safety on a daily or annual basis; however, these impacts occur for a substantially longer period under the excavation closure option (28 years for excavation closure compared to 13 and 12 years for CIP and hybrid closures, respectively). Thus, CIP and hybrid closure options best satisfy the third objective of ash basin closure—to minimize risk and disturbance to humans from closure.

[77] Sensitivity analyses exploring different assumptions and subsequent effects to relative risk ratings are provided in Appendix E.

10 Conclusion 4: All closure options for the MSS ash basin create environmental disturbance.

Environmental services are derived from ecological processes or functions that have value to individuals or society, with provision of a healthy environment to humans being one of the most essential environmental services. Environmental services that support human health include functions to purify freshwater, provide food, supply recreational opportunities, and contribute to cultural values (MEA 2005). For example, forests provide habitat for deer that are hunted for food; surface water supports fish populations that are food for bald eagles, a previously threatened and endangered species highly valued by our society;[78] and soil and wetlands purify groundwater and surface water, respectively, by adsorbing contaminants. Central to weighing the net environmental benefits of the closure options under consideration here is understanding how they differentially impact the variety of environmental services at the site and in the area.

MSS, though an industrial site, supports a diversity of habitats that provide environmental services. Figure 10-1 illustrates the types of habitats at the site. The ash impoundment provides habitat that supports birds and mammals; the open water habitat of the impoundment also removes solids from surface water by providing a low-flow environment in which ash particles and other solids can settle into the sediment before the treated water can enter Lake Norman. The onsite forest provides biodiversity protection in the form of foraging, shelter, and breeding habitat for birds and mammals, among other types of organisms; watershed protection; landscape beauty; and carbon sequestration (Bishop and Landell-Mills 2012). Beyond MSS, the Catawba River and Lake Norman provide aquatic habitat that supports a variety of fish and aquatic life (Duke Energy 2018a), which then provide food for birds and mammals.

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78 Bald eagles were taken off the federal list of threatened and endangered species in 2007 (https://www.fws.gov/midwest/eagle/).

Figure 10-1. Map of habitat types currently present at Marshall. Reproduced from CAP-2 Appendix F, Figure 2-6 (HDR 2016a).

Plants serve a vital ecosystem role by converting solar energy and carbon dioxide into food (for themselves) and oxygen. Plants then become food for other organisms. As such, "plants provide the energy and air required by most life forms on Earth."[79] NPP represents a measure of the mass of chemically fixed carbon produced by a plant community during a given period and reflects the rate at which different ecosystems are able to sequester carbon. Given the foundational role of primary production in supporting ecological food webs and healthy air, NPP is a good surrogate for environmental services provided by different habitat types (Efroymson et al. 2003). For example, the annual NPP of a temperate forest habitat is approximately 2.5 times higher than for temperate grasslands or freshwater ecosystems (Ricklefs 2008). By multiplying the acres of habitat type by NPP, NPP becomes a single metric by which to compare the different levels of environmental services impacted by ash basin closure.[80]

The fourth objective for ash basin closure, to minimize environmental disturbance, is represented by the environmental services protection of biodiversity and natural beauty. For purposes of the NEBA, these considerations were evaluated based on differences in habitat-derived services estimated from the NPP of impacted habitat acres under the closure options.

10.1 Excavation closure results in a greater net loss of environmental services than CIP or hybrid closure.

Regardless of the closure option, habitat, and habitat-derived environmental services, will be altered. CIP closure requires removing existing habitat within the footprint of the ash basin, possible temporary removal of forest habitat to create a borrow pit to source earthen materials for the cap, and restoring the ash basin with grass cap habitat. Excavation closure requires temporary loss and future modification of existing habitats within the footprint of the ash basin; permanent conversion of some forest habitat to create additional landfill capacity; temporary removal of forest habitat to create a borrow pit to source earthen materials for fill material for the landfill cap; restoring the ash basin with a mixture of grass cap, open field, and forest

79 https://earthobservatory.nasa.gov/GlobalMaps/view.php?d1=MOD17A2_M_PSN

80 I used rates of NPP by stand age from He et al. (2012, Figure 2c.) for mixed forests as the basis for establishing NPP of on-site wooded habitats and used relative rates of NPP from Ricklefs (2008) to scale NPP for other habitat types.

habitat; and restoring the new landfill capacity with grass cap. The hybrid option requires temporary loss and future modification of existing habitats within the footprint of the ash basin, temporary removal of forest habitat to create a borrow pit to source earthen materials for the cap, and restoring the reduced area of ash in the basin with a mixture of grass cap, open field, and forest habitat. All closure options include restoration of the ash basin footprint, but the collateral losses of habitat, the differences in service levels of restored habitat, and the timelines for recovery of the habitats vary substantially. This makes it challenging to appreciate the net gain or loss of environmental services. To address this challenge, I used HEA to quantify the differences in environmental services resulting from each closure option.

HEA is an assessment method widely used in NRDA to facilitate restoration scaling for environmental services (Dunford et al. 2004; Desvousges et al. 2018; Penn undated). Numerous damage assessment restoration plans based on the use of HEA can be found on the U.S. Fish and Wildlife Service[81] and NOAA[82] websites and include sites such as the St. Lawrence River near Massena, New York; Onondaga Lake near Syracuse, New York; and LaVaca Bay in Texas. As Desvousges et al. (2018) describe, use of HEA has expanded in recent years beyond its original applications for NRDA to address environmental service losses from other causes such as forest fires and climate change. As the authors note, HEA has also been used as an assessment tool in NEBA applications, such as evaluating the effects of transmission line routing on habitats of greater sage-grouse (*Centrocercus urophasianus*), a proposed threatened species.

The objective of HEA is to estimate the amount of compensatory services necessary to equal the value of the services lost because of a specific release or incident. The method calculates debits based on services lost because of resource losses and credits for services gained due to resource gains. The latter are often scaled to compensate for, or offset, the loss in services. A discount rate is used to standardize the different time intervals in which the debits and credits occur, so the services are usually expressed in terms of discounted acre-years of equivalent habitat, or DSAYs (Dunford et al. 2004; Desvousges et al. 2018; Penn undated).

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81 www.doi.gov/restoration

82 www.darrp.noaa.gov

The HEA methodology was used here to estimate changes in environmental service levels that will accrue under closure options. Environmental services currently provided by the site will be eliminated when the ash basin is closed. After closure is complete, there will be a new level of environmental services provided as habitat is restored. Since post-closure habitats may differ from those that currently occur onsite, future services could be greater or less than what occurs at present. Similarly, land used as a borrow area or converted to landfill, as per the closure options, will also impact the net level of services, as services currently provided by those habitats may be reduced or eliminated. The environmental service losses and gains from onsite and offsite habitats must be considered together when determining the overall net effect of a closure option.

A common ecological metric is required to make comparisons between service gains and losses from various habitat types. For purposes of this evaluation, I used annual NPP as the metric to standardize across habitat types. In terms of habitats currently occurring on the site, wooded areas have the highest NPP, so that is used as the basis for defining service level, and the service levels for other habitat types (open fields, open water) are expressed as a proportion of that baseline service. Based on He et al. (2012), and assuming a tree stand age of 50 years, NPP would be approximately 6.4 tons of carbon per hectare per year (6.4 t C/ha/yr) in wooded areas onsite. Based on relative rates of NPP from Ricklefs (2008), the NPP for open field and open water habitats would be approximately 40% of the temperate forest rate. To prevent overestimation of NPP in open water areas of the ash basin that may not provide the same level of NPP as natural freshwater habitats (perhaps from limited abundance or diversity of vegetation), I assumed that open water areas of the ash basin produce NPP that is 25% that of natural ecosystems.[83] Therefore, I applied a four-fold habitat quality factor to scale NPP at these open water areas of the ash basin to approximately 10% of the rate for wooded habitats. Deforested land for borrow areas was assumed to be reforested after closure was complete, and

[83] I observed open water areas of the ash basin that supported aquatic vegetation but do not know the extent of vegetation in the open water areas of the ash basin. Thus, I made a conservative assumption (i.e., one that reduces the present value of the habitat) that these areas of the ash basin provide a reduced level of NPP compared to natural open freshwater areas.

landfill areas were assumed to recover to grass cap. The grass cap on landfill was given a service value of 8%,[84] as was done for CIP.

For each closure option, I used the acreage of existing habitat types and the level of service of that habitat type to establish a baseline level of service. Based on the timelines for the various closure options, a HEA was conducted to calculate the net change in service flow of the closure area over the next 150 years at a 3% discount rate.[85] Similarly, a HEA was run to calculate the net change in environmental services deriving from areas used either as borrow or for landfill expansion. Because NPP standardizes service levels across habitat types, the DSAY estimates for all affected habitats can be summed to calculate the net service gain/loss associated with each closure option. In addition to the assumptions identified above, several other assumptions were made to support the HEA, which are described in Appendix D.

Results of the HEA are presented in Table 10-1.[86] The results indicate that all closure options will result in a net loss of environmental services due primarily to temporary or permanent loss of forest habitat for borrow and landfill areas, reduced NPP services provided by a grass cap (cap and landfill areas), and the long delay for restoration of forested habitat in the ash basin (excavation and hybrid options) and borrow pit (all options). These factors, collectively, adversely affect environmental services provided by the ash-impacted habitat acres such that environmental services produced after closure will not compensate for the service losses resulting from the closure. There are net losses for all closure options, with hybrid closure creating the least NPP service loss. [87]

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[84] An open field provides a relatively lower NPP service level than forest habitat (40% of forest NPP; Ricklefs 2008), and since a grass cap requires periodic maintenance mowing, for purposes of the HEA it was assumed never to reach a level of NPP service equivalent to an open field. Grass cap was assumed to have 20% of the NPP service level for open field, which is 8% of forest NPP.

[85] Environmental services in future years are discounted, which places a lower value on benefits that will take longer to accrue. The basis for this is that humans place greater value on services in the present and less value on services that occur in the future.

[86] A full description of the methods, assumptions, results, and sensitivity analyses for the HEA are provided in Appendix D.

[87] Note, however, that the environmental services lost due to the currently defined CIP closure could be offset (see discussion in Section 11) by a suitable reforestation project that would then result in the CIP closure option producing no net loss of habitat-derived environmental services in the HEA model.

Table 10-1. Summary of NPP DSAYs for CIP and excavation closure options

		CIP	Excavation	Hybrid
Ash basin losses	Open Field	−8	−8	−8
	Grass Cap	−324	−306	−324
	Open Water	−253	−239	−253
	Wetland	−89	−84	−89
	Broadleaf Forest	−1,757	−1,645	−1,757
	Needle Leaf Forest	−1	−1	−1
	Scrub/Shrub	−1,542	−1,453	−1,542
	Wetland Forest	−25	−24	−25
	Total losses	−4,002	−3,758	−4,002
Ash basin post-closure gains	Open Field		89	111
	Grass Cap	784	164	495
	Open Water		329	541
	Wetland		12	15
	Broadleaf Forest		1,627	1,033
	Needle Leaf Forest		122	77
	Scrub/Shrub		309	384
	Wetland Forest		49	80
	Total gains	784	2,704	2,737
Landfill/borrow losses	Forest	−1,508	−5,286	−754
	Open Field			
	Grass Cap		−9	
	Total losses	−1,508	−5,295	−754
Landfill/borrow post-closure gains	Forest	823	1,022	424
	Grass cap		126	
	Total gains	823	1,148	424
Net Gain/Loss per Option		**−3,903**	**−5,202**	**−1,594**

Note: DSAYs for specific habitat types are reported here rounded to the nearest whole number. As such, the net gain/loss per option differs slightly from the sum of the individual DSAYs reported in the table.

10.2 NEBA – Minimize Environmental Disturbance

The impact of the closure options on environmental services was computed as the percentage difference in DSAYs produced by the closure option and the absolute value of the DSAY losses. The DSAY losses represent the NPP services that would have been produced by the site, borrow areas, and landfills but for the project closure. The DSAY gains represent the NPP services restored after project closure plus any future gains realized from existing habitats before remediation begins. The sum of DSAY losses and gains represents the net change of NPP services for the project resulting from closure. Dividing the net DSAYs by the absolute value of the DSAY losses provides a percentage of the impact. From these calculations, the CIP closure will have a 71% impact; excavation closure will have a 57% impact; and hybrid closure will have a 34% impact (Table 10-2). These percent changes were input to the risk-ranking matrix (Table 5-4) along with the duration of the closure activities (13 years CIP; 28 years excavation; 12 years hybrid) to evaluate, within the NEBA construct, which of the closure options best minimizes environmental disturbances (Table 10-3).

Table 10-2. Percent impact of ash basin closure options

	CIP	Excavation	Hybrid
DSAY Losses[a]	5,509	9,053	4,756
DSAY Gains	1,607	3,851	3,161
Percent Impact (%)	71%	57%	34%

[a] Absolute value of DSAY losses is equivalent to baseline services of the affected habitat, but for the closure.

Table 10-3. Summary of relative risk ratings for habitat changes that affect provision of environmental services. Darker shading and higher codes indicate greater impact.

Objective	**Minimize Environmental Disturbance**
Hazard	Habitat Change
Attribute	DSAYs
Scenario	
Baseline	baseline
CIP	**4E**
Excavation	**6D**
Hybrid	**4C**

CIP closure, as currently defined, though having a lower net DSAY loss than excavation closure has a higher percent impact because the net NPP services lost are a larger fraction of the NPP services that would have existed but for closure of the ash basin, which is a consequence of the low level of NPP services provided by the 502 acres of grass cap after closure (8% of forest NPP). Conversely, the greater net NPP service loss under excavation closure is a smaller fraction of the services that would have existed but for the closure because the excavation closure option can lead to the creation of forest in a large proportion of the footprint of the ash basin and the land for landfilling (and loss of forest habits that are ultimately replaced with low NPP grass cap). Hybrid closure has the least net NPP service loss of the options considered, and it also has the lowest percent impact from the closure because the net NPP services lost are a smaller fraction of the NPP services that would have existed but for closure of the ash basin, which results from the larger forest habitat gained and smaller grass cap footprint compared to CIP.

Within the objective of minimizing environmental disturbance from closure, my analyses indicate that all closure options adversely impact habitat-derived environmental services and produce comparable decreases in net NPP services; however, the lower impact and shorter duration of hybrid closure better satisfies the fourth objective of ash basin closure—to minimize risk and disturbance to the local environment from closure.

11 Conclusion 5: Hybrid closure maximizes environmental services.

Identifying environmental actions that maximize environmental services (the fifth objective for ash basin closure) is a function of NEBA (Efroymson et al. 2003, 2004) and the overarching objective that encompasses each of the other four objectives and all of the environmental services that have been considered to this point. Table 11-1 summarizes the relative risk ratings for all attributes and objectives. Impacts to environmental services considered in this NEBA focused on key community-relevant concerns. Risk to construction workers from construction operations, risks to local and global populations from increased greenhouse gas emissions, and "wear-and-tear" damage to roadways from trucking were not estimated. Each of these risks, however, would scale with the duration, frequency, and intensity of construction operations.

Sensitivity analyses of the specifications of the NEBA framework show that the specific relative risk ratings presented in this NEBA can change depending on how baseline is defined (see Appendix E). The purpose of the risk matrix, and the risk ratings that result from it, is to consolidate the results from a variety of different analyses for a variety of different data types and attributes into a single framework for comparative analysis. It is imperative, however, to consider the underlying information used to develop the risk ratings to interpret the differences between closure options, particularly when percent impacts or durations of closure options are similar but receive different risk ratings.

As noted in Section 5, NEBA analysis provides an opportunity to better understand the net environmental benefits of possible closure options. If Duke Energy's preferred closure option for reasons not considered in the NEBA does not best maximize environmental services to the local community as currently defined, the NEBA results provide insight into how environmental services could be improved for that closure option. For instance, if Duke Energy's preferred closure option for MSS is CIP closure but the HEA results for the currently defined CIP closure option estimate a net environmental service loss of 3,903 DSAYs, Duke Energy could consider incorporating into an updated CIP closure plan for MSS a mitigation project that compensates for the net environmental service losses projected from the currently defined CIP closure option.

As an example, if Duke Energy started a reforestation project outside of the ash basin in 2022 (when onsite preparation of the ash basin begins), the reforestation project would gain 24.3 DSAYs/acre over the lifetime of the site (150 years in the HEA), requiring an approximate 160 acre project to compensate for the 3,903 DSAY loss projected in the HEA. Re-analysis of the HEA component of the NEBA for the updated possible closure options would then result in no net environmental losses (as NPP services) from habitat alteration of the basin for CIP closure, but net losses would remain under the hybrid and excavation closure options.

From the closure options considered and the analyses presented in this report, which are based on a scientific definition of risk acceptability and include no value weighting, all closures as currently defined provide equivalent protection of human and ecological health from CCR exposure; however, the hybrid closure option best satisfies the fifth objective of ash basin closure—to maximize local environmental services—because it results in less disturbance to the local community over time compared to excavation closure and produces the least disturbance to the environment.

Table 11-1. NEBA for closure of the ash basin at Marshall.
Darker shading and higher alphanumeric codes indicate greater impact.

Objective	**Protect Human Health from CCR**							**Protect Ecological Health from CCR**						**Minimize Human Disturbance**			**Minimize Environmental Disturbance**
Hazard	Exposure to CCR							Exposure to CCR						Noise and Traffic Congestion	Traffic Accidents	Air Pollution	Habitat Change
Potentially Affected Populations	Local Residents/Visitors	Onsite Construction Workers	Offsite Recreational Swimmers	Offsite Recreational Waders	Offsite Recreational Boaters	Offsite Recreational Fishers	Offsite Subsistence Fishers	Fish Populations	Aquatic Omnivore Birds (mallard)	Aquatic Piscivore Birds (great blue heron)	Aquatic Carnivore Birds (bald eagle)	Aquatic Herbivore Mammals (muskrat)	Aquatic Piscivore Mammals (river otter)	Local Residents/Visitors	Local Residents/Visitors	Reasonable Maximum Exposure	DSAYs
Scenario																	
Baseline	--	--	--	--	--	--	--	--	--	--	--	--	--	baseline	baseline	baseline	baseline
CIP	--	--	--	--	--	--	--	--	--	--	--	--	--	**4B**	**4A**	--	**4E**
Excavation	--	--	--	--	--	--	--	--	--	--	--	--	--	**6A**	**6A**	--	**6D**
Hybrid	--	--	--	--	--	--	--	--	--	--	--	--	--	**4B**	**4A**	--	**4C**

"--" indicates "no meaningful risk."

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Appendix A

Curriculum Vitae of
Dr. Ann Michelle Morrison, Sc.D.

Exponent®
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Ann Michelle Morrison, Sc.D.

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Professional Profile

Dr. Morrison has over 20 years of experience evaluating the relationship between anthropogenic contamination and health effects to aquatic life and humans. Dr. Morrison specializes in natural resource damage assessment (NRDA), environmental causal analysis, and assessments of water quality conditions. Dr. Morrison has provided scientific consultation regarding the design of field studies for NRDA, and she has worked closely with legal counsel during scientific assessments and settlement negotiations with state and federal trustees. Dr. Morrison has performed detailed technical assessments of injuries to aquatic resources, including vegetation, benthic infauna, fishes, shellfishes, and corals. She has also developed site-specific sediment toxicity thresholds based on the empirical relationships of chemical concentrations to biological effects. She has provided expert testimony concerning injury to aquatic resources and the net environmental benefits of remediation alternatives.

Projects she has been involved with have concerned oil spills, sewage releases, heavy metal contamination, and various industrial and municipal facilities that have generated complex releases to the environment. Dr. Morrison applies statistical tools and weight-of-evidence approaches to delineate exposure zones, predict the likelihood of contamination events, evaluate net environmental benefits, and assess causation. She uses a broad knowledge of aquatic life and human health to assess risk and injury to these populations.

Academic Credentials & Professional Honors

Sc.D., Environmental Health, Harvard University, 2004

M.S., Environmental Health, Harvard University, 2001

B.S., Biology, Rhodes College, 1997

Prior Experience

Senior Scientist, Sole Proprietor, Morrison Environmental Data Services, 2004–2007

Data Analyst, ETI Professionals, 2005

Scientist, NIH Toxicology Training Grant, Harvard School of Public Health, 2000–2004

Guest Student, Woods Hole Oceanographic Institution, Stegeman Lab, 2001–2004

Science Intern, Massachusetts Water Resources Authority, 03-05/2000, 10/2000-10/2001

Research technician, Bermuda Biological Station for Research, Inc., Benthic Ecology Research Program (BERP), Bermuda, 01/1998-09/1999, 06-08/2000

Research Intern, Bermuda Biological Station for Research, Inc., Benthic Ecology Research Program (BERP), Bermuda, 05/1997-12/1997

NSF Research Experience for Undergraduates Fellowship, Bermuda Biological Station for Research, Inc., Benthic Ecology Research Program (BERP), Bermuda, 08-11/1996

Professional Affiliations

American Chemical Society — ACS

Society for Risk Analysis — SRA

Society of Environmental Toxicology and Chemistry — SETAC

North Atlantic Chapter of SETAC

Publications

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Deines AM, Palmquist K, Morrison AM. Global Status and Risk of Non-Native Fish Aquaculture. 148th Annual Meeting of the American Fisheries Society, Atlantic City, NJ. August 19–23, 2018.

Morrison AM, Palmquist K, Kashuba R. Baseline in the Open-Access and “Big Data” Era. Law Seminars International. Washington, D.C. March 1, 2018.

Palmquist K, Morrison AM, Edwards ME. Addressing white hat bias: Lessons from environmental litigation. Society of Environmental Toxicology and Chemistry (SETAC) North America 38th Annual Meeting, Minneapolis, MN. November 12–16, 2017.

Palmquist KR, Ginn TC, Morrison AM, Boehm PD. 2017. Addressing Spatial Data Gaps in Deep-sea Benthic Sediment Sampling Following a Large-Scale Oil Spill. Battelle Sediment Conference in New Orleans, LA.

Morrison AM. The Science. Natural Resource Damages 101. Law Seminars International. Washington, D.C. March 9, 2016.

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Boehm PD, Morrison AM. The Interplay of Data Needs and Data Analysis Frameworks to Optimize the Collection and Use of Data from Oil Spills. Gulf of Mexico Research Initiative Conference. Tampa, FL. February 1–4, 2016.

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Stanley AM, Coughlin KA, Shine JP, Coull BA, Rex AC. Receiver operating characteristic analysis is a simple and effective tool for using rainfall data to predict bathing beach bacterial water quality. 102nd General Meeting, American Society for Microbiology, Salt Lake City, UT. May 2002.

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Smith SR, Grayston LM, Stanley AM, Webster G, McKenna SA. CARICOMP coral reef monitoring: A comparison of continuous intercept chain and video transect techniques. Scientific Aspects of Coral Reef Assessment, Monitoring and Management, National Coral Reef Institute (NCRI), Nova Southeastern University, Ft. Lauderdale, FL. 1999.

Project Experience

Dr. Morrison has been involved in numerous complex projects relating to environmental contamination and potential risk to humans and biological resources in the affected environment.

Risk Assessments and Natural Resource Assessments

Expert witness concerning net environmental benefits from coal ash closure alternatives at two coal ash plants in North Carolina. *Roanoke River Basin Association v. Duke Energy Progress,* LLC, United States District Court, Middle District of North Carolina, Case No. 1:16-cv-607 and *Roanoke River Basin Association v. Duke Energy Progress,* LLC, United States District Court, Middle District of North Carolina, Case No. No. 1:17-cv-452.

Expert witness concerning potential damages to terrestrial and aquatic resources, including coral reefs, endangered sea turtles, fish and shellfish, and seagrass beds, resulting from a coastal development project on the Caribbean island of Nevis. Anne Hendricks Bass vs. Director of Physical Planning, Development Advisory Committee, and Caribbean Development Consultant Limited. Eastern Caribbean Supreme Court, in the High Court of Justice Saint Christopher and Nevis, Nevis Circuit, Civil Case No. NEVHCV2016/0014.

Expert witness concerning potential impacts to California fishery populations from the Refugio oil spill. Andrews et al. v. Plains All American Pipeline, L.P. et al. United States District Court, Central District of California, Wester Division, Case No. 2:15-cv-04113-PSG-JEM.

Provided analysis and technical support in Florida v. Georgia United States Supreme Court case that considered questions of causation relative to alleged adverse ecological changes in downstream river and bay populations.

Conducted a comprehensive review of an environmental impact assessment of potential impacts to coral reefs from a proposed dairy farm development in Hawaii.

Provided scientific support for the Deepwater Horizon NRDA in the Gulf of Mexico.

Developed a cooperative NRDA field study in the offshore waters of the Gulf of Mexico to collect sediment samples for analysis of chemistry, toxicology, and benthic infauna.

Expert witness concerning alleged injuries to aquatic resources from disposal of bauxite ore processing wastes for the case: Commissioner of the Department of Planning and Natural Resources, Alicia V. Barnes, et al. v. Virgin Islands Alumina Company et al. District Court of the Virgin Islands, Division of St. Croix, Civil Case No. 2005-0062.

Developed decision management products for beach water quality stakeholders using statistical data analysis tools such as receiver operating characteristic (ROC) curves and Bayesian networks to improve public beach advisories related to elevated fecal bacteria.

Developed net environmental benefit analysis (NEBA) for a lead contaminated river. This analysis used site-specific data to evaluate the costs and benefits of two different remediation options that were being considered. The NEBA was successfully used by the client to negotiate a higher remediation goal than original proposed by the state Department of Environmental Protection.

Performed ROC curve analyses of site-specific polycyclic aromatic hydrocarbon (PAH) toxicity data to assess the relationship between PAH concentration and toxicity at three ecological risk assessment projects in Wisconsin. The curves were used to identify site-specific toxicity thresholds for PAH concentration in sediment that were indicative of various zones of toxicity (no toxicity, low toxicity, and high toxicity), with very limited misidentification of sediments.

Provided research support to calculate site-specific no-observed-adverse-effect level (NOAEL) and lowest-observed-adverse-effect level (LOAEL) concentrations for mammals and birds for use in a baseline ecological risk assessment in Wisconsin.

Performed ROC curve analysis of national mercury toxicity data to assess the relationship between mercury concentration and toxicity. The curves were also used to identify a threshold mercury concentration for sediment that indicates likely toxicity, with very limited misidentification of sediments that are not toxic.

Assembled and analyzed data and reviewed remedial investigations to conduct a screening-level ecological risk assessment for sediment, surface water, and groundwater for a site in Connecticut. The chemicals considered were total petroleum hydrocarbons (TPH), metals, and PAHs.

Reviewed species lists and created summary descriptions of organisms that could be potentially impacted by dam construction on a high-altitude river in the Caribbean. This information was important to develop the risk assessment from dam construction.

Researched the toxicity of malathion to fish to support a technical review of the National Marine Fisheries biological opinion for the registration of pesticides containing malathion.

Ecological and Toxicity Studies

Conducted surveys to assess the health of coral reefs, seagrass beds, and mangrove swamps in the nearshore environment of Bermuda. Projects included area-wide habitat surveys as well as targeted sites potentially impacted by a heavy metals dump, hot water effluent from an incinerator, sedimentation from cruise ship traffic, and chronic release of raw sewage. In addition to ecological surveys, water quality was assessed through measurements of trace metals in water, sediment, and coral tissue.

Surveyed juvenile coral recruitment in the Florida Keys to evaluate if marine protected areas (MPAs) provide a benefit to coral recruitment.

Studied cytochrome P450 family enzymes, including CYP51 and CYP1, examining their sensitivity to environmental chemicals and their evolution through molecular biology and biochemistry approaches.

Environmental Forensics Projects

Performed document review, information management, and technical writing for numerous complex projects that dealt with historical petroleum contamination and multiple site owners in several types of environmental media.

Reviewed documents, assembled data, and researched metal concentrations associated with crude oil and railroads in support of a Superfund project in Oklahoma.

Examined the correlation of multiple contaminants (PAHs, metals) with polychlorinated biphenyl (PCB) congeners at a historically contaminated site in Alabama to identify the likely origins of the PCB contamination.

Performed statistical analysis to determine source contribution in a chemical fingerprinting case at a Superfund site in Washington that involved hydrocarbons in water, sediment, and groundwater.

Human Health Projects

Organized, managed, and simplified a complex database of field sampling reports for a litigation case in Louisiana regarding human air exposure to PAHs.

Performed data analysis and document review for a Superfund site in Oklahoma. The analyses used hydrocarbon chromatograms and limited PAH and metal data to identify the likely sources of contamination.

Researched and compiled screening-level human health inhalation toxicity values for refinery-related gases for an overseas project.

Developed a questionnaire and related database for industrial hygiene surveys to support regulatory compliance for a highly specialized industry.

Appendix B

Human Health and Ecological Risk Assessment Summary Update for Marshall Steam Station

HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT

SUMMARY UPDATE

For

MARSHALL STEAM STATION
8320 EAST CAROLINA HIGHWAY 150
TERRELL, NORTH CAROLINA 28682

NOVEMBER 2018

PREPARED FOR

DUKE ENERGY CAROLINAS, LLC
526 SOUTH CHURCH STREET
CHARLOTTE, NORTH CAROLINA 28202

Matt Huddleston, Ph.D.
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1.0 INTRODUCTION

This update to the Marshall Steam Station (MSS or Site) human health and ecological risk assessment incorporates results from sampling events conducted August 1989 through July 2018. The samples were collected from surface water, sediment, and groundwater. This update was performed in support of a Net Environmental Benefits Analysis. As set forth below in detail, this updated risk assessment concludes that: (1) the MSS ash basin does not cause any material increase in risks to human health for potential human receptors located on-Site or off-Site; and (2) the MSS ash basin does not cause any material increase in risks to ecological receptors.

The original 2016 risk assessment was a component of the Corrective Action Plan Part 2 pertaining to MSS (HDR, 2016). To assist in corrective action decision making, the risk assessment characterized potential effects on humans and wildlife exposed to naturally occurring elements, often associated with coal ash, present in environmental media. Corrective action is to be implemented with the goal of ensuring future site conditions remain protective of human health and the environment, as required by the 2014 North Carolina General Assembly Session Law 2014-122, Coal Ash Management Act (CAMA). The risk assessment was updated as part of the 2018 Comprehensive Site Assessment (CSA) Update report (SynTerra, 2018). This update follows the methods of the 2016 risk assessment (HDR, 2016) and is based on U.S. Environmental Protection Agency (USEPA) risk assessment guidance (USEPA, 1989; 1991; 1998).

Areas of wetness (AOWs), or seeps, are not subject to this risk assessment update. AOWs associated with engineered structures, also referred to as "constructed seeps," have been addressed in a National Pollutant Discharge Elimination System (NPDES) permit. Other AOWs (non-constructed seeps) are now addressed under a Special Order by Consent (SOC) issued by the North Carolina Environmental Management Commission (EMC SOC WQ S17-009). Many AOWs are expected to reduce in flow or be eliminated after decanting (*i.e.*, removal of the free water). The SOC requires that any seeps remaining after decanting must be addressed with a corrective action plan that must "protect public health, safety, and welfare, the environment, and natural resources" (EMC SOC WQ S17-009, 2. d.).

This risk assessment update includes results from samples of surface water, sediment, and groundwater collected since the 2018 CSA update. New information regarding groundwater flow and the treatment of source areas other than the ash basin has resulted in refinement of exposure pathways and exposure areas. The Conceptual Site Models (CSMs) (**Figures 1 and 2**) reflect potentially complete exposure pathways with potential risks, and ecological exposure areas are depicted in **Figure 3**. Human health risks were evaluated Site-wide and in adjacent areas, so no exposure area figure is provided. Changes to the CSMs include:

- Exposure to coal combustion residual (CCR) constituents by Site workers is considered incomplete, because Duke Energy maintains strict health and safety requirements and training. The use of personal protective equipment (*e.g.*, boots, gloves, safety glasses) and other safety behaviors exhibited by Site workers limits exposure to CCR constituents. Following conservative risk assessment practices, the initial risk assessment report considered CCR constituent exposure pathways for Site workers to be potentially complete. Further information has revealed that on-Site worker exposure pathways are incomplete, and this risk assessment update has been revised to reflect this change.

- Surface water sampling and sediment sampling of Lake Norman allows for direct assessment of those areas, rather than using AOW data as a surrogate.

Results from samples of surface water, sediment, and groundwater were compared with human health and ecological screening values (**Attachments 1 and 2**) to identify constituents of potential concern (COPCs) for further review. Exposure point concentrations (EPCs) were calculated for COPCs (**Attachments 3 and 4**) to incorporate into human health and ecological risk models. Results of risk estimates (**Attachments 5 and 6**) are summarized below.

2.0 SUMMARY OF RISK FINDINGS

2.1 Human Health

There is no exposure to residential receptors at MSS because no one lives on-Site or near enough to the Site to be affected by groundwater migration from the ash basin. Potential receptors off-Site are recreational users of Lake Norman, including swimmers, waders, boaters, and fishers. However, background concentrations of the same elements are greater or also present similar risks to the same potential receptors. Those risks are not associated with the ash basin.

- There is no increase in cancer risks attributable to the ash basin associated with the boater, swimmer, and wader exposure scenarios.
    - There is no increase in cancer risks for the boater, swimmer, and wader exposure scenarios attributable to the ash basin. Incorporating hexavalent chromium concentrations in surface water samples collected since the 2018 CSA update produced modeled potential carcinogenic risks under the boater, swimmer, and wader scenarios. However, surface water hexavalent chromium concentrations detected in background surface water samples (locations SW-7 and SW-8) were as much as 2.1 µg/L, compared to the EPC calculated from sampling data for use in the risk assessment of 0.5 µg/L.
    - No evidence of non-carcinogenic risks for the recreational swimmer, wader, or boater exposure scenarios associated with Lake Norman was identified.
- There is no increase in cancer risks attributable to the ash basin associated with the fisher exposure scenario.
    - There is no increase in cancer risks for the fisher exposure scenario attributable to the ash basin. Hexavalent chromium concentrations in surface water produced modeled results of potential carcinogenic risks under the recreational and subsistence fishing exposure scenarios. However, surface water hexavalent chromium concentrations collected from the upgradient stream (sample locations SW-7 and SW-8) were as much as 2.1 µg/L, compared to the EPC calculated from sampling data for use in the risk assessment of 0.5 µg/L. There is, therefore, no increase in cancer risks due to the ash basin. Moreover, risk estimates from fish consumption are based on CCR constituent concentrations in fish tissue

modeled from concentrations detected in surface water. Thus, the modeled concentration of hexavalent chromium in fish tissue is likely overestimated. [1]

- There is no material increase in non-carcinogenic risks for the fisher exposure scenarios attributable to the ash basin. Potential non-carcinogenic risks were modeled for the recreational and subsistence fisher potentially exposed to cobalt detected in Lake Norman. Subsistence fishing, defined by USEPA (2000) as ingestion of 170 grams (0.375 pounds) of fish per day, has not been identified on Lake Norman.[2] But even if there were subsistence fishers using the water body, there would be no material increase in risks to them posed by the ash basin. Concentrations of cobalt in upgradient surface water (sample locations SW-7 and SW-8) were as much as 3.5 μg/L, compared to the EPC used in the risk assessment of 10 μg/L. When substituted into the risk model, the background cobalt concentration would also result in estimated risks. Moreover, risk estimates from fish consumption are based on CCR constituent concentrations in fish tissue modeled from concentrations detected in surface water. The modeled concentration of cobalt in fish tissue is likely overestimated, due to conservative assumptions concerning bioconcentration rates. This, together with conservative assumptions on fish consumption rates, tends to overestimate risks.

- The updated risk assessment found no evidence of risks associated with exposure to groundwater by Site workers. Trespasser exposure to AOWs was not evaluated because AOWs are addressed in the SOC. There is therefore no material increase in risks associated with onsite exposure scenarios.

[1] For conservative estimation of hexavalent chromium concentrations in fish tissue, the recreational and subsistence fisher exposure models used in this risk assessment assume a hexavalent chromium bioconcentration factor (BCF) of 200 (NRCP, 1996). Bioconcentration is the process by which a chemical is absorbed by an organism from the ambient environment through its respiratory and dermal surfaces (Arnot and Gobus, 2006). The degree to which bioconcentration occurs is expressed as the BCF. Published BCFs for hexavalent chromium in fish can be as low as one, suggesting that potential bioconcentration in fish is low (USEPA, 1980; 1984; Fishbein, 1981; ATSDR, 2012). The conservative BCF of 200 used here likely overestimates the hexavalent chromium concentration in fish tissue.

[2] To put the fish ingestion rate into context, a 170 gram per day fish meal is approximately equal to six ounces or approximately five fish sticks per meal (see http://gortons.com/product/original-batter-tenders); it is assumed that the subsistence fisher catches this amount of fish in the local water body and has such a fish meal once per day, every day for years.

In summary, there is no material increase in risks to human health attributable to the MSS ash basin.

2.2 Ecological

There is no evidence of ecological risks associated with Lake Norman and a tributary (Exposure Area 1).

- In practice, ecological risks are quantified by comparing an average daily dose (ADD) of a constituent to a toxicity reference value (TRV) for a given wildlife receptor. The ratio of the ADD and TRV is the hazard quotient (HQ), where an HQ less than unity (1) indicates no evidence of risks. TRVs are generally no-observed-adverse-effects-levels (NOAEL) or a lowest-observed-adverse-effects-levels (LOAEL) from toxicity studies published in scientific literature.
- No HQs that were based on NOAELs and LOAELs exceeded unity for the wildlife receptors (mallard duck, great blue heron, bald eagle, muskrat, and river otter) exposed to surface water and sediments.

In summary, there is no evidence of ecological risks attributable to the MSS ash basin.

3.0 REFERENCES

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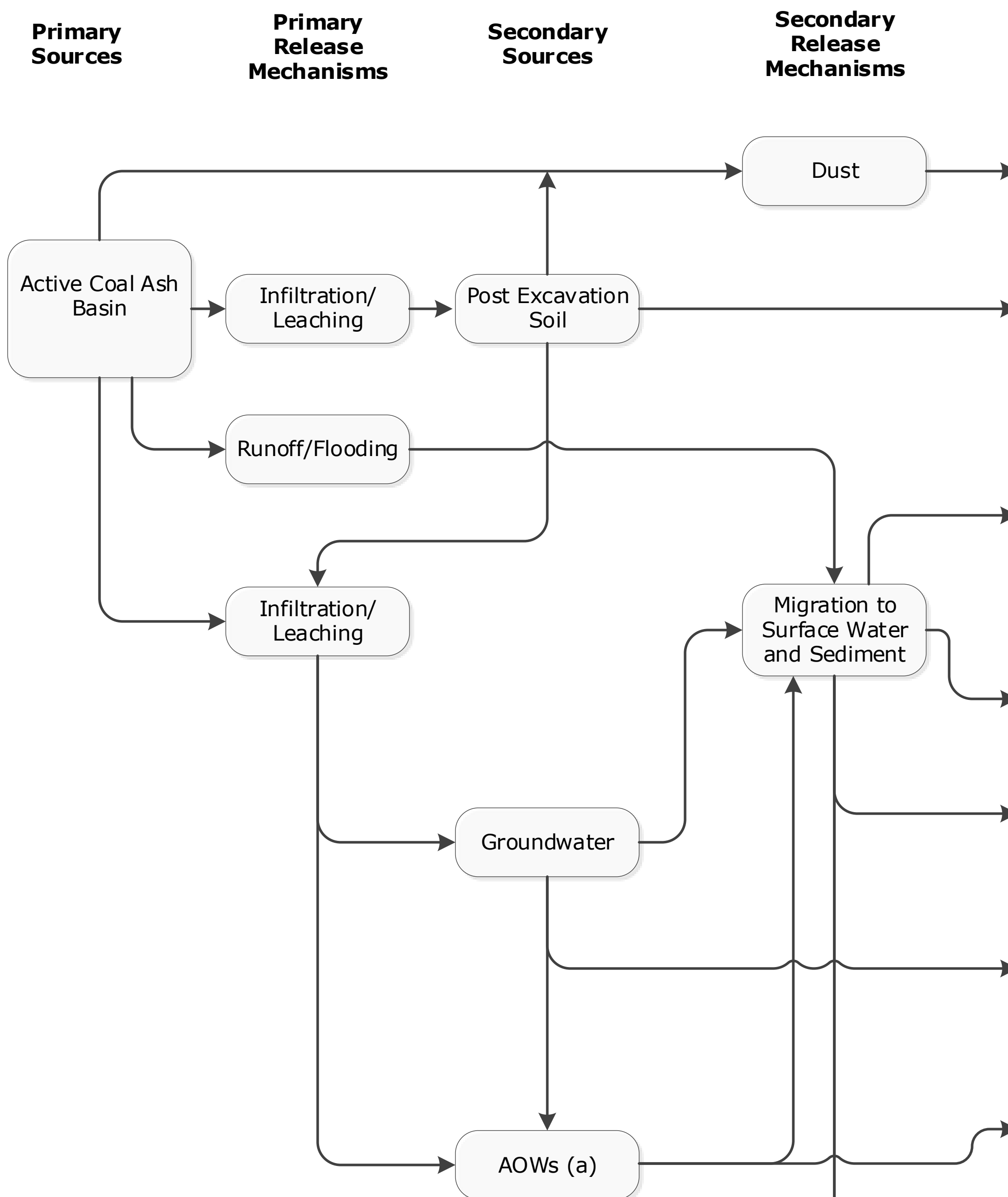
FIGURES



Potential Exposure Media	Potential Exposure Route	Current/ Future Off-Site Resident Adult/Child	Current/ Future On-Site Recreational Trespasser	Current/ Future Off-Site Recreational Swimmer	Current/ Future Off-Site Recreational Wader	Current/ Future Off-Site Recreational Boater	Current/ Future Off-Site Recreational / Subsistence Fisher	Current/ Future On-site Commercial/ Industrial Worker	Current/ Future On-Site Construction Worker
		Human Receptors							
Outdoor Air	Inhalation	○	○	○	○	○	○	○	○
Soil Remaining Post-Excavation (b)	Incidental Ingestion	○	○	○	○	○	○	○	○
	Dermal Contact	○	○	○	○	○	○	○	○
Surface Water (Off-site) (d)	Drinking Water Use (e)	○	○	○	○	○	○	○	○
	Incidental Ingestion	○	○	●(f)	●(f)	○	○	○	○
	Dermal Contact	○	○	●	●	●	●	○	○
Sediment (Off-site) (c)	Incidental Ingestion	○	○	○	○	○	○	○	○
	Dermal Contact	○	○	○	○	○	○	○	○
Fish Tissue (c)	Ingestion	○	○	○	○	○	●	○	○
Groundwater	Drinking Water Use	○	○	○	○	○	○	○	○
	Incidental Ingestion	○	○	○	○	○	○	○	○(g)
	Dermal Contact	○	○	○	○	○	○	○	○(g)
AOW Water (On-site)	Dermal Contact	○	○	○	○	○	○	○	○
AOW Soil (On-site)	Dermal Contact	○	○	○	○	○	○	○	○
Surface Water (On-site) (d)	Incidental Ingestion	○	○	○	○	○	○	○	○
	Dermal Contact	○	○	○	○	○	○	○	○
Sediment (On-site) (d)	Incidental Ingestion	○	○	○	○	○	○	○	○
	Dermal Contact	○	○	○	○	○	○	○	○

NOTES

● Potentially complete exposure pathway based on results of 2018 risk assessment update.

○ Pathway evaluated and found incomplete/insignificant.

(a) Areas of wetness (AOWs) are addressed in the Special Order by Consent (SOC) and not evaluated in the risk assessment update at this time.

(b) Pathway incomplete as long as ash remains in place; re-evaluation upon excavation (if conducted) may be warranted.

(c) Concentration of COPC in fish tissue modeled from surface water concentration.

(d) Site-wide data are used to evaluate on-site exposure.

(e) Lake Norman is a source of public drinking water i.e., WS-IV, water is treated before use. There are no private residences located hydraulically downgradient of on-site groundwater.

(f) Incidental surface water ingestion assumed only to occur for receptors for the swimming and wading scenarios.

(g) Groundwater exposure evaluated in the risk assessment update, although an incomplete exposure pathway for construction worker.

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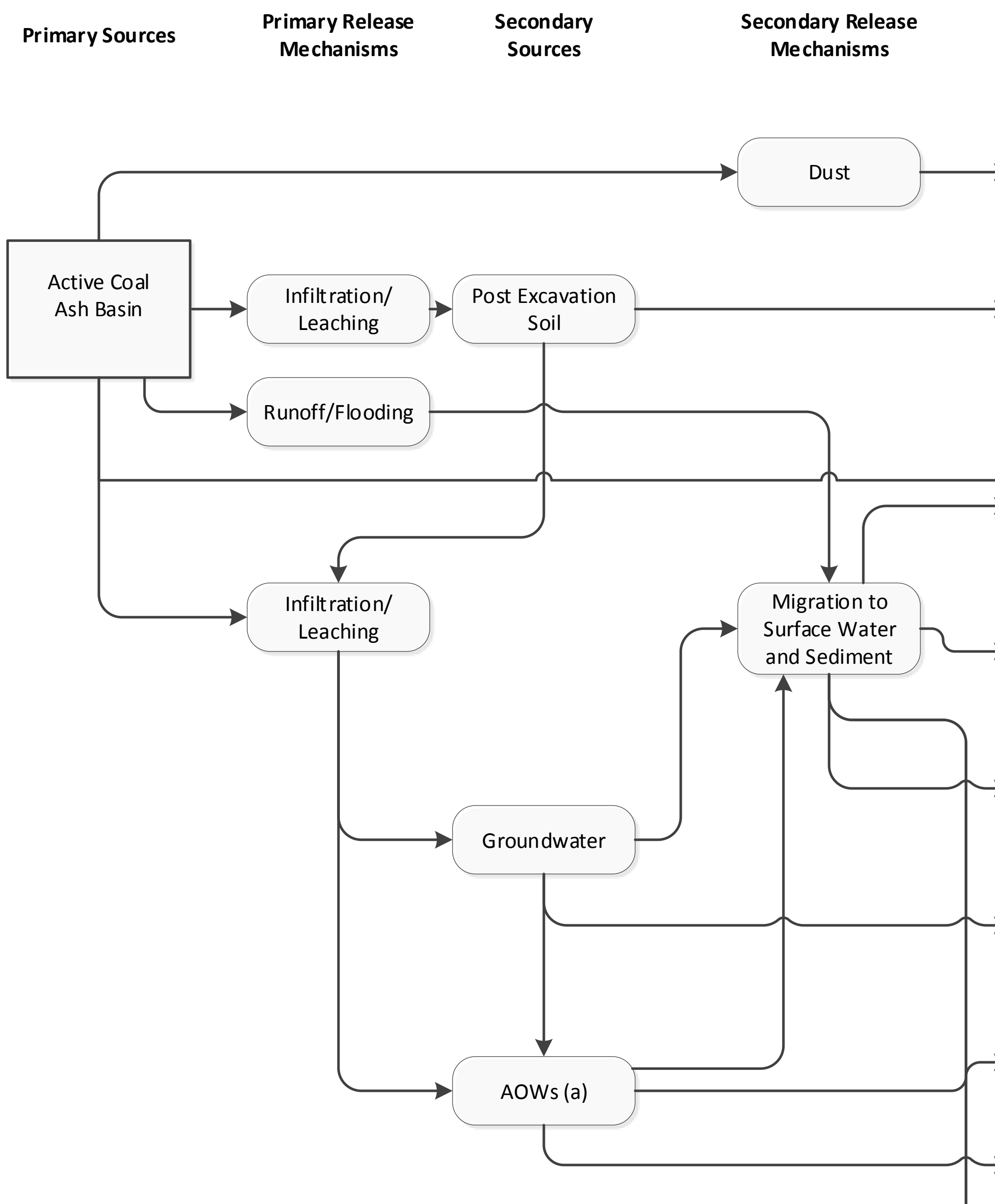
FIGURE 1
HUMAN HEALTH RISK ASSESSMENT
CONCEPTUAL SITE MODEL
MARSHALL STEAM STATION
TERRELL, NORTH CAROLINA



		AQUATIC RECEPTORS						TERRESTRIAL RECEPTORS (e)			
				Avian (f)		Mammal		Avian		Mammal	
Potential Exposure Media	Potential Exposure Route	Fish	Benthic Invertebrates	Mallard (Omnivore)	Great Blue Heron (Piscivore)	Muskrat (Herbivore)	River Otter (Piscivore)	Robin (Omnivore)	Red-Tailed Hawk (Carnivore)	Meadow Vole (Herbivore)	Red Fox (Carnivore)
Outdoor Air	Inhalation	○	○	○	○	○	○	○	○	○	○
Soil Remaining Post-Excavation (b)	Plant/Incidental Ingestion	○	○	○	○	○	○	○	○	○	○
	Direct Contact	○	○	○	○	○	○	○	○	○	○
Surface Water (Off-site)	Ingestion	○	○	○	○	○	○	○	○	○	○
	Direct Contact	●(d)	●(d)	○	○	○	○	○	○	○	○
Sediment (Off-site)	Plant/Incidental Ingestion	○	○	○	○	○	○	○	○	○	○
	Direct Contact	○	●(d)	○	○	○	○	○	○	○	○
Fish Tissue (c)	Ingestion	○	○	○	○	○	○	○	○	○	○
Groundwater	Ingestion	○	○	○	○	○	○	○	○	○	○
	Direct Contact	○	○	○	○	○	○	○	○	○	○
AOW Water (On-site)	Ingestion	○	○	○	○	○	○	○	○	○	○
AOW Soil (On-site)	Plant/Incidental Ingestion	○	○	○	○	○	○	○	○	○	○
Surface Water (On-site)	Ingestion	○	○	○	○	○	○	○	○	○	○
	Direct Contact	○	○	○	○	○	○	○	○	○	○
Sediment (On-site)	Plant/Incidental Ingestion	○	○	○	○	○	○	○	○	○	○
	Direct Contact	○	○	○	○	○	○	○	○	○	○

NOTES

● Potentially complete exposure pathways based on results o 2018 risk assessment update.

○ Pathway evaluated and found incomplete/insignificant.

(a) Areas of wetness (AOWs) are addressed in the Special Order by Consent (SOC) and not evaluated in the risk assessment update at this time.

(b) Pathway incomplete as long as ash remains in place; re-evaluation upon excavation (if conducted) may be warranted.

(c) Concentration of COPC in fish tissue modeled from surface water concentration.

(d) Based on screening against aquatic life criteria.

(e) Exposure to terrestrial receptors was not evaluated because AOWs are addressed in the SOC.

(f) Bald eagle (carnivore) included as a receptor associated with aquatic habitat.

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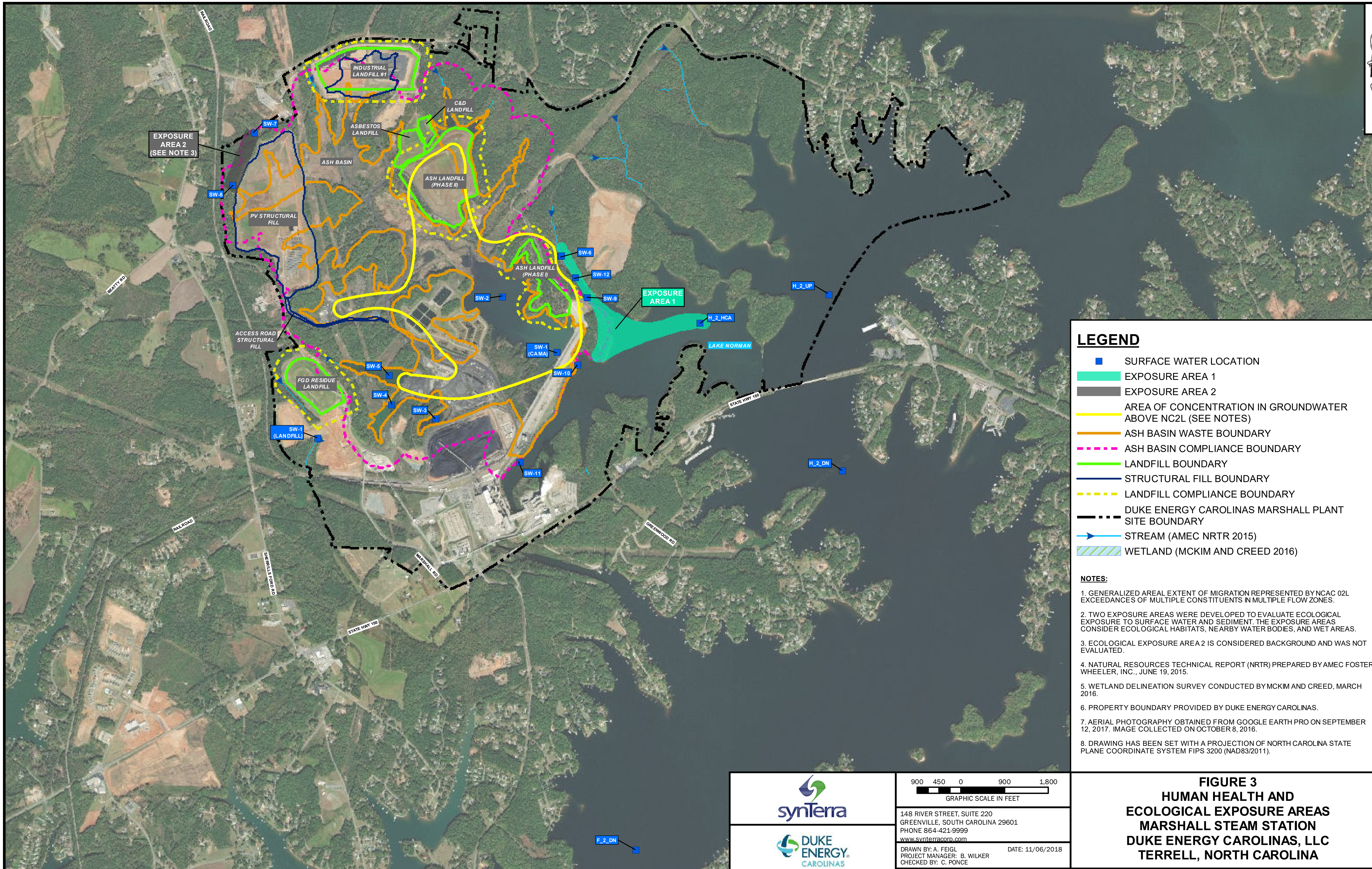
FIGURE 2
ECOLOGICAL RISK ASSESSMENT
CONCEPTUAL SITE MODEL
MARSHALL STEAM STATION
TERRELL, NORTH CAROLINA



LEGEND

- SURFACE WATER LOCATION
- EXPOSURE AREA 1
- EXPOSURE AREA 2
- AREA OF CONCENTRATION IN GROUNDWATER ABOVE NC2L (SEE NOTES)
- ASH BASIN WASTE BOUNDARY
- ASH BASIN COMPLIANCE BOUNDARY
- LANDFILL BOUNDARY
- STRUCTURAL FILL BOUNDARY
- LANDFILL COMPLIANCE BOUNDARY
- DUKE ENERGY CAROLINAS MARSHALL PLANT SITE BOUNDARY
- STREAM (AMEC NRTR 2015)
- WETLAND (MCKIM AND CREED 2016)

NOTES:

1. GENERALIZED AREAL EXTENT OF MIGRATION REPRESENTED BY NCAC 02L EXCEEDANCES OF MULTIPLE CONSTITUENTS IN MULTIPLE FLOW ZONES.
2. TWO EXPOSURE AREAS WERE DEVELOPED TO EVALUATE ECOLOGICAL EXPOSURE TO SURFACE WATER AND SEDIMENT. THE EXPOSURE AREAS CONSIDER ECOLOGICAL HABITATS, NEARBY WATER BODIES, AND WET AREAS.
3. ECOLOGICAL EXPOSURE AREA 2 IS CONSIDERED BACKGROUND AND WAS NOT EVALUATED.
4. NATURAL RESOURCES TECHNICAL REPORT (NRTR) PREPARED BY AMEC FOSTER WHEELER, INC., JUNE 19, 2015.
5. WETLAND DELINEATION SURVEY CONDUCTED BY MCKIM AND CREED, MARCH 2016.
6. PROPERTY BOUNDARY PROVIDED BY DUKE ENERGY CAROLINAS.
7. AERIAL PHOTOGRAPHY OBTAINED FROM GOOGLE EARTH PRO ON SEPTEMBER 12, 2017. IMAGE COLLECTED ON OCTOBER 8, 2016.
8. DRAWING HAS BEEN SET WITH A PROJECTION OF NORTH CAROLINA STATE PLANE COORDINATE SYSTEM FIPS 3200 (NAD83/2011).

900 450 0 900 1,800

GRAPHIC SCALE IN FEET

148 RIVER STREET, SUITE 220
GREENVILLE, SOUTH CAROLINA 29601
PHONE 864-421-9999
www.synterracorp.com

DRAWN BY: A. FEIGL DATE: 11/06/2018
PROJECT MANAGER: B. WILKER
CHECKED BY: C. PONCE

FIGURE 3
HUMAN HEALTH AND ECOLOGICAL EXPOSURE AREAS
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC
TERRELL, NORTH CAROLINA

P:\Duke Energy Progress.1026\00 GIS BASE DATA\Marshall\Mapdocs\MISC\RiskAssessment\Fig03_Marshall_ExposureAreas.mxd

ATTACHMENTS

TABLE 1-1
HUMAN HEALTH SCREENING - GROUNDWATER
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC, TERRELL, NC

Analyte	CAS	Number of Samples	Frequency of Detection	Range of Detection (µg/L)		Concentration Used for Screening (µg/L)	15A NCAC 02L .0202 Standard (e) (µg/L)	15A NCAC 02L .0202 IMAC (e) (µg/L)	DHHS Screening Level (d) (µg/L)	Federal MCL/ SMCL (c) (µg/L)	Tap Water RSL HI = 0.2 (a) (µg/L)	Screening Value Used (µg/L)	COPC?
				Min.	Max.								
Aluminum	7429-90-5	997	573	6	54,500	54,500	NA	NA	3,500	50 to 200 (i)	4,000	3,500	Y
Antimony	7440-36-0	1,438	299	0.1	9.7	9.7	1	NA	1	6	1.56 (m)	1	Y
Arsenic	7440-38-2	1,854	1,158	0.04	973	973	10	NA	10	10	0.052 (h,jj)	10	Y
Barium	7440-39-3	1,855	1,855	8.3	2,830	2,830	700	NA	700	2,000	760	700	Y
Beryllium	7440-41-7	1,308	662	0.01	9.9	9.9	NA	4	4	4	5	4	Y
Boron	7440-42-8	1,753	844	3.3	30,900	30,900	700	NA	700	NA	800	700	Y
Cadmium	7440-43-9	1,855	335	0.024	7.5	7.5	2	NA	2	5	1.84	2	Y
Chromium (Total)	7440-47-3	1,855	1,375	0.091	202	202	10	NA	10	100	4,400 (n)	10	Y
Chromium (VI)	18540-29-9	781	605	0.0087	142	142	NA	NA	0.07	NA	0.035 (jj)	0.07	Y
Cobalt	7440-48-4	1,308	1,127	0.01	216	216	NA	1	1	NA	1.2	1	Y
Copper	7440-50-8	1,568	913	0.11	1,700	1,700	1,000	NA	1,000	1,300 (k)	160	1,000	Y
Lead	7439-92-1	1,855	677	0	18.61	18.61	15	NA	15	15 (l)	15 (jj)	15	Y
Lithium	7439-93-2	470	445	0.16	748	748	NA	NA	NA	NA	8	8	Y
Manganese	7439-96-5	1,568	1,393	0	12,900	12,900	50	NA	200	50 (i)	86	50	Y
Mercury	7439-97-6	1,855	145	0.007	1.2	1.2	1	NA	1	2	1.14 (o)	1	Y
Molybdenum	7439-98-7	1,284	854	0.081	103	103	NA	NA	18	NA	20	18	Y
Nickel	7440-02-0	1,465	944	0.13	173	173	100	NA	100	NA	78 (p)	100	Y
Selenium	7782-49-2	1,855	671	0.092	119	119	20	NA	20	50	20	20	Y
Strontium	7440-24-6	987	979	3.7	18,700	18,700	NA	NA	2,100	NA	2,400	2,100	Y
Thallium	7440-28-0	1,438	407	0.015	3.6	3.6	0.2	NA	0.2	2	0.04 (q)	0.2	Y
Vanadium	7440-62-2	1,011	870	0.069	57.5	57.5	NA	NA	0.3	NA	17.2	0.3	Y
Zinc	7440-66-6	1,568	833	0	315	315	1	NA	1	5,000 (i)	1,200	1	Y

* Data evaluated includes data from 2015 to 2nd quarter 2018, unless otherwise noted

Prepared by: HEG Checked by: HES

Notes:

AWQC - Ambient Water Quality Criteria
CAMA - Coal Ash Management Act
North Carolina Session Law 2014-122,
http://www.ncleg.net/Sessions/2013/Bills
/Senate/PDF/S729v7.pdf
CAS - Chemical Abstracts Service
CCC - Criterion Continuous Concentration
CMC - Criterion Maximum Concentration
COPC - Constituent of Potential Concern
DENR - Department of Environment and Natural Resources
DHHS - Department of Health and Human Services
ESV - Ecological Screening Value
HH - Human Health
HI - Hazard Index
IMAC - Interim Maximum Allowable Concentration
MCL - Maximum Contaminant Level
mg/kg - milligrams/kilogram
NA - Not Available
NC - North Carolina
NCAC - North Carolina Administrative Code
ORNL - Oak Ridge National Laboratory
PSRG - Preliminary Soil Remediation Goal
Q - Qualifier
RSL - Regional Screening Level
RSV - Refinement Screening Value
SMCL - Secondary Maximum Contaminant Level
SSL - Soil Screening Level
su - Standard units
µg/L - micrograms/liter
USEPA - United States Environmental Protection Agency
WS - Water Supply
< - Concentration not detected at or above the reporting limit
j - Indicates concentration reported below Practical Quantitation Limit (PQL) but above Method Detection Limit (MDL) and therefore concentration is estimated

TABLE 1-1
HUMAN HEALTH SCREENING - GROUNDWATER
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC, TERRELL, NC

(a) - USEPA Regional Screening Levels (May 2018). Values for Residential Soil, Industrial Soil, and Tap Water. HI = 0.2. Accessed October 2018.
https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables
(b) - USEPA National Recommended Water Quality Criteria. USEPA Office of Water and Office of Science and Technology. Accessed October 2018.
https://www.epa.gov/wqc/national-recommended-water-quality-criteria-human-health-criteria-table
USEPA AWQC Human Health for the Consumption of Organism Only apply to total concentrations.
(c) - USEPA 2018 Edition of the Drinking Water Standards and Health Advisories. March 2018. Accessed October 2018.
https://www.epa.gov/sites/production/files/2018-03/documents/dwtable2018.pdf
(d) - DHHS Screening Levels. Department of Health and Human Services, Division of Public Health, Epidemiology Section, Occupational and Environmental Epidemiology Branch. http://portal.ncdenr.org/c/document_library/get_file?p_l_id=1169848&folderId=24814087&name=DLFE-112704.pdf
(e) - North Carolina 15A NCAC 02L .0202 Groundwater Standards & IMACs. http://portal.ncdenr.org/c/document_library/get_file?uuid=1aa3fa13-2c0f-45b7-ae96-5427fb1d25b4&groupId=38364
Amended April 2013.
(f) - North Carolina 15A NCAC 02B Surface Water and Wetland Standards. Amended January 1, 2015.
http://reports.oah.state.nc.us/ncac/title%2015a%20-%20environmental%20quality/chapter%2002%20-%20environmental%20management/subchapter%20b/subchapter%20b%20rules.pdf
WS standards are applicable to all Water Supply Classifications. WS standards are based on the consumption of fish and water.
Human Health Standards are based on the consumption of fish only unless dermal contact studies are available.
For Class C, use the most stringent of freshwater (or, if applicable, saltwater) column and the Human Health column.
For a WS water, use the most stringent of Freshwater, WS and Human Health. Likewise, Trout Waters and High Quality Waters must adhere to the most stingent of all applicable standards.
(g) - USEPA Region 4. 2018. Region 4 Ecological Risk Assessment Supplemental Guidance. March 2018 Update.
https://www.epa.gov/sites/production/files/2018-03/documents/era_regional_supplemental_guidance_report-march-2018_update.pdf
(h) - Value applies to inorganic form of arsenic only.
(i) - Value is the Secondary Maximum Contaminant Level.
https://www.epa.gov/dwstandardsregulations/secondary-drinking-water-standards-guidance-nuisance-chemicals
(j) - Value for Total Chromium.
(k) - Copper Treatment Technology Action Level is 1.3 mg/L.
(l) - Lead Treatment Technology Action Level is 0.015 mg/L.
(m) - RSL for Antimony (metallic) used for Antimony.
(n) - Value for Chromium (III), Insoluble Salts used for Chromium.
(o) - RSL for Mercuric Chloride used for Mercury.
(p) - RSL for Nickel Soluble Salts used for Nickel.
(q) - RSL for Thallium (Soluble Salts) used for Thallium.
(r) - Criterion expressed as a function of total hardness (mg/L). Value displayed is the site-specific total hardness of mg/L.
(s) - Value for Inorganic Mercury.
(t) - Acute AWQC is equal to 1/[(f1/CMC1) + (f2/CMC2)] where f1 and f2 are the fractions of total selenium that are treated as selenite and selenate, respectively, and CMC1 and CMC2 are 185.9 µg/gL and 12.82 µg/gL, respectively. Calculated assuming that all selenium is present as selenate, a likely overly conservative assumption.
(u) - Criterion expressed as a function of total hardness (mg/L). Value displayed is the site-specific total hardness of mg/L.
(v) - Chloride Action Level for Toxic Substances Applicable to NPDES Permits is 230,000 µg/gL.
(w) - Applicable only to persons with a sodium restrictive diet.
(x) - Los Alamos National Laboratory ECORISK Database. http://www.lanl.gov/community-environment/environmental-stewardship/protection/eco-risk-assessment.php
(y) - Long, Edward R., and Lee G. Morgan. 1991. The Potential for Biological Effects of Sediment-Sorbed Contaminants Tested in the National Status and Trends Program.
NOAA Technical Memorandum NOS OMA 52. Used effects range low (ER-L) for chronic and effects range medium (ER-M) for acute.
(z) - MacDonald, D.D.; Ingersoll, C.G.; Smorong, D.E.; Lindskoog, R.A.; Sloane, G.; and T. Bernacki. 2003. Development and Evaluation of Numerical Sediment Quality Assessment Guidelines for Florida Inland Waters. Florida Department of Environmental Protection, Tallahassee, FL. Used threshold effect concentration (TEC) for the ESV and probable effect concentration (PEC) for the RSV.
(aa) - Persaud, D., R. Jaagumagi and A. Hayton. 1993. Guidelines for the protection and management of aquatic sediment quality in Ontario. Ontario Ministry of the Environment. Queen's Printer of Ontario.
(bb) - Los Alamos National Laboratory ECORISK Database. September 2017. http://www.lanl.gov/environment/protection/eco-risk-assessment.php (µg/kg dw)
(cc) - Great Lakes Initiative (GLI) Clearinghouse resources Tier II criteria revised 2013. http://www.epa.gov/gliclearinghouse/
(dd) - Suter, G.W., and Tsao, C.L. 1996. Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota: 1996 Revision. ES/ER/TM-96/R2.
http://www.esd.ornl.gov/programs/ecorisk/documents/tm96r2.pdf
(ee) - USEPA. Interim Ecological Soil Screening Level Documents. Accessed October 2018. http://www2.epa.gov/chemical-research/interim-ecological-soil-screening-level-documents
(ff) - Efroymson, R.A., M.E. Will, and G.W. Suter II, 1997a. Toxicological Benchmarks for Contaminants of Potential Concern for Effects on Soil and Litter Invertebrates and Heterotrophic Process:
1997 Revision. Oak Ridge National Laboratory, Oak Ridge, TN. ES/ER/TM-126/R2. (Available at http://www.esd.ornl.gov/programs/ecorisk/documents/tm126r21.pdf)
(gg) - Efroymson, R.A., M.E. Will, G.W. Suter II, and A.C. Wooten, 1997b. Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Terrestrial Plants:
1997 Revision. Oak Ridge National Laboratory, Oak Ridge, TN. ES/ER/TM-85/R3. (Available at http://www.esd.ornl.gov/programs/ecorisk/documents/tm85r3.pdf)
(hh) - North Carolina Preliminary Soil Remediation Goals (PSRG) Table. HI = 0.2. September 2015. http://portal.ncdenr.org/c/document_library/get_file?uuid=0f601ffa-574d-4479-bbb4-253af0665bf5&groupId=38361
(ii) - As part of the water quality evaluation conducted under the CSA, pH was measured and is reported as a metric data set. The pH comparison criteria are included as ranges as opposed to single screening values. pH is not typically included as part of a risk assessment based on potential toxic effects, therefore; pH was not investigated further as a category 1 COPC. Water quality relative to pH will be addressed as a component of water quality monitoring programs for the site.
(jj) - Hazard Index = 0.1

TABLE 1-2
HUMAN HEALTH SCREENING - SEDIMENT
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC, TERRELL, NC

Analyte	CAS	Number of Samples	Frequency of Detection	Range of Detection (mg/kg)		Concentration Used for Screening (mg/kg)	NC PSRG Residential Health Screening Level (hh) (mg/kg)	Residential Soil RSL (a) HI = 0.2 (mg/kg)	NC PSRG Industrial Health Screening Level (hh) (mg/kg)	Industrial Soil RSL (a) HI = 0.2 (mg/kg)	Residential Screening Value Used (mg/kg)	Industrial Screening Value Used (mg/kg)	Residential COPC?	Industrial COPC?
				Min.	Max.									
Aluminum	7429-90-5	1	1	NA	12,900	12,900	15,000	15,400	100,000	220,000	15,000	100,000	N	N
Antimony	7440-36-0	1	0	ND	ND	ND	6.2 (m)	6.2 (m)	94 (m)	94 (m)	6.2	94	N	N
Arsenic	7440-38-2	1	0	ND	ND	ND	0.68 (h)	0.68 (h, jj)	3 (h)	3 (h, jj)	0.68	3	N	N
Barium	7440-39-3	1	1	NA	128	128	3,000	3,000	44,000	44,000	3,000	44,000	N	N
Beryllium	7440-41-7	1	1	NA	0.93	0.93	32	32	460	460	32	460	N	N
Boron	7440-42-8	1	0	ND	ND	ND	3,200	3,200	46,000	46,000	3,200	46,000	N	N
Cadmium	7440-43-9	1	0	ND	ND	ND	14	14.2	200	196	14	200	N	N
Chromium (III)	16065-83-1	1	1	NA	45.6	45.6	24,000	24,000	100,000	360,000	24,000	100,000	N	N
Cobalt	7440-48-4	1	1	NA	11.3	11.3	4.6	4.6	70	70	4.6	70	Y	N
Copper	7440-50-8	1	1	NA	11.4	11.4	620	620	9,400	9,400	620	9,400	N	N
Lead	7439-92-1	1	1	NA	9.2	9.2	400	400 (jj)	800	800 (jj)	400	800	N	N
Manganese	7439-96-5	1	1	NA	115	115	360	360	5,200	5,200	360	5,200	N	N
Mercury	7439-97-6	1	1	NA	0.021	0.021	4.6 (o)	4.6 (o)	3.1 (o)	70 (o)	4.6	3.1	N	N
Molybdenum	7439-98-7	1	0	ND	ND	ND	78	78	1,200	1,160	78	1,200	N	N
Nickel	7440-02-0	1	1	NA	18.7	18.7	300 (p)	300 (p)	4,400 (p)	4,400 (p)	300	4,400	N	N
Selenium	7782-49-2	1	1	NA	4.1	4.1	78	78	1,200	1,160	78	1,200	N	N
Strontium	7440-24-6	1	1	NA	38	38	9,400	9,400	100,000	140,000	9,400	100,000	N	N
Thallium	7440-28-0	1	0	ND	ND	ND	0.16 (q)	0.156 (q)	2.4 (q)	2.4 (q)	0.16	2.4	N	N
Vanadium	7440-62-2	1	1	NA	59.7	59.7	78	78	1,160	1,160	78	1,160	N	N
Zinc	7440-66-6	1	1	NA	32.8	32.8	4,600	4,600	70,000	70,000	4,600	70,000	N	N

* Data evaluated includes data from 2015 to 2nd quarter 2018, unless otherwise noted

Prepared by: HEG Checked by: HES

Notes:

AWQC - Ambient Water Quality Criteria
CAMA - Coal Ash Management Act
North Carolina Session Law 2014-122, http://www.ncleg.net/Sessions/2013/Bills/Senate/PDF/S729v7.pdf
CAS - Chemical Abstracts Service
CCC - Criterion Continuous Concentration
CMC - Criterion Maximum Concentration
COPC - Constituent of Potential Concern
DENR - Department of Environment and Natural Resources
DHHS - Department of Health and Human Services
ESV - Ecological Screening Value
HH - Human Health
HI - Hazard Index
IMAC - Interim Maximum Allowable Concentration
MCL - Maximum Contaminant Level
mg/kg - milligrams/kilogram
NA - Not Available
NC - North Carolina
NCAC - North Carolina Administrative Code
ORNL - Oak Ridge National Laboratory
PSRG - Preliminary Soil Remediation Goal
Q - Qualifier
RSL - Regional Screening Level
RSV - Refinement Screening Value
SMCL - Secondary Maximum Contaminant Level
SSL - Soil Screening Level
su - Standard units
µg/L - micrograms/liter
USEPA - United States Environmental Protection Agency
WS - Water Supply
< - Concentration not detected at or above the reporting limit
j - Indicates concentration reported below Practical Quantitation Limit (PQL) but above Method Detection Limit (MDL) and therefore concentration is estimated

(a) - USEPA Regional Screening Levels (May 2018). Values for Residential Soil, Industrial Soil, and Tap Water. HI = 0.2. Accessed October 2018.
https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables

(b) - USEPA National Recommended Water Quality Criteria. USEPA Office of Water and Office of Science and Technology. Accessed October 2018.
https://www.epa.gov/wqc/national-recommended-water-quality-criteria-human-health-criteria-table
USEPA AWQC Human Health for the Consumption of Organism Only apply to total concentrations.

(c) - USEPA 2018 Edition of the Drinking Water Standards and Health Advisories. March 2018. Accessed October 2018.
https://www.epa.gov/sites/production/files/2018-03/documents/dwtable2018.pdf

(d) - DHHS Screening Levels. Department of Health and Human Services, Division of Public Health, Epidemiology Section, Occupational and Environmental Epidemiology Branch. http://portal.ncdenr.org/c/document_library/get_file?p_l_id=1169848&folderId=24814087&name=DLFE-112704.pdf

TABLE 1-2
HUMAN HEALTH SCREENING - SEDIMENT
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC, TERRELL, NC

(e) - North Carolina 15A NCAC 02L .0202 Groundwater Standards & IMACs. http://portal.ncdenr.org/c/document_library/get_file?uuid=1aa3fa13-2c0f-45b7-ae96-5427fb1d25b4&groupId=38364
Amended April 2013.

(f) - North Carolina 15A NCAC 02B Surface Water and Wetland Standards. Amended January 1, 2015.
http://reports.oah.state.nc.us/ncac/title%2015a%20-%20environmental%20quality/chapter%2002%20-%20environmental%20management/subchapter%20b/subchapter%20b%20rules.pdf
WS standards are applicable to all Water Supply Classifications. WS standards are based on the consumption of fish and water.
Human Health Standards are based on the consumption of fish only unless dermal contact studies are available.
For Class C, use the most stringent of freshwater (or, if applicable, saltwater) column and the Human Health column.
For a WS water, use the most stringent of Freshwater, WS and Human Health. Likewise, Trout Waters and High Quality Waters must adhere to the most stingent of all applicable standards.

(g) - USEPA Region 4. 2018. Region 4 Ecological Risk Assessment Supplemental Guidance. March 2018 Update.
https://www.epa.gov/sites/production/files/2018-03/documents/era_regional_supplemental_guidance_report-march-2018_update.pdf

(h) - Value applies to inorganic form of arsenic only.

(i) - Value is the Secondary Maximum Contaminant Level.
https://www.epa.gov/dwstandardsregulations/secondary-drinking-water-standards-guidance-nuisance-chemicals

(j) - Value for Total Chromium.

(k) - Copper Treatment Technology Action Level is 1.3 mg/L.

(l) - Lead Treatment Technology Action Level is 0.015 mg/L.

(m) - RSL for Antimony (metallic) used for Antimony.

(n) - Value for Chromium (III), Insoluble Salts used for Chromium.

(o) - RSL for Mercuric Chloride used for Mercury.

(p) - RSL for Nickel Soluble Salts used for Nickel.

(q) - RSL for Thallium (Soluble Salts) used for Thallium.

(r) - Criterion expressed as a function of total hardness (mg/L). Value displayed is the site-specific total hardness of mg/L.

(s) - Value for Inorganic Mercury.

(t) - Acute AWQC is equal to 1/[(f1/CMC1) + (f2/CMC2)] where f1 and f2 are the fractions of total selenium that are treated as selenite and selenate, respectively, and
CMC1 and CMC2 are 185.9 µg/L and 12.82 µg/L, respectively. Calculated assuming that all selenium is present as selenate, a likely overly conservative assumption.

(u) - Criterion expressed as a function of total hardness (mg/L). Value displayed is the site-specific total hardness of mg/L.

(v) - Chloride Action Level for Toxic Substances Applicable to NPDES Permits is 230,000 µg/L.

(w) - Applicable only to persons with a sodium restrictive diet.

(x) - Los Alamos National Laboratory ECORISK Database. http://www.lanl.gov/community-environment/environmental-stewardship/protection/eco-risk-assessment.php

(y) - Long, Edward R., and Lee G. Morgan. 1991. The Potential for Biological Effects of Sediment-Sorbed Contaminants Tested in the National Status and Trends Program.
NOAA Technical Memorandum NOS OMA 52. Used effects range low (ER-L) for chronic and effects range medium (ER-M) for acute.

(z) - MacDonald, D.D.; Ingersoll, C.G.; Smorong, D.E.; Lindskoog, R.A.; Sloane, G.; and T. Bernacki. 2003. Development and Evaluation of Numerical Sediment Quality Assessment Guidelines for
Florida Inland Waters. Florida Department of Environmental Protection, Tallahassee, FL. Used threshold effect concentration (TEC) for the ESV and probable effect concentration (PEC) for the RSV.

(aa) - Persaud, D., R. Jaagumagi and A. Hayton. 1993. Guidelines for the protection and management of aquatic sediment quality in Ontario. Ontario Ministry of the Environment. Queen's Printer of Ontario.

(bb) - Los Alamos National Laboratory ECORISK Database. September 2017. http://www.lanl.gov/environment/protection/eco-risk-assessment.php (µg/kg dw)

(cc) - Great Lakes Initiative (GLI) Clearinghouse resources Tier II criteria revised 2013. http://www.epa.gov/gliclearinghouse/

(dd) - Suter, G.W., and Tsao, C.L. 1996. Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota: 1996 Revision. ES/ER/TM-96/R2.
http://www.esd.ornl.gov/programs/ecorisk/documents/tm96r2.pdf

(ee) - USEPA. Interim Ecological Soil Screening Level Documents. Accessed October 2018. http://www2.epa.gov/chemical-research/interim-ecological-soil-screening-level-documents

(ff) - Efroymson, R.A., M.E. Will, and G.W. Suter II, 1997a. Toxicological Benchmarks for Contaminants of Potential Concern for Effects on Soil and Litter Invertebrates and Heterotrophic Process:
1997 Revision. Oak Ridge National Laboratory, Oak Ridge, TN. ES/ER/TM-126/R2. (Available at http://www.esd.ornl.gov/programs/ecorisk/documents/tm126r21.pdf)

(gg) - Efroymson, R.A., M.E. Will, G.W. Suter II, and A.C. Wooten, 1997b. Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Terrestrial Plants:
1997 Revision. Oak Ridge National Laboratory, Oak Ridge, TN. ES/ER/TM-85/R3. (Available at http://www.esd.ornl.gov/programs/ecorisk/documents/tm85r3.pdf)

(hh) - North Carolina Preliminary Soil Remediation Goals (PSRG) Table. HI = 0.2. September 2015. http://portal.ncdenr.org/c/document_library/get_file?uuid=0f601ffa-574d-4479-bbb4-253af0665bf5&groupId=38361

(ii) - As part of the water quality evaluation conducted under the CSA, pH was measured and is reported as a metric data set. The pH comparison criteria are included as ranges as opposed to single screening values. pH is not typically included
as part of a risk assessment based on potential toxic effects, therefore; pH was not investigated further as a category 1 COPC. Water quality relative to pH will be addressed as a component of water quality monitoring programs for the site.

(jj) - Hazard Index = 0.1

TABLE 1-3
HUMAN HEALTH SCREENING - SURFACE WATER
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC, TERRELL, NC

Analyte	CAS	Number of Samples	Frequency of Detection	Range of Detection (µg/L)		Concentration Used for Screening (µg/L)	15A NCAC 02L .0202 Standard (e) (µg/L)	15A NCAC 02L .0202 IMAC (e) (µg/L)	15A NCAC 02B Water Supply (WS) (f) (µg/L)	15A NCAC 02B Human Health (HH) (f) (µg/L)	USEPA AWQC Consumption of Water and Organism (b) (µg/L)	USEPA AWQC Consumption of Organism Only (b) (µg/L)	Federal MCL/ SMCL (c) (µg/L)	Tap Water RSL HI = 0.2 (a) (µg/L)	Screening Value Used (µg/L)	COPC?
				Min.	Max.											
Aluminum	7429-90-5	22	17	57.5	701	701	NA	NA	NA	NA	NA	NA	50 to 200 (i)	4,000	50	Y
Antimony	7440-36-0	23	14	0.11	0.75	0.75	1	NA	NA	NA	5.6	640	6	1.56 (m)	1	N
Arsenic	7440-38-2	28	23	0.16	2.4	2.4	10	NA	10	10	0.018 (h)	0.14 (h)	10	0.052 (h, jj)	10	N
Barium	7440-39-3	28	28	12.7	140	140	700	NA	1,000	NA	1,000	NA	2,000	760	700	N
Beryllium	7440-41-7	23	10	0.014	0.17	0.17	NA	4	NA	NA	NA	NA	4	5	4	N
Boron	7440-42-8	28	24	46.1	3,500	3,500	700	NA	NA	NA	NA	NA	NA	800	700	Y
Cadmium	7440-43-9	28	5	0.028	0.086	0.086	2	NA	NA	NA	NA	NA	5	1.84	2	N
Chromium (Total)	7440-47-3	28	20	0.12	1.1	1.1	10	NA	NA	NA	NA	NA	100	4,400 (n)	10	N
Chromium (VI)	18540-29-9	20	12	0.016	1.1	1.1	NA	NA	NA	NA	NA	NA	NA	0.035 (jj)	0.035	Y
Cobalt	7440-48-4	23	21	0.068	24.6	24.6	NA	1	NA	NA	NA	NA	NA	1.2	1	Y
Copper	7440-50-8	28	26	0.13	7.4	7.4	1,000	NA	NA	NA	1,300	NA	1,300 (k)	160	1,000	N
Lead	7439-92-1	28	14	0.053	0.73	0.73	15	NA	NA	NA	NA	NA	15 (l)	15 (jj)	15	N
Lithium	7439-93-2	4	2	0.56	0.59	0.59	NA	NA	NA	NA	NA	NA	NA	8	8	N
Manganese	7439-96-5	23	23	18.4	1,600	1,600	50	NA	200	NA	50	100	50 (i)	86	50	Y
Mercury	7439-97-6	28	27	4.39E-04	0.0082	0.0082	1	NA	NA	NA	NA	NA	2	1.14 (o)	1	N
Molybdenum	7439-98-7	23	17	0.09	2.6	2.6	NA	NA	NA	NA	NA	NA	NA	20	20	N
Nickel	7440-02-0	28	13	0.24	12.7	12.7	100	NA	25	NA	610	4,600	NA	78 (p)	100	N
Selenium	7782-49-2	28	8	0.25	2	2	20	NA	NA	NA	170	4,200	50	20	20	N
Strontium	7440-24-6	23	23	25.7	1,800	1,800	NA	NA	NA	NA	NA	NA	NA	2,400	2,400	N
Thallium	7440-28-0	28	8	0.018	0.11	0.11	0.2	NA	NA	NA	0.24	0.47	2	0.04 (q)	0.2	N
Vanadium	7440-62-2	23	21	0.23	2.4	2.4	NA	NA	NA	NA	NA	NA	NA	17.2	17	N
Zinc	7440-66-6	28	12	2.7	9.2	9.2	1	NA	NA	NA	7,400	26,000	5,000 (i)	1,200	1	Y

* Data evaluated includes data from 2015 to 2nd quarter 2018, unless otherwise noted.

Prepared by: HEG Checked by: HES

Notes:

AWQC - Ambient Water Quality Criteria
CAMA - Coal Ash Management Act
North Carolina Session Law 2014-122,
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CAS - Chemical Abstracts Service
CCC - Criterion Continuous Concentration
CMC - Criterion Maximum Concentration
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ESV - Ecological Screening Value
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IMAC - Interim Maximum Allowable Concentration
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mg/kg - milligrams/kilogram
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NCAC - North Carolina Administrative Code
ORNL - Oak Ridge National Laboratory
PSRG - Preliminary Soil Remediation Goal
Q - Qualifier
RSL - Regional Screening Level
RSV - Refinement Screening Value
SMCL - Secondary Maximum Contaminant Level
SSL - Soil Screening Level
su - Standard units
µg/L - micrograms/liter
USEPA - United States Environmental Protection Agency
WS - Water Supply
< - Concentration not detected at or above the reporting limit

TABLE 1-3
HUMAN HEALTH SCREENING - SURFACE WATER
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC, TERRELL, NC

(a) - USEPA Regional Screening Levels (May 2018). Values for Residential Soil, Industrial Soil, and Tap Water. HI = 0.2. Accessed October 2018.
https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables
(b) - USEPA National Recommended Water Quality Criteria. USEPA Office of Water and Office of Science and Technology. Accessed October 2018.
https://www.epa.gov/wqc/national-recommended-water-quality-criteria-human-health-criteria-table
USEPA AWQC Human Health for the Consumption of Organism Only apply to total concentrations.
(c) - USEPA 2018 Edition of the Drinking Water Standards and Health Advisories. March 2018. Accessed October 2018.
https://www.epa.gov/sites/production/files/2018-03/documents/dwtable2018.pdf
(d) - DHHS Screening Levels. Department of Health and Human Services, Division of Public Health, Epidemiology Section, Occupational and Environmental
Epidemiology Branch. http://portal.ncdenr.org/c/document_library/get_file?p_l_id=1169848&folderId=24814087&name=DLFE-112704.pdf
(e) - North Carolina 15A NCAC 02L .0202 Groundwater Standards & IMACs. http://portal.ncdenr.org/c/document_library/get_file?uuid=1aa3fa13-2c0f-45b7-ae96-5427fb1d25b4&groupId=38364
Amended April 2013.
(f) - North Carolina 15A NCAC 02B Surface Water and Wetland Standards. Amended January 1, 2015.
http://reports.oah.state.nc.us/ncac/title%2015a%20-%20environmental%20quality/chapter%2002%20-%20environmental%20management/subchapter%20b/subchapter%20b%20rules.pdf
WS standards are applicable to all Water Supply Classifications. WS standards are based on the consumption of fish and water.
Human Health Standards are based on the consumption of fish only unless dermal contact studies are available.
For Class C, use the most stringent of freshwater (or, if applicable, saltwater) column and the Human Health column.
For a WS water, use the most stringent of Freshwater, WS and Human Health. Likewise, Trout Waters and High Quality Waters must adhere to the most stingent of all applicable standards.
(g) - USEPA Region 4. 2018. Region 4 Ecological Risk Assessment Supplemental Guidance. March 2018 Update.
https://www.epa.gov/sites/production/files/2018-03/documents/era_regional_supplemental_guidance_report-march-2018_update.pdf
(h) - Value applies to inorganic form of arsenic only.
(i) - Value is the Secondary Maximum Contaminant Level.
https://www.epa.gov/dwstandardsregulations/secondary-drinking-water-standards-guidance-nuisance-chemicals
(j) - Value for Total Chromium.
(k) - Copper Treatment Technology Action Level is 1.3 mg/L.
(l) - Lead Treatment Technology Action Level is 0.015 mg/L.
(m) - RSL for Antimony (metallic) used for Antimony.
(n) - Value for Chromium (III), Insoluble Salts used for Chromium.
(o) - RSL for Mercuric Chloride used for Mercury.
(p) - RSL for Nickel Soluble Salts used for Nickel.
(q) - RSL for Thallium (Soluble Salts) used for Thallium.
(r) - Criterion expressed as a function of total hardness (mg/L). Value displayed is the site-specific total hardness of mg/L.
(s) - Value for Inorganic Mercury.
(t) - Acute AWQC is equal to 1/[(f1/CMC1) + (f2/CMC2)] where f1 and f2 are the fractions of total selenium that are treated as selenite and selenate, respectively, and
CMC1 and CMC2 are 185.9 µg/L and 12.82 µg/L, respectively. Calculated assuming that all selenium is present as selenate, a likely overly conservative assumption.
(u) - Criterion expressed as a function of total hardness (mg/L). Value displayed is the site-specific total hardness of mg/L.
(v) - Chloride Action Level for Toxic Substances Applicable to NPDES Permits is 230,000 µg/L.
(w) - Applicable only to persons with a sodium restrictive diet.
(x) - Los Alamos National Laboratory ECORISK Database. http://www.lanl.gov/community-environment/environmental-stewardship/protection/eco-risk-assessment.php
(y) - Long, Edward R., and Lee G. Morgan. 1991. The Potential for Biological Effects of Sediment-Sorbed Contaminants Tested in the National Status and Trends Program.
NOAA Technical Memorandum NOS OMA 52. Used effects range low (ER-L) for chronic and effects range medium (ER-M) for acute.
(z) - MacDonald, D.D.; Ingersoll, C.G.; Smorong, D.E.; Lindskoog, R.A.; Sloane, G.; and T. Bernacki. 2003. Development and Evaluation of Numerical Sediment Quality Assessment Guidelines for
Florida Inland Waters. Florida Department of Environmental Protection, Tallahassee, FL. Used threshold effect concentration (TEC) for the ESV and probable effect concentration (PEC) for the RSV.
(aa) - Persaud, D., R. Jaagumagi and A. Hayton. 1993. Guidelines for the protection and management of aquatic sediment quality in Ontario. Ontario Ministry of the Environment. Queen's Printer of Ontario.
(bb) - Los Alamos National Laboratory ECORISK Database. September 2017. http://www.lanl.gov/environment/protection/eco-risk-assessment.php (µg/kg dw)
(cc) - Great Lakes Initiative (GLI) Clearinghouse resources Tier II criteria revised 2013. http://www.epa.gov/gliclearinghouse/
(dd) - Suter, G.W., and Tsao, C.L. 1996. Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota: 1996 Revision. ES/ER/TM-96/R2.
http://www.esd.ornl.gov/programs/ecorisk/documents/tm96r2.pdf
(ee) - USEPA. Interim Ecological Soil Screening Level Documents. Accessed October 2018. http://www2.epa.gov/chemical-research/interim-ecological-soil-screening-level-documents
(ff) - Efroymson, R.A., M.E. Will, and G.W. Suter II, 1997a. Toxicological Benchmarks for Contaminants of Potential Concern for Effects on Soil and Litter Invertebrates and Heterotrophic Process:
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(gg) - Efroymson, R.A., M.E. Will, G.W. Suter II, and A.C. Wooten, 1997b. Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Terrestrial Plants:
1997 Revision. Oak Ridge National Laboratory, Oak Ridge, TN. ES/ER/TM-85/R3. (Available at http://www.esd.ornl.gov/programs/ecorisk/documents/tm85r3.pdf)
(hh) - North Carolina Preliminary Soil Remediation Goals (PSRG) Table. HI = 0.2. September 2015. http://portal.ncdenr.org/c/document_library/get_file?uuid=0f601ffa-574d-4479-bbb4-253af0665bf5&groupId=38361
(ii) - As part of the water quality evaluation conducted under the CSA, pH was measured and is reported as a metric data set. The pH comparison criteria are included as ranges as opposed to single screening values. pH is not typically included
as part of a risk assessment based on potential toxic effects, therefore; pH was not investigated further as a category 1 COPC. Water quality relative to pH will be addressed as a component of water quality monitoring programs for the site.
(jj) - Hazard Index = 0.1

TABLE 2-1
ECOLOGICAL SCREENING - SEDIMENT
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC, TERRELL, NC

Analyte	CAS	Number of Samples	Frequency of Detection	Range of Detection (mg/kg)		Concentration Used for Screening (mg/kg)	USEPA Region 4 Sediment Screening Values (g) (mg/kg)				Screening Value Used (mg/kg)	COPC?
				Min.	Max.		ESV		RSV			
Aluminum	7429-90-5	1	1	NA	12,900	12,900	25,000	(x)	58,000	(x)	25,000	N
Antimony	7440-36-0	1	0	ND	ND	ND	2	(y)	25	(y)	2	N
Arsenic	7440-38-2	1	0	ND	ND	ND	9.8	(z)	33	(z)	10	N
Barium	7440-39-3	1	1	NA	128	128	20	(z)	60	(z)	20	Y
Beryllium	7440-41-7	1	1	NA	0.93	0.93	NA		NA		NA	N
Boron	7440-42-8	1	0	ND	ND	ND	NA		NA		NA	N
Cadmium	7440-43-9	1	0	ND	ND	ND	1	(z)	5	(z)	1	N
Chromium (Total)	7440-47-3	1	1	NA	45.6	45.6	43.4	(z)	111	(z)	43	Y
Cobalt	7440-48-4	1	1	NA	11.3	11.3	50	(aa)	NA	(aa)	50	N
Copper	7440-50-8	1	1	NA	11.4	11.4	31.6	(z)	149	(z)	31.6	N
Lead	7439-92-1	1	1	NA	9.2	9.2	35.8	(z)	128	(z)	35.8	N
Manganese	7439-96-5	1	1	NA	115	115	460	(bb)	1,100	(bb)	460	N
Mercury	7439-97-6	1	1	NA	0.021	0.021	0.18	(z)	1.1	(z)	0.18	N
Molybdenum	7439-98-7	1	0	ND	ND	ND	NA		NA		NA	N
Nickel	7440-02-0	1	1	NA	18.7	18.7	22.7	(z)	48.6	(z)	22.7	N
Selenium	7782-49-2	1	1	NA	4.1	4.1	0.8	(bb)	1.2	(bb)	0.8	Y
Strontium	7440-24-6	1	1	NA	38	38	NA		NA		NA	N
Thallium	7440-28-0	1	0	ND	ND	ND	NA		NA		NA	N
Vanadium	7440-62-2	1	1	NA	59.7	59.7	NA		NA		NA	N
Zinc	7440-66-6	1	1	NA	32.8	32.8	121	(z)	459	(z)	121	N

* Data evaluated includes data from 2015 to 2nd quarter 2018, unless otherwise noted

Prepared by: HEG Checked by: ARD

Notes:

AWQC - Ambient Water Quality Criteria
CAMA - Coal Ash Management Act
North Carolina Session Law 2014-122, http://www.ncleg.net/Sessions/2013/Bills/Senate/PDF/S729v7.pdf
CAS - Chemical Abstracts Service
CCC - Criterion Continuous Concentration
CMC - Criterion Maximum Concentration
COPC - Constituent of Potential Concern
DENR - Department of Environment and Natural Resources
DHHS - Department of Health and Human Services
ESV - Ecological Screening Value
HH - Human Health
HI - Hazard Index
IMAC - Interim Maximum Allowable Concentration
MCL - Maximum Contaminant Level
mg/kg - milligrams/kilogram
NA - Not Available
su - Standard units
µg/L - micrograms/liter
USEPA - United States Environmental Protection Agency
WS - Water Supply
< - Concentration not detected at or above the reporting limit
j - Indicates concentration reported below Practical Quantitation Limit (PQL) but above Method Detection Limit (MDL) and therefore concentration is estimated

TABLE 2-1
ECOLOGICAL SCREENING - SEDIMENT
MARSHALL STEAM STATION
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(a) - USEPA Regional Screening Levels (May 2018). Values for Residential Soil, Industrial Soil, and Tap Water. HI = 0.2. Accessed October 2018.
https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables
(b) - USEPA National Recommended Water Quality Criteria. USEPA Office of Water and Office of Science and Technology. Accessed October 2018.
https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table
USEPA AWQC Human Health for the Consumption of Organism Only apply to total concentrations.
(c) - USEPA 2018 Edition of the Drinking Water Standards and Health Advisories. March 2018. Accessed October 2018.
https://www.epa.gov/sites/production/files/2018-03/documents/dwtable2018.pdf
(d) - DHHS Screening Levels. Department of Health and Human Services, Division of Public Health, Epidemiology Section, Occupational and Environmental
Epidemiology Branch. http://portal.ncdenr.org/c/document_library/get_file?p_l_id=1169848&folderId=24814087&name=DLFE-112704.pdf
(e) - North Carolina 15A NCAC 02L .0202 Groundwater Standards & IMACs. http://portal.ncdenr.org/c/document_library/get_file?uuid=1aa3fa13-2c0f-45b7-ae96-5427fb1d25b4&groupId=38364
Amended April 2013.
(f) - North Carolina 15A NCAC 02B Surface Water and Wetland Standards. Amended January 1, 2015.
http://reports.oah.state.nc.us/ncac/title%2015a%20-%20environmental%20quality/chapter%2002%20-%20environmental%20management/subchapter%20b/subchapter%20b%20rules.pdf
WS standards are applicable to all Water Supply Classifications. WS standards are based on the consumption of fish and water.
Human Health Standards are based on the consumption of fish only unless dermal contact studies are available.
For Class C, use the most stringent of freshwater (or, if applicable, saltwater) column and the Human Health column.
For a WS water, use the most stringent of Freshwater, WS and Human Health. Likewise, Trout Waters and High Quality Waters must adhere to the most stingent of all applicable standards.
(g) - USEPA Region 4. 2018. Region 4 Ecological Risk Assessment Supplemental Guidance. March 2018 Update.
https://www.epa.gov/sites/production/files/2018-03/documents/era_regional_supplemental_guidance_report-march-2018_update.pdf
(h) - Value applies to inorganic form of arsenic only.
(i) - Value is the Secondary Maximum Contaminant Level.
https://www.epa.gov/dwstandardsregulations/secondary-drinking-water-standards-guidance-nuisance-chemicals
(j) - Value for Total Chromium.
(k) - Copper Treatment Technology Action Level is 1.3 mg/L.
(l) - Lead Treatment Technology Action Level is 0.015 mg/L.
(m) - RSL for Antimony (metallic) used for Antimony.
(n) - Value for Chromium (III), Insoluble Salts used for Chromium.
(o) - RSL for Mercuric Chloride used for Mercury.
(p) - RSL for Nickel Soluble Salts used for Nickel.
(q) - RSL for Thallium (Soluble Salts) used for Thallium.
(r) - Criterion expressed as a function of total hardness (mg/L). Value displayed is the site-specific total hardness of mg/L.
(s) - Value for Inorganic Mercury.
(t) - Acute AWQC is equal to 1/[(f1/CMC1) + (f2/CMC2)] where f1 and f2 are the fractions of total selenium that are treated as selenite and selenate, respectively, and
CMC1 and CMC2 are 185.9 µg/L and 12.82 µg/L, respectively. Calculated assuming that all selenium is present as selenate, a likely overly conservative assumption.
(u) - Criterion expressed as a function of total hardness (mg/L). Value displayed is the site-specific total hardness of mg/L.
(v) - Chloride Action Level for Toxic Substances Applicable to NPDES Permits is 230,000 µg/L.
(w) - Applicable only to persons with a sodium restrictive diet.
(x) - Los Alamos National Laboratory ECORISK Database. http://www.lanl.gov/community-environment/environmental-stewardship/protection/eco-risk-assessment.php
(y) - Long, Edward R., and Lee G. Morgan. 1991. The Potential for Biological Effects of Sediment-Sorbed Contaminants Tested in the National Status and Trends Program.
NOAA Technical Memorandum NOS OMA 52. Used effects range low (ER-L) for chronic and effects range medium (ER-M) for acute.
(z) - MacDonald, D.D.; Ingersoll, C.G.; Smorong, D.E.; Lindskoog, R.A.; Sloane, G.; and T. Bernacki. 2003. Development and Evaluation of Numerical Sediment Quality Assessment Guidelines for
Florida Inland Waters. Florida Department of Environmental Protection, Tallahassee, FL. Used threshold effect concentration (TEC) for the ESV and probable effect concentration (PEC) for the RSV.
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(bb) - Los Alamos National Laboratory ECORISK Database. September 2017. http://www.lanl.gov/environment/protection/eco-risk-assessment.php (µg/kg dw)
(cc) - Great Lakes Initiative (GLI) Clearinghouse resources Tier II criteria revised 2013. http://www.epa.gov/gliclearinghouse/
(dd) - Suter, G.W., and Tsao, C.L. 1996. Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota: 1996 Revision. ES/ER/TM-96/R2.
http://www.esd.ornl.gov/programs/ecorisk/documents/tm96r2.pdf
(ee) - USEPA. Interim Ecological Soil Screening Level Documents. Accessed October 2018. http://www2.epa.gov/chemical-research/interim-ecological-soil-screening-level-documents
(ff) - Efroymson, R.A., M.E. Will, and G.W. Suter II, 1997a. Toxicological Benchmarks for Contaminants of Potential Concern for Effects on Soil and Litter Invertebrates and Heterotrophic Process:
1997 Revision. Oak Ridge National Laboratory, Oak Ridge, TN. ES/ER/TM-126/R2. (Available at http://www.esd.ornl.gov/programs/ecorisk/documents/tm126r21.pdf)
(gg) - Efroymson, R.A., M.E. Will, G.W. Suter II, and A.C. Wooten, 1997b. Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Terrestrial Plants:
1997 Revision. Oak Ridge National Laboratory, Oak Ridge, TN. ES/ER/TM-85/R3. (Available at http://www.esd.ornl.gov/programs/ecorisk/documents/tm85r3.pdf)
(hh) - North Carolina Preliminary Soil Remediation Goals (PSRG) Table. HI = 0.2. September 2015. http://portal.ncdenr.org/c/document_library/get_file?uuid=0f601ffa-574d-4479-bbb4-253af0665bf5&groupId=38361

TABLE 2-2
ECOLOGICAL SCREENING - SURFACE WATER
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC, TERRELL, NC

Analyte	CAS	Number of Samples	Frequency of Detection	Range of Detection (µg/L)		Concentration Used for Screening (µg/L)	15A NCAC 2B Freshwater Aquatic Life Acute (f) (µg/L)		15A NCAC 2B Freshwater Aquatic Life Chronic (f) (µg/L)		USEPA Region 4 Freshwater Acute Screening Values (g) (µg/L)		USEPA Region 4 Freshwater Chronic Screening Values (g) (µg/L)		USEPA AWQC (b) CMC (acute) (µg/L)		USEPA AWQC (b) CCC (chronic) (µg/L)		Screening Value Used (µg/L)	COPC?
				Min.	Max.		Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved		
Aluminum	7429-90-5	22	17	57.5	701	701	NA	NA	NA	NA	750 (b)	NA	87 (b)	NA	750	NA	87	NA	87	Y
Antimony	7440-36-0	23	14	0.11	0.75	0.75	NA	NA	NA	NA	900 (cc)	NA	190 (cc)	NA	NA	NA	NA	NA	190	N
Arsenic	7440-38-2	24	23	0.16	2.4	2.4	NA	340	NA	150	340 (b, h)	NA	150 (b, h)	NA	340 (h)	NA	150 (h)	NA	150	N
Barium	7440-39-3	24	24	12.7	140	140	NA	NA	NA	NA	2000 (cc)	NA	220 (cc)	NA	NA	NA	NA	NA	220	N
Beryllium	7440-41-7	23	10	0.014	0.17	0.17	NA	65	NA	6.5	31 (r, cc)	NA	3.6 (r, cc)	NA	NA	NA	NA	NA	4	N
Boron	7440-42-8	24	24	46.1	3500	3,500	NA	NA	NA	NA	34,000 (cc)	NA	7,200 (cc)	NA	NA	NA	NA	NA	7200	N
Cadmium	7440-43-9	24	5	0.028	0.086	0.086	NA	NA	NA	NA	1.1 (r)	NA	0.16 (r)	NA	NA	1.8 (r)	0.27 (r)	NA	0.16	N
Chromium (Total)	7440-47-3	24	20	0.12	1.1	1.1	NA	NA	50	NA	1,022 (n, r)	NA	48.8 (n, r)	NA	NA	NA	NA	NA	50	N
Chromium (VI)	18540-29-9	20	12	0.016	1.1	1.1	NA	16	NA	11	16	NA	11	NA	NA	16	NA	11	11	N
Cobalt	7440-48-4	23	21	0.068	24.6	24.6	NA	NA	NA	NA	120 (cc)	NA	19 (cc)	NA	NA	NA	NA	NA	19	Y
Copper	7440-50-8	24	22	0.13	7.4	7	NA	NA	NA	NA	7.3 (r)	NA	5.16 (r)	NA	NA	NA	NA	NA	5.16	Y
Lead	7439-92-1	24	13	0.053	0.73	0.73	NA	NA	NA	NA	33.8 (r)	NA	1.32 (r)	NA	NA	65.0 (r)	NA	2.5 (r)	1	N
Lithium	7439-93-2	4	2	0.56	0.59	0.59	NA	NA	NA	NA	910 (cc)	NA	440 (cc)	NA	NA	NA	NA	NA	440	N
Manganese	7439-96-5	23	23	18.4	1600	1,600	NA	NA	NA	NA	1,680 (cc)	NA	93 (cc)	NA	NA	NA	NA	NA	93	Y
Mercury	7439-97-6	24	23	4.39E-04	0.0082	0.0082	NA	NA	0.012	NA	1.4 (b, s)	NA	0.77 (b, s)	NA	NA	1.4 (s)	NA	0.77 (s)	0.012	N
Molybdenum	7439-98-7	23	17	0.09	2.6	2.6	NA	NA	NA	NA	7,200 (cc)	NA	800 (cc)	NA	NA	NA	NA	NA	800	N
Nickel	7440-02-0	24	13	0.24	12.7	12.7	NA	NA	NA	NA	261 (r)	NA	29 (r)	NA	NA	470 (r)	NA	52 (r)	29	N
Selenium	7782-49-2	24	8	0.25	2	2	NA	NA	5	NA	20 (cc)	NA	5 (cc)	NA	NA	NA	NA	NA	5	N
Strontium	7440-24-6	23	23	25.7	1800	1800	NA	NA	NA	NA	48,000 (cc)	NA	5,300 (cc)	NA	NA	NA	NA	NA	5300	N
Thallium	7440-28-0	24	8	0.018	0.11	0.11	NA	NA	NA	NA	54 (cc)	NA	6 (cc)	NA	NA	NA	NA	NA	6	N
Vanadium	7440-62-2	23	21	0.23	2.4	2.4	NA	NA	NA	NA	79 (cc)	NA	27 (cc)	NA	NA	NA	NA	NA	27	N
Zinc	7440-66-6	24	10	2.7	9.2	9.2	NA	NA	NA	NA	67 (r)	NA	67 (r)	NA	120 (r)	NA	120 (r)	NA	67	N

* Data evaluated includes data from 2015 to 2nd quarter 2018, unless otherwise noted

Prepared by: HEG Checked by: ARD

Notes:

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mg/kg - milligrams/kilogram
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WS - Water Supply
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TABLE 2-2
ECOLOGICAL SCREENING - SURFACE WATER
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC, TERRELL, NC

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(e) - North Carolina 15A NCAC 02L .0202 Groundwater Standards & IMACs. http://portal.ncdenr.org/c/document_library/get_file?uuid=1aa3fa13-2c0f-45b7-ae96-5427fb1d25b4&groupId=38364
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(f) - North Carolina 15A NCAC 02B Surface Water and Wetland Standards. Amended January 1, 2015.
http://reports.oah.state.nc.us/ncac/title%2015a%20-%20environmental%20quality/chapter%2002%20-%20environmental%20management/subchapter%20b/subchapter%20b%20rules.pdf
WS standards are applicable to all Water Supply Classifications. WS standards are based on the consumption of fish and water.
Human Health Standards are based on the consumption of fish only unless dermal contact studies are available.
For Class C, use the most stringent of freshwater (or, if applicable, saltwater) column and the Human Health column.
For a WS water, use the most stringent of Freshwater, WS and Human Health. Likewise, Trout Waters and High Quality Waters must adhere to the most stingent of all applicable standards.
(g) - USEPA Region 4. 2018. Region 4 Ecological Risk Assessment Supplemental Guidance. March 2018 Update.
https://www.epa.gov/sites/production/files/2018-03/documents/era_regional_supplemental_guidance_report-march-2018_update.pdf
(h) - Value applies to inorganic form of arsenic only.
(i) - Value is the Secondary Maximum Contaminant Level.
https://www.epa.gov/dwstandardsregulations/secondary-drinking-water-standards-guidance-nuisance-chemicals
(j) - Value for Total Chromium.
(k) - Copper Treatment Technology Action Level is 1.3 mg/L.
(l) - Lead Treatment Technology Action Level is 0.015 mg/L.
(m) - RSL for Antimony (metallic) used for Antimony.
(n) - Value for Chromium (III), Insoluble Salts used for Chromium.
(o) - RSL for Mercuric Chloride used for Mercury.
(p) - RSL for Nickel Soluble Salts used for Nickel.
(q) - RSL for Thallium (Soluble Salts) used for Thallium.
(r) - Criterion expressed as a function of total hardness (mg/L). Value displayed is the site-specific total hardness of mg/L.
(s) - Value for Inorganic Mercury.
(t) - Acute AWQC is equal to 1/[(f1/CMC1) + (f2/CMC2)] where f1 and f2 are the fractions of total selenium that are treated as selenite and selenate, respectively, and
CMC1 and CMC2 are 185.9 µg/L and 12.82 µg/L, respectively. Calculated assuming that all selenium is present as selenate, a likely overly conservative assumption.
(u) - Criterion expressed as a function of total hardness (mg/L). Value displayed is the site-specific total hardness of mg/L.
(v) - Chloride Action Level for Toxic Substances Applicable to NPDES Permits is 230,000 µg/L.
(w) - Applicable only to persons with a sodium restrictive diet.
(x) - Los Alamos National Laboratory ECORISK Database. http://www.lanl.gov/community-environment/environmental-stewardship/protection/eco-risk-assessment.php
(y) - Long, Edward R., and Lee G. Morgan. 1991. The Potential for Biological Effects of Sediment-Sorbed Contaminants Tested in the National Status and Trends Program.
NOAA Technical Memorandum NOS OMA 52. Used effects range low (ER-L) for chronic and effects range medium (ER-M) for acute.
(z) - MacDonald, D.D.; Ingersoll, C.G.; Smorong, D.E.; Lindskoog, R.A.; Sloane, G.; and T. Bernacki. 2003. Development and Evaluation of Numerical Sediment Quality Assessment Guidelines for
Florida Inland Waters. Florida Department of Environmental Protection, Tallahassee, FL. Used threshold effect concentration (TEC) for the ESV and probable effect concentration (PEC) for the RSV.
(aa) - Persaud, D., R. Jaagumagi and A. Hayton. 1993. Guidelines for the protection and management of aquatic sediment quality in Ontario. Ontario Ministry of the Environment. Queen's Printer of Ontario.
(bb) - Los Alamos National Laboratory ECORISK Database. September 2017. http://www.lanl.gov/environment/protection/eco-risk-assessment.php (µg/kg dw)
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(ff) - Efroymson, R.A., M.E. Will, and G.W. Suter II, 1997a. Toxicological Benchmarks for Contaminants of Potential Concern for Effects on Soil and Litter Invertebrates and Heterotrophic Process:
1997 Revision. Oak Ridge National Laboratory, Oak Ridge, TN. ES/ER/TM-126/R2. (Available at http://www.esd.ornl.gov/programs/ecorisk/documents/tm126r21.pdf)
(gg) - Efroymson, R.A., M.E. Will, G.W. Suter II, and A.C. Wooten, 1997b. Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Terrestrial Plants:
1997 Revision. Oak Ridge National Laboratory, Oak Ridge, TN. ES/ER/TM-85/R3. (Available at http://www.esd.ornl.gov/programs/ecorisk/documents/tm85r3.pdf)
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TABLE 3-1
SUMMARY OF EXPOSURE POINT CONCENTRATIONS
HUMAN HEALTH - GROUNDWATER
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC, TERRELL, NC

Constituent	Reporting Units	Number of Samples	Frequency of Detection	Minimum Detected Concentration	Maximum Detected Concentration	Mean of Detected Concentration	UCL Selected	UCL	Exposure Point Concentration	Exposure Point Concentration (mg/L)
Aluminum	µg/L	997	573	6	54,500	535.9	95% KM (Chebychev) UCL	587.7	587.7	0.5877
Antimony	µg/L	1,438	299	0.1	9.7	0.602	95% KM (Chebychev) UCL	0.372	0.372	0.000372
Arsenic	µg/L	1,854	1,158	0.04	973	9.468	95% KM (Chebychev) UCL	12.23	12.23	0.01223
Barium	µg/L	1,855	1,855	8.3	2,830	142.1	95% Chebychev (Mean, Sd) UCL	165	165	0.165
Beryllium	µg/L	1,308	662	0.01	9.9	0.503	95% KM (Chebychev) UCL	0.389	0.389	0.000389
Boron	µg/L	1,753	844	3.3	30,900	1,983	95% KM (Chebychev) UCL	1212	1212	1.212
Cadmium	µg/L	1,855	335	0.024	7.5	0.368	95% KM (Chebychev) UCL	0.148	0.148	0.000148
Chromium	µg/L	1,855	1,375	0.091	202	4.628	95% KM (Chebychev) UCL	4.798	4.798	0.004798
Chromium (VI)	µg/L	781	605	0.0087	142	1.734	95% KM (Chebychev) UCL	2.582	2.582	0.002582
Cobalt	µg/L	1,308	1,127	0.01	216	8.225	95% KM (Chebychev) UCL	10.01	10.01	0.01001
Copper	µg/L	1,568	913	0.11	1,700	4.446	95% KM (Chebychev) UCL	7.7	7.7	0.0077
Lead	µg/L	1,855	677	0	18.61	0.581	99% KM (Chebychev) UCL	0.486	0.486	0.000486
Lithium	µg/L	470	445	0.16	748	13.6	95% KM (Chebychev) UCL	24.09	24.09	0.02409
Manganese	µg/L	1,568	1,393	0	12,900	413.8	99% KM (Chebychev) UCL	660.5	660.5	0.6605
Mercury	µg/L	1,855	145	0.007	1.2	0.166	95% KM (Chebychev) UCL	0.0442	0.0442	0.0000442
Molybdenum	µg/L	1,284	854	0.081	103	2.849	95% KM (Chebychev) UCL	2.756	2.756	0.002756
Nickel	µg/L	1,465	944	0.13	173	7.576	95% KM (Chebychev) UCL	6.685	6.685	0.006685
Selenium	µg/L	1,855	671	0.092	119	9.189	95% KM (Chebychev) UCL	4.771	4.771	0.004771
Strontium	µg/L	987	979	3.7	18,700	1,444	95% KM (Chebychev) UCL	1730	1730	1.73
Thallium	µg/L	1,438	407	0.015	3.6	0.205	95% KM (Chebychev) UCL	0.118	0.118	0.000118
Vanadium	µg/L	1,011	870	0.069	57.5	2.618	95% KM (Chebychev) UCL	2.879	2.879	0.002879
Zinc	µg/L	1,568	833	0	315	15.74	99% KM (Chebychev) UCL	14.95	14.95	0.01495

* Data evaluated includes data from 2015 to 2nd quarter 2018, unless otherwise noted

Prepared by: HEG Checked by: ARD

Notes:

---: Calculations were not performed due to lack of samples

ND - Not Determined

Mean - Arithmetic mean

UCL - 95% Upper Confidence Limit

mg/L - milligrams per liter

µg/L - micrograms per liter

(a)- Mean calculated by ProUCL using the Kaplan-Meier (KM) estimation method for non-detect values: only given for datasets with FOD less than 100% and that met the minimum sample size and FOD requirements for use with ProUCL; see note (b).

(b)- Sample size was greater than or equal to 10 and the number of detected values was greater than or equal to 6, therefore, a 95% UCL was calculated by ProUCL. The UCL shown is the one recommended by ProUCL. If more than one UCL was recommended, the higher UCL was selected. ProUCL, version 5.0

(c) - 0 is defined as a number of samples analyzed or the frequency of detection among samples.

(d) - The 95% UCL values are calculated using the ProUCL software (V. 5.0; USEPA, 2013a). The ProUCL software performs a goodness-of-fit test that accounts for data sets without any non-detect observations, as well as data sets with non-detect observations. The software then determines the distribution of the data set for which the EPC is being derived (e.g., normal, lognormal, gamma, or non-discernable), and then calculates a conservative and stable 95% UCL value in accordance with the framework described in "Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites" (USEPA, 2002b). The software includes numerous algorithms for calculating 95% UCL values, and provides a recommended UCL value based on the algorithm that is most applicable to the statistical distribution of the data set. ProUCL will calculate a 95% UCL where there are 3 or more total samples with detected concentrations. Where too few samples or detects are available, the maximum detected concentration is used as the EPC.

TABLE 3-2
SUMMARY OF EXPOSURE POINT CONCENTRATIONS
HUMAN HEALTH - SEDIMENT
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC, TERRELL, NC

Constituent	Reporting Units	Number of Samples	Frequency of Detection	Minimum Detected Concentration	Maximum Detected Concentration	Mean Detected Concentration	UCL Selected	UCL	Exposure Point Concentration (mg/kg)
Cobalt	mg/kg	1	1	NA	11.3	NA	---	---	11.3

* Data evaluated includes data from 2015 to 2nd quarter 2018, unless otherwise noted

Prepared by: HEG Checked by: ARD

Notes:

---: Calculations were not performed due to lack of samples

Mean - Arithmetic mean

mg/kg - milligrams per kilogram

ND - Not Determined

UCL - 95% Upper Confidence Limit

(a)- Mean calculated by ProUCL using the Kaplan-Meier (KM) estimation method for non-detect values: only given for datasets with FOD less than 100% and that met the minimum sample size and FOD requirements for use with ProUCL; see note (b).

(b)- Sample size was greater than or equal to 10 and the number of detected values was greater than or equal to 6, therefore, a 95% UCL was calculated by ProUCL. The UCL shown is the one recommended by ProUCL. If more than one UCL was recommended, the higher UCL was selected. ProUCL, version 5.0

(c) - 0 is defined as a number of samples analyzed or the frequency of detection among samples.

(d) - The 95% UCL values are calculated using the ProUCL software (V. 5.0; USEPA, 2013a). The ProUCL software performs a goodness-of-fit test that accounts for data sets without any non-detect observations, as well as data sets with non-detect observations. The software then determines the distribution of the data set for which the EPC is being derived (e.g., normal, lognormal, gamma, or non-discernable), and then calculates a conservative and stable 95% UCL value in accordance with the framework described in "Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites" (USEPA, 2002b). The software includes numerous algorithms for calculating 95% UCL values, and provides a recommended UCL value based on the algorithm that is most applicable to the statistical distribution of the data set. ProUCL will calculate a 95% UCL where there are 3 or more total samples with detected concentrations. Where too few samples or detects are available, the maximum detected concentration is used as the EPC.

TABLE 3-3
SUMMARY OF EXPOSURE POINT CONCENTRATIONS
HUMAN HEALTH - SURFACE WATER
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC, TERRELL, NC

Constituent	Number of Samples	Frequency of Detection	Minimum Detected Concentration	Maximum Detected Concentration	Mean Detected Concentration	UCL Selected	UCL	Exposure Point Concentration	Exposure Point Concentration (mg/L)
Aluminum	22	17	57.5	701	216.9	95% KM H-UCL	263.9	263.9	0.2639
Boron	28	24	46.1	3,500	549.9	95% KM (Chebyshev) UCL	1,148	1,148	1.148
Chromium(VI)	20	12	0.016	1.1	0.389	95% Gamma Adjusted KM-UCL	0.517	0.517	0.000517
Cobalt	23	21	0.068	24.6	3.298	95% Gamma Adjusted KM-UCL	6.483	6.483	0.006483
Manganese	23	23	18.4	1,600	378.1	95% Student's-t UCL	501	501	0.501
Zinc	28	12	2.7	9.2	5.305	95% KM (t) UCL	5.891	5.891	0.005891

* Data evaluated includes data from 2015 to 2nd quarter 2018, unless otherwise noted

Prepared by: HEG Checked by: HES

Notes:

---: Calculations were not performed due to lack of samples

ND - Not Determined

Mean - Arithmetic mean

UCL - 95% Upper Confidence Limit

mg/L - milligrams per liter

μg/L - micrograms per liter

(a)- Mean calculated by ProUCL using the Kaplan-Meier (KM) estimation method for non-detect values: only given for datasets with FOD less than 100% and that met the minimum sample size and FOD requirements for use with ProUCL; see note (b).

(b)- Sample size was greater than or equal to 10 and the number of detected values was greater than or equal to 6, therefore, a 95% UCL was calculated by ProUCL. The UCL shown is the one recommended by ProUCL. If more than one UCL was recommended, the higher UCL was selected. ProUCL, version 5.0

(c) - 0 is defined as a number of samples analyzed or the frequency of detection among samples.

(d) - The 95% UCL values are calculated using the ProUCL software (V. 5.0; USEPA, 2013a). The ProUCL software performs a goodness-of-fit test that accounts for data sets without any non-detect observations, as well as data sets with non-detect observations. The software then determines the distribution of the data set for which the EPC is being derived (e.g., normal, lognormal, gamma, or non-discernable), and then calculates a conservative and stable 95% UCL value in accordance with the framework described in "Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites" (USEPA, 2002b). The software includes numerous algorithms for calculating 95% UCL values, and provides a recommended UCL value based on the algorithm that is most applicable to the statistical distribution of the data set. ProUCL will calculate a 95% UCL where there are 3 or more total samples with detected concentrations. Where too few samples or detects are available, the maximum detected concentration is used as the EPC.

TABLE 4-1
SUMMARY OF EXPOSURE POINT CONCENTRATIONS
ECOLOGICAL - SEDIMENT
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC, TERRELL, NC

Constituent	Reporting Units	Number of Samples	Frequency of Detection	Minimum Detected Concentration	Maximum Detected Concentration	Mean Detected Concentration	UCL Selected	UCL	Exposure Point Concentration (mg/kg)
Barium	mg/kg	1	1	NA	128	---	---	---	128
Chromium (Total)	mg/kg	1	1	NA	45.6	---	---	---	45.6
Selenium	mg/kg	1	1	NA	4.1	---	---	---	4.1

* Data evaluated includes data from 2015 to 2nd quarter 2018, unless otherwise noted

Prepared by: HEG Checked by: ARD

Notes:

---: Calculations were not performed due to lack of samples

Mean - Arithmetic mean

mg/kg - milligrams per kilogram

µg/L - micrograms per liter

UCL - 95% Upper Confidence Limit

(a)- Sample size was greater than or equal to 10 and the number of detected values was greater than or equal to 6, therefore, a 95% UCL was calculated by ProUCL. The UCL shown is the one recommended by ProUCL. If more than one UCL was recommended, the higher UCL was selected. ProUCL, version 5.0

(b) - 0 is defined as a number of samples analyzed or the frequency of detection among samples.

(c) - The 95% UCL values are calculated using the ProUCL software (V. 5.0; USEPA, 2013a). The ProUCL software performs a goodness-of-fit test that accounts for data sets without any non-detect observations, as well as data sets with non-detect observations. The software then determines the distribution of the data set for which the EPC is being derived (e.g., normal, lognormal, gamma, or non-discernable), and then calculates a conservative and stable 95% UCL value in accordance with the framework described in "Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites" (USEPA, 2002b). The software includes numerous algorithms for calculating 95% UCL values, and provides a recommended UCL value based on the algorithm that is most applicable to the statistical distribution of the data set. ProUCL will calculate a 95% UCL where there are 3 or more total samples with detected concentrations. Where too few samples or detects are available, the maximum detected concentration is used as the EPC.

TABLE 4-2
SUMMARY OF EXPOSURE POINT CONCENTRATIONS
ECOLOGICAL - SURFACE WATER
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC, TERRELL, NC

Constituent	Reporting Units	Number of Samples	Frequency of Detection	Minimum Detected Concentration	Maximum Detected Concentration	Mean Detected Concentration	UCL Selected	UCL	Exposure Point Concentration	Exposure Point Concentration (mg/L)
Aluminum	µg/L	22	17	57.5	701	216.9	95% KM H-UCL	263.9	263.9	0.2639
Cobalt	µg/L	23	21	0.068	24.6	3.298	95% Gamma Adjusted KM-UCL	6.483	6.483	0.006483
Copper	µg/L	24	22	0.13	7.4	1.5	95% KM (Chebychev) UCL	2.696	2.696	0.002696
Manganese	µg/L	23	23	18.4	1600	378.1	95% Student's-t UCL	501	501	0.501

* Data evaluated includes data from 2015 to 2nd quarter 2018, unless otherwise noted

Prepared by: HEG Checked by: ARD

Notes:

---: Calculations were not performed due to lack of samples

Mean - Arithmetic mean

mg/L - milligrams per liter

µg/L - micrograms per liter

UCL - 95% Upper Confidence Limit

(a)- Sample size was greater than or equal to 10 and the number of detected values was greater than or equal to 6, therefore, a 95% UCL was calculated by ProUCL. The UCL shown is the one recommended by ProUCL. If more than one UCL was recommended, the higher UCL was selected. ProUCL, version 5.0

(b) - 0 is defined as a number of samples analyzed or the frequency of detection among samples.

(c) - The 95% UCL values are calculated using the ProUCL software (V. 5.0; USEPA, 2013a). The ProUCL software performs a goodness-of-fit test that accounts for data sets without any non-detect observations, as well as data sets with non-detect observations. The software then determines the distribution of the data set for which the EPC is being derived (e.g., normal, lognormal, gamma, or non-discernable), and then calculates a conservative and stable 95% UCL value in accordance with the framework described in "Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites" (USEPA, 2002b). The software includes numerous algorithms for calculating 95% UCL values, and provides a recommended UCL value based on the algorithm that is most applicable to the statistical distribution of the data set. ProUCL will calculate a 95% UCL where there are 3 or more total samples with detected concentrations. Where too few samples or detects are available, the maximum detected concentration is used as the EPC.

TABLE 5-1
SUMMARY OF ON-SITE GROUNDWATER EPC/RBC COMPARISON
CONSTRUCTION - CONSTRUCTION WORKER (ADULT)
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC, TERRELL, NC

COPC	CAS	Risk-Based Concentration				Ash Basin-Groundwater	Risk Ratio	
		Non-Cancer (mg/L)	Cancer (mg/L)	Final (mg/L)	Basis	Exposure Point Concentration (mg/L)	Non-Cancer	Cancer
Aluminum	7429-90-5	9.6E+04	nc	9.6E+04	nc	0.6	0.00001	nc
Antimony	7440-36-0	1.7E+01	nc	1.7E+01	nc	0.0004	0.00002	nc
Arsenic	7440-38-2	2.9E+01	4.5E+02	2.9E+01	nc	0.01	0.0004	nc
Barium	7440-39-3	5.0E+03	nc	5.0E+03	nc	0.2	0.00003	nc
Beryllium	7440-41-7	4.8E+02	nc	4.8E+02	nc	0.0004	0.000001	nc
Boron	7440-42-8	1.9E+04	nc	1.9E+04	nc	1	0.00006	nc
Cadmium	7440-43-9	1.0E+01	nc	1.0E+01	nc	0.0001	0.00001	nc
Chromium, Total	7440-47-3	8.6E+03	nc	8.6E+03	nc	0.005	0.0000006	nc
Chromium (VI)	18540-29-9	2.8E+01	7.6E+01	2.8E+01	nc	0.003	0.00009	nc
Cobalt	7440-48-4	3.3E+02	nc	3.3E+02	nc	0.01	0.0000	nc
Copper	7440-50-8	3.8E+03		3.8E+03	nc	0.008	0.0000	nc
Lead [(a,b)]	7439-92-1	NA				0.0005	NC	nc
Lithium	7439-93-2	NA				0.02	NC	nc
Manganese	7439-96-5	2.2E+03	nc	2.2E+03	nc	0.7	0.000	nc
Mercury	7439-97-6	5.0E+01		5.0E+01	nc	0.00004	0.000	nc
Molybdenum	7439-98-7	4.8E+02	nc	4.8E+02	nc	0.003	0.00001	nc
Nickel	7440-02-0	1.0E+03	nc	1.0E+03	nc	0.007	0.00001	nc
Selenium	7782-49-2	4.8E+02	nc	4.8E+02	nc	0.005	0.00001	nc
Strontium	7440-24-6	1.9E+05	nc	1.9E+05	nc	2	0.000009	nc
Thallium	7440-28-0	NA				0.0001	NA	nc
Vanadium	7440-62-2	9.6E+02	nc	9.6E+02	nc	0.003	0.000003	nc
Zinc	7440-66-6	3.1E+04	nc	3.1E+04	nc	0.01	0.000000	nc
						Cumulative Risk	**0.001**	**0.00E+00**

Prepared by: HHS Checked by: TCP

Notes:

COPC - Chemical of potential concern
c - Remedial goal based on cancer risk
nc - Remedial goal based on non-cancer hazard index
NA - No toxicity value available; remedial goal not calculated
NC - Not Calculated

[(a)] USEPA has an action level of 15 ug/L for lead in drinking water (USEPA, 2012b). Refer to Attachment D, Section 2.5 of the *Marshall Steam Station CAP* (HDR 2015).

[(b)] Lead was not included in the cumulative risk calculation, as risk for lead is typically evaluted using biokinetic models. Lead concentrations are less than the conservative action level of 15 ug/L. Groundwater at the site is not used for drinking water.

Exposure Routes Evaluated

Incidental Ingestion	Yes
Dermal Contact	Yes
Ambient Vapor Inhalation	No

Target Hazard Index (per Chemical)	**1E+00**
Target Cancer Risk (per Chemical)	**1E-04**

TABLE 5-2
SUMMARY OF OFF-SITE SEDIMENT EPC/RBC COMPARISON
RECREATIONAL SWIMMER - CHILD, ADOLESCENT, and ADULT
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC, TERRELL, NC

COPC	CAS	Risk-Based Concentration				Sediment	Risk Ratio	
		Non-Cancer (mg/kg)	Cancer (mg/kg)	Final (mg/kg)	Basis	Exposure Point Concentration (mg/kg)	Non-Cancer	Cancer
Cobalt	7440-48-4	3.7E+03	nc	3.7E+03	nc	11	0.003	nc
					Cumulative Risk		**0.003**	**0.00E+00**

Prepared by: HHS Checked by: TCP

Notes:

COPC - Chemical of potential concern

c - Remedial goal based on cancer risk

nc - remedial goal based on non-cancer hazard index

Exposure Routes Evaluated	
Incidental Ingestion	Yes
Dermal Contact	Yes
Particulate Inhalation	No
Ambient Vapor Inhalation	No
Target Hazard Index (per Chemical)	**1E+00**
Target Cancer Risk (per Chemical)	**1E-04**

TABLE 5-3
SUMMARY OF OFF-SITE SURFACE WATER EPC/RBC COMPARISON
RECREATIONAL SWIMMER - CHILD, ADOLESCENT, and ADULT
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC, TERRELL, NC

COPC	CAS	Risk-Based Concentration				Surface Water	Risk Ratio	
		Non-Cancer (mg/L)	Cancer (mg/L)	Final (mg/L)	Basis	Exposure Point Concentration (mg/L)	Non-Cancer	Cancer
Aluminum	7429-90-5	1.1E+03	nc	1.1E+03	nc	0.3	0.0002	nc
Boron	7440-42-8	2.2E+02	nc	2.2E+02	nc	1	0.01	nc
Chromium (VI)	18540-29-9	3.3E-01	2.0E-02	2.0E-02	c	0.0005	0.002	2.6E-02
Cobalt	7440-48-4	3.5E-01	nc	3.5E-01	nc	0.01	0.02	nc
Manganese	7439-96-5	4.1E+01	nc	4.1E+01	nc	0.5	0.01	nc
Zinc	7440-66-6	3.4E+02	nc	3.4E+02	nc	0.006	NC	nc
					Cumulative Risk		**0.04**	**2.6E-02**

Prepared by: HHS Checked by: TCP

Notes:

COPC - Chemical of potential concern

c - Remedial goal based on cancer risk

nc - Remedial goal based on non-cancer hazard index

NA - No toxicity value available; remedial goal not calculated

NC - Not Calculated

Exposure Routes Evaluated

Incidental Ingestion	Yes
Dermal Contact	Yes
Ambient Vapor Inhalation	No
Target Hazard Index (per Chemical)	**1E+00**
Target Cancer Risk (per Chemical)	**1E-04**

TABLE 5-4
SUMMARY OF OFF-SITE SEDIMENT EPC/RBC COMPARISON
RECREATIONAL WADER - CHILD, ADOLESCENT, and ADULT
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC, TERRELL, NC

COPC	CAS	Risk-Based Concentration				Sediment	Risk Ratio	
		Non-Cancer (mg/kg)	Cancer (mg/kg)	Final (mg/kg)	Basis	Exposure Point Concentration (mg/kg)	Non-Cancer	Cancer
Cobalt	7440-48-4	3.7E+03	nc	3.7E+03	nc	11	0.003	nc
					Cumulative Risk		**0.003**	**0.00E+00**

Prepared by: HHS Checked by: TCP

Notes:

COPC - Chemical of potential concern

c - Remedial goal based on cancer risk

nc - Remedial goal based on non-cancer hazard index

Exposure Routes Evaluated

Incidental Ingestion	Yes
Dermal Contact	Yes
Particulate Inhalation	No
Ambient Vapor Inhalation	No
Target Hazard Index (per Chemical)	**1E+00**
Target Cancer Risk (per Chemical)	**1E-04**

TABLE 5-5
SUMMARY OF OFF-SITE SURFACE WATER EPC/RBC COMPARISON
RECREATIONAL WADER - CHILD, ADOLESCENT, and ADULT
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC, TERRELL, NC

COPC	CAS	Risk-Based Concentration				Surface Water	Risk Ratio	
		Non-Cancer	Cancer	Final	Basis	Exposure Point Concentration	Non-Cancer	Cancer
		(mg/L)	(mg/L)	(mg/L)		(mg/L)		
Aluminum	7429-90-5	1.2E+03	nc	1.2E+03	nc	0.3	0.0002	nc
Boron	7440-42-8	2.4E+02	nc	2.4E+02	nc	1	0.005	nc
Chromium (VI)	18540-29-9	9.5E-01	8.3E-02	8.3E-02	c	0.0005	0.001	6.2E-03
Cobalt	7440-48-4	3.6E-01	nc	3.6E-01	nc	0.01	0.02	nc
Manganese	7439-96-5	9.0E+01	nc	9.0E+01	nc	0.5	0.01	nc
Zinc	7440-66-6	3.6E+02	nc	3.6E+02	nc	0.006	0.00002	nc
					Cumulative Risk		**0.03**	**6.2E-03**

Prepared by: HHS Checked by: TCP

Notes:

NA - No toxicity value available; remedial goal not calculated

COPC - Chemical of potential concern

NC - Not Calculated

c - Remedial goal based on cancer risk

nc - Remedial goal based on non-cancer hazard index

Exposure Routes Evaluated

Incidental Ingestion	Yes
Dermal Contact	Yes
Ambient Vapor Inhalation	No
Target Hazard Index (per Chemical)	**1E+00**
Target Cancer Risk (per Chemical)	**1E-04**

TABLE 5-6
SUMMARY OF OFF-SITE SURFACE WATER EPC/RBC COMPARISON
RECREATIONAL BOATER - RECREATIONAL BOATER (ADULT)
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC, TERRELL, NC

COPC	CAS	Risk-Based Concentration				Surface Water Exposure Point Concentration	Risk Ratio	
		Non-Cancer (mg/L)	Cancer (mg/L)	Final (mg/L)	Basis	(mg/L)	Non-Cancer	Cancer
Aluminum	7429-90-5	5.6E+04	nc	5.6E+04	nc	0.3	0.000005	nc
Boron	7440-42-8	1.1E+04	nc	1.1E+04	nc	1	0.0001	nc
Chromium (VI)	18540-29-9	2.1E+00	9.8E-01	9.8E-01	c	0.0005	0.0005	5.3E-04
Cobalt	7440-48-4	4.2E+01	nc	4.2E+01	nc	0.01	0.0002	nc
Manganese	7439-96-5	3.1E+02	nc	3.1E+02	nc	0.5	0.002	nc
Zinc	7440-66-6	2.8E+04	nc	2.8E+04	nc	0.006	0.0000002	nc
					Cumulative Risk		**0.0024**	**5.3E-04**

Prepared by: HHS Checked by: TCP

Notes:

COPC - Chemical of potential concern

c - Remedial goal based on cancer risk

nc - Remedial goal based on non-cancer hazard index

NA - No toxicity value available; remedial goal not calculated

NC - Not Calculated

Exposure Routes Evaluated

Incidental Ingestion	No
Dermal Contact	Yes
Ambient Vapor Inhalation	No
Target Hazard Index (per Chemical)	**1E+00**
Target Cancer Risk (per Chemical)	**1E-04**

TABLE 5-7
SUMMARY OF OFF-SITE SURFACE WATER EPC/RBC COMPARISON
RECREATIONAL FISHER - RECREATIONAL FISHER (ADULT)
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC, TERRELL, NC

COPC	CAS	Risk-Based Concentration				Surface Water	Risk Ratio	
		Non-Cancer (mg/L)	Cancer (mg/L)	Final (mg/L)	Basis	Exposure Point Concentration (mg/L)	Non-Cancer	Cancer
Aluminum	7429-90-5	5.6E+04	nc	5.6E+04	nc	0.3	0.000005	nc
Boron	7440-42-8	1.1E+04		1.1E+04	nc	1	0.0001	nc
Chromium (VI)	18540-29-9	2.1E+00	9.8E-01	9.8E-01	c	0.0005	0.0005	5.3E-04
Cobalt	7440-48-4	4.2E+01	nc	4.2E+01	nc	0.01	0.0002	nc
Manganese	7439-96-5	3.1E+02	nc	3.1E+02	nc	0.5	0.002	nc
Zinc	7440-66-6	2.8E+04	nc	2.8E+04	nc	0.006	0.0000002	nc
					Cumulative Risk		**0.002**	**5.3E-04**

Prepared by: HHS Checked by: TCP

Notes:

COPC - Chemical of potential concern
c - Remedial goal based on cancer risk
nc - Remedial goal based on non-cancer hazard index

NA - No toxicity value available; remedial goal not calculated
NC - Not Calculated

Exposure Routes Evaluated

Incidental Ingestion	No
Dermal Contact	Yes
Ambient Vapor Inhalation	No
Target Hazard Index (per Chemical)	**1E+00**
Target Cancer Risk (per Chemical)	**1E-04**

TABLE 5-8
SUMMARY OF FISH TISSUE EPC/RBC COMPARISON
FISHER - RECREATIONAL(ADULT AND ADOLESCENT)
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC, TERRELL, NC

COPC	CAS	Risk-Based Concentration - Fish Tissue								Lowest Non-Cancer RBC Value	Lowest Cancer RBC Value	BCF (unitless)	Risk-Based Concentration - Surface Water				Surface Water	Risk Ratio	
		Adult				Adolescent													
		Non-Cancer	Cancer	Final	Basis	Non-Cancer	Cancer	Final	Basis				Non-Cancer	Cancer	Final	Basis	Exposure Point Concentration	Non-Cancer	Cancer
		(mg/kg)	(mg/kg)	(mg/kg)		(mg/kg)	(mg/kg)	(mg/kg)					(mg/L)	(mg/L)	(mg/L)		(mg/L)		
Aluminum	7429-90-5	4.6E+03	nc	4.6E+03	nc	5.8E+03	nc	5.8E+03	nc	4.6E+03	nc	2.7	1.7E+03	nc	1.7E+03	nc	0.3	0.0002	nc
Boron	7440-42-8	9.1E+02	nc	9.1E+02	nc	1.2E+03	nc	1.2E+03	nc	9.1E+02	nc	0.3	3.0E+03	nc	3.0E+03	nc	1	0.000	nc
Chromium (VI)	18540-29-9	1.4E+01	6.4E+00	6.4E+00	c	1.7E+01	2.7E+00	2.7E+00	c	1.4E+01	2.7E+00	200	6.9E-02	1.4E-02	1.4E-02	c	0.0005	0.0	0.04
Cobalt	7440-48-4	1.4E+00	nc	1.4E+00	nc	1.7E+00	nc	1.7E+00	nc	1.4E+00	nc	400	3.4E-03	nc	3.4E-03	nc	0.01	1.9	nc
Manganese	7439-96-5	6.4E+02	nc	6.4E+02	nc	8.1E+02	nc	8.1E+02	nc	6.4E+02	nc	2.4	2.7E+02	nc	2.7E+02	nc	0.5	0.002	nc
Zinc	7440-66-6	1.4E+03	nc	1.4E+03	nc	1.7E+03	nc	1.7E+03	nc	1.4E+03	nc	2059	6.7E-01	nc	6.7E-01	nc	0.006	0.01	nc
																	Cumulative Risk	**1.9**	**3.8E-02**

Prepared by: HHS Checked by: TCP

Notes:
COPC - Chemical of potential concern
c - Remedial goal based on cancer risk
nc - Remedial goal based on non-cancer hazard index
NA - No toxicity value available; remedial goal not calculated
NC - Not Calculated
BCF - Bioconcentration Factor
Surface water RBC = Fish Tissue RBC / BCF

Exposure Routes Evaluated
Ingestion Yes

Target Hazard Index (per Chemical) 1E+00
Target Cancer Risk (per Chemical) 1E-04

TABLE 5-9
SUMMARY OF FISH TISSUE EPC/RBC COMPARISON
FISHER - SUBSISTENCE (ADULT AND CHILD)
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC, TERRELL, NC

COPC	CAS	Risk-Based Concentration - Fish Tissue								Lowest Non-Cancer RBC Value	Lowest Cancer RBC Value	BCF (unitless)	Risk-Based Concentration - Surface Water				Surface Water	Risk Ratio	
		Adult				Child													
		Non-Cancer (mg/kg)	Cancer (mg/kg)	Final (mg/kg)	Basis	Non-Cancer (mg/kg)	Cancer (mg/kg)	Final (mg/kg)	Basis				Non-Cancer (mg/L)	Cancer (mg/L)	Final (mg/L)	Basis	Exposure Point Concentration (mg/L)	Non-Cancer	Cancer
Aluminum	7429-90-5	4.7E+02	nc	4.7E+02	nc	1.5E+02	nc	1.5E+02	nc	1.5E+02	nc	2.7	5.7E+01	nc	5.7E+01	nc	0.3	0.005	nc
Boron	7440-42-8	9.4E+01	nc	9.4E+01	nc	3.1E+01	nc	3.1E+01	nc	3.1E+01	nc	0.3	1.0E+02	nc	1.0E+02	nc	1	0.01	nc
Chromium (VI)	18540-29-9	1.4E+00	6.6E-01	6.6E-01	c	4.6E-01	3.6E-02	3.6E-02	c	4.6E-01	3.6E-02	200	2.3E-03	1.8E-04	1.8E-04	c	0.0005	0.23	2.872
Cobalt	7440-48-4	1.4E-01	nc	1.4E-01	nc	4.6E-02	nc	4.6E-02	nc	4.6E-02	nc	400	1.1E-04	nc	1.1E-04	nc	0.01	56	nc
Manganese	7439-96-5	6.6E+01	nc	6.6E+01	nc	2.1E+01	nc	2.1E+01	nc	2.1E+01	nc	2.4	8.9E+00	nc	8.9E+00	nc	0.5	0.06	nc
Zinc	7440-66-6	1.4E+02	nc	1.4E+02	nc	4.6E+01	nc	4.6E+01	nc	4.6E+01	nc	2059	2.2E-02	nc	2.2E-02	nc	0.006	0.3	nc
																Cumulative Risk		**57**	**2.87E+00**

Prepared by: HHS Checked by: TCP

Notes:
COPC - Chemical of potential concern
c - Remedial goal based on cancer risk
nc - remedial goal based on non-cancer hazard index
There is no evidence of subsistence fishing occuring in the waterbody evaluated.
NA - No toxicity value available; remedial goal not calculated
NC - Not Calculated
BCF - Bioconcentration Factor
Surface water RBC = Fish Tissue RBC / BCF

Exposure Routes Evaluated
Ingestion Yes

Target Hazard Index (per Chemical) 1E+00
Target Cancer Risk (per Chemical) 1E-04

TABLE 5-10
SUMMARY OF EXPOSURE POINT CONCENTRATION COMPARISON TO RISK-BASED CONCENTRATION
MARSHALL STEAM STATION
DUKE ENERGY CAROLINAS, LLC, TERRELL, NC

Source Table (PRG Tables)	Media	Exposure Pathway	Risk Ratio - Non- cancer	Risk Ratio - cancer
TABLE 5-1	Groundwater-On-Site	CONSTRUCTION - CONSTRUCTION WORKER (ADULT)	0.001	0.00E+00
TABLE 5-2	Sediment- Off-Site	OFF-SITE RECREATIONAL SWIMMER - CHILD, ADOLESCENT, and ADULT	0.003	0.00E+00
TABLE 5-3	Surface Water- Off-Site	OFF-SITE RECREATIONAL SWIMMER - CHILD, ADOLESCENT, and ADULT	0.04	2.62E-02
TABLE 5-4	Sediment- Off-Site	OFF-SITE RECREATIONAL WADER - CHILD, ADOLESCENT, and ADULT	0.003	0.00E+00
TABLE 5-5	Surface Water- Off-Site	OFF-SITE RECREATIONAL WADER - CHILD, ADOLESCENT, and ADULT	0.03	6.22E-03
TABLE 5-6	Surface Water- Off-Site	OFF-SITE RECREATIONAL BOATER - OFF-SITE RECREATIONAL BOATER (ADULT)	0.002	5.27E-04
TABLE 5-7	Surface Water- Off-Site	OFF-SITE RECREATIONAL FISHER (ADULT)	0.002	5.27E-04
TABLE 5-8	Biota (fish)- Off-Site	OFF-SITE FISHER - RECREATIONAL (ADULT AND ADOLESCENT)	2	3.83E-02
TABLE 5-9	Biota (fish)- Off-Site	OFF-SITE RECREATIONAL FISHER (ADULT)	57	2.87E+00

Prepared by: HHS Checked by: TCP

Table 1
Exposure Parameters for Ecological Receptors
Ecological Exposure Area 1
Baseline Ecological Risk Assessment
Duke Energy
Marshall Steam Station - Terrell, NC

	Parameter	Body Weight	Food Ingestion Rate	Water Ingestion Rate	Dietary Composition						Home Range	Seasonal Use Factor[j]
					Plants	Mammal/Terr. Vertebrates	Fish	Invertebrates	Birds	Soil		
	Algorithm ID	BW	IR_F	IR_W	P_F	A_M	A_F	A_I	A_B	S_F	HR	SUF
	Units	kg	kg/kg BW/day	L/kg BW/day	%	%	%	%	%	%	hectares	unitless
Ecological Receptors	**HERBIVORE**											
	Meadow Vole[a]	0.033	0.33	0.21	97.6%	0%	0%	0%	0%	2.4%	0.027	1
	Muskrat[b]	1.17	0.3	0.97	99.3%	0%	0%	0%	0%	0.7%	0.13	1
	OMNIVORE											
	Mallard Duck[c]	1.134	0.068	0.057	48.3%	0%	0%	48.3%	0%	3.3%	435	1
	American Robin[d]	0.08	0.129	0.14	40%	0%	0%	58%	0%	2%	0.42	1
	CARNIVORE											
	Red-Tailed Hawk[e]	1.06	0.18	0.058	0%	91.5%	0%	0%	8.5%	0%	876	1
	Bald Eagle[f]	3.75	0.12	0.058	0%	28%	58%	0%	13.5%	0.5%	2199	1
	Red Fox[g]	4.54	0.16	0.085	6%	89%	0%	2%	0%	3%	1226	1
	PISCIVORE											
	River Otter[h]	6.76	0.19	0.081	0%	0%	100%	0%	0%	0%	348	1
	Great Blue Heron[i]	2.229	0.18	0.045	0%	0%	90%	9.5%	0%	0.5%	227	1

NOTES:

BW - Body Weight
kg - Kilograms
IR - Ingestion Rate
HR - Home Range
SUF - Seasonal Use Factor

P_F - Plant Matter Ingestion Percentage
A_M - Mammal/Terrestrial Vertebrate ingestion percentage
A_F - Fish Ingestion Percentage
A_B - Bird Ingestion Percentage
S_F - Soil Ingestion Percentage

kg/kg BW/day - Kilograms Food per Kilograms Body Weight per Day
L/kg BW/day - Liters Water per Kilogram Body Weight per Day

[a] BW, IR_f, IR_w, P_F, HR from USEPA 1993 (sections 2-328 and 2-329); S_F from Sample and Suter 1994
[b] BW, IR_f, IR_w, P_F, HR from USEPA 1993 (sections 2-340 and 2-341); S_F from TechLaw Inc. 2013; IR_F from Nagy 2001
[c] BW, P_F, A_I, HR from USEPA 1993 (sections 2-43 and 2-45); S_F from Beyer et al. 1994; IR_F from Nagy 2001
[d] BW, P_F, A_I, HR from USEPA 1993 (sections 2-197 and 2-198); S_F from Sample and Suter 1994; IR_F from Nagy 2001
[e] BW, P_F, A_M, A_B, IR_F, HR from USEPA 1993 (sections 2-82 and 2-83)
[f] BW, P_F, A_F, A_M, A_B, HR from USEPA 1993 (sections 2-91 and 2-97); IR_F from Nagy 2001
[g] BW, P_F, A_F, A_I, HR from USEPA 1993 (sections 2-224 and 2-225); S_F from Beyer et al. 1994
[h] BW, IR_w, A_F, HR from USEPA 1993 (sections 2-264 and 2-266); S_F from Sample and Suter 1994; IR_F from Nagy 2001
[i] BW, P_F, A_F, A_I, HR from USEPA 1993 (sections 2-8 and 2-9); S_F from Sample and Suter 1994; IR_F from Nagy 2001
[j] Seasonal Use Factor is set to a default of 1 to be overly conservative and protective of ecological receptors.

Table 2
Toxicity Reference Values for Ecological Receptors
Ecological Exposure Area 1
Baseline Ecological Risk Assessment
Duke Energy
Marshall Steam Station - Terrell, NC

Analyte	TRVs (NOAEL)								
	Aquatic					Terrestrial			
	Mallard Duck (mg/kg/day)	Great Blue Heron (mg/kg/day)	Bald Eagle (mg/kg/day)	Muskrat (mg/kg/day)	River Otter (mg/kg/day)	American Robin (mg/kg/day)	Red-Tailed Hawk (mg/kg/day)	Meadow Vole (mg/kg/day)	Red Fox (mg/kg/day)
Aluminum[a]	110	110	110	1.93	1.93	110	110	1.93	1.93
Antimony[a]	NA	NA	NA	0.059	0.059	NA	NA	0.059	0.059
Arsenic[b]	2.24	2.24	2.24	1.04	1.04	2.24	2.24	1.04	1.04
Barium[c]	20.8	20.8	20.8	51.8	51.8	20.8	20.8	51.8	51.8
Beryllium[a]	NA	NA	NA	0.532	0.532	NA	NA	0.532	0.532
Boron[a, b]	28.8	28.8	28.8	28	28	28.8	28.8	28	28
Cadmium[a]	1.47	1.47	1.47	0.77	0.77	1.47	1.47	0.77	0.77
Calcium	EN	EN	EN	EN	EN	EN	EN	EN	EN
Chromium, Total[d]	1	1	1	2740	2740	1	1	2740	2740
Chromium VI (hexavalent)[a]	NA	NA	NA	9.24	9.24	NA	NA	9.24	9.24
Chromium III[a]	2.66	2.66	2.66	2.4	2.4	2.66	2.66	2.4	2.4
Cobalt[a]	7.61	7.61	7.61	7.33	7.33	7.61	7.61	7.33	7.33
Copper[a]	4.05	4.05	4.05	5.6	5.6	4.05	4.05	5.6	5.6
Iron	EN	EN	EN	EN	EN	EN	EN	EN	EN
Lead[b]	1.63	1.63	1.63	4.7	4.7	1.63	1.63	4.7	4.7
Magnesium	EN	EN	EN	EN	EN	EN	EN	EN	EN
Manganese[a]	179	179	179	51.5	51.5	179	179	51.5	51.5
Mercury[e]	3.25	3.25	3.25	1.01	1.01	3.25	3.25	1.01	1.01
Molybdenum[a, d]	3.53	3.53	3.53	0.26	0.26	3.53	3.53	0.26	0.26
Nickel[a]	6.71	6.71	6.71	1.7	1.7	6.71	6.71	1.7	1.7
Potassium	EN	EN	EN	EN	EN	EN	EN	EN	EN
Selenium[a]	0.29	0.29	0.29	0.143	0.143	0.29	0.29	0.143	0.143
Sodium	EN	EN	EN	EN	EN	EN	EN	EN	EN
Strontium[a, d]	NA	NA	NA	263	263	NA	NA	263	263
Thallium[a]	NA	NA	NA	0.015	0.015	NA	NA	0.015	0.015
Titanium	NA	NA	NA	NA	NA	NA	NA	NA	NA
Vanadium[a]	0.344	0.344	0.344	4.16	4.16	0.344	0.344	4.16	4.16
Zinc[a]	66.1	66.1	66.1	75.4	75.4	66.1	66.1	75.4	75.4
Nitrate[d]	NA	NA	NA	507	507	NA	NA	507	507

Table 2 (Cont.)

Analyte	TRVs (LOAEL)								
	Aquatic					Terrestrial			
	Mallard Duck (mg/kg/day)	Heron (mg/kg/day)	Bald Eagle (mg/kg/day)	Muskrat (mg/kg/day)	River Otter (mg/kg/day)	Robin (mg/kg/day)	Hawk (mg/kg/day)	Meadow Vole (mg/kg/day)	Red Fox (mg/kg/day)
Aluminum[a]	1100	1100	1100	19.3	19.3	1100	1100	19.3	19.3
Antimony[a]	NA	NA	NA	0.59	0.59	NA	NA	0.59	0.59
Arsenic[b]	40.3	40.3	40.3	1.66	1.66	40.3	40.3	1.66	1.66
Barium[c]	41.7	41.7	41.7	75	75	41.7	41.7	75	75
Beryllium[a]	NA	NA	NA	6.6	6.6	NA	NA	6.6	6.6
Boron[a, b]	100	100	100	93.6	93.6	100	100	93.6	93.6
Cadmium[a]	2.37	2.37	2.37	10	10	2.37	2.37	10	10
Calcium	EN	EN	EN	EN	EN	EN	EN	EN	EN
Chromium, Total[d]	5	5	5	27400	27400	5	5	27400	27400
Chromium VI (hexavalent)[a]	NA	NA	NA	40	40	NA	NA	40	40
Chromium III[a]	2.66	2.66	2.66	9.625	9.625	2.66	2.66	9.625	9.625
Cobalt[a]	7.8	7.8	7.8	10.9	10.9	7.8	7.8	10.9	10.9
Copper[a]	12.1	12.1	12.1	9.34	9.34	12.1	12.1	9.34	9.34
Iron	EN	EN	EN	EN	EN	EN	EN	EN	EN
Lead[b]	3.26	3.26	3.26	8.9	8.9	3.26	3.26	8.9	8.9
Magnesium	EN	EN	EN	EN	EN	EN	EN	EN	EN
Manganese[a]	348	348	348	71	71	348	348	71	71
Mercury[e]	0.37	0.37	0.37	0.16	0.16	0.37	0.37	0.16	0.16
Molybdenum[a, d]	35.3	35.3	35.3	2.6	2.6	35.3	35.3	2.6	2.6
Nickel[a]	11.5	11.5	11.5	3.4	3.4	11.5	11.5	3.4	3.4
Potassium	EN	EN	EN	EN	EN	EN	EN	EN	EN
Selenium[a]	0.579	0.579	0.579	0.215	0.215	0.579	0.579	0.215	0.215
Sodium	EN	EN	EN	EN	EN	EN	EN	EN	EN
Strontium[a, d]	NA	NA	NA	2630	2630	NA	NA	2630	2630
Thallium[a]	NA	NA	NA	0.075	0.075	NA	NA	0.075	0.075
Vanadium[a]	0.688	0.688	0.688	8.31	8.31	0.688	0.688	8.31	8.31
Zinc[a]	66.5	66.5	66.5	75.9	75.9	66.5	66.5	75.9	75.9
Nitrate[d]	NA	NA	NA	1130	1130	NA	NA	1130	1130

NOTES:

NOAEL - No Observed Adverse Effects Level

LOAEL - Lowest Observed Effects Level

EN - Essential nutrient

NA - Not available

TRV - Toxicity Reference Value

[a] CH2M Hill. 2014. Tier 2 Risk-Based Soil Concentrations Protective of Ecological Receptors at the Hanford Site. CHPRC-01311. Revision 2. July. Http://pdw.hanford.gov/arpir/pdf.cfm?accession=0088115

[b] USEPA 2005 EcoSSL

[c] Only a single paper (Johnson et al., 1960) with data on the toxicity of barium hydroxide to one avian species (chicken) was identified by USEPA (2005); therefore, an avian TRV could not be derived and an Eco-SSL could not be calculated for avian wildlife (calculation requires a minimum of three results for two test species). Johnson et al. (1960) reports a subchronic NOAEL of 208.26 mg/kg/d. The NOAEL was multiplied by an uncertainty factor of 0.1 to derive a very conservative TRV of 20.8 mg/kg/d.

[d] Sample et al. 1996

Table 3
Exposure Area and Area Use Factors for Ecological Receptors
Ecological Exposure Area 1
Baseline Ecological Risk Assessment
Duke Energy
Marshall Steam Station - Terrell, NC

Exposure Point	Exposure Area[a] (hectares)	Area Use Factor (AUF)								
		Mallard Duck	Great Blue Heron	Muskrat	River Otter	Bald Eagle	American Robin	Red-Tailed Hawk	Meadow Vole	Red Fox
Ecological Exposure Area 1	14.6	3.36%	6.43%	100%	4.20%	0.66%	100%	1.667%	100%	1.19%

NOTES:
[a] Ecological Exposure Area 1 is east of the active ash basin. It includes the shore of Lake Norman and a feeder stream as well as some open water habitat in Lake Norman.

Table 4
EPCs for Use in the Risk Assessment
Ecological Exposure Area 1
Baseline Ecological Risk Assessment
Duke Energy
Marshall Steam Station - Terrell, NC

		Aquatic EPCs[a, b]	
COPC	**CASRN**	**Sediment EPC Used in Risk Assessment[c] (mg/kg)**	**Surface Water EPC Used in Risk Assessment (mg/L)**
Aluminum	7429-90-5		0.2639
Barium	7440-39-3	128	
Chromium, Total	7440-47-3	45.6	
Cobalt	7440-48-4		0.006483
Copper	7440-50-8		0.002696
Manganese	7439-96-5		0.501
Selenium	7782-49-2	4	

NOTES:
COPC - Constituent of Potential Concern
CASRN - Chemical Abstracts Service Registration Number
EPC - Exposure Point Concentration

[a] EPCs for surface water are based on 95% UCLs. EPCs for sediment are based on maximum values.

[b] Surface water and sediment EPCs are used to evaluate aquatic receptors.

[c] Analysis of solids (i.e., soil and sediment) was reported as dry weight.

Table 5
Calculation of Average Daily Doses for Mallard Duck
Ecological Exposure Area 1
Baseline Ecological Risk Assessment
Duke Energy
Marshall Steam Station - Terrell, NC

									AVERAGE DAILY DOSE VIA:																
									WATER		PLANTS/VEGETATION				INVERTEBRATES			SOIL							
	EPC_w	EPC_s			EPC_p			EPC_i	NIR_w	ADD_W	P_f	NIR_f	NIR_p	ADD_p	A_f	NIR_a	ADD_a	S_f	NIR_s	ADD_s	BF	ADD_t	SUF	AUF	ADD_{tot}
Analyte	COPEC in Water (mg/L)	COPEC in Solid (mg/kg)	Slope, or Plant Uptake (BAF)	Intercept	Estimated[1] Concentration in Vegetation (mg/kg dry)	Slope, or Invertebrate Uptake (BAF)	Intercept	Estimated[2] Concentration in Invertebrates (mg/kg dry)	Water Ingestion Rate (L/kg BW/day)	Unadjusted Average Daily Dose Water (mg/kg/day)	Fraction Diet Plant Matter (percent)	Food Ingestion Rate, Wet (kg/kg BW/day)	Plant Ingestion Rate, Dry (kg/kg BW/day)	Unadjusted Average Daily Dose Plant (mg/kg/day)	Fraction Diet Invertebrates (percent)	Invertebrates Ingestion Rate (kg dry/kg BW/day)	Unadjusted Average Daily Dose Invertebrates (mg/kg/day)	Fraction Diet Soil (percent)	Soil Ingestion3 Rate (kg dry/kg BW/day)	Unadjusted Average Daily Dose Soil (mg/kg/day)	Bioavailability[3] (percent)	Omnivore Intake (mg/kg/day)	Seasonal Use Factor (unitless)	Area Use Factor (Exposure Area/Home Range)	Adjusted Total Omnivore Average Daily Dose (mg/kg/day)
Aluminum	0.2639		0.0008		0	1		0	0.057	0.015	48%	0.068	0.0049	0	48%	0.007	0	3.3%	0.00029	0	100%	0.02	1	0.034	0.000505
Barium		128	0.03		3.84	1		128	0.057	0	48%	0.068	0.0049	0.018918	48%	0.007	0.9249	3.3%	0.00029	0.03734	100%	0.9811	1	0.034	0.032930
Chromium, Total		45.6	0.0015		0.0684	0.1		4.56	0.057	0	48%	0.068	0.0049	0.000337	48%	0.007	0.0329	3.3%	0.00029	0.01330	100%	0.04659	1	0.034	0.001564
Cobalt	0.0065		0.004		0	1		0	0.057	0.0004	48%	0.068	0.0049	0	48%	0.007	0	3.3%	0.00029	0	100%	0.0004	1	0.034	0.000012
Copper	0.0027								0.057	0.00015	48%	0.068	0.0049	0	48%	0.007	0	3.3%	0.00029	0	100%	0.0002	1	0.034	0.000005
Manganese	0.501								0.057	0.029	48%	0.068	0.0049	0	48%	0.007	0	3.3%	0.00029	0	100%	0.03	1	0.034	0.000958
Selenium		4.1	1.104	-0.678	2.4102	0.7		2.87	0.057	0	48%	0.068	0.0049	0.011874	48%	0.007	0.0207	3.3%	0.00029	0.00120	100%	0.033808081	1	0.034	0.001135

NOTES:

EPC - Exposure Point Concentration
NIR - Normalized Ingestion Rate
ADD - Average Daily Dose
BF - Bioavailability Factor
BAF - Bioaccumulation Factor
BCF - Bioconcentration Factor
SUF - Seasonal Use Factor
AUF - Area Use Factor

[1] Bechtel Jacobs Company 1998a; Baes et al. 1984 (Mo); Environmental Restoration Division - Manual ERD-AG-003 1999; default value of 1 is used for constituents for which a BAF could not be found.

[2] Bechtel Jacobs Company 1998b, Table 2, median BAFs for sediment to benthic invertebrates for As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn; Sample et al. 1998b (earthworms) for Mn; default value of 1 is used for constituents for which a BAF could not be found.

[3] Bioavailability is set to a default of 100% to be conservative and protective of ecological receptors.

Table 6
Calculation of Average Daily Doses for Great Blue Heron
Ecological Exposure Area 1
Baseline Ecological Risk Assessment
Duke Energy
Marshall Steam Station - Terrell, NC

								AVERAGE DAILY DOSE VIA:													
								WATER		FISH				INVERTEBRATES							
	EPC_w	EPC_s		EPC_{fish}			EPC_i	NIR_w	ADD_w	A_f	NIR_f	NIR_a	ADD_a	A_f	NIR_a	ADD_a	BF	ADD_t	SUF	AUF	ADD_{tot}
Analyte	COPEC in Water (mg/L)	COPEC in Solid (mg/kg)	Fish Uptake (BCF)	Estimated[1] Concentration in Fish (mg/kg)	Slope, or Invertebrate Uptake (BAF)	Intercept	Estimated[2] Concentration in Invertebrates (mg/kg dry)	Water Ingestion Rate (L/kg BW/day)	Unadjusted Average Daily Dose Water (mg/kg/day)	Fraction Diet Animal Matter (percent)	Food Ingestion Rate, Wet (kg/kg BW/day)	Fish Ingestion Rate (kg/kg BW/day)	Unadjusted Average Daily Dose (mg/kg/day)	Fraction Diet Invertebrates (percent)	Invertebrates Ingestion Rate (kg dry/kg BW/day)	Unadjusted Average Daily Dose Invertebrates (mg/kg/day)	Bioavailability[3] (percent)	Piscivore Intake (mg/kg/day)	Seasonal Use Factor (unitless)	Area Use Factor (Exposure Area/Home Range)	Adjusted Total Piscivore Average Daily Dose (mg/kg/day)
Aluminum	0.2639		0.1	0.03	1		0.26	0.045	0.012	90%	0.18	0.162	0.004	10%	0.004	0.001	100%	0.02	1	0.064	0.001
Barium		128	4	0	1		0	0.045	0	90%	0.18	0.162	0	10%	0.004	0	100%	0	1	0.064	0
Chromium, Total		45.6	200	0	0.1		0	0.045	0	90%	0.18	0.162	0	10%	0.004	0	100%	0	1	0.064	0
Cobalt	0.006483		300	1.94	1		0.01	0.045	0.0003	90%	0.18	0.162	0.315	10%	0.004	0.00002	100%	0.32	1	0.064	0.020
Copper	0.002696		50	0.13	1.556		0.004	0.045	0.0001	90%	0.18	0.162	0.022	10%	0.004	0.00002	100%	0.022	1	0.064	0.001
Manganese	0.501		400	200.40	0.682	-0.809	0.28	0.045	0.023	90%	0.18	0.162	32.465	10%	0.004	0.001	100%	32.49	1	0.064	2.090
Selenium		4.1	8	0.00	0.7		0	0.045	0.000	90%	0.18	0.0405	0.000	10%	0.004	0.0000	100%	0.000	1	0.064	0.000

NOTES:

EPC - Exposure Point Concentration
NIR - Normalized Ingestion Rate
ADD - Average Daily Dose
BF - Bioavailability Factor
BAF - Bioaccumulation Factor
BCF - Bioconcentration Factor
SUF - Seasonal Use Factor
AUF - Area Use Factor

[1] Al (Voigt et al. 2015), mean of fish tissue BAFs; Cu (USEPA 1980); Environmental Restoration Division - Manual ERD-AG-003 1999.

[2] Bechtel Jacobs Company 1998b, Table 2, median BAFs for sediment to benthic invertebrates for As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn; Sample et al. 1998b (earthworms) for Mn; default value of 1 is used for constituents for which a BAF could not be found.

[3] Bioavailability is set to a default of 100% to be conservative and protective of ecological receptors.

Table 7
Calculation of Average Daily Doses for Bald Eagle
Ecological Exposure Area 1
Baseline Ecological Risk Assessment
Duke Energy
Marshall Steam Station - Terrell, NC

								AVERAGE DAILY DOSE VIA:															
								WATER		VERTEBRATE PREY						SOIL							
	EPC_w	EPC_s			EPC_{mb}		EPC_{fish}	NIR_w	ADD_w	P_{fish}	P_{mb}	NIR_f	NIR_{fish}	NIR_{mb}	ADD_a	S_f	NIR_s	ADD_s	BF	ADD_t	SUF	AUF	ADD_{TOT}
Analyte	**COPEC in Water (mg/L)**	**COPEC in Solid (mg/kg)**	**Slope, or Vertebrate Uptake (BAF)**	**Intercept**	**Estimated[1] Concentration in Mammals and Birds (mg/kg)**	**Fish Uptake (BCF)**	**Estimated[2] Concentration in Fish (mg/kg)**	**Water Ingestion Rate (L/kg BW/day)**	**Unadjusted Average Daily Dose Water (mg/kg/day)**	**Fraction of Diet Fish (percent)**	**Fraction of Diet Mammal + Birds (percent)**	**Food Ingestion Rate, Wet (kg/kg BW/day)**	**Fish Ingestion Rate (kg/kg BW/Day**	**Mammal/Bird Ingestion Rate (kg/kg BW/day)**	**Unadjusted Average Daily Dose (mg/kg/day)**	**Fraction Diet Soil (percent)**	**Soil Ingestion Rate (kg dry/kg BW/day)**	**Unadjusted Average Daily Dose Soil (mg/kg/day)**	**Bioavailability[3] (percent)**	**Carnivore Intake (mg/kg/day)**	**Seasonal Use Factor**	**Area Use Factor (Exposure Area/Home Range)**	**Adjusted Total Carnivore Average Daily Dose (mg/kg/day)**
Aluminum	0.2639		1		0	0.1	0.02639	0.058	0.02	58%	42%	0.12	0.0696	0.0498	0.002	0.5%	0.0006	0	100%	0.02	1	0.00664	0.0001
Barium		128	0.7	-1.412	7.27	4	0	0.058	0	58%	42%	0.12	0.0696	0.0498	0.36	0.5%	0.0006	0.00998	100%	0.3723	1	0.00664	0.002472
Chromium, Total		45.6	0.1444	-1.4599	0.40	200	0	0.058	0	58%	42%	0.12	0.0696	0.0498	0.02	0.5%	0.0006	0.00356	100%	0.02364	1	0.00664	0.00015693
Cobalt	0.006483					300	1.9449	0.058	0.0004	58%	42%	0.12	0.0696	0.0498	0.14	0.5%	0.0006	0	100%	0.136	1	0.00664	0.000901
Copper	0.002696					50	0.1348	0.058	0.0002	58%	42%	0.12	0.0696	0.0498	0.01	0.5%	0.0006	0	100%	0.01	1	0.00664	0.000
Manganese	0.501		0.004		0	400	200.4	0.058	0.03	58%	42%	0.12	0.0696	0.0498	13.95	0.5%	0.0006	0	100%	13.98	1	0.00664	0.093
Selenium		4.1	0.3764	-0.4158	1.12	8	0	0.058	0.00	58%	42%	0.12	0.0696	0.0498	0.06	0.5%	0.0006	0.00032	100%	0.06	1	0.00664	0.0003732

NOTES:

EPC - Exposure Point Concentration
NIR - Normalized Ingestion Rate
ADD - Average Daily Dose
BF - Bioavailability Factor
BAF - Bioaccumulation Factor
BCF - Bioconcentration Factor
SUF - Seasonal Use Factor
AUF - Area Use Factor

[1] Sample et al. 1998a; EPA 2007 EcoSSLs, Att 4-1, Table 4a
[2] Al (Voigt et al. 2015), mean of fish tissue BAFs; Cu (USEPA 1980); Environmental Restoration Division - Manual ERD-AG-003 1999.
[3] Bioavailability is set to a default of 100% to be conservative and protective of ecological receptors.

Table 8
Calculation of Average Daily Doses for Muskrat
Ecological Exposure Area 1
Baseline Ecological Risk Assessment
Duke Energy
Marshall Steam Station - Terrell, NC

						AVERAGE DAILY DOSE VIA:													
						WATER		PLANTS / VEGETATION				SOIL							
	EPC_w	EPC_s			EPC_p	NIR_W	ADD_w	P_f	NIR_f	NIR_p	ADD_p	S_f	NIR_s	ADD_s	BF	ADD_t	SUF	AUF	ADD_{tot}
Analyte	COPEC in Water (mg/L)	COPEC in Solid (mg/kg)	Slope, or Plant Uptake (BAF)	Intercept	Estimated[1] Concentration in Vegetation (mg/kg dry)	Water Ingestion Rate (L/kg BW/day)	Unadjusted Average Daily Dose Water (mg/kg/day)	Fraction Diet Plant Matter (percent)	Food Ingestion Rate, Wet (kg/kg BW/day)	Plant Ingestion Rate, Dry (kg/kg/day)	Unadjusted Average Daily Dose Plant (mg/kg/day)	Fraction Diet Soil (percent)	Soil Ingestion Rate (kg dry/kg BW/day)	Unadjusted Average Daily Dose Soil (mg/kg/day)	Bioavailability[2] (percent)	Herbivore Intake (mg/kg/day)	Seasonal Use Factor (unitless)	Area Use Factor (Exposure Area/Home Range)	Adjusted Total Herbivore Average Daily Dose (mg/kg/day)
Aluminum	0.2639		0.0008		0	0.97	0.26	99%	0.3	0.045	0	1%	0.000273	0	100%	0.26	1	1	0.26
Barium		128	0.03		3.8400	0.97	0	99%	0.3	0.045	0.17159	1%	0.000273	0.00454	100%	0.18	1	1	0.18
Chromium, Total		45.6	0.0015		0.0684	0.97	0	99%	0.3	0.045	0.00306	1%	0.000273	0.00162	100%	0.005	1	1	0.005
Cobalt	0.006483		0.004		0	0.97	0.01	99%	0.3	0.045	0	1%	0.000273	0	100%	0.01	1	1	0.01
Copper	0.002696					0.97	0.003	99%	0.3	0.045	0	1%	0.000273	0	100%	0.003	1	1	0.003
Manganese	0.501		0.05		0	0.97	0.49	99%	0.3	0.045	0	1%	0.000273	0	100%	0.49	1	1	0.49
Selenium		4.1	1.104	-0.678	2.4102	0.97	0.00	99%	0.3	0.045	0.10770	1%	0.000273	0.00015	100%	0.11	1	1	0.11

NOTES:

EPC - Exposure Point Concentration
NIR - Normalized Ingestion Rate
ADD - Average Daily Dose
BF - Bioavailability Factor
BAF - Bioaccumulation Factor
BCF - Bioconcentration Factor
SUF - Seasonal Use Factor
AUF - Area Use Factor

[1] Bechtel Jacobs Company 1998a; Baes et al. 1984 (Mo); Environmental Restoration Division - Manual ERD-AG-003 1999; default value of 1 is used for constituents for which a BAF could not be found.

[2] Bioavailability is set to a default of 100% to be conservative and protective of ecological receptors.

Table 9
Calculation of Average Daily Doses for River Otter
Ecological Exposure Area 1
Baseline Ecological Risk Assessment
Duke Energy
Marshall Steam Station - Terrell, NC

					AVERAGE DAILY DOSE VIA:										
					DRINKING WATER		FISH								
	EPC_w	EPC_s		EPC_{PREY}	NIR_w	ADD_w	P_f	NIR_f	NIR_a	ADD_a	BF	ADD_t	SUF	AUF	ADD_{tot}
Analyte	COPEC in Water (mg/L)	COPEC in Solid (mg/kg)	Fish Uptake (BCF)	Estimated[1] Concentration in Fish (mg/kg)	Water Ingestion Rate (L/kg BW/day)	Unadjusted Average Daily Dose Water (mg/kg/day)	Fraction Diet Animal Matter (percent)	Food Ingestion Rate, Wet (kg/kg BW/day)	Fish Ingestion Rate (kg/kg BW/day)	Unadjusted Average Daily Dose (mg/kg/day)	Bioavailability[2] (percent)	Piscivore Intake (mg/kg/day)	Seasonal Use Factor (unitless)	Area Use Factor (Exposure Area/Home Range)	Adjusted Total Piscivore Average Daily Dose (mg/kg/day)
Aluminum	0.2639		0.1	0.03	0.081	0.021	100%	0.19	0.19	0.005	100%	0.026	1	0.042	0.001107
Barium		128	4	0	0.081	0	100%	0.19	0.19	0	100%	0	1	0.042	0
Chromium, Total		45.6	200	0	0.081	0	100%	0.19	0.19	0	100%	0	1	0.042	0
Cobalt	0.006483		300	1.94	0.081	0.001	100%	0.19	0.19	0.37	100%	0.37	1	0.042	0.015525
Copper	0.002696		50	0.13	0.081	0.0002	100%	0.19	0.19	0.026	100%	0.026	1	0.042	0.001084
Manganese	0.501		400	200.4	0.081	0.041	100%	0.19	0.19	38.08	100%	38.117	1	0.042	1.59914
Selenium		4.1	8	0.00	0.081	0.000	100%	0.19	0.19	0.000	100%	0.000	1	0.042	0.000000

NOTES:

EPC - Exposure Point Concentration
NIR - Normalized Ingestion Rate
ADD - Average Daily Dose
BF - Bioavailability Factor
BAF - Bioaccumulation Factor
BCF - Bioconcentration Factor
SUF - Seasonal Use Factor
AUF - Area Use Factor

[1] Al (Voigt et al. 2015), mean of fish tissue BAFs; Cu (USEPA 1980); Environmental Restoration Division - Manual ERD-AG-003 1999.
[2] Bioavailability is set to a default of 100% to be conservative and protective of ecological receptors.

Table 10
Hazard Quotients for COPCs - Aquatic Receptors
Ecological Exposure Area 1
Baseline Ecological Risk Assessment
Duke Energy
Marshall Steam Station - Terrell, NC

Analyte	Wildlife Receptor Hazard Quotient Estimated using the 'No Observed Adverse Effects Level'				
	Aquatic				
	Mallard Duck	Great Blue Heron	Bald Eagle[1]	Muskrat	River Otter
Aluminum	4.59E-06	1.00E-05	6.04E-05	1.33E-01	5.74E-04
Barium	1.58E-03		3.19E-04	3.40E-03	
Chromium, Total	1.56E-03		6.64E-03	1.71E-06	
Cobalt	1.63E-06	2.67E-03	8.72E-04	8.58E-04	2.12E-03
Copper	1.27E-06	3.49E-04	1.64E-03	4.67E-04	1.94E-04
Manganese	5.35E-06	1.17E-02	3.71E-05	9.44E-03	3.11E-02

Analyte	Wildlife Receptor Hazard Quotient Estimated using the 'Lowest Observed Adverse Effects Level'				
	Aquatic				
	Mallard Duck	Great Blue Heron	Bald Eagle[1]	Muskrat	River Otter
Aluminum	4.59E-07	1.00E-06	6.04E-06	1.33E-02	5.74E-05
Barium	7.90E-04		1.59E-04	2.35E-03	
Chromium, Total	3.13E-04		1.33E-03	1.71E-07	
Cobalt	1.59E-06	2.60E-03	8.51E-04	5.77E-04	1.42E-03
Copper	4.26E-07	1.17E-04	5.49E-04	2.80E-04	1.16E-04
Manganese	2.75E-06	6.00E-03	1.91E-05	6.84E-03	2.25E-02

NOTES:

Hazard Quotients greater than or equal to 1 are highlighted in gray and in boldface.

NM - Not measured due to lack of a Toxicity Reference Value

[1] The bald eagle was added to this risk assessment model because the species is federally protected and represents a raptor that preys upon fish, primarily, while the Red-Tailed Hawk primarily preys upon small terrestrial vertebrates (e.g., rodents, snakes, etc.). Hazard quotient calculations for the Bald Eagle include hypothetical consumption of fish that inhabit adjacent surface water areas in addition to terrestrial vertebrates that inhabit adjacent areas.

Appendix C

Exposure Modeling and Human Health Risk Assessment for Diesel Emissions

Air Dispersion Modeling for Marshall Ash Basin Closure

I used screening models to evaluate the potential for both cancer and non-cancer risks from diesel exhaust emissions due to increased trucking operations related to the closure of the coal ash basin at the Duke Energy Marshall Steam Station (MSS). The calculated cancer and non-cancer risks are associated with increased diesel trucking activity near residential properties that lie along transportation corridors near MSS. Modelling was conducted for the cap in place (CIP) closure option, the excavation closure option, and the hybrid option. Details of these closure options are provided in the main body of the report.

Emission rates for the fleet of diesel trucks operating as part of closure activities were calculated based on truck activity and emission factors representative of the region from the U.S. Environmental Protection Agency (EPA) Mobile Vehicle Emissions Simulator (MOVES). I estimated airborne concentrations of emitted pollutants using the EPA model AERMOD for atmospheric dispersion and transport. AERMOD is a Gaussian plume model that accounts for the impacts of meteorology and land characteristics on airborne pollutants. Together these tools allowed for the estimation of airborne concentrations of diesel particulate matter (DPM) emitted from passing trucks and subsequent calculation of potential non-cancer health impacts (hazard index [HI]) and cancer risk estimates (excess lifetime cancer risk [ELCR]).

The following sections detail the data and models used in this evaluation, including the meteorological data, trucking operations, emissions calculations, and dispersion modeling. I also include additional discussion of the results and associated uncertainties.

Methodology

Meteorological Data

AERMOD-ready five-year[1] meteorological data sets of hourly surface meteorological data for the years 2012–2016 were generated from the National Weather Service (NWS) Automated Surface Observing System (ASOS) station at the Statesville Regional Airport (KSVH) in Statesville, North Carolina.[2] The Statesville Regional Airport is located approximately 18 km from Duke Energy's MSS. I judged this station to be representative of the meteorology in the region of MSS. Surface parameters applied to the modeling study included wind speed and direction, temperature, pressure, relative humidity, and cloud cover. Twice daily rawinsonde[3] observations of upper air winds and temperatures were taken from Piedmont Triad International Airport (KGSO), which at 107 km from MSS is the closest upper air sounding site.

The meteorological data were processed using AERMET (v16216) with default options.[4] AERSURFACE[5] was used to define the land-use characteristics in the region around the surface observational site (i.e., Statesville Regional Airport). The surface characteristics, which are important when calculating the level of atmospheric dispersion in meteorological modeling, include surface roughness, albedo,[6] and Bowen ratio.[7]

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1 Use of five years of meteorological data is standard in regulatory application of AERMOD (EPA Guideline on Air Quality Models, Section 8.3.1, 2005).

2 Integrated surface hourly weather observations are available at ftp://ftp.ncdc.noaa.gov/pub/data/noaa/.

3 A rawinsonde is a device typically carried by weather balloons that collects meteorological and atmospheric data, especially regarding winds.

4 AERMET is an EPA program that will read standard recorded meteorological observations, calculate boundary layer meteorological parameters, and output the data in a format readable by the AERMOD model (U.S. EPA 2016).

5 AERSURFACE is the EPA model used to calculate average land-use characteristics. It can read standard databases and calculate the average values of surface roughness, albedo, and Bowen ratios, consistent with EPA recommended methods.

6 Albedo is the ratio of reflected flux density to incident flux density. It indicates how much incoming energy is absorbed by the land surface. Light surfaces (such as snow) will reflect higher levels of incoming energy.

7 Bowen ratio is the ratio of sensible to latent heat fluxes from the earth's surface up into the air. Lower Bowen ratio indicates greater water content in the land surface.

Trucking Operations

Diesel emissions estimates from trucking are based on the number of trucks passing a given receptor location along transportation corridors used during ash basin closure. The total number of truckloads required for transporting ash, earthen fill, and geosynthetic materials under the MSS closure options were projected by Duke Energy (2018b). These truckloads equate to 41,164 total truck passes for the CIP options, 58,605 total truck passes for the excavation option, and 40,919 truck passes for the hybrid option. Additional loads of onsite ash-hauling trucks were not included. I included only loads hauling earthen fill, geosynthetic materials, and other materials in transportation emissions estimates for all options because trucks hauling ash in the excavation and hybrid closure options do not leave MSS. Trucks hauling earthen fill are assumed to travel 11 miles one way from the site, and trucks hauling geosynthetic material are assumed to travel from Georgetown, South Carolina. Air modeling is conducted for a receptor along the transportation route within the 11-mile radius traveled both by trucks hauling earthen fill and by trucks hauling geosynthetic material. Trucks are assumed to travel in round trips, so the number of material loads was doubled to represent the number of truck passes.

AERMOD

The AERMOD modeling system (U.S. EPA 2016) is a steady-state plume model that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of surface and elevated sources. EPA's "Guideline on Air Quality Models" (U.S. EPA 2016) identifies AERMOD as the preferred refined dispersion modeling technique for receptors within 50 km of a modeled source.

The latest version of AERMOD (v16216r) was used with default options to conduct the modeling.

Modeled Source and Receptors

AERMOD was configured to simulate an approximately 1-km stretch of road. This road segment was assumed representative of any segment along the proposed transportation corridors. The road emission source was modeled as a continuous distribution of emission along the road due to the passage of multiple trucks. In the cross-road direction, the emissions drop off based on a normal (or Gaussian) distribution. The road emissions were represented using a line of closely spaced volume sources running down the center of the road. Volume sources define the initial pollutant distribution based on an initial release height and the standard deviation of the normal distribution in both the vertical and horizontal directions (sigma-y and sigma-z). The appropriate values for the release height and standard deviations were calculated based on guidance in EPA’s Haul Road Working Group Final Report (U.S. EPA 2010).

Transport and dispersion of pollutants away from the road segment may be sensitive to the predominant wind directions at the site and the orientation of the road compared to those predominant wind directions. To fully evaluate the impacts of any road segment, four orientations of the road were considered. Modeled orientations included roads running north/south, east/west, northeast/southwest, and northwest/southeast. For each modeled road orientation, receptors were included on both sides of the road to represent impacts at distances between 10 and 150 m from the edge of the road. The representative road segments and sampling receptor locations are shown in Figure C-1.

AERMOD was run for the five-year period (2012–2016) defined by the meteorological data. The resulting five-year average dispersion factors were assumed representative of long-term average dispersion of truck roadway emissions along roads in this region.

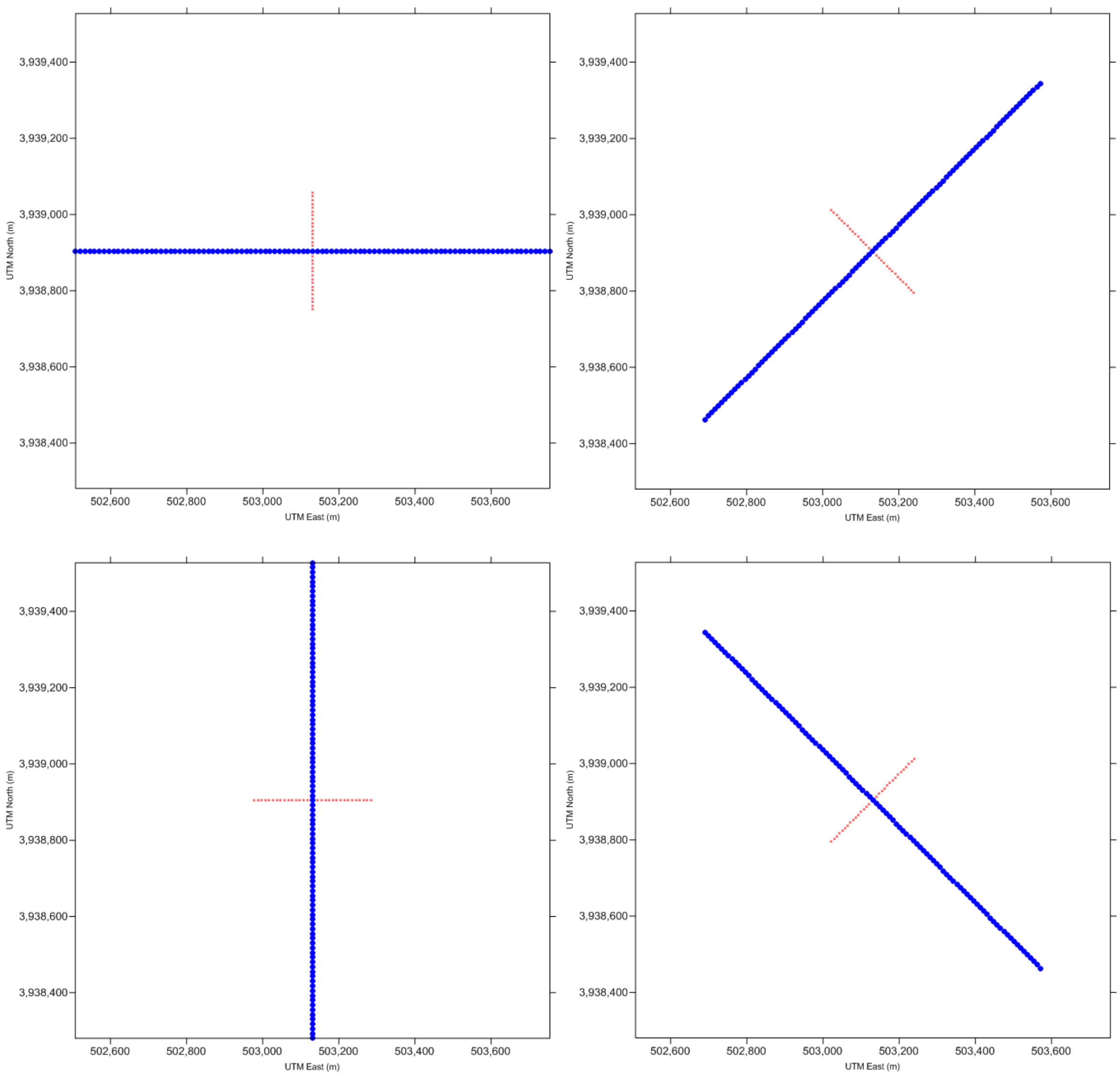

Figure C-1. Location of road sources (blue) and sampling receptors (red) for each of 4 road orientations

Source Emission Rates

Emission rates for mobile sources are typically calculated based on a combination of emission factors and activity rates. The emission factors define the amount of pollutant emitted per unit distance traveled (grams of pollutant per kilometer traveled), and the activity rates define how much activity occurs (i.e., the number of kilometers driven by the vehicles). Emission factors will be specific to the type of vehicle being considered, the model year, the age of the vehicle, and the local climate. For this evaluation, EPA's MOVES model was used to define fleet average emission factors for various years between 2018 and 2050 (2050 is the last year simulated by MOVES) (U.S. EPA 2015). The 2050 emission factors were retained for all years after 2050. These emission factors are specific to North Carolina and have been selected to represent large, single unit diesel trucks.

Tailpipe emissions from diesel trucks (DPM) are the subset of PM_{10} of particular interest when evaluating the cancer and non-cancer risk estimates in this analysis. The DPM emission factors generated by MOVES were multiplied by the expected number of trucks under each of the considered closure options to calculate emission rates for each option.

For the cancer risk analysis, emissions were calculated as an average over the regulatory default 70-year residential exposure duration. If the truck activity for a closure option occurs over a shorter period, the duration of the truck activity exposure is factored into the 70-year averaging time (OEHHA 2015). These average emission rates were multiplied by the dispersion factors calculated by AERMOD to predict airborne concentrations. The resulting values were then multiplied by the cancer unit risk factor[8] to quantify cancer risk.

[8] A "reasonable estimate" for the inhalation unit risk of 3.0×10^{-4} $(\mu g/m^3)^{-1}$ was applied based on California guidelines (OEHHA 2015).

For the non-cancer analysis, airborne concentrations of DPM were calculated and compared to the non-cancer risk threshold of 5 µg/m^3.[9] In this case, the average concentrations are not tied to a 70-year period and are calculated over the period of operation for each closure option.

[9] North Carolina defers to the EPA's chronic non-cancer reference concentration (RfC) for DPM of 5 µg/m^3 based on diesel engine exhaust to estimate risk from diesel emissions (Integrated Risk Information System [IRIS]. U.S. EPA. Diesel engine exhaust).

Uncertainties

A number of uncertainties should be considered when evaluating the modeled results. First, air dispersion modeling is a mathematical calculation of pollutant transport and dispersion and may differ from real world conditions. Typically, for regulatory applications, air dispersion models are expected to predict concentrations within a factor of two (40 CFR Part 51). Longer averaging periods, such as those used in this study, would often have lower uncertainties as compared with shorter average periods such as 1-hour or 24-hour averages.

The calculation of emission factors is meant to represent fleet average characteristics. The fleet of trucks used at this specific site may differ from the average values included in MOVES. This may result in higher or lower actual emission rates. Additionally, MOVES includes predictions of future year emission factors based on typical patterns of vehicle turnover and any regulations scheduled to be implemented in future years. Not all future regulations are presently known and future conditions may vary from these estimates.

For the non-cancer risk, an evaluation of the average concentrations was calculated over the actual period of activity, which varies between closure options. For this portion of the evaluation, there was no accounting for how long the emissions were present. The non-cancer risk value is generally considered applicable over a period of approximately eight years. For activities that occur for less than eight years, comparison with this risk value may overstate the actual risk. Correspondingly, for activities that run significantly longer than eight years, there may be sub-periods with higher average concentrations and higher associated non-cancer risk.

Results

Worst-case impacts were calculated for each distance from the modeled road. The worst-case result represents the highest value calculated over the four road orientations. This may not be the same orientation for all distances. For example, a road that runs northeast/southwest aligns with the predominant wind direction. This results in higher concentrations for receptors close to the road. For receptors farther away from the edge of the road, the worst case occurs for a northwest/southeast road where winds are perpendicular to the road. Worst-case results are reported in Table 9-2 of the main report. The following sections include results for all road orientations and distances from both sides of the road.

Model-estimated cancer risk

ELCR results for the four road orientations and both sides of the road are provided in Table C-1.

Table C-1. ELCR estimates from DPM exposure due to trucking operations associated with closure of MSS under a CIP closure, an excavation closure, and a hybrid closure. Results for each road orientation and distances from both sides of the road (ELCR columns per orientation).

	E-W Run		NE-SW Run		N-S Run		NW-SE Run	
CIP								
10 m	3.7E-09	4.3E-09	4.6E-09	4.5E-09	4.1E-09	3.8E-09	3.4E-09	3.5E-09
20 m	3.3E-09	3.9E-09	3.9E-09	3.8E-09	3.8E-09	3.4E-09	3.4E-09	3.5E-09
30 m	2.6E-09	3.1E-09	3.1E-09	2.9E-09	3.1E-09	2.6E-09	2.7E-09	2.8E-09
40 m	2.1E-09	2.5E-09	2.5E-09	2.3E-09	2.5E-09	2.1E-09	2.2E-09	2.3E-09
50 m	1.8E-09	2.1E-09	2.1E-09	1.9E-09	2.2E-09	1.8E-09	1.9E-09	2.0E-09
60 m	1.5E-09	1.8E-09	1.8E-09	1.7E-09	1.9E-09	1.5E-09	1.6E-09	1.7E-09
70 m	1.3E-09	1.6E-09	1.5E-09	1.4E-09	1.7E-09	1.3E-09	1.4E-09	1.5E-09
80 m	1.2E-09	1.4E-09	1.4E-09	1.3E-09	1.5E-09	1.2E-09	1.3E-09	1.3E-09
90 m	1.1E-09	1.3E-09	1.2E-09	1.1E-09	1.3E-09	1.0E-09	1.2E-09	1.2E-09
100 m	9.5E-10	1.2E-09	1.1E-09	1.0E-09	1.2E-09	9.5E-10	1.0E-09	1.1E-09
110 m	8.7E-10	1.1E-09	1.0E-09	9.1E-10	1.1E-09	8.6E-10	9.6E-10	1.0E-09
120 m	8.0E-10	9.9E-10	9.3E-10	8.3E-10	1.0E-09	7.9E-10	8.9E-10	9.4E-10
130 m	7.4E-10	9.2E-10	8.6E-10	7.6E-10	9.5E-10	7.3E-10	8.3E-10	8.7E-10
140 m	6.8E-10	8.6E-10	7.9E-10	7.0E-10	8.9E-10	6.7E-10	7.7E-10	8.1E-10
150 m	6.4E-10	8.0E-10	7.4E-10	6.4E-10	8.3E-10	6.3E-10	7.2E-10	7.6E-10
Excavation								
10 m	3.0E-09	3.5E-09	3.8E-09	3.7E-09	3.4E-09	3.1E-09	2.8E-09	2.9E-09
20 m	2.7E-09	3.2E-09	3.2E-09	3.1E-09	3.2E-09	2.8E-09	2.8E-09	2.9E-09
30 m	2.1E-09	2.5E-09	2.5E-09	2.4E-09	2.5E-09	2.2E-09	2.2E-09	2.3E-09
40 m	1.7E-09	2.1E-09	2.0E-09	1.9E-09	2.1E-09	1.8E-09	1.8E-09	1.9E-09
50 m	1.5E-09	1.7E-09	1.7E-09	1.6E-09	1.8E-09	1.5E-09	1.5E-09	1.6E-09
60 m	1.3E-09	1.5E-09	1.5E-09	1.4E-09	1.6E-09	1.3E-09	1.3E-09	1.4E-09
70 m	1.1E-09	1.3E-09	1.3E-09	1.2E-09	1.4E-09	1.1E-09	1.2E-09	1.2E-09
80 m	9.7E-10	1.2E-09	1.1E-09	1.0E-09	1.2E-09	9.6E-10	1.0E-09	1.1E-09
90 m	8.7E-10	1.1E-09	1.0E-09	9.2E-10	1.1E-09	8.6E-10	9.5E-10	1.0E-09
100 m	7.8E-10	9.7E-10	9.1E-10	8.3E-10	1.0E-09	7.8E-10	8.6E-10	9.1E-10
110 m	7.1E-10	8.9E-10	8.3E-10	7.5E-10	9.2E-10	7.1E-10	7.9E-10	8.4E-10
120 m	6.6E-10	8.2E-10	7.6E-10	6.8E-10	8.5E-10	6.5E-10	7.3E-10	7.7E-10
130 m	6.1E-10	7.6E-10	7.0E-10	6.2E-10	7.8E-10	6.0E-10	6.8E-10	7.2E-10
140 m	5.6E-10	7.1E-10	6.5E-10	5.7E-10	7.3E-10	5.5E-10	6.3E-10	6.7E-10
150 m	5.2E-10	6.6E-10	6.1E-10	5.3E-10	6.8E-10	5.1E-10	5.9E-10	6.3E-10
Hybrid								
10 m	3.3E-09	3.8E-09	4.1E-09	4.1E-09	3.7E-09	3.4E-09	3.0E-09	3.2E-09
20 m	3.0E-09	3.5E-09	3.5E-09	3.4E-09	3.4E-09	3.1E-09	3.0E-09	3.1E-09
30 m	2.3E-09	2.8E-09	2.7E-09	2.6E-09	2.8E-09	2.4E-09	2.4E-09	2.5E-09
40 m	1.9E-09	2.3E-09	2.2E-09	2.1E-09	2.3E-09	1.9E-09	2.0E-09	2.1E-09
50 m	1.6E-09	1.9E-09	1.9E-09	1.7E-09	1.9E-09	1.6E-09	1.7E-09	1.8E-09
60 m	1.4E-09	1.6E-09	1.6E-09	1.5E-09	1.7E-09	1.4E-09	1.5E-09	1.5E-09
70 m	1.2E-09	1.4E-09	1.4E-09	1.3E-09	1.5E-09	1.2E-09	1.3E-09	1.3E-09
80 m	1.1E-09	1.3E-09	1.2E-09	1.1E-09	1.3E-09	1.1E-09	1.1E-09	1.2E-09
90 m	9.4E-10	1.2E-09	1.1E-09	1.0E-09	1.2E-09	9.4E-10	1.0E-09	1.1E-09
100 m	8.5E-10	1.1E-09	9.9E-10	9.0E-10	1.1E-09	8.5E-10	9.4E-10	9.9E-10
110 m	7.8E-10	9.7E-10	9.1E-10	8.2E-10	1.0E-09	7.7E-10	8.6E-10	9.1E-10
120 m	7.1E-10	8.9E-10	8.3E-10	7.4E-10	9.2E-10	7.1E-10	8.0E-10	8.4E-10
130 m	6.6E-10	8.3E-10	7.7E-10	6.8E-10	8.5E-10	6.5E-10	7.4E-10	7.8E-10
140 m	6.1E-10	7.7E-10	7.1E-10	6.3E-10	7.9E-10	6.0E-10	6.9E-10	7.3E-10
150 m	5.7E-10	7.2E-10	6.6E-10	5.8E-10	7.4E-10	5.6E-10	6.5E-10	6.8E-10

Model-estimated non-cancer risk

HI results for the four road orientations and both sides of the road are provided in Table C-2.

Table C-2. HI estimates from DPM exposure due to trucking operations associated with closure of MSS under a CIP closure, an excavation closure, and a hybrid closure. Results for each road orientation and distances from both sides of the road (HI columns per orientation).

	E-W Run			NE-SW Run			N-S Run			NW-SE Run	
CIP											
10 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
20 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
30 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
40 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
50 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
60 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
70 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
80 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
90 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
100 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
110 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
120 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
130 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
140 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
150 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
Excavation											
10 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
20 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
30 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
40 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
50 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
60 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
70 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
80 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
90 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
100 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
110 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
120 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
130 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
140 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
150 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
Hybrid											
10 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
20 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
30 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
40 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
50 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
60 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
70 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
80 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
90 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
100 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
110 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
120 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
130 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
140 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
150 m	0.0000	0.0000		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000

Appendix D

Habitat Equivalency Analysis

Habitat Equivalency Analysis

Habitat equivalency analysis (HEA) was used to estimate changes in environmental service levels under different closure options for the Duke Energy Marshall Steam Station (MSS). The extent of environmental service flows currently provided by ash basin habitats (wooded areas, open field, open water, etc.) and associated sites (borrow/landfill areas) was calculated and compared to service flows provided by post-closure habitats in these areas.

The HEA proceeded in four steps:

1. **Estimate habitat areas:** The acres of different habitat types (e.g., forest, open field, open water, wetland) that would be affected by closure under each closure option (i.e., cap in place [CIP], excavation, and hybrid closures) were estimated from aerial imagery.
2. **Evaluate environmental service levels:** The relative level of environmental services provided by these habitats was estimated in terms of net primary productivity (NPP).
3. **Apply discounting for future services:** The relative levels of environmental services were calculated over time according to the construction implementation schedule developed by Duke Energy (2018) and expressed in units of discounted service acre-years (DSAYs).
4. **Calculate discounted environmental services:** DSAYs were summed across the gains and losses of each habitat type to produce a net gain or loss in environmental service levels for each closure option.

Estimate Habitat Areas

Acreages of current habitat types were calculated from geographic information system (GIS) files provided by Duke Energy that included spatial representations of the current acreage of open field, wetland, wooded area, and open water habitats surrounding the ash basin. The acreages of ash basin to be closed and land converted to landfill or borrow pit were based on information provided by Duke Energy (2018b) according to the assumptions below. For the excavation and hybrid options, the closure-by-removal portions of the ash basin were assumed to be restored to historical, pre-basin conditions. Historical acreage of forested, open field, and stream habitat types were estimated by measuring 1964 aerial photographs retrieved using the U.S. Geological Service's Earth Explore (earthexplorer.usgs.gov). Unclassified current habitat areas in the ash basin footprint were assumed to be bare ground and to have a 0% service value. Historical habitat types were broadly classified into forest, open water, and open-unclassified areas since not all currently measured habitat types (e.g., scrub-shrub) could be resolved from historical images. Historical areas of forest sub-habitat types not resolved in the historical imagery were estimated by assuming the current (non-basin) site-wide percentages of broadleaf forest (91%), needleleaf forest (8.3%), and wetland forest (<1%) were applied to the historical forest areas within the ash basin footprint. Historical areas of open-unclassified (as forest or open water) habitat types were estimated by assuming the current site-wide percentages of scrub-shrub (72%), emergent wetland (3%), and open field (25%) applied to these areas within the historical ash basin footprint. It is important to note that not all closure options impacted all basin habitat areas, thus different closure options may be modeled in the HEA using different total areas.

Additional assumptions used to calculate habitat areas included:

- Stream habitats in the ash basin were not indicated for MSS in historical imagery and not included in the NPP services in ash basin restoration.
- Fill material for closure was assumed to be derived from excavation of basin dam features and new onsite borrow pits. The areal extent of these borrow pits was calculated from the volume (cubic yards) of required earthen fill material, assuming borrow pits would be dug to 15 ft.
- Area lost to borrow pit excavation was assumed to contain forest habitat, which is the predominant non-basin habitat type on the MSS property.
- Borrow material required for CIP closure of the Unit 5 basin was assumed to not be available from closure activities in the active ash basin.

Evaluate Environmental Services

NPP was used to standardize environmental services across habitat types. NPP is a measure of how much photosynthesis occurs in an area greater than the amount required by the plants for immediate respiration needs. Fundamentally, NPP is a measure of the energy available to perform environmental services and is a useful currency for comparing habitats (Efroymson et al. 2003). NPP is often referred to in terms of carbon fixation or carbon storage, as the removal of carbon from the atmosphere is a primary reaction of photosynthesis.

Of the habitats currently occurring on the site, broadleaf, needleleaf, and mixed forested areas have the highest NPP; that is, per acre of forest, photosynthesis fixes more carbon/produces more energy for environmental services (Ricklefs 2008). As such, NPP service levels for all habitat types were normalized to the NPP service level of forested habitat. Specifically, the service levels for all habitat types were expressed as a proportion of the maximum wooded area service level (He et al. 2012).

To compare results between the different closure options, a set of assumptions was used for all options evaluated.

- Figure 22.12 from Ricklefs (2008) was used as the basis for determining relative rates of NPP for different ecosystem types. For this evaluation, temperate forest (woodland) was considered the base habitat with a relative NPP of 100%. Other habitat types were normalized as a proportion of that value based on the relative levels of NPP shown in Ricklefs' Figure 22.12 (2008), using temperate grassland as representative of open fields and freshwater environments as representative of open water.
    - Based on Ricklefs' Figure 22.12 (2008), NPP values for open field and open water habitats were assumed to be 40% of the forest value. However, because aquatic habitats of the ash basin may not be functionally equivalent to naturally occurring freshwater ecosystems (e.g., less abundant or diverse vegetation), a habitat quality

adjustment factor of 4 was applied, lowering the relative NPP value for ash basin open water habitat to 10% of temperate forest NPP.

- Figure 2c from He et al. (2012) was used to estimate NPP of woodland areas based on stand age.
  - The NPP functions for the three forest types (broadleaf, needleleaf, mixed) from Figure 2c of He et al. (2012) were digitized to allow calculation of NPP by stand age. For example, for mixed forests this function shows rapidly increasing NPP up to a maximum at 45 years, after which the NPP declines slightly to level off at approximately 85% of the maximum.
  - All wooded areas currently occurring in the ash basin or on borrow or landfill areas were assumed to be 50 years old, which, based on He et al. (2012), provide approximately 97% of maximum NPP function in the case of broadleaf and mixed forests and 84% for needleleaf forests. Other habitats were normalized from the higher value using the relative rates of NPP described above.
- Baseline levels of service (NPP) in the absence of closure activities were assumed to continue at the current rate for 150 years, accounting for slight changes in wooded area NPP by age as calculated from the NPP function of He et al. (2012).

Apply Discounting for Future Services

HEA applies a discounting function when calculating the amount of environmental services derived from an acre over a year and uses as its metric a discounted service acre-year, or DSAY. Discounting is necessary because environmental services occurring in the future are assumed to be less valuable to people than the same services performed now (Dunford et al. 2004; Desvousges et al. 2018; Penn undated). This allows the environmental services occurring far in the future to be considered on par with contemporary services. Thus, factors determining when closure and remediation begin and the duration of these processes are important parameters of the final DSAY estimate.

I used the closure schedule provided by Duke Energy (2018b) to develop timelines for habitat loss and gain under each closure option. For purposes of the HEA, only site preparation, construction, and site restoration times were included. Pre-design and design permitting periods were assumed to have no effect on environmental services. The closure schedule estimated duration of each activity in months; however, since the HEA model calculates DSAYs on an annual basis, the activity durations were rounded up the nearest full year. This has a negligible impact on DSAY estimates.

The following assumptions were then used to standardize timing of activities among the closure options:

- For all closure options, removal of existing onsite habitats was assumed to occur in the year that construction begins and was assumed to be completed the same year such that no environmental service is provided by the end of the first construction year.
- Environmental services of areas used for borrow or as landfill were assumed to be lost in the year construction starts, and borrow/landfill site preparation was assumed to be complete the same year such that no environmental service is provided by the end of the first construction year.
- Environmental service gains from restoration (ash basin and borrow area) were assumed to begin in the year following completion of construction activities.
- Post-closure habitats were presumed eventually to provide the same level of service as equivalent pre-closure habitats with the following conditions:
    - Forests would be age 0 in the year when restoration was completed and would generate an increasing level of NPP as they grow,

following the rates calculated from the NPP curves of He et al. (2012).

    – Restored open field habitat would take five years (based on professional judgement) to reach the baseline relative to forest NPP of 40%, with service levels increasing linearly over that time.
    – Restored wetland and stream habitat would be functionally equivalent to natural freshwater ecosystems and would provide an NPP relative to forests of 40% after five years (based on professional judgement), increasing linearly over that time.
    – Periodic mowing is required to maintain a grass cap, so grass cap was assumed never to reach a level of service equivalent to an open field. Grass cap was assumed to have 20% of the NPP service level for open field, which is 8% of forest NPP. Grass cap was assigned a post-closure service level of 8%, with full service attained in 2 years.
    – Bare ground was assumed to provide no environmental service.
- The base year for discounting is 2019 for all closure options.
- A discount rate of 3% is applied for all closure options.
- The HEA is run for 150 years for all closure options.

Calculate Discounted Environmental Services

Calculation of DSAYs is a summation of the discounted losses and gains in service values across habitat types. The net DSAYs calculated for each closure option are reported in Table 10-1 of the main body of this report.

A sensitivity analysis of key parameters (based on professional experience) and assumptions used in the HEA was conducted to evaluate how sensitive the HEA results are to changes in (1) the duration over which the services were evaluated (i.e., 150 years), (2) the assumed relative NPP of ash basin open water and open fields, and (3) habitat created by restoration of borrow areas. The results are discussed in the context of uncertainty in the net environmental benefit analysis (NEBA) in Appendix E.

Appendix E

Net Environmental Benefit Analysis

Net Environmental Benefit Analysis

Net environmental benefit analysis (NEBA) is a structured framework for comparing impacts and benefits to environmental services to support decision-making (Efroymson et al. 2003, 2004). In the NEBA application for the Marshall Steam Station (MSS) ash basin closure, a risk-ranking approach, based on that described by Robberson (2006), was applied. The risk-ranking approach develops alphanumerical estimates of relative risk by closure option and by attribute (e.g., risk to a receptor, change in environmental services), which allows comparison of the relative differences in impact between closure options to a variety of attributes. In this way, tradeoffs can be visualized to inform decision-making.

Risk-Ranking Matrix

The risk-ranking matrix includes two axes that characterize risk. The y-axis shows the level of impact, or risk, to an attribute, and the x-axis shows the duration of the impact (which is directly related to the time to recovery). Both are important to evaluate the relative differences in risk posed by closure options. A moderate level of impact over a long duration can potentially have an overall greater negative impact on the environment than a higher impact over a very short period (Robberson 2006). The pattern of shading of the risk matrix conveys this general principle, though the exact shading of the cells is based on best professional judgement. Robberson (2006) describes darker shading as indicating a higher level of concern over the level of impact to a resource or environmental service. The NEBA matrix developed by the Operational Science Advisory Team-2 (OSAT 2011) used a similar color coding approach to compare risk from further cleanup of oil on beaches of the Gulf of Mexico following the Deepwater Horizon oil spill. The risk-ranking matrix used in the NEBA of closure options for the MSS ash basin is shown in Table E-1.

Table E-1. Risk-ranking matrix for impacts and risk from closure activities. Darker shading and higher codes indicate greater impact.

		Duration of Impact (years)							
		>50 **(8)**	35–50 **(7)**	26–35 **(6)**	16–25 **(5)**	10–15 **(4)**	5–9 **(3)**	1–4 **(2)**	<1 **(1)**
% Impact	No meaningful risk	--	--	--	--	--	--	--	--
	<5 % **(A)**	**8A**	**7A**	**6A**	**5A**	**4A**	**3A**	**2A**	**1A**
	5–19% **(B)**	**8B**	**7B**	**6B**	**5B**	**4B**	**3B**	**2B**	**1B**
	20–39% **(C)**	**8C**	**7C**	**6C**	**5C**	**4C**	**3C**	**2C**	**1C**
	40–59% **(D)**	**8D**	**7D**	**6D**	**5D**	**4D**	**3D**	**2D**	**1D**
	60–79% **(E)**	**8E**	**7E**	**6E**	**5E**	**4E**	**3E**	**2E**	**1E**
	>80% **(F)**	**8F**	**7F**	**6F**	**5F**	**4F**	**3F**	**2F**	**1F**

The percent impact levels (e.g., <5%, 5–19%) were defined based on best professional judgement and regulatory precedent. A <5% impact characterizes a very minor potential or expected impact that may be functionally indistinct from baseline conditions due to uncertainty in metrics or the estimated effects. As such, this level of impact was given no shading, regardless of the duration of impact. Impacts between 5–19% are considered low in the NEBA framework (Efroymson et al. 2003). This impact level was shaded to reflect this low risk. Levels of impact >20% were separated at intervals of 20% based on best professional judgement and consistent with the risk-ranking approach used by Robberson (2006).

Similarly, the categories used to define duration of impact were based on best professional judgment and regulatory precedent. Robberson (2006) defines recovery in <1 year as “rapid,” with shading that indicates a generally low level of concern across the levels of impact. The remaining time categories in the risk-ranking matrix were divided to separate relatively short duration and time to recovery (e.g., 1–4 years, 5–9 years) from longer periods (e.g., 26–35 years). Approximately five-year periods were used to divide duration categories up to 15 years; after 15 years, approximately 10-year periods were used. This reflects that smaller differences in time are more important to distinguishing impacts from closure activities that last for shorter periods; however, as impact duration increases differences in a few years are a diminishing fraction of the total duration of the closure activities.

As Robberson (2006) notes, the exact size of the risk matrix is a function of decisions made about scaling the matrix, which is a function of the closure and remediation being considered and the attributes included in the NEBA. For example, the duration of impact categories could have been expanded to twelve (e.g., <1 year, 1–3 years, 3–6 years, 6–9 years, 9–12 years, 12–15 years, 15–20 years, 20–25 years, 26–35 years, 36–50 years, and >50 years) which would have changed the alphanumeric risk ratings and perhaps some of the shading of attributes evaluated in the NEBA. The purpose of the risk matrix, and the risk ratings that result from it, is to consolidate the results from a variety of different analyses for a variety of different data types and attributes into a single framework for comparative analysis. It is imperative, however, to consider the underlying information used to develop the risk ratings to interpret the differences between closure options, particularly when percent impacts or durations of closure options are similar but receive different risk ratings. It is inappropriate to assume a risk rating for one attribute is scientifically equivalent to the risk rating of another attribute because the comparative metrics that form the foundation of the risk ratings can be fundamentally different (e.g., a hazard quotient for risk to a bird species is different from discounted service acre-years [DSAYs] for environmental services from a habitat). Thus, the risk ratings in the NEBA matrix permit a relative comparison of impacts between closure options within attributes. Decision-makers can use the NEBA framework to identify the relative impacts of closure options across many different attributes, but the NEBA matrix does not, by design, elevate, or increase the value of, any specific risk or benefit in the framework.

Risk Rating Sensitivity

Uncertainty in a NEBA can be evaluated by examining the uncertainty in the assumptions and analyses used as inputs to the risk-ranking matrix. The following sections examine how differences in assumptions could affect relative risk ratings in the NEBA framework for attributes found to have levels of impact. Attributes for which no meaningful risk was found (e.g., human health risk assessments, ecological health risk assessments) are not included in the following discussion.

Noise and congestion from trucking traffic

I used the number of trucks per day passing[1] a receptor along a near-site transportation corridor as a metric to examine the differences in noise and traffic congestion under the closure options. I compared the increase in truck passes due to hauling earthen fill, geosynthetic material, and other materials under the closure options[2] to the current number of truck passes for the same receptor.

The current (or baseline) number of truck passes was estimated from North Carolina Department of Transportation (NCDOT) annual average daily traffic (AADT) data collected at thousands of locations across the state and the proportion of road miles driven by large trucks in North Carolina. AADT is an estimated daily traffic volume at a specific location, which captures traffic in all lanes traveling in both directions and is assumed to represent typical traffic volume for a year.[3] Not all AADT data, however, differentiate between large trucks such as those to be used in ash basin closure and other traffic such as cars, which is a relevant distinction when considering impacts to communities from increased noise. NCDOT performs vehicle classification[4] on trucking routes to estimate annualized truck percentage to apply to AADT to determine truck AADT (NCDOT 2015). The average annualized truck percentage for Catawba County is 6.6%.

The precise transportation corridor for trucks travelling to and from MSS during ash basin closure is unknown; however, likely corridors in the communities local to MSS can be identified by examining road maps and AADT statistics. MSS is located on a peninsula of Lake Norman

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1 Truck passes per day resulting from trucking activities is calculated as the total number of loads required to transport earthen fill, geosynthetic materials, and other materials multiplied by two to account for return trips. The resulting total number of passes is then divided evenly among the total number of months of trucking time multiplied by 26 working days per month.

2 Truck trips to haul ash were not included in the estimate for MSS ash basin closures because trucks hauling ash would not leave the MSS property and would not affect community receptors along the transportation corridors.

3 AADT is calculated from two days of traffic counts at each station during weekdays, excluding holidays. Raw monitoring data consists of counts of axle pairs made by pneumatic tube counters that are converted to traffic volume by applying axle correction factors and expanded to annual estimates by seasonal correction factors. Derived AADT values are checked for quality against nearby stations and historical station-specific values (NCDOT 2014).

4 Vehicle classification is assigned based on number of axles, space between axles, weight of the first axle, and total weight of the vehicle.

that consists primarily of sparse lakeside communities and rural forest and farmland. The peninsula is crossed by NC Highway (NC) 150, which transects the peninsula immediately south of MSS providing the only east-west bridge crossing of Lake Norman in this area (Figure E-1). NC 150 is heavily traveled, and the NCDOT traffic stations nearest the main plant entrance road report 18,000 AADT (NCDOT Station ID 1700756 in 2017) and 17,000 AADT (NCDOT Station ID 1700802 in 2017). Heavy trucks are likely to use this section of road when hauling construction material for ash basin closure; however, they are unlikely to use the main plant entrance for construction activities. The northern end of the ash basin is adjacent to Island Point Rd (North Carolina State Road [SR] 1838), which is the most likely path for construction traffic from the basin to SR 1848 (Sherrills Ford Rd) and connecting with NC 150. This section of Island Point Rd serves a community of lakeside homes, and traffic monitoring stations on Island Point Rd near the basin report 2,300 AADT in 2017 (NCDOT Station ID 1701940 and NCDOT Station ID 1703452). To best capture trucking related impacts to sensitive communities along the transportation corridor, I assumed a baseline truck passes per day of 153, which was computed by multiplying 2,300 AADT (2017 estimate from Island Point Rd NCDOT Station ID 1701940) by the average percent of truck AADT for Catawba counties (6.6%; NCDOT 2015).[5]

[5] AADT data are not available for every road or every location along a road. It is possible during closure of the MSS ash basin that trucks will utilize less traveled roads (i.e., with lower AADT), which would have a lower baseline truck passes per day estimate and result in a higher percent impact from ash basin closure for these sensitive communities; however, by choosing the lowest available AADT estimate from roads within 10 miles of MSS along the most likely transportation corridors to and from MSS to a major road (e.g., highway), my analyses have considered sensitive communities that would be more affected by traffic noise and congestion from ash basin closure trucking.

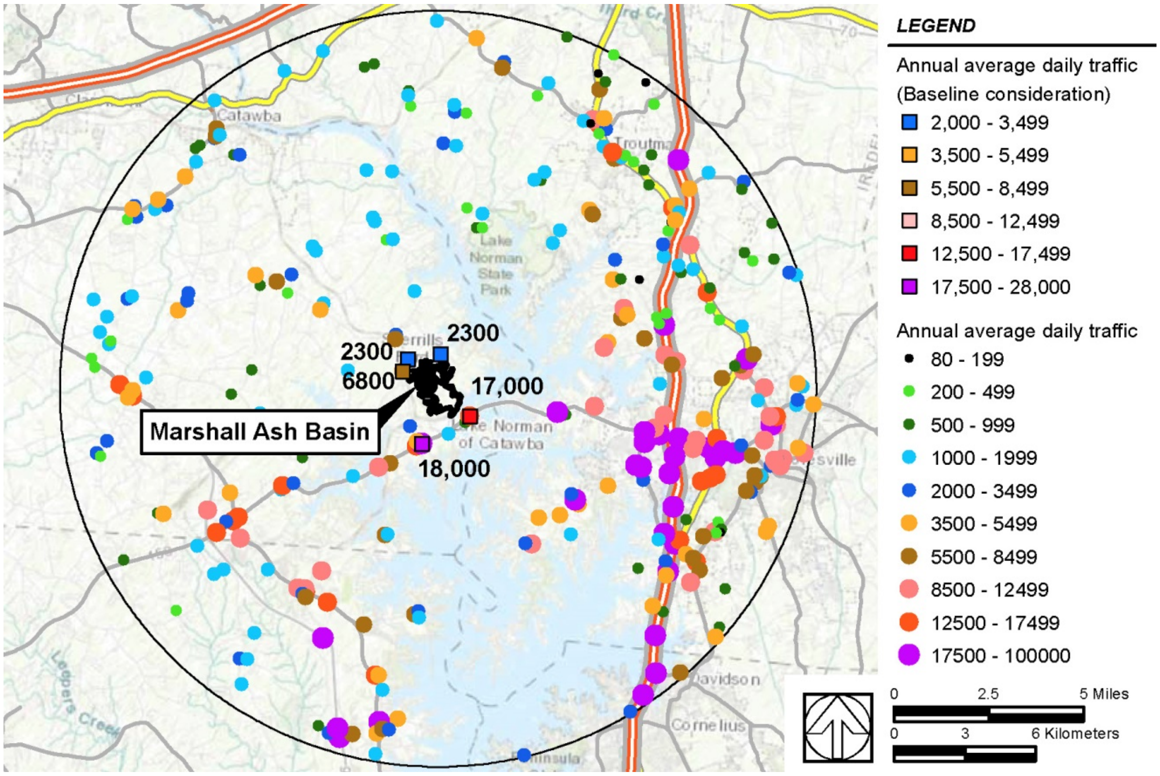

Figure E-1. NCDOT annual average daily traffic (AADT) measurement stations near MSS. Traffic stations and AADT values considered when determining the baseline number of truck passes are indicated as squares.

The sensitivity of the NEBA relative risk ratings to the baseline assumption of 153 trucks per day was evaluated by calculating relative risk ratings for a range of baseline truck traffic levels, based on the minimum and maximum AADT values for any NCDOT station within a 50-mile radius of the MSS ash basin, using AADT from the most recent year that data are available for a particular station, and assuming 6.6% truck traffic as previously described. Figure E-2 plots the resulting percent impact for closure options along with the resulting relative risk rating across the range of 2 to 12,113 truck passes per day.

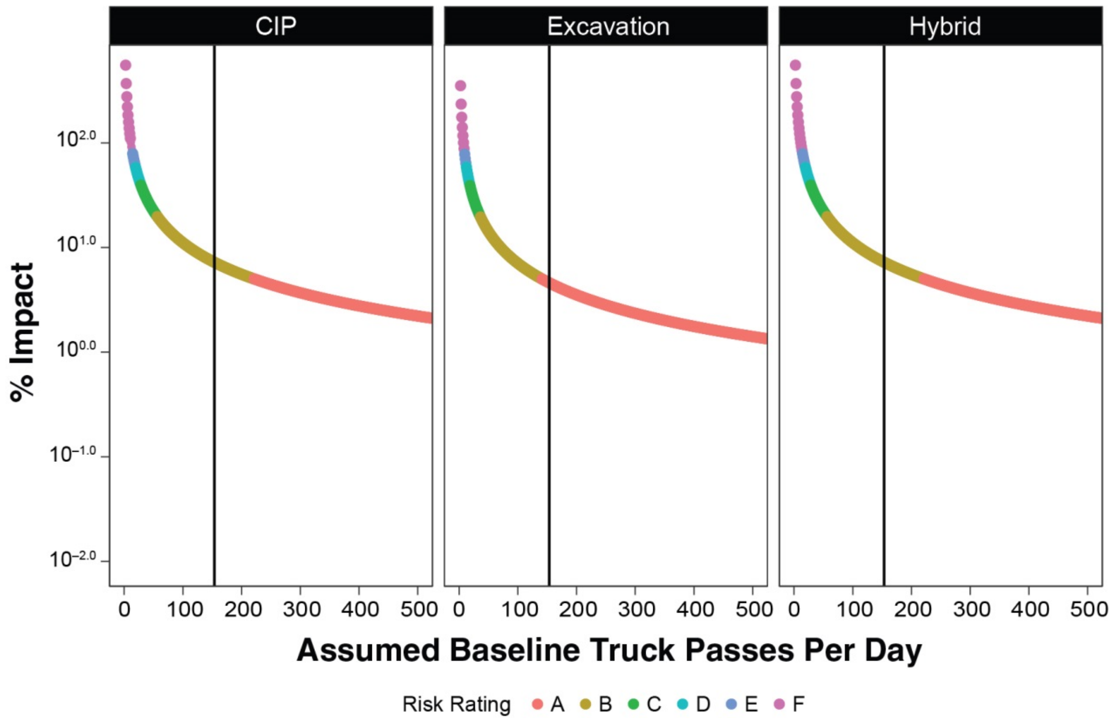

Figure E-2. Sensitivity of NEBA relative risk rating for noise and congestion impacts from trucking operations. The vertical line indicates the assumed baseline 153 truck passes per day. The y-axis is plotted on a log10 scale and the X axis is truncated at 500 to improve visualization.

Using a baseline truck passes per day of 153, the CIP and hybrid closure options fall into the second lowest relative risk rating (B, 5–19%), while the excavation closure option has the lowest risk rating (A, <5%) for traffic-induced noise and congestion during closure of the MSS ash basin (Figure E-2). The relative risk rating for CIP and hybrid closure options could be reduced to the lowest rating (A) if the baseline traffic assumption was increased to at least 221 truck passes per day. Higher risk ratings would result from a lower baseline truck traffic assumption; decreasing the baseline truck traffic assumption to 55 raises the risk rating to C for the CIP and hybrid closure options. At 153 truck passes per day, the risk rating for the excavation closure option is near the baseline threshold. A decrease in the assumed baseline from 153 to 140 truck passes per day would increase the risk rating for the excavation closure option from A to B.

Traffic accidents

I evaluated risk of traffic accidents by comparing the average number of annual offsite road miles driven between closure options relative to a baseline estimate of the current annual road miles driven.[6] I chose a baseline of 129 million annual truck road miles based on the reported total vehicle miles traveled in Catawba County, North Carolina (NCDOT 2017), multiplied by the county average 6.6% contribution of trucks to total AADT (NCDOT 2015).

The sensitivity of the NEBA relative risk ratings to the baseline assumption of 129 million truck miles per year was evaluated by calculating relative risk ratings for alternative baseline truck mile assumptions derived from the counties in North Carolina with the minimum (Hyde County) and maximum (Mecklenburg County) reported vehicle miles driven, resulting in a sensitivity range estimated from 6.2 million to 641 million truck miles per year. Figure E-3 plots the resulting percent impact for the closure options, along with the resulting relative risk ratings across this range of truck miles per year.

[6] The difference between the baseline miles assumption and the closure assumption was divided by the baseline miles assumption and multiplied by 100 to get a percent impact.

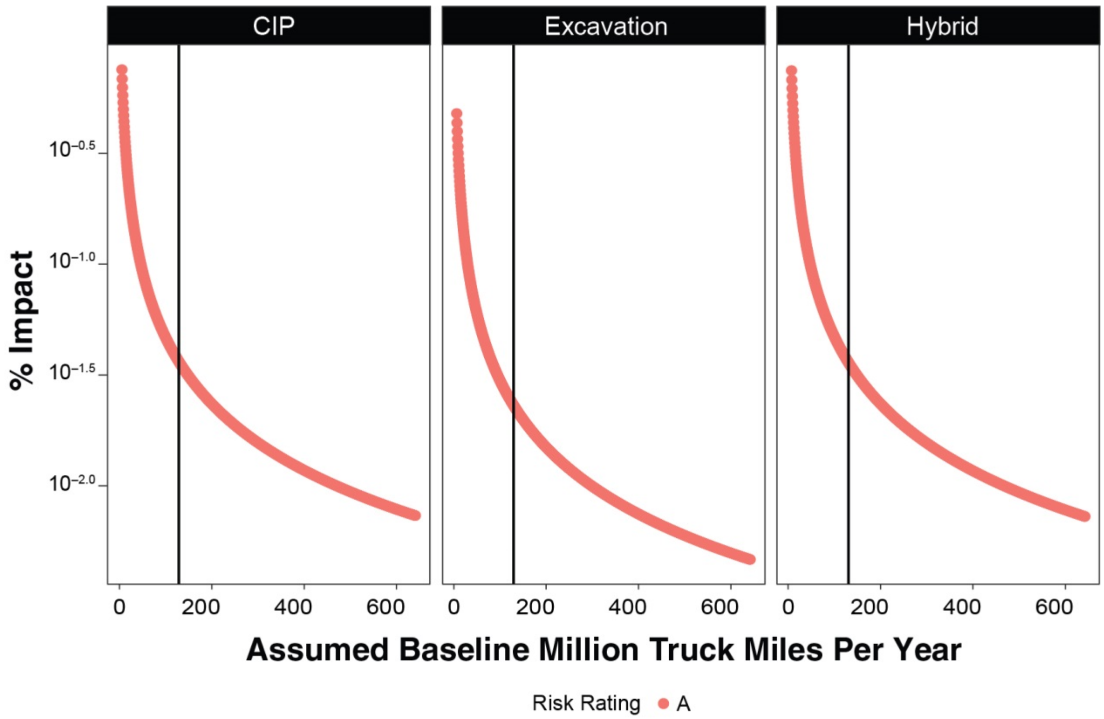

Figure E-3. Sensitivity of NEBA relative risk rating for traffic accidents due to trucking activities. The vertical line indicates the assumed baseline 129 million truck miles per year. The y-axis is plotted on a log10 scale to improve visualization.

Using the 129-million-truck-miles baseline assumption, all closure options have an impact of less than 0.1%. All closure options have a relative risk rating of A (<5%). These relative risk ratings do not appear to be sensitive to lower assumed baseline annual truck miles. The vertical lines in Figure E-3 indicate the location of the baseline assumption. Reducing the baseline assumption to the 6.2 million truck miles minimum does not increase percent impact to greater than 0.8% for any option and the risk ratings remain unchanged.

Habitat Equivalency Analysis

Uncertainty in the habitat equivalency analysis (HEA) that examined disruption of environmental services from ash basin closure was explored through sensitivity analyses of key assumptions in the HEA. To test sensitivity, I re-ran HEA models with the following changes:

1. Running the HEA for 100 years instead of 150 years.

2. Assuming the open water habitats of the ash basin provide environmental services at 40% of wooded areas instead of 10%.
3. Assuming open field habitats provide environmental services at 20% of wooded areas instead of 40%.
4. Assuming borrow area under the CIP option for the inactive basin is restored to open field, not reforested.

For each sensitivity analysis, all parameters in the base model were held constant except the one parameter varied to understand the sensitivity of the model to each assumption (Table E-2).

Table E-2. Change in DSAYs from base model[a] for key HEA assumptions

Closure Option	100-year model[b]	Ash basin water 40%[c]	Borrow becomes field[d]	Open Field 20%[e]
CIP	128	−760	−449	4
Excavation	−28	−716	−558	−38
Hybrid	−1	−760	−231	−48

[a] Base models were run for 150 years with ash basin open water NPP services at 10%, borrow fields were assumed to become forest (CIP and hybrid) or mixed forest/grass cap (excavation), and open field NPP services at 40%.
[b] Base models except the HEA was run for 100 years.
[c] Base models except ash basin open water NPP service at 40%.
[d] Base models except forested areas of borrow pits were assumed to become open field for all options.
[e] Base models except open field NPP services decreased to 20%.

Running HEAs for 100 years increased net DSAYs slightly for the CIP option and decreased net DSAYs slightly for the two other closure options. Increasing the ash basin open water service level to 40% resulted in similar net negative DSAYs for all options. Assuming borrow areas would be returned to open field resulted in a decrease in net DSAYs for all closure options. Assuming open field NPP at 20% slightly increased CIP DSAYs and slightly decreased DSAYs for the other two options.

Looking at the change in net DSAYs between the sensitivity models and their base models, the changes in assumptions have relatively consistent effects on net DSAYs. For example, changing ash basin open water services from 10 percent to 40 percent affects all closure options similarly, since the same level of service change is applied over the same area for all closure options, with the slight difference due to the year when remediation starts and hence services are lost. Assuming open field services at 20% results in a small net loss for the hybrid and CIP options since the level of service provided by restored open fields is halved. Assuming that borrow acreage is restored to open field and not forest habitat after borrow is complete results in a net loss for all three options since all include reforestation of at least part of the borrow area. However, since the directionality of net NPP services provided by the closure options does not change under this sensitivity analysis (i.e., the hybrid option still results in the least net loss), this demonstrates that the model can differentiate between relative differences in NPP service level changes with consistency.

Changes in net DSAYs with changing assumptions may change the relative risk rating applied to a closure option in the NEBA. However, the relative similarity in the way DSAYs change with assumptions between the various closure options and the result that the hybrid option results in the least net NPP services losses under any sensitivity analysis support the relative risk ratings for decision support in the NEBA.

Closure Option Assumptions

The following assumptions were used to calculate NEBA input values related to trucking activities and habitat acreages.

- The density of ash was assumed to be 1.2 ash tons/CY.
- Borrow pit acreage required to supply earthen fill and cover material was assumed to be dug to a depth of 15 ft to meet volume requirements. Borrow pits not specifically identified were assumed to contain a mixed forest habitat that would be restored upon closure completion.
- Excavation was assumed to proceed at a rate of 1,000,000 CY/year for all types of excavation material combined including ash, underlying over-excavated or residual soil, and dam and embankment material.
- CIP cover systems were assumed to require two layers of geosynthetic material. New landfill areas were assumed to require seven layers of

geosynthetic material. Geosynthetic material was assumed to be transported from Georgetown, South Carolina, at a rate of six loads per day and 3 acres per load.

- Covers/caps for both CIP and landfills were assumed to receive 18 in. of cover soil plus 6 in. of topsoil. New landfills also were assumed to receive 2 ft of liner soil. Topsoil was assumed to come from an offsite commercial facility requiring no additional borrow area.
- Unless otherwise specified, offsite borrow material and topsoil were assumed to be from sources 11 miles away (one way).
- Offsite truck capacity was assumed to be 20 CY of ash or earthen material.
- Working hours were assumed to be 10 hr/day, 6 days/week, and 26 days/month.
- Earthen fill material was assumed to be hauled in at a rate based on 1,000,000 CY/year.
- In excavated areas, 1 ft of over-excavation of residual soil was assumed. When restoring these areas, 6 in. of top soil addition was assumed necessary to establish vegetative stabilization over the total area.