The Chemours Company
Fayetteville Works
22828 NC Highway 87 W
Fayetteville, NC 28306

April 11, 2019

Dr. Joe Ghiold, Ph.D., Project Manager
Facility Management Branch
Hazardous Waste Section
Division of Waste Management
NC Department of Environmental Quality
1646 Mail Service Center
Raleigh, NC 27699-1646

Re: Cape Fear River PFAS Mass Loading Model Scope of Work
Chemours Fayetteville Works
Fayetteville, North Carolina
EPA ID No. NCD 047 368 642

Dear Dr. Ghiold:

Enclosed, please find a PDF copy of the *Cape Fear River PFAS Mass Loading Model Scope of Work* for the Chemours Fayetteville Works. This document presents a description of the model that will account for sources of per- and polyfluoroalkyl substances (PFAS) from the Facility at and near the Chemours Fayetteville Works, North Carolina site that reach the Cape Fear River. This document meets the requirements of Paragraph 12 (b) of the Consent Order dated February 25, 2019. Geosyntec Consultants of NC, PC has been approved as the third-party consultant by NCDEQ as required under Paragraph 12 (c) of the Consent Order.

If you have any questions or need any additional information, please contact me at Brian.D.Long@Chemours.com.

Respectfully submitted,

Brian D. Long
Plant Manager

cc: Christel Compton – Chemours Fayetteville Works
File
Enclosures

Geosyntec Consultants of NC, PC

CHEMOURS FAYETTEVILLE WORKS CAPE FEAR RIVER PFAS MASS LOADING MODEL SCOPE OF WORK

Prepared for

The Chemours Company FC, LLC
Fayetteville Works
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Prepared by

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Geosyntec Project Number TR0795

April 2019

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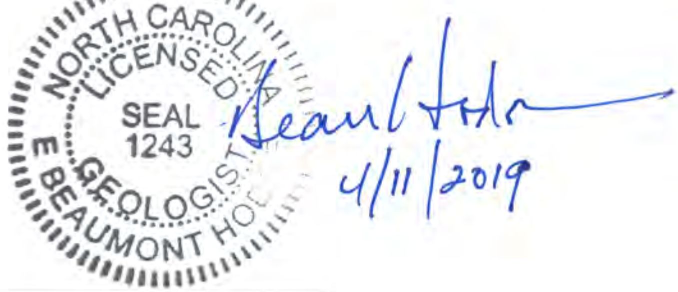
ACRONYMS AND ABBREVIATIONS

%	percent
bgs	below ground surface
CFPUA	Cape Fear River Public Authorities
Chemours	The Chemours Company FC, LLC
CO	Consent Order
DuPont	E.I. du Pont de Nemours and Company
ft	feet
Geosyntec	Geosyntec Consultants of NC, PC
HFPO-DA	hexafluoropropylene oxide dimer acid
Kuraray	Kuraray America Inc.
LTW	long-term wells
mL	milliliter
NC	North Carolina
NCDEQ	North Carolina Department of Environmental Quality
PFAS	Per- and polyfluoroalkyl substances
PFCA	perfluorocarboxylic acids
PFOA	perfluorooctanoic acid
PFOS	perfluorooctanesulfonic acid
PFSA	perfluorosulfonic acids
PMPA	2,3,3,3-Tetrafluoro-2-(trifluoromethoxy)propanoic acid
SOP	Standard Operating Protocol
USGS	United States Geological Survey

"I certify that I am personally familiar with the information contained in this submittal, including supporting documents accompanying this report, and that the material and information contained herein is, to the best of my knowledge and belief, true, accurate and complete."



Geosyntec Consultants of NC, PC is licensed to practice engineering in North Carolina. The certification number (Firm's License Number) is C-3500.

Geosyntec Consultants of NC, PC is licensed to practice geology in North Carolina. The certification number (Firm's License Number) is C-295.

1. INTRODUCTION AND OBJECTIVES

Geosyntec Consultants of NC, PC (Geosyntec) has prepared this scope of work document for The Chemours Company FC, LLC (Chemours) for the Fayetteville Works facility in Bladen County, North Carolina. The purpose of the scope of work is to describe activities planned to address Paragraphs 12(b) and 12(c) of the signed consent order (CO) dated 25 February 2019 between the North Carolina Department of Environmental Quality (NCDEQ), Cape Fear River Watch and Chemours.

CO Paragraph 12 relates to the "Accelerated Reduction of PFAS Contamination in the Cape Fear River and Downstream Water Intakes". CO Paragraph 12(a) requires a per- and polyfluoroalkyl substances (PFAS) Reduction Plan of PFAS loading to the Cape Fear River from the Facility (i.e. the Site). CO Paragraph 12(b) requires development of a model that accounts for all sources of PFAS from the Facility contributing loading of PFAS into the Cape Fear River, Willis Creek, Georgia Branch, and Old Outfall 002. CO Paragraph 12(c) requires Chemours to contract a third party approved by NCDEQ to prepare a modeling scope of work to be reviewed by NCDEQ and Cape Fear River Watch. Geosyntec has been approved by NCDEQ and contracted by Chemours to perform the modeling effort for CO Paragraph 12(b).

1.1 Objectives

The objective of this scope of work document is to describe the proposed modeling analyses (the PFAS mass loading model) that will be performed to estimate Site associated PFAS mass loading from the Site and from offsite sources to the Cape Fear River directly and through its tributaries Willis Creek, Georgia Branch Creek, Old Outfall 002, three groundwater seeps on the hill slope to the Cape Fear River and discharging groundwater that reach the Cape Fear River from the Site.

PFAS mass loading is defined in this model as the combined mass per unit time (e.g. nanograms per second) from potential sources. The model will estimate PFAS contributions from multiple pathways (i.e. compartments) such as the various creeks and groundwater. The PFAS loadings for the pathways will then be summed and used to estimate Cape Fear River concentrations using measured Cape Fear River flow volumes. These estimated concentrations will then be compared to measured in-river concentrations as an assessment of model calibration. In the PFAS Reduction Plan required in CO Paragraph 12(a), this model will be used to assess potential reductions in PFAS mass loading to the Cape Fear River based on current and future interim remedial actions at the Site.

The proposed activities (i.e. scope of work) for the PFAS mass loading model assessment are:

- Identify potential PFAS loading pathways from the Site to the Cape Fear River;

- Evaluate mass loading contributions from each identified potential pathway and relative contributions to total loading from each pathway;
- Incorporate new fieldwork and data collected as part of ongoing site assessment activities to refine estimates of model parameters;
- Model estimated PFAS concentrations in the Cape Fear River under various scenarios (e.g., “dry” i.e., baseflow and “wet” i.e., storm events) and compare to measured in-river values;
- Model estimated mass loading reductions based on proposed PFAS loading reduction actions.

1.2 Document Organization

The remainder of this document contains the following sections:

- **Section 2 – Site Background** – this section describes Site background and use;
- **Section 3 – Site Setting** – this section describes the Site setting, including Site geology and hydrogeology, known distribution of PFAS as they relate to PFAS loading to the Cape Fear River, and identified potential PFAS transport pathways;
- **Section 4 – PFAS Mass Loading Model Design** – this section describes how the PFAS mass loading model will be constructed and developed to support the Cape Fear River PFAS Reduction Plan required in CO Paragraph 12(a);
- **Section 5 – Model Calibration and Sensitivity Analysis –** this section describes how the model will be calibrated, including identifying calibration datasets; and procedures for addressing uncertainties associated with the model;
- **Section 6 – Summary –** this section describes how the model will be used to support the Cape Fear River PFAS Reduction Plan; and
- **Section 7 – References -** this section lists work plan reference documentation.

2. SITE BACKGROUND

The Site is located within a 2,177-acre property at 22828 NC Highway 87, approximately 15 miles southeast of the city of Fayetteville along the Bladen-Cumberland county line in North Carolina. **Figure 1** presents an overview of the Site. The Site is bounded by NC Highway 87 to the west, Cape Fear River to the east, and on the north and south by undeveloped areas and farmland. Willis Creek and Georgia Branch Creek, tributaries to the Cape Fear River, are located toward the northern and southern property boundaries, respectively with Georgia Branch Creek being offsite for its entire course.

The Site property was originally purchased by E.I. du Pont de Nemours and Company (DuPont) in 1970 for production of nylon strapping and elastomeric tape. DuPont sold its Butacite® and SentryGlas® manufacturing units to Kuraray America Inc. (Kuraray) in June 2014 and subsequently separated its specialty chemicals business to Chemours in July 2015. Presently, the Site consists of five manufacturing areas (**Figure 1**): (Area 1) Chemours Monomers IXM; (Area 2) Chemours Polymer Processing Aid (PPA); (Area 3) Kuraray Butacite®; (Area 4) Kuraray SentryGlas®; and (Area 5) DuPont Company polyvinyl fluoride (PVF) resin manufacturing unit. In addition to the manufacturing operations, Chemours operates two natural gas-fired boilers and a wastewater treatment plant (WWTP) for the treatment of process and sanitary wastewaters from Chemours, Kuraray, and DuPont.

3. SITE SETTING

This section describes the Site setting, including the physical setting of the Site, the Cape Fear River, Site geology and hydrogeology, the distribution of PFAS as it relates to PFAS loading to the Cape Fear River, and potential transport pathways of PFAS from the Site to the Cape Fear River.

3.1 Physical Site Setting, Topography and Drainage

The developed portion (manufacturing area) of the Site is located on a relatively flat topographic plateau at an approximate elevation of 145 feet above mean sea level (ft MSL) and approximately 70 feet above the Cape Fear River floodplain. **Figure 2** presents a topographic map of the Site and surrounding areas. Surface topography generally remains flat to the west with a gentle increase of about five feet to a topographic divide near NC Highway 87. However, ground surface elevations decrease from the topographic plateau at the manufacturing area towards the Cape Fear River to the east as well as its tributaries, Willis Creek to the north and Georgia Branch to the south. Topographic relief from the main manufacturing area decreases by approximately 100 feet in elevation towards the Cape Fear river bank to the east; decreases from 40 to 100 feet in elevation to Willis Creek from the Site boundary to the Cape Fear River; and decreases by 15 to 25 feet in elevation where the Georgia Branch Creek channel runs along the property line. Inclined topographic relief combined with overland flow and groundwater seeps have created natural drainage networks. These channels shown in **Figure 2** have been observed to contain a steady flow of water where they intersect groundwater. These channels and the water that flows in them are herein referred to as Seeps and discharge directly into the Cape Fear River (Seep A, Seep B and Seep C; **Figure 2**).

3.2 Cape Fear River

The Cape Fear River and its entire watershed are located in the state of North Carolina (**Figure 3**). The Cape Fear River drains 9,164 square miles and empties into the Atlantic Ocean near the City of Wilmington, North Carolina. The Site is situated on the western bank of the Cape Fear River and draws water from the Cape Fear River and returns over 95% of this water via Outfall 002 after being used primarily as non-contact cooling water. Two lock and dam systems with USGS stream gauges are located downstream of the Site: (1) W.O. Huske Lock and Dam, located 0.5 river miles from the Site (USGS 02105500); and (2) Cape Fear Lock and Dam #1, located 55 river miles downstream (USGS 02105769).

The Cape Fear River is also a water source for downstream communities of the Chemours Site. For instance, Bladen Bluffs and Kings Bluff Intake Canal, located approximately 5 miles and 55 miles downstream from the Site, serve as Cape Fear River water intakes for the Lower Cape Fear

Water and Sewer Authority which in turn provides water to Cape Fear Public Utility Authority (CFPUA) and other water providers. Drinking water sourced from the Cape Fear River does contain certain chemicals including 1,4-dioxane, trihalomethanes associated with bromide content in raw river water, pharmaceuticals, personal care products, endocrine disrupting chemicals, and PFAS. A brief description of these chemicals in the Cape Fear River was reported previously (Geosyntec, 2018a).

3.3 Regional Geology

The Site is located within the Coastal Plain Physiographic Province of North Carolina. The Coastal Plain Physiographic Province extends from the Fall Line, a sinuous and erosionally-defined boundary separating the metamorphic and igneous rocks of the Piedmont Province to the northwest, to the present-day coast. The Coastal Plain Physiographic Province is characterized by a southeastward thickening wedge of late Cretaceous to Holocene age sediments that overlie a Paleozoic age crystalline basement.

Based on the geologic map of North Carolina (NCGS, 1985), the Site is underlain by the Black Creek Formation which ranges in age from early Campanian through early Maastrichtian of the Late Cretaceous epoch (approximately 66 to 84 million years ago; Sohl and Owens, 1991). The Black Creek Formation is divided locally into three sub units from oldest to youngest: Tar Heel Formation, Bladen Formation and Donoho Creek Formation. In general, the Black Creek Formation is characterized by lignitic clay with thin beds and laminae of fine-grained micaceous sand as well as thick lenses of cross-bedded sand. The upper portion of the formation may also contain glauconitic, fossiliferous clayey sand lenses.

3.4 Site Geology

Based on the lithology logged during onsite investigations (Parsons 2014, Parsons 2018a, Parsons 2019), the Site is underlain by the following hydrogeologic units, listed below from ground surface to depth (**Figure 4**):

1. A silty sand unit with thin discontinuous interbedded silt/clay lenses, referred to herein as the Perched Zone.

2. A laterally discontinuous, stiff clay lens underlying the Perched Zone. This clay lens appears to be limited in lateral extent to the east, north and south by local topography and pinches out (terminates) to the west of the manufacturing area based on lithologic logging and limited geophysical survey (Parsons, 2018a). The depth to the top of the clay lens is approximately 15 to 18 feet bgs. The clay lens becomes thinner moving west across the manufacturing area and ranges from approximately one foot to approximately 19 feet thick.

3. Fine- to medium-grained sand interbedded with silt/clay lenses, the saturated portion of which is herein referred to as the Surficial Aquifer. The sand extends to a depth of approximately 65 feet below ground surface (bgs) (elevation of +80 feet MSL).

4. Beneath the surficial unit is a 7 to 15 foot-thick, stiff, lignitic clay identified as the Black Creek Confining Unit. This Cretaceous-aged, regionally-extensive unit is encountered at the Site at an approximate elevation of +65 to +77 feet MSL. While the lateral continuity of this unit was verified north-south across the Site through lithologic borings, the east-west extent of this unit has not been verified through borings (Parsons, 2014). However, during recent field work described in the *Creeks, Old Outfall 002 and Seeps Assessment Workplan* (Geosyntec, 2019) this unit was observed to outcrop along the bluff face adjacent to the Cape Fear River, and along an embankment near Old Outfall 002 at similar elevations.

5. Beneath the Black Creek Confining Unit is the regionally-extensive Black Creek Aquifer, which is approximately 8 to 20 feet thick and is encountered at depths between 80 and 100 feet bgs (elevation of approximately +45 to +65 feet MSL).

6. Beneath the Black Creek Aquifer is a massive dense clay (with minor sand stringers) that has been identified as the Upper Cape Fear Confining Unit. This unit has not been fully penetrated at the Site.

3.5 Site Hydrogeology

Hydrostratigraphic units of interest in the vicinity of the Site include a Perched Zone, the Surficial Aquifer and the Black Creek Aquifer. While the Surficial Aquifer and Black Creek Aquifer are regionally extensive features the Perched Zone is limited in extent to the top of the clay lens that underlies most of the manufacturing area. These hydrostratigraphic units are described further below (**Figure 4**):

- Perched Zone - Groundwater in the Perched Zone appears to be controlled by the topography and lateral limits of the clay lens that underlies most of the manufacturing area (Parsons 2017, 2019). Historically, groundwater in the perched zone appears to have mainly resulted from: (1) past seepage of water through the bottom of the North/South Sediment Basins that are used to settle out solids from Cape Fear River water; (2) past infiltration of water from the cooling water channel around the Monomers IXM Area, and (3) infiltration of rainfall. The sediment basins and the cooling water channel were lined in November 2018 as part of the ongoing Site remedial actions to reduce infiltration to the Perched Zone. In the latest assessment performed in October and November 2018

(Parsons, 2019) Perched Zone water likely flows in a radial pattern away from a potentiometric high near the sedimentation basins. Where perched water is present, it is encountered from approximately 6 feet bgs at the basins to a depth of approximately 20 feet bgs along the edges of the Perched Zone west of the basins.

- Surficial Aquifer – The Surficial Aquifer is encountered at approximately 40 feet bgs and extends to a depth of approximately 65 feet below ground surface (bgs) (elevation of approximately +110 to +80 feet MSL). Groundwater elevations range from approximately 100 to 107 feet above MSL in the western areas of the Site to approximately 93 feet above MSL in the eastern areas of the Site, indicating that groundwater flow is generally toward the Cape Fear River. The water level of the Cape Fear River is typically near +30 feet MSL, which is lower than the base elevation of the Surficial Aquifer. This elevation difference suggests that water from the Perched Zone and the Surficial Aquifer will reach the Cape Fear River from a potential combination of groundwater seepage on the hillslope and subsequent flow to the Cape Fear River (observed), and potential infiltration to the Black Creek Aquifer and subsequent discharge to the Cape Fear River.

- The Black Creek Aquifer – The Black Creek Aquifer is potentially under semi-confined to confined conditions at portions of the Site where it is separated from the overlying Surficial Aquifer by the clay Black Creek Confining unit. As noted above, the lateral extent of the clay confining unit has not been verified towards the eastern portion of the Site. Groundwater flow in the Black Creek Aquifer is toward the Cape Fear River. At the Site, only the Black Creek Aquifer is in direct connection to the Cape Fear River with the potential exception of the Surficial Aquifer during extreme flood events.

3.5.1 Groundwater Seeps

During recent field work being performed as part of the *Creeks, Old Outfall 002 and Seeps Assessment Workplan* (Geosyntec, 2019) groundwater seeps were observed. This groundwater seeped to surface where the Perched Zone, Surficial Zone and the Black Creek Aquifer intersect the side of the bluff slope below the facility. The groundwater seeps out and flows towards the Cape Fear River in a series of naturally occurring erosional channels (**Figure 2**). These channels have been observed to contain a steady flow of water where they intersect groundwater. These channels and the water that flows in them are herein referred to as Seeps. The three seeps observed on the eastern bluff adjacent to the Cape Fear River from north to south are named Seep A, Seep B and Seep C.

3.5.2 Tributaries to the Cape Fear River

In addition to the three on-site seeps (**Figure 2**), there are three perennial surface water features that are tributaries to the Cape Fear River at or adjacent to the Site. To the north of the Site is Willis Creek, in proximity to the water intake for the Site. To the south of the Site is Georgia Branch Creek which discharges to the Cape Fear River approximately 7,500 feet south of the W.O. Huske Dam. At the Site is Old Outfall 002 which is fed by discharging groundwater. Old Outfall 002 discharges into the Cape Fear River approximately 1,350 feet south of W.O. Huske Dam.

3.6 PFAS Sources and Distribution in Environmental Media

PFAS associated with the Site are fluoroether compounds manufactured at the Site. Fluoroethers are a fluorochemical with at least one ether bond (a carbon-oxygen-carbon bond) in the molecule. Site-associated PFAS compounds are presently analyzed using the Table 3+ standard operating protocol (SOP) method, a method developed by Chemours in conjunction with analytical laboratories. Prior to the development of method Table 3+ SOP, method Table 3 SOP, which had fewer PFAS analytes, was used.

The following subsection describes PFAS sources and distribution as they relate to constructing the PFAS mass loading model for CO Paragraph 12(a) and (b). A more detailed presentation of the sources and distribution of PFAS at Site will be prepared as part of the on and offsite Assessment pursuant to CO Paragraph 18. PFAS impacts to environmental media have come from primarily wastewater conveyances, and industrial process activities resulting in emissions to air. To date, PFAS have been analyzed for and detected in soil, groundwater, and surface water.

3.6.1 PFAS Distribution in Soil

Historical soil investigations have indicated that hexafluoropropylene oxide dimer acid (HFPO-DA) and other PFAS were detected in the site soil samples collected between depths of 0.0 to 10 feet bgs; Parsons, 2018b).

3.6.2 PFAS Distribution in Onsite Groundwater

PFAS compounds have been detected in monitoring wells screened in each of the Perched Zone, Surficial Aquifer and Black Creek Aquifer. Elevated concentrations of PFAS are generally observed in the Perched Zone underneath the Monomers IXM Area. PFAS concentrations in the Surficial Aquifer are generally lower than the Perched Zone, by one to two orders of magnitude. PFAS compounds were also detected in the Black Creek Aquifer wells installed below the manufacturing area. PFAS detections have also been reported in the five LTW wells adjacent the Cape Fear River.

3.6.3 PFAS Distribution in Surface Water

On and near-site surface water features including the Cape Fear River, Old Outfall 002, two tributaries adjacent to the Site (Willis Creek and Georgia Branch) and onsite Seeps (Seep A, Seep B, and Seep C) have been investigated (Geosyntec, 2018b; Geosyntec, 2018c; Geosyntec 2019; Parsons, 2018c). Additional data continue to be collected for these features through ongoing additional investigations (Geosyntec, 2019).

Results of the completed investigations previously reported show PFAS compounds were detected in these surface water features. Perflourinated carboxylic acid (PFCAs), e.g. perfluorooctanoic acid (PFOA) and Perfluorinated sulfonic acids (PFSAs) e.g. perfluorosulfonic acid (PFOS) were detected throughout the Cape Fear River watershed and in the Cape Fear River are unrelated to the Site (Geosyntec, 2018c). The investigations also showed that HFPO-DA (i.e. GenX) and other Site Associated PFAS analyzed by method Table 3 / Table 3+ were detected in the Cape Fear River after the Site and are associated with the Site.

There are two surface water intakes along the Cape Fear River for public utilities; Bladen Bluff (7.5 miles downstream from the Site) and King's Bluff Intake Canal (55 miles downstream from the Site). Approximately half the detected total PFAS load at King's Bluff are potentially associated with sources upstream of the Site while the remainder are potentially associated with the Site (Geosyntec, 2018c).

3.7 Potential PFAS Transport Pathways to Cape Fear River

Potential pathways for PFAS originating from releases at Site to reach the Cape Fear River were identified by reviewing available Site data at the time of developing this scope. Nine potential pathways (**Table 1**) were identified as potentially contributing to observed in-river PFAS concentrations. These pathways represent compartments to model as part of the PFAS loading model. The potential pathways are listed below, and shown on the conceptual diagram provided in **Figure 5:**

Transport Pathway 1: Contributions from non-Chemours related sources upstream of the Site in the Cape Fear River;

Transport Pathway 2: Groundwater discharge to Willis Creek and stormwater to Willis Creek;

Transport Pathway 3: Direct aerial deposition on the Cape Fear River and its tributaries;

Transport Pathway 4: Inflow from Outfall 002 including Site stormwater;

Transport Pathway 5: Inflow from groundwater seeps;

Transport Pathway 6: Upwelling groundwater contribution from onsite discharge of Black Creek Aquifer groundwater;

Transport Pathway 7: Groundwater discharge to Old Outfall 002 and stormwater runoff;

Transport Pathway 8: Off-Site groundwater discharge from locations upstream and downstream of the Site to the Cape Fear River; and,

Transport Pathway 9: Groundwater discharge to Georgia Branch Creek and stormwater runoff.

4. PFAS MASS LOADING MODEL DESIGN

This section describes how the PFAS Mass Loading Model will be developed. The objective of the model is to assess the relative contributions of PFAS mass loadings from the various transport pathways by which PFAS originating from Site can reach the Cape Fear River. The model comprises multi-compartments that describe bulk PFAS mass transfer to the Cape Fear River. Each compartment represents a pathway that has been parameterized primarily using site-measured data. This approach is designed to identify broad trends in mass loading to the Cape Fear River for a range of conditions and support identification of potential target pathways for actions to achieve objectives for mass load and corresponding concentration reductions of Site associated PFAS in the Cape Fear River.

Site associated PFAS concentrations in the Cape Fear River are controlled by the PFAS mass loading to the Cape Fear River and the volume of water flowing through the Cape Fear River. PFAS mass load entering the Cape Fear River is defined in this model as the combined mass per unit time or mass load (e.g. nanograms per second) from potential pathways identified in Section 3.5 above. Total PFAS mass load entering the Cape Fear River is calculated as:

$$CFR_{TM} = \begin{cases} \sum_{n=1}^{n=9} \sum_{i=1}^{i=56} M_{n,i} = \sum_{n=1}^{n=9} \sum_{i=1}^{i=56} \left(C_{n,i} \times Q_n\right) \quad : \quad Q_n \rightarrow wet. \\ \sum_{n=1}^{n=9} \sum_{i=1}^{i=56} M_{n,i} = \sum_{n=1}^{n=9} \sum_{i=1}^{i=56} \left(C_{n,i} \times Q_n\right) \quad : \quad Q_n \rightarrow dry. \end{cases}$$

where,

CFR_{TM} = total PFAS mass load entering the Cape Fear River measured in mass per unit time [MT^{-1}], typically nanograms per second.

n = represents each of the 9 potential PFAS transport pathways listed in **Table 1**.

i = represents each of the 56 PFAS constituents listed in **Table 2**.

$M_{n,i}$ = mass load of each PFAS constituent *i* from each potential pathway *n* with measured units in mass per unit time [MT^{-1}], typically nanograms per second.

$C_{n,i}$ = concentration of each PFAS constituent *i* from each potential pathway *n* with measured units in mass per unit volume [ML^{-3}], typically nanograms per liter.

Q_n = volumetric flow rate from each potential pathway *n* with measured units in volume per time [L^3T^{-1}], typically liters per second, for two flow scenarios representing storm (*wet.*) and quiescent (*dry.*) conditions.

The Site associated PFAS mass loading for each potential pathway will be estimated using the approaches described in the following sub-sections. The result of these estimates will then be used to calculate the total PFAS mass loading of Site related PFAS using the above formula. A similar analytical mass loading model was previously developed for HFPO-DA in February 2018 (Appendix A of Parsons, 2018a; **Appendix A**). The model was able to estimate HFPO-DA concentrations in the Cape Fear River at two downstream utility intake locations, Bladen Bluffs and Kings Bluff Intake Canal.

Model inputs for each potential pathway (i.e., PFAS concentrations and volumetric flow of water) will be a combination of measured data, calculations and best estimates, as available at the time of model development. **Table 1** summarizes both the transport pathways and the type of model input data proposed to be used for developing this model and is discussed further below. Measured model inputs will come from two characterization events conducted in 2019. One event will be a "dry weather" event representing baseflow conditions and the other will be a "wet weather" event captured during a storm event. The following subsections describe how PFAS mass loading from the different PFAS transport pathways listed in **Table 1** will be estimated in the model and field work that will be performed to support these estimations.

4.1 Upstream Cape Fear River (Transport Pathway 1)

The estimated upstream PFAS mass loading contribution to Cape Fear River will be estimated using measured Cape Fear River concentration and flow data. Sampling locations, analytical methods and assessment techniques for PFAS concentrations in the Cape Fear River will generally follow the *Creeks, Old Outfall 002 and Seeps Assessment Workplan* (Geosyntec, 2019). As noted in this document, one sample was collected immediately upstream of the Site (River Mile 76) to estimate upstream PFAS mass loading contribution to Cape Fear River. Another sample was collected approximately 7 miles downstream of the Site (River Mile 84) for model calibration (**Section 5**). Both samples were collected at the thalweg (i.e., deepest point of the river transect) at mid-depth in the water column. An additional upstream sample (e.g., 10 miles upstream of the Site) will also be collected for additional model refinements. The Cape Fear River volumetric flow rate will be obtained from the USGS flow gauging station at the W.O. Huske Dam, ID 02105500 (USGS, 2018).

4.2 Tributaries – Willis Creek, Georgia Branch Creek, and Old Outfall 002 (Transport Pathways 2, 7 and 9)

Tributaries contributing to PFAS mass loading into the Cape Fear River include Willis Creek, Georgia Branch Creek, and Old Outfall 002. Mass loading of PFAS from these tributaries to the Cape Fear River will be estimated using measured PFAS concentrations and flow data. PFAS samples will be collected at each tributary at a location near the discharge point to the Cape Fear River, but still far enough upstream in the tributary where they are not potentially influenced by the Cape Fear River (e.g., Old Outfall 002 channel mouth sampling location in **Figure 1**). Sample locations and methods are outlined in the *Creeks, Old Outfall 002 and Seeps Assessment Workplan* (Geosyntec, 2019).

Volumetric discharge rates for the tributaries will be obtained from two independent flow measurement methods as outlined in the *Creeks, Old Outfall 002 and Seeps Assessment Workplan* (Geosyntec, 2019): (1) point velocity measurements and the cross-sectional area of the stream using the Mean Section Method (Rantz, 1982), and (2) salt dilution gauging.

For the Old Outfall 002 at the water capture and treatment location Option B, a flume or a weir will be installed to provide an enhanced assessment of baseflow volumes and for the mass loading model, including how flow volumes vary with storm events.

4.3 Aerial Deposition to the Cape Fear River (Transport Pathway 3)

The mass loading from direct aerial deposition of PFAS to the Cape Fear River will be estimated using air deposition modeling results for HFPO-DA from the Site (ERM, 2018). Based on the reported aerial extent and deposition contours, average deposition rates to the Cape Fear River will be calculated. Calculated deposition rates will be combined with the river surface area and the residence time of flowing Cape Fear River water to estimate a mass loading from aerial deposition. A similar approach was employed when previously estimating the HFPO-DA mass loading due to aerial deposition (**Appendix A**). The mass loading of other PFAS compounds will be estimated by using the relative concentration ratios of other Site associated PFAS to HFPO-DA based on measured concentrations from offsite wells.

4.4 Onsite Groundwater (Transport Pathways 5 and 6)

Based on the current characterization of the Site, there are two groundwater PFAS mass loading pathways to the Cape Fear River. First, the indirect pathway of groundwater to seeps to river, and second, the direct pathway of Black Creek groundwater discharging directly to the river.

4.4.1 Indirect Pathway – Groundwater to Seeps to River (Transport Pathway 5)

The PFAS mass loading from the seeps to the Cape Fear River will be estimated using measured PFAS concentrations and seep volumetric flow rates. The flow rates and PFAS concentrations of the three seep features that discharge to the Cape Fear River were measured as part of the field effort for the *Creeks, Old Outfall 002 and Seeps Assessment Workplan* (Geosyntec, 2019). These data, and one more dataset to be collected during a wet event will be used to assess the PFAS mass loading into the Cape Fear River. Additionally, at the mouth of each seep a flume or a weir will be installed to measure the baseflow volumetric flow rates in the seeps and the increase in flow rates during storm events.

4.4.2 Direct Pathway – Black Creek Groundwater Discharge to River (Transport Pathway 6)

At site, only the Black Creek Aquifer is in hydraulic connection with the Cape Fear River. Therefore, only the Black Creek Aquifer discharges directly into the Cape Fear River. The PFAS mass loading of discharging onsite Black Creek Aquifer groundwater to the Cape Fear River will be developed using two different approaches:

- a forward assessment based on Darcy's Law using hydrogeological data; and
- an inverse calculation using results from the PFAS mass loading model.

The forward assessment onsite groundwater mass loading will be estimated using groundwater concentration data from LTW wells at the Cape Fear River bank and volumetric discharge calculated using Darcy's Law from the following measured or estimated inputs (1) hydraulic gradient from LTW Well water level data and Cape Fear River water gauge height reported from USGS (USGS, 2018); (2) representative discharge area; and (3) hydraulic conductivity.

The inverse approach will calculate the contribution of onsite groundwater by first calculating the total PFAS mass load in the Cape Fear River from measured in Cape Fear River concentrations and flow rates. Then the onsite groundwater estimate will be calculated by subtracting the value of all other pathways from the calculated Cape Fear River PFAS mass load. The difference between these two numbers will be attributed to pathways non-quantitated, in this case onsite groundwater discharge.

Two approaches are proposed to assess onsite groundwater mass loading since the forward groundwater mass loading estimate has much more uncertainty than the mass loading estimates for the outfalls or creeks. This is because the groundwater mass loading estimates are based on measured concentrations and calculated (estimated) flow values. Groundwater flow can be highly heterogenous, and hydraulic conductivity can vary by two orders of magnitude in the same aquifer. Consequently, this leads to uncertainty in groundwater discharge rates that also can span two orders of magnitude. By contrast, the uncertainty in the mass loading estimates for the creeks, seeps and Outfall 002 is much more constrained since all the water carrying the PFAS mass load for each feature is present at surface in defined channel and can relatively easily and with much greater certainty have flow rates measured (i.e. salt dilution gauging, flumes or weirs, etc.).

4.5 Outfall 002 and Facility Stormwater Runoff (Transport Pathway 4)

The mass loading of PFAS from Outfall 002 to the Cape Fear River will be estimated using measured PFAS concentrations and measured Outfall 002 volumetric flowrates. Chemours collects two composite samples of Outfall 002 water each week for analysis for HFPO-DA and Table 3 compounds. The results of these analyses will be used in the PFAS Loading Model. Chemours also records the volume of flow discharging to the Cape Fear River from Outfall 002 daily. These flow values will be used in the PFAS Loading Model. These data will capture all water flowing through Outfall 002. This includes non-contact cooling water, treated non-Chemours process wastewater (DuPont and Kuraray process water), treated sanitary water and stormwater within the manufacturing area of the Site.

4.6 Offsite Groundwater (Transport Pathway 8)

The offsite groundwater PFAS mass loading contributions will be estimated by first separating offsite discharging groundwater into different zones. In each zone, the discharge mass loading will be estimated using residential well PFAS concentration data and volumetric discharge rate estimated using Darcy's Law from the following measured or estimated inputs (1) hydraulic gradient from available well water level data and Cape Fear River water gauge height reported from USGS (USGS, 2018); (2) representative discharge area; and (3) hydraulic conductivity.

4.7 Summary of Supporting Field Work

Field work will be performed to help support the development of the PFAS mass loading model. The three planned field work components are described in the list below:

1. Concentration and flow rate measurements at the mouths of the tributaries and seeps and in the Cape Fear River as described in the *Creeks, Old Outfall 002 and Seeps Assessment Workplan* (Geosyntec 2019). This effort was performed during dry weather. This field work was completed in early February 2019, with the exception of sampling at Georgia Branch Creek where access agreements are still pending for certain locations in the creek.

2. Wet weather sampling and flow rate measurements at mouths of the tributaries and seeps and in the Cape Fear River as described in the *Creeks, Old Outfall 002 and Seeps Assessment Workplan* (Geosyntec 2019). This field work has not yet been performed.

3. Installation of V-notch weirs of flumes at the CO Paragraph 12(e) identified treatment location for Old Outfall 002 and at the mouth of the three seeps from Site that flow into the Cape Fear River. Weirs and flumes both provide a method to estimate stream water flow by inspecting the water level flowing through the device. The higher the water level, the faster the flow. Level loggers will be placed in the flumes or weirs to record the flow rate going through these locations on 10-minute intervals based on a calculation converting water level to flow rate.

   The Old Outfall 002 location was selected since its baseflow needs to be established for compliance with the consent order. The seeps were selected as additional flume or weir locations because of their anticipated importance to the PFAS reductions plan. Preliminary data and analyses indicate that together the seeps and Old Outfall 002 contribute in excess of 50% of the PFAS load to the Cape Fear River. This field work has not yet been performed.

4. Slug testing of the five LTW wells to measure the hydraulic conductivity of Black Creek Aquifer near the Cape Fear River. These data will support the estimates of onsite groundwater discharge. This field work has not yet been performed.

5. MODEL CALIBRATION AND SENSITIVITY ANALYSIS

The PFAS mass loading model will be calibrated in order to help provide accurate and relevant estimates of pathway contributions to Cape Fear River and benefits from potential reduction actions. Then the sensitivity of the model to potential variability of input parameters will be assessed to understand the uncertainties in the model and which parameters have the greatest influence on PFAS loads in the Cape Fear River. Both the calibration and sensitivity scope of work are described in the subsections below.

5.1 Model Calibration

The total PFAS mass loading will be calculated from the concentration and flow data collected for the mass loading components in **Table 1** during both a dry weather time period (i.e., baseflow conditions) and during a storm event. The performance of the PFAS mass loading model will be assessed by doing a mass balance calculation by summing the mass loading pathways and comparing the result to estimated mass loads in the Cape Fear River based on measurements of Cape Fear River PFAS concentrations and volumetric flow rates. These data will be collected by Chemours, and potentially from third party data sources such as CFPUA depending on the timing, availability and appropriateness of these data (i.e. raw water data analyses are required for this analysis, not finished water analyses). The model will then be calibrated by adjusting parameters within ranges of assumed or observed measurement variabilities. A first iteration of this model was calibrated similarly as presented in the Mass Flux Assessment in Appendix A of the Parsons, 2018a *Focused Feasibility Study Report – PFAS Remediation.* This earlier version created a predictive model of Cape Fear River concentrations that was calibrated by varying the hydraulic conductivity parameter for discharging groundwater. Notably, this earlier iteration did not include the groundwater seeps which had not yet been identified. Based on initial data, to be reported in detail in as part of this modeling scope of work, the groundwater seeps comprise a significant fraction of the PFAS mass load previously ascribed to discharging groundwater.

5.2 Sensitivity Analysis

A sensitivity analysis will be performed to assess potential uncertainties in modeled results, specifically how the potential range of model input parameters values affects the estimated PFAS mass loads in the Cape Fear River. The sensitivity analysis will identify model input parameters that have the greatest effect on calculated mass loads in the Cape Fear River. Elements that will be included in the sensitivity analysis include evaluating model sensitivities to varying:

- Aerial deposition rates for PFAS;

- Flow rates at Willis Creek, Georgia Branch, Old Outfall 002 and Seep A, Seep B, and Seep C;
- Calculated discharging groundwater flow rate;
- Offsite groundwater discharge rates; and
- PFAS concentrations.

Additional model input parameters may be identified during the model calibration process. Reductions in model uncertainties will be attempted through additional field and/or analytical effort as necessary and possible in the timeframe available.

6. SUMMARY

This document described a scope of work for preparing a PFAS mass loading model. The model will estimate the mass load of PFAS associated with the Site reaching the Cape Fear River by estimating and then summing the PFAS loads from the identified PFAS transport pathways. The model will be used to evaluate which pathways contribute the greatest load of PFAS originating from the Site to the Cape Fear River. The outcome of this assessment will form the basis for identifying which pathways to address and then assessing the benefits of potential actions on these pathways to reduce PFAS loading to the Cape Fear River. The final outcome of this effort will be a Cape Fear River PFAS Loading Reductions Plan that describes the actions, supported by interim bench marks, that Chemours proposes implementing within a two- or five-year time period to reduce PFAS loads at downstream water intakes.

7. REFERENCES

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USGS, 2018. National Water Information System: Web Interface. Accessed March 2019. https://waterdata.usgs.gov/nwis/uv?site_no=02105500

TABLES

TABLE 1
PFAS MASS LOADING MODEL POTENTIAL PATHWAYS
Chemours Fayetteville Works, North Carolina

Transport Pathway No.	PFAS Transport Pathway	Concentration Data[1]	Flow Data[1]
1	**Up-Stream Cape Fear River**	***Measured*** from samples collected in the Cape Fear River	***Estimated*** from flow data measured at Site at the W.O. Huske Dam
2	**Willis Creek**	***Measured*** from samples collected in Willis Creek	***Measured*** from salt dilution gauging and flow velocity meter data
3	**Aerial Deposition on Cape Fear River**	***Estimated*** from air deposition modelling results[2]	***Estimated*** from air deposition modelling results[2]
4	**Outfall 002**	***Measured*** from composite samples collected from Outfall 002	***Measured*** daily Outfall 002 flow rates are recorded by Site Staff.
5	**Groundwater Seeps (Seep A, Seep B and Seep C)**	***Measured*** from samples collected in the seeps	***Measured*** from salt dilution gauging and weir data
6	**Upwelling On-Site Groundwater**	***Measured*** from samples collected from LTW wells adjacent to the River	***Estimated*** based on measured and estimated hydrogeological parameters
7	**Old Outfall 002**	***Measured*** from samples collected in Old Outfall 002	***Measured*** from salt dilution gauging, flow meter and weir data
8	**Off-Site Groundwater (Up & Downstream)**	***Measured*** from groundwater samples collected at residences near the River	***Estimated*** based on measured and estimated hydrogeological parameters
9	**Georgia Branch Creek**	***Measured*** from samples collected in Georgia Branch Creek	***Measured*** from salt dilution gauging and flow velocity meter data

Notes
1 - Flow and concentration data are multiplied together to estimate the PFAS mass load in the Cape Fear River originating from each pathway.
2 - ERM, 2018. Modeling Report: HFPO-DA Atmospheric Deposition and Screening Groundwater Effects. 27 April 2018.

TABLE 2
ANALYTICAL METHODS AND ANALYTE LIST
Chemours Fayetteville Works, North Carolina

Analytical Method	Common Name	Chemical Name	CASN	Chemical Formula	PQL (ng/L)	
					TestAmerica	Eurofins Lancaster
Table 3+ Lab SOP	HFPO-DA	Hexafluoropropylene oxide dimer acid	13252-13-6	C6HF11O3	2.0	2.0
	PEPA	Perfluoroethoxypropyl carboxylic acid	267239-61-2	C5HF9O3	20	20
	PFECA-G	Perfluoro-4-isopropoxybutanoic acid	801212-59-9	C12H9F9O3S	2.0	2.0
	PFMOAA	Perfluoro-2-methoxyaceticacid	674-13-5	C3HF5O3	5.0	5.0
	PFO2HxA	Perfluoro(3,5-dioxahexanoic) acid	39492-88-1	C4HF7O4	2.0	2.0
	PFO3OA	Perfluoro(3,5,7-trioxaoctanoic) acid	39492-89-2	C5HF9O5	2.0	2.0
	PFO4DA	Perfluoro(3,5,7,9-tetraoxadecanoic) acid	39492-90-5	C6HF11O6	2.0	2.0
	PMPA	Perfluoromethoxypropyl carboxylic acid	13140-29-9	C4HF7O3	10	10
	Hydro-EVE Acid	Perfluoroethoxsypropanoic acid	773804-62-9	C8H2F14O4	2.0	2.0
	EVE Acid	Perflouroethoxypropionic acid	69087-46-3	C8HF13O4	2.0	2.0
	MMF	Difluoromalonic acid	1514-85-8	C3H2F2O4	100	100
	MTP	Perfluoro-2-methoxypropanoic acid	93449-21-9	C4H4F4O3	20	20
	PPF Acid	Pentafluoropentionic acid	422-64-0	C3HF5O2	20	20
	PFECA B	Perfluoro-3,6-dioxaheptanoic acid	151772-58-6	C5HF9O4	2.0	2.0
	R-EVE	R-EVE	N/A	C8H2F12O5	2.0	2.0
	PFO5DA	Perfluoro-3,5,7,9,11-pentaoxadodecanoic acid	39492-91-6	C7HF13O7	2.0	2.0
	Byproduct 4	Byproduct 4	N/A	C7H2F12O6S	2.0	2.0
	Byproduct 6	Byproduct 6	N/A	C6H2F12O4S	2.0	2.0
	Byproduct 5	Byproduct 5	N/A	C7H3F11O7S	2.0	2.0
	DFSA	Difluoro-sulfo-acetic acid	422-67-3	C2H2F2O5S	100	100
	NVHOS	Perflouroethoxysulfonic acid	1132933-86-8	C4H2F8O4S	2.0	2.0
	PES	Perfluoroethoxyethanesulfonic acid	113507-82-7	C4HF9O4S	2.0	2.0
	PFESA-BP1	Byproduct 1	29311-67-9	C7HF13O5S	2.0	2.0
	PFESA-BP2	Byproduct 2	749836-20-2	C7H2F14O5S	2.0	2.0
EPA Method 537 Mod	PFBA	Perfluorobutanoic acid	375-22-4	C4HF7O2	2.0	5.5
	PFDA	Perfluorodecanoic acid	335-76-2	C10HF19O2	2.0	1.8
	PFDoA	Perfluorododecanoic acid	307-55-1	C12HF23O2	2.0	1.8
	PFHpA	Perfluoroheptanoic acid	375-85-9	C7HF13O2	2.0	0.91
	PFNA	Perfluorononanoic acid	375-95-1	C9HF17O2	2.0	1.8
	PFOA	Perfluorooctanoic acid	335-67-1	C8HF15O	2.0	0.91
	PFPeA	Perfluorohexanoic acid	307-24-4	C5HF9O2	2.0	1.8
	PFPeA	Perfluoropentanoic acid	2706-90-3	C5HF9O2	2.0	5.5
	PFTeA	Perfluorotetradecanoic acid	376-06-7	C14HF27O2	2.0	0.91
	PFTriA	Perfluorotridecanoic acid	72629-94-8	C13HF25O2	2.0	0.91
	PFUnA	Perfluoroundecanoic acid	2058-94-8	C11HF21O2	2.0	1.8
	PFBS	Perfluorobutanesulfonic acid	375-73-5	C4HF9SO	2.0	0.91
	PFDS	Perfluorodecanesulfonic acid	335-77-3	C10HF21O3S	2.0	1.8
	PFHpS	Perfluoroheptanesulfonic acid	375-92-8	C7HF15O3S	2.0	1.8
	PFHxS	Perfluorohexanesulfonic acid	355-46-4	C6HF13SO3	2.0	1.8
	PFNS	Perfluorononanesulfonic acid	68259-12-1	C9HF19O3S	2.0	1.8
	PFOS	Perfluorooctanesulfonic acid	1763-23-1	C8HF17SO3	2.0	1.8
	PFPeS	Perfluoropentanesulfonic acid	2706-91-4	C5HF11O3S	2.0	1.8
	10:6 FTS	10:2-fluorotelomersulfonic acid	120226-60-0	C12H5F21O3	2.0	2.7
	4:2 FTS	4:2 fluorotelomersulfonic acid	757124-72-4	C6H5F9O3S	20	2.7
	6:2 FTS	6:2 fluorotelomersulfonic acid	27619-97-2	C8H5F13SO3	20	1.8
	8:2 FTS	8:2 fluorotelomersulfonic acid	39108-34-4	C10H5F17O3S	20	5.5
	NEtFOSAA	NEtFOSAA	2991-50-6	C12H8F17NO4S	20	2.7
	NEtPFOSA	NEtPFOSA	4151-50-2	C10H6F17NO2S	2.0	8.2
	NEtPFOSAE	NEtPFOSAE	1691-99-2	C12H10F17NO3S	2.0	2.7
	NMeFOSAA	NMeFOSAA	2355-31-9	C11H6F17NO4S	20	2.7
	NMePFOSA	NMePFOSA	31506-32-8	C9H4F17NO2S	2.0	8.2
	NMePFOSAE	NMePFOSAE	24448-09-7	C11H8F17NO3S	2.0	2.7
	PFDOS	Perfluorododecanesulfonic acid	79780-39-5	C12HF25O3S	2.0	0.91
	PFODA	Perfluorohexadecanoic acid	67905-19-5	C16HF31O2	2.0	0.91
	PFODA	Perfluorooctadecanoic acid	16517-11-6	C18HF35O2	2.0	1.8
	PFOSA	Perfluorooctanesulfonamide	754-91-6	C8H2F17NO2S	2.0	2.7

Notes:

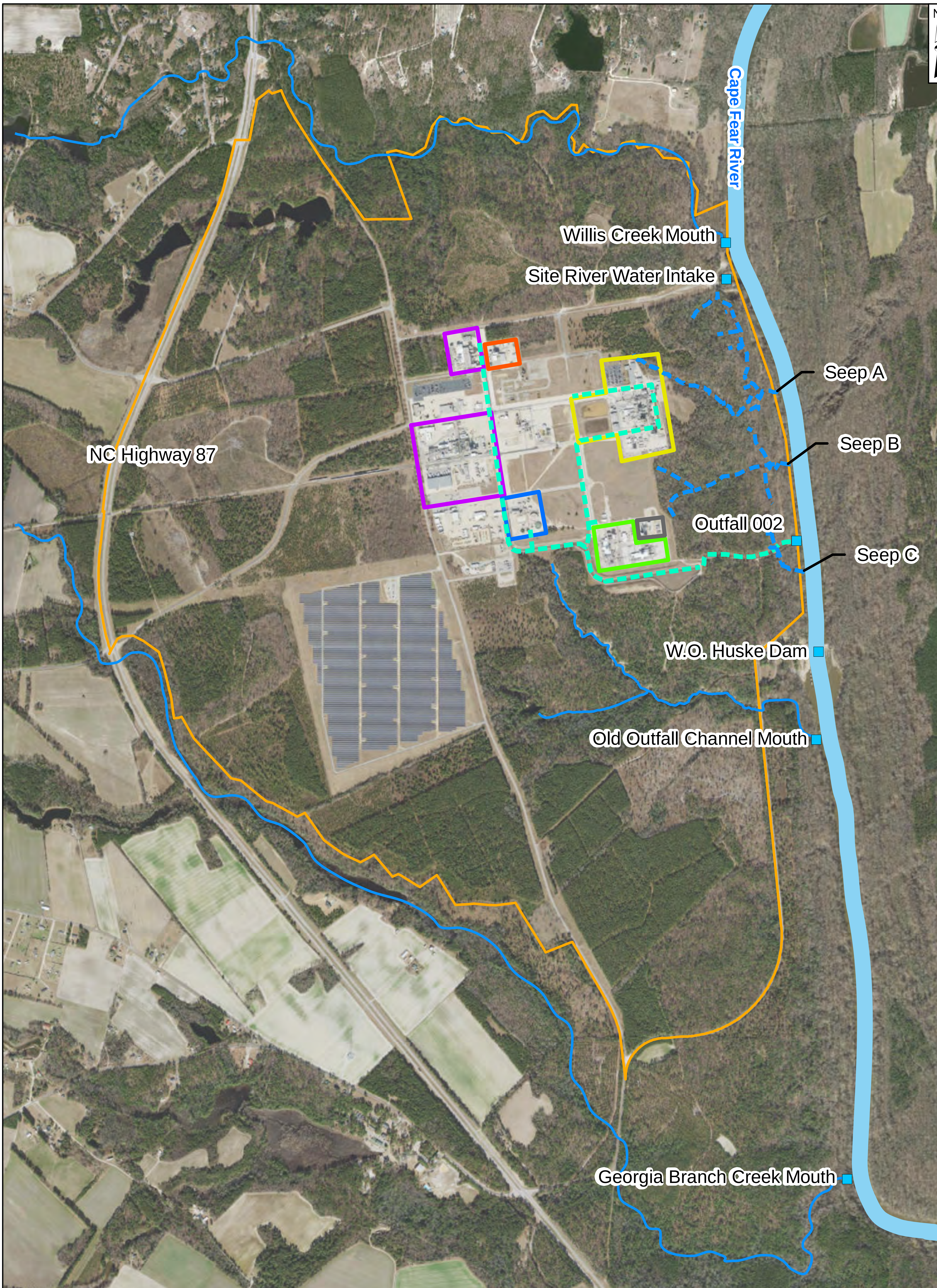
EPA - Environmental Protection Agency SOP - Standard Operating Protocol

PQL - practical quantitation limit

ng/L - nanograms per liter

PFAS - per- and polyfluoroalkyl substances

FIGURES



Legend

- Site Features
- Cape Fear River
- Nearby Tributaries
- Observed Seep (Natural Drainage)
- Site Drainage Network
- Site Boundary

Areas at Site

- Chemours Monomers IXM
- Chemours PPA
- Dupont / Dow Leased
- Former Teflon Production
- Kuraray America Leased
- Wastewater Treatment Plant

Notes:
Basemap Sources: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

2,000 1,000 0 2,000 Feet

Site Location Map

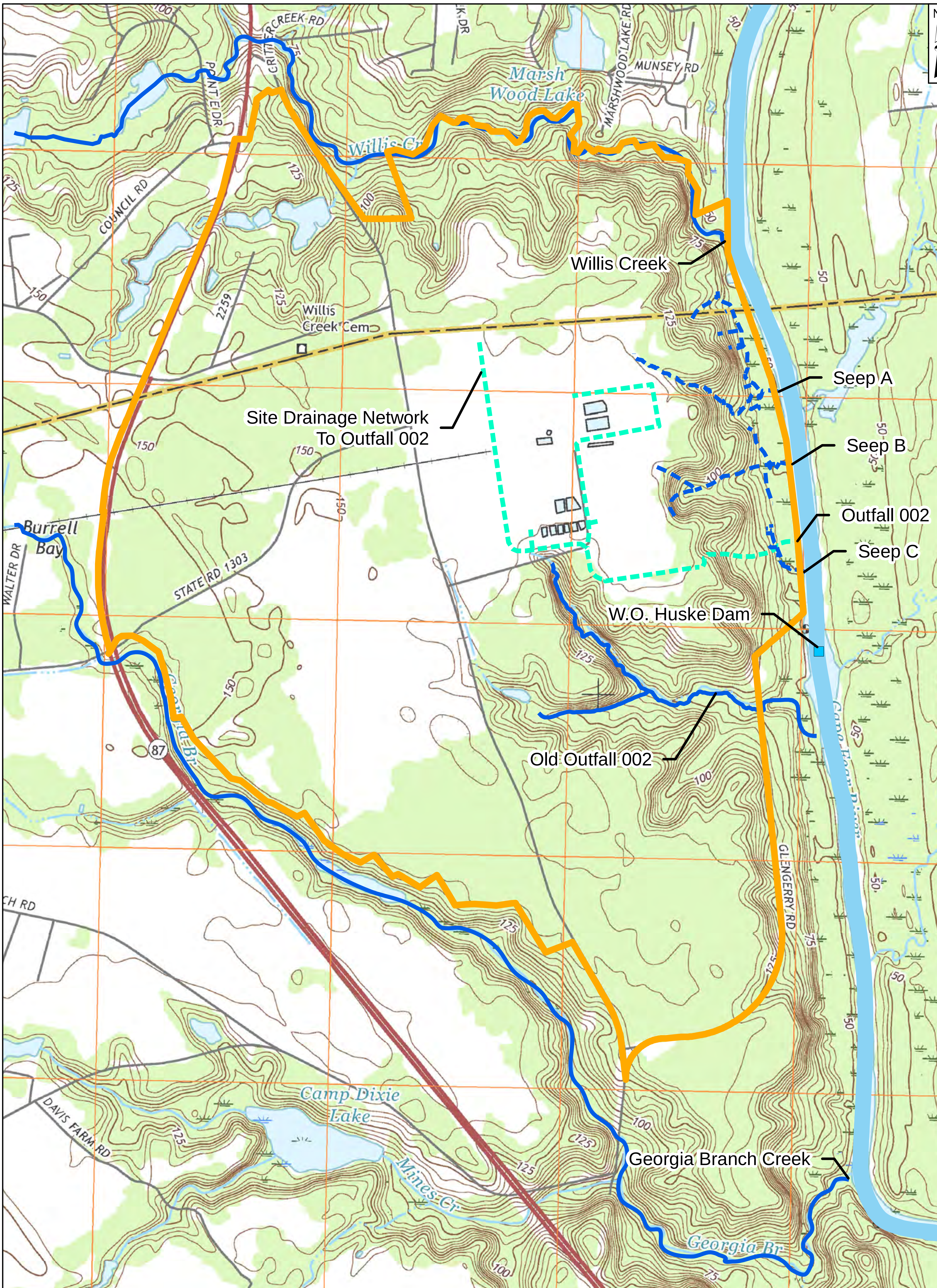
Chemours Fayetteville Works, North Carolina

Geosyntec
Consultants of NC, PC
NC License No.: C-3500

Figure 1

Raleigh | April 2019

Path: E:\TR0726\CapeFear_Report_2019\TR0726_SiteFeatures.mxd; JK; 04/10/2019



Legend

- Site Features
- Site Drainage Network
- Chemours Fayetteville Works
- Observed Seep (Natural Drainage)
- Cape Fear River
- Nearby Tributaries

Notes:
Basemap sources: Esri, Garmin, USGS, NPS (World Terrain Reference); Esri, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community (World Hillshade)

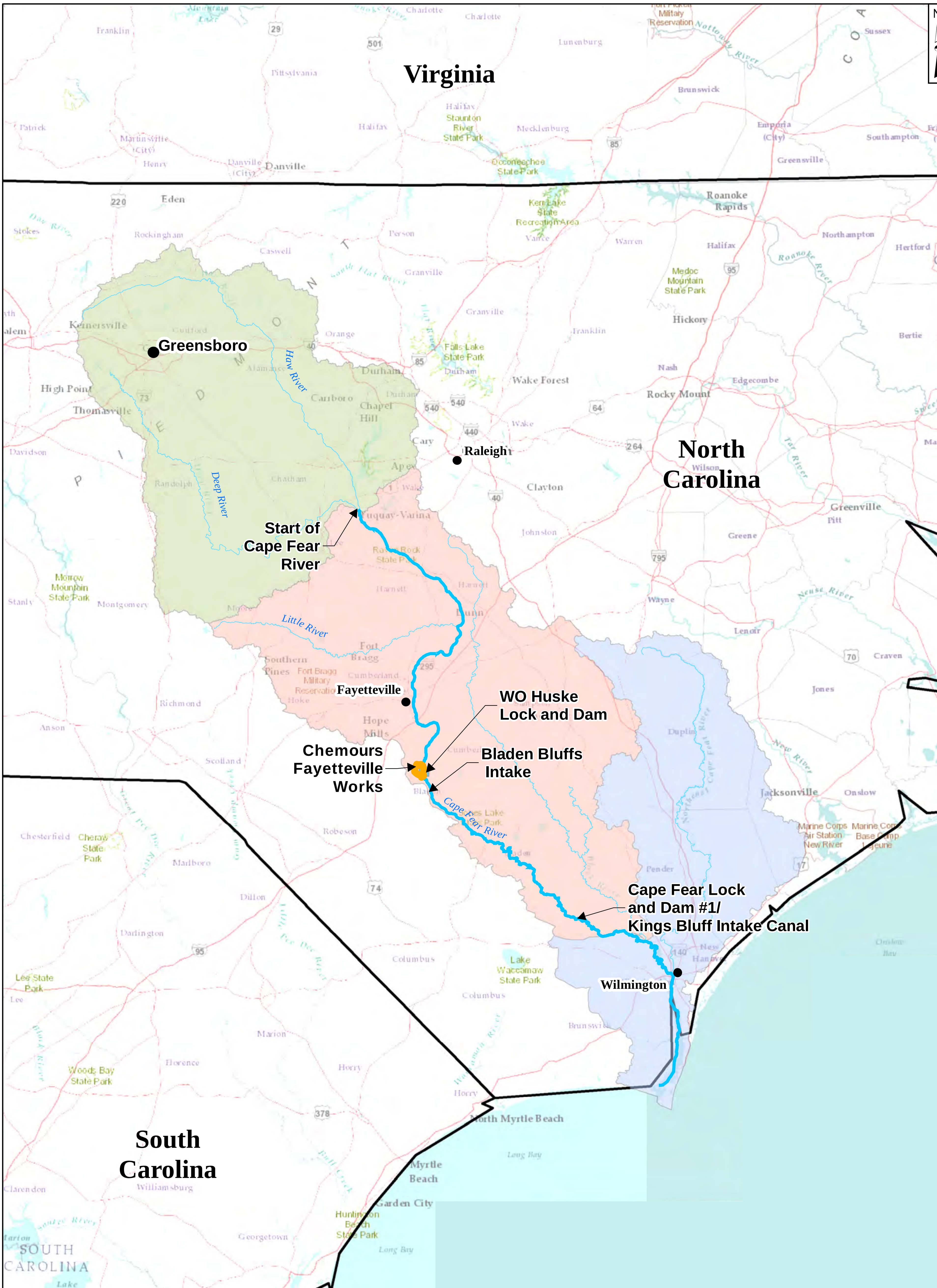
2,000 1,000 0 2,000 Feet

Site Topographic Map

Chemours Fayetteville Works, North Carolina

Geosyntec
Consultants of NC, PC
NC License No.: C-3500

Raleigh	April 2019	Figure 2



Legend

Chemours Fayetteville Works	Upper Basin
Cape Fear River	Middle Basin
	Lower Basin

Notes:
Basemap sources: Esri, Garmin, USGS, NPS (World Terrain Reference); Esri, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community (World Hillshade)

20 10 0 20 Miles

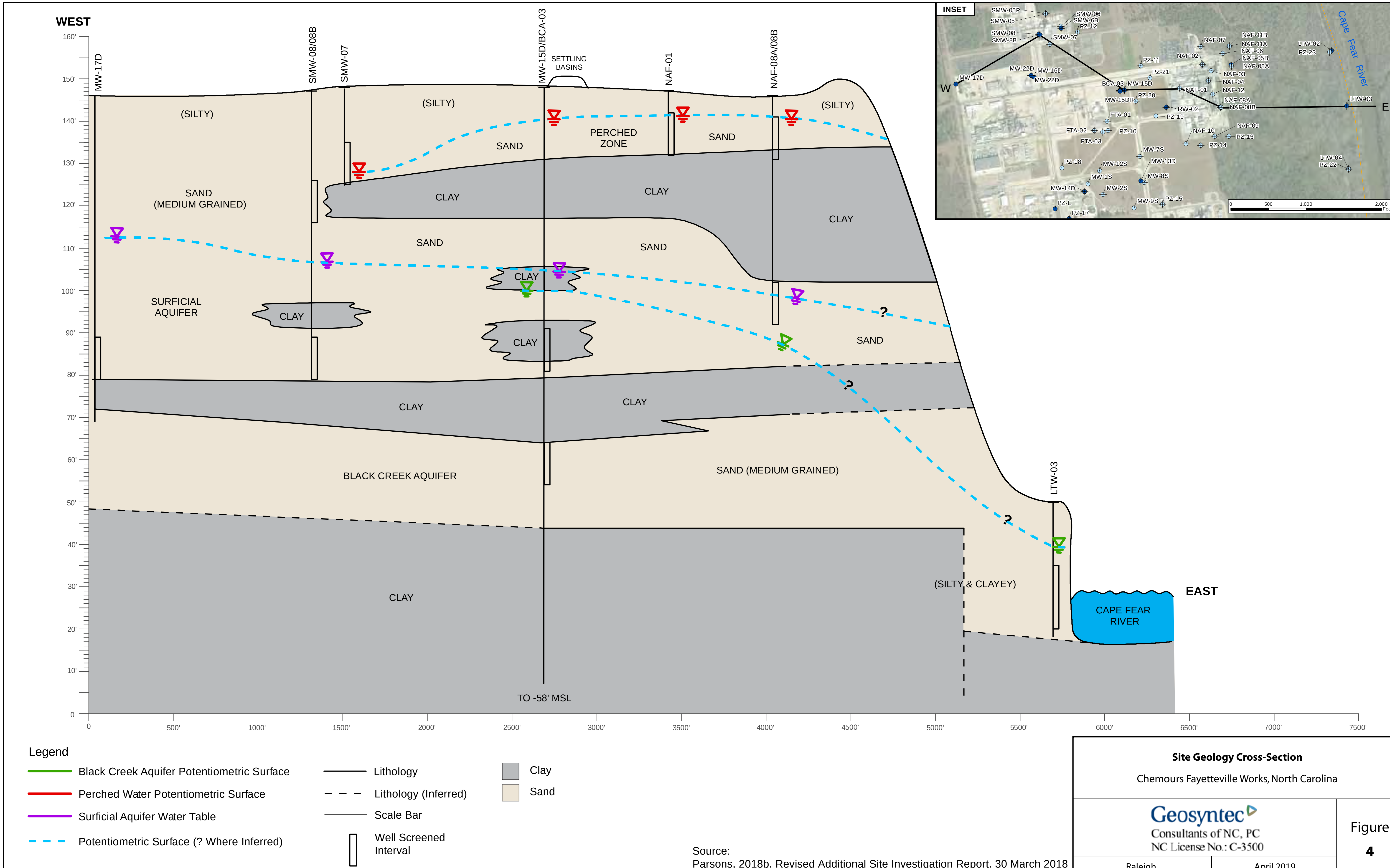
Cape Fear River Watershed and Downstream Public Utility Intakes

Chemours Fayetteville Works, North Carolina

Geosyntec
Consultants of NC, PC
NC License No.: C-3500

Guelph | April 2019

Figure 3



Source:
Parsons, 2018b. Revised Additional Site Investigation Report. 30 March 2018

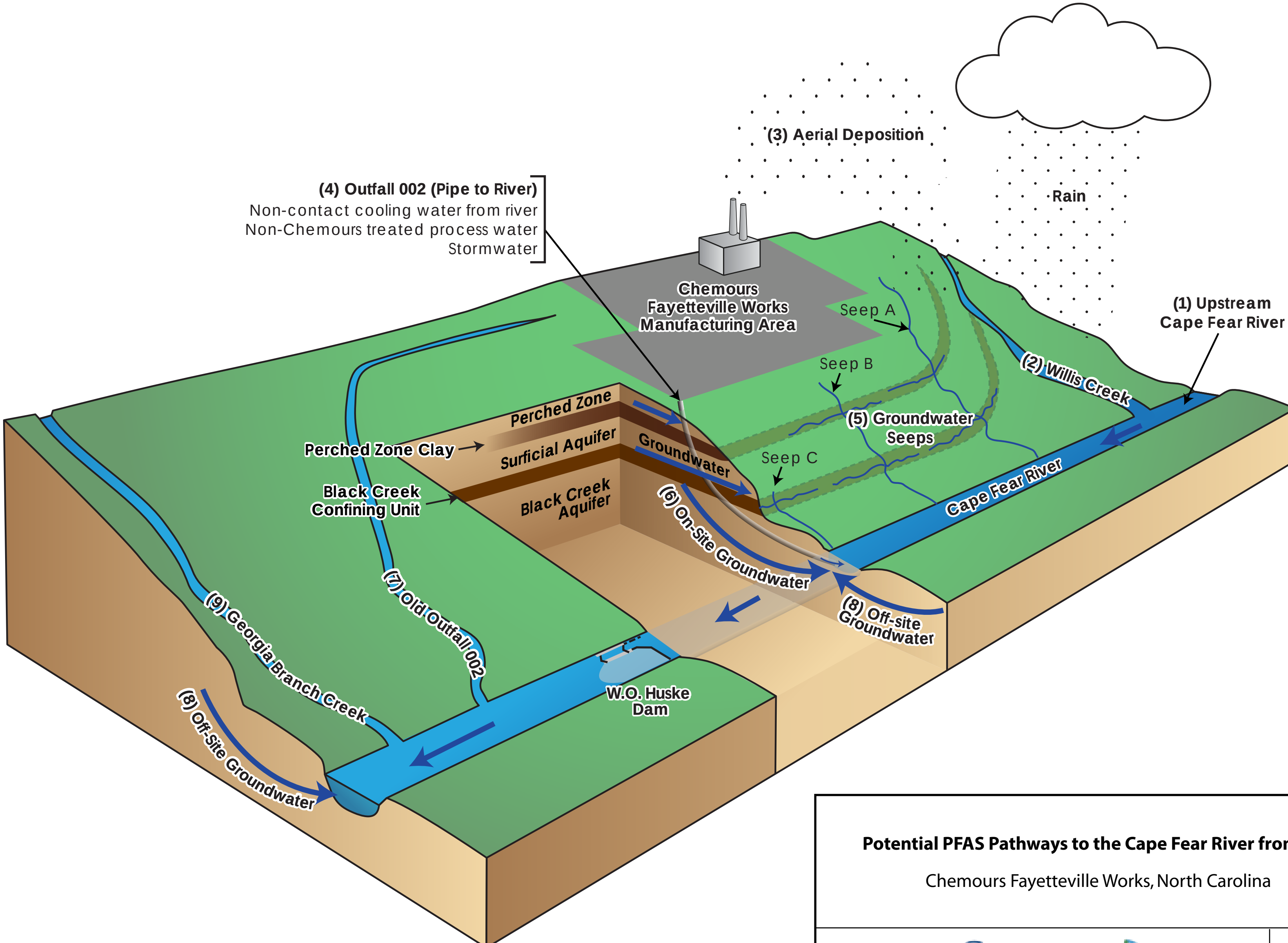
Site Geology Cross-Section

Chemours Fayetteville Works, North Carolina

Geosyntec
Consultants of NC, PC
NC License No.: C-3500

Raleigh | April 2019

Figure 4



Note:
Figure is schematic depicting potential PFAS transport pathways to the Cape Fear River at and near Site. The figure is not to scale.

Potential PFAS Pathways to the Cape Fear River from Site Chemours Fayetteville Works, North Carolina		
Geosyntec Consultants of NC, PC NC License No.: C-3500		Figure 5
Raleigh	April 2019	

APPENDIX A

Supplemental Information

Parsons, 2018a. Focused Feasibility Study Report – PFAS Remediation, Chemours Fayetteville Works. RCRA Permit No. NCD047362642-R2-M3.

APPENDIX A
MASS FLUX ASSESSMENT

PARSONS

CAPE FEAR RIVER DIMER ACID CONCENTRATION AND MASS FLUX ASSESSMENT SUMMARY

Dimer Acid is present in the Cape Fear River (the river) down river of the Chemours Fayetteville Works Site (the Site). Dimer Acid river concentrations are controlled by Dimer Acid mass flux to the river and the volume of water flowing in the river. An assessment of Dimer Acid mass flux in the river was performed to achieve the following objectives:

- Identify potential pathways for Dimer Acid to reach the river;
- Evaluate the mass flux contributions from each potential pathway; and
- Estimate future concentrations of Dimer Acid in the river by preparing an analytical model.

The objectives listed above build upon each other and were thus fulfilled sequentially. The paragraphs below describe how each objective was fulfilled, and the observations obtained from each objective.

Identify Potential Pathways

Potential pathways for Dimer Acid to reach the river were identified by reviewing Site cross sections, Site aerial imagery, Site data and discussions with Chemours personnel. Identified potential pathways are listed below and are graphically represented in the conceptual image presented in Figure 1:

- The up-stream river;
- Willis Creek;
- Direct aerial deposition to the river;
- Outfall 002;
- On-Site upwelling groundwater;
- Surface water runoff;
- Flow in the historic outfall channel;
- Off-Site (up- and down-river) upwelling groundwater; and
- Georgia Branch Creek.

Evaluate Mass Flux Contributions

The mass flux reaching the river is the combined mass per unit time (e.g. nanograms per second) from each identified potential pathway listed above. For mass transported by water (e.g. groundwater, surface water, outfalls) mass flux is calculated by multiplying the volumetric flow of the water (e.g. liters per second) by the concentration of Dimer Acid in the water (e.g. nanograms per liter; ng/L). Mass flux for each potential pathway was estimated using Site data, and representative physical properties where Site data were unavailable. The mass flux assessment was prepared and compared to Site data. This included data collected as part of a surface water sampling event conducted on 26-27 September 2017. Sample collection dates for data used to quantify each pathway are presented in Table 1.

The data used to quantify the mass flux for each pathway and the results of the assessment are presented in Table 2. The results are compared against the average, down-river Dimer Acid concentration from the 26-27 September 2017 sampling event, 39.25 ng/L. The mass flux assessment estimated that the combined mass flux contributions to the river would result in a Dimer Acid concentration ranging from 26 to 64 ng/L, (i.e. 66% to 160%) of observed Dimer Acid on 26-27 September. The two largest contributors of Dimer Acid mass flux were first upwelling Site groundwater and second the Historic Outfall. Upwelling groundwater was estimated to potentially contribute between 12 to 47 ng/L, (i.e. 30% to 120%) of observed Dimer Acid in the river. The Historic Outfall, using data from 16 January 2017, was estimated to contributed 9 ng/L (i.e. 23%) to observed river concentrations.

It should be noted that upwelling groundwater mass flux estimates have more uncertainty than any of the mass flux estimates for the outfalls or creeks. This is because the groundwater mass flux estimates are based on measured concentrations and calculated (estimated) flow, while for creeks and outfalls both concentrations and flow were measured. Consequently, a second approach was used to estimate upwelling groundwater contributions to in-river Dimer Acid concentrations. The second approach estimated these contributions by subtracting all other mass flux contributions from the observed river concentrations. Based on this assessment upwelling groundwater was estimated to contribute between 22.5 to 26 ng/L (i.e. 57% to 66%) of Dimer Acid concentrations observed in the river, which is within the range of the previous estimate.

Estimate Future River Dimer Acid Concentrations

An analytical river mass flux model was created to estimate future river Dimer Acid concentrations. The model estimated both Dimer Acid: i) concentrations in the river; and ii) travel times in river water. Specifically travel times are estimated for the down-stream public utility water intakes at Bladen Bluffs, 7.5 miles down-river, and Kings Bluff Intake Canal, 55 miles down-river. The model was created in Microsoft Excel using the following data sources:

i. Input mass fluxes from the mass flux assessment;

ii. Outfall 002 concentration and flow data provided by Chemours to calculate Outfall 002 mass flux for specific dates; and

iii. Daily mean river volumetric flow data and gauge height data reported by United States Geological Survey (USGS) for the W.O. Huske Dam gauging station.

The model operates by first estimating mass flux inputs into the river for a given date using the approach described for the mass flux assessment. Model calculations are only performed for dates where measured Outfall 002 concentration and flow data exist. The concentration of Dimer Acid in the river is then calculated by dividing the mass flux (e.g. nanograms per second) by the USGS reported river flow rate (e.g. liters per second). Next the arrival time of this water at the down-river intakes is estimated using the estimated river water velocity. River water velocities were estimated by calculating how quickly the measured volumetric flow of water must pass through the estimated cross-sectional area of the river. River cross sectional areas were estimated using river gauging data from the 26 to 27 September 2017 sampling event and USGS reported river gauge heights.

River mass flux model results using input data from 14 June 2017 to 29 January 2018 are presented in Figure 2 for Bladen Bluffs and Figure 3 for Kings Bluff Intake Canal. In each figure the modeled results are compared to publicly reported, measured river concentrations. The river mass flux model results show a good fit compared to observed river Dimer Acid concentrations at the two down-river water intake locations.

Since 1 August 2017 river concentrations have been measured to be less than 140 ng/L except for the temporary increase in early October 2017, which matches the model results. The increase in October 2017 was related to a temporary increase in Outfall 002 concentrations and mass flux. Assuming standard operating conditions at the Site and similar environmental conditions, future river concentrations are estimated to remain below 140 ng/L.

TABLE 1
POTENTIAL DIMER ACID PATHWAYS TO CAPE FEAR RIVER AND DATA SOURCES FOR ASSESSMENT
Chemours Fayetteville Works

Pathway	Concentration Data	Flow Data
Up-Stream River	26-27 Sept. 2017 Data	26-27 Sept. 2017 Data
Willis Creek	26-27 Sept. 2017 Data	16 Jan. 2018 Data
Aerial Deposition on River	Estimated from NCDEQ Air Dispersion Modelling	
Outfall 002	26-27 Sept. 2017 Data	26-27 Sept. 2017 Data
On-Site Groundwater	26-27 Sept. 2017 Data	Calculated
Surface Water Run-Off	Inferred. No Rain.	Inferred. No Rain.
Historic Outfall Channel	16 Jan. 2018 Data	16 Jan. 2018 Data
Off-Site Groundwater (Up & Down River)	Residential Well Data	Calculated
Georgia Branch Creek	26-27 Sept. 2017 Data	16 Jan. 2018 Data

TABLE 2
POTENTIAL PATHWAY ESTIMATED DIMER ACID MASS FLUXES COMPARED TO MEASURED RIVER CONCENTRATIONS
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Potential Pathway	Concentration (ng/L)	Flow (L/s)	Mass Flux (ng/s)	Estimated Contribution to River Concentration (ng/L)
Up-Stream River	0	25,500	0	0
Willis Creek	310 – 450	170 – 250	52,700 - 112,500	2.0 - 4.5
Aerial Deposition on River[1]	--	--	6,000	0.25
Outfall 002	35	900	31,500	1.25
On-Site Groundwater[2]	25,000 – 50,000	12 – 24	300,000 – 1,200,00	12 – 47
Surface Water Run-Off[3]	NA	NA	0	0
Historic Outfall	8,400	27	227,000	9
Off-Site Groundwater (Up & Down River)[4]	147 – 179	110 – 180	16,000 - 32,250	0.5 - 1.25
Georgia Branch Creek	540 – 1,100	8 – 16	4,500 – 17,500	0.2 – 0.7
Total Estimated Mass Flux and Corresponding River Concentration	**--**	**--**	**665,000 – 1,625,000**	**26 – 64**
Measured[5] Concentration and Flow Down River 5 Miles and Calculated Mass Flux	**39.25**	**25,500**	**1,000,000**	**39.25**

Notes

[1] Direct aerial deposition to the river mass flux estimates were made based on NCDEQ presented modelling results.
https://www.ncleg.net/documentsites/committees/house2017-185/Meetings/3%20-%20Nov%2030%202017/DEQ%20Final%20PowerPoint%20Pres.pdf

[2] On-Site groundwater flux range estimated assuming discharge areas of 18,500 to 37,000 square meters, calculated gradient of 0.064 between LTW Wells to Cape Fear River, measured maximum and average LTW Well concentrations of 50,000 and of to 25,000 ng/L, and a estimated hydraulic conductivity of 10^{-5} m/s, representative of silty sand.

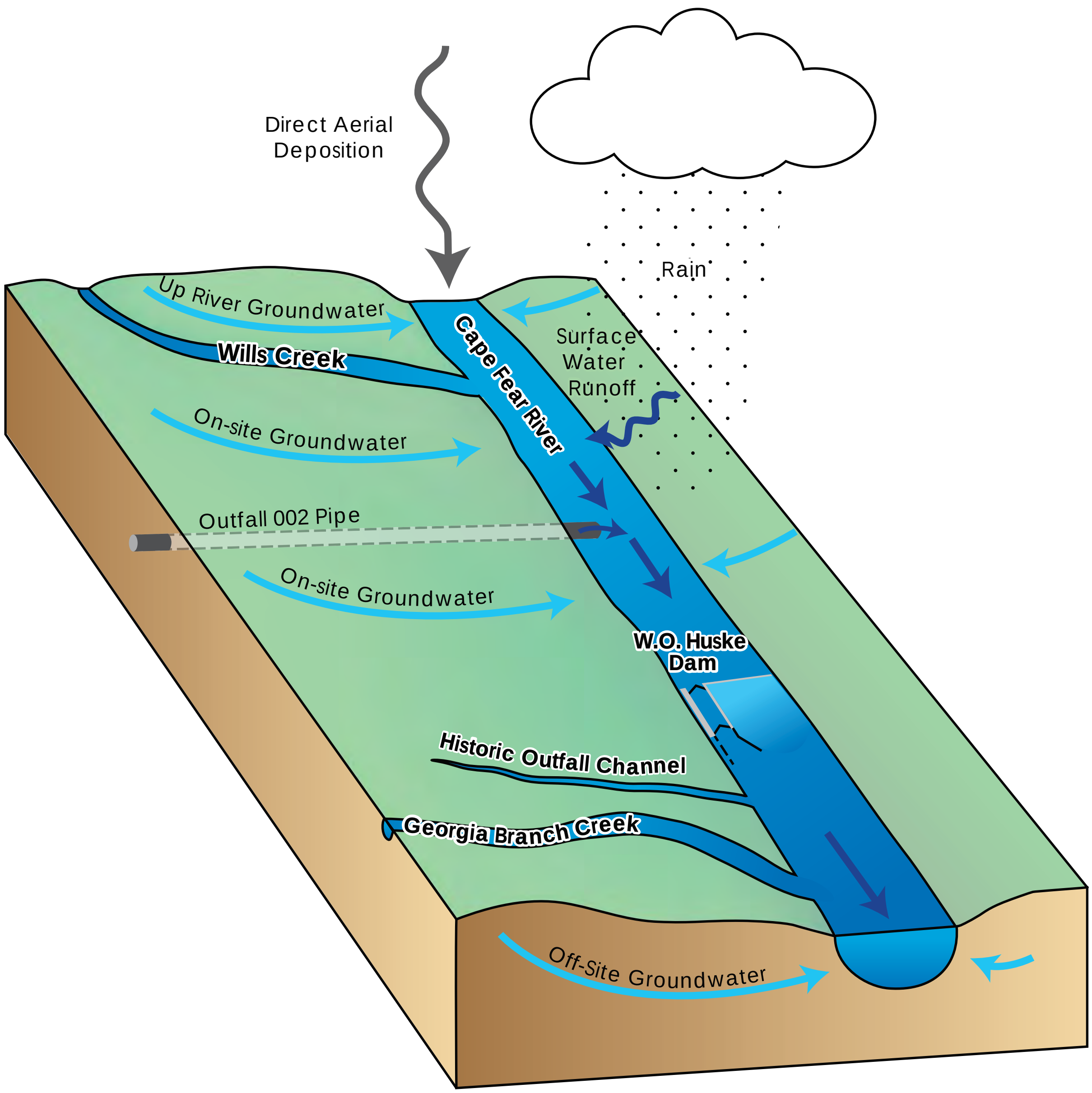
[3]During the 26-27 September 2017 sampling event there was no rain before or during the event, therefore the run-off flux is 0 ng/s.

[4] Off-Site groundwater was estimated using residential well concentration data and the same hydraulic conductivity value, 10^{-5} m/s, used for on-Site groundwater upwelling estimates. The on-Site gradient value, 0.064, was used in estimating upwelling on the same side of the river as the site (west). A lower gradient, 0.0064, was used for the opposite side of the river (east) where land surface topography is more subdued.

[5] Measured data are from the 26-27 September 2017 surface water sampling event.

Acronyms

L/s - liters per second
m/s - meters per second
ng/L - nanograms per liter
ng/s - nanograms per second



Conceptual Diagram: Potential Dimer Acid Pathways to Cape Fear River

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Figure 1

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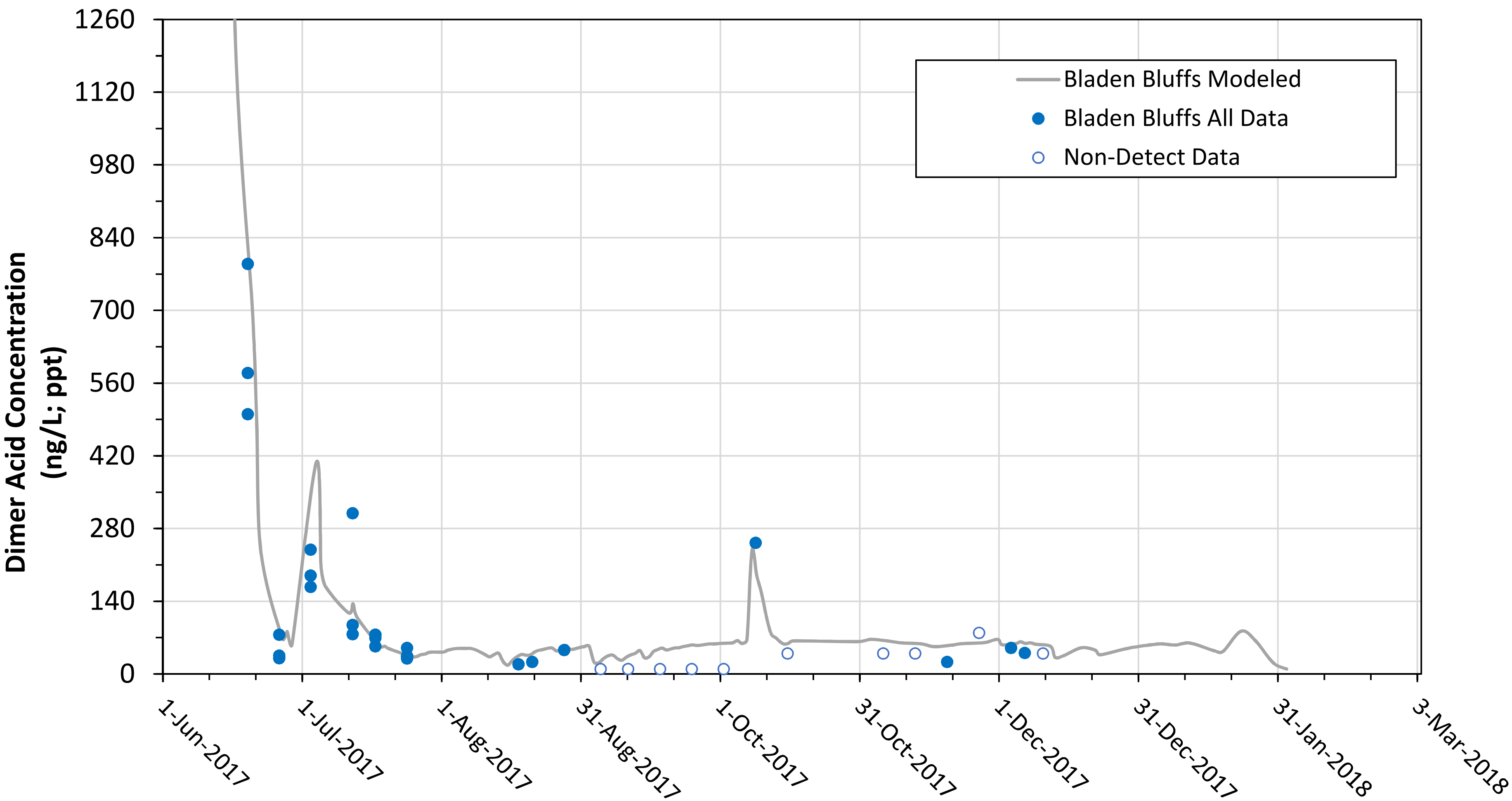

Notes:
ng/L - nanograms per liter
ppt - parts per trillion

River Mass Flux Model Estimates at Bladen Bluffs

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Figure **2**

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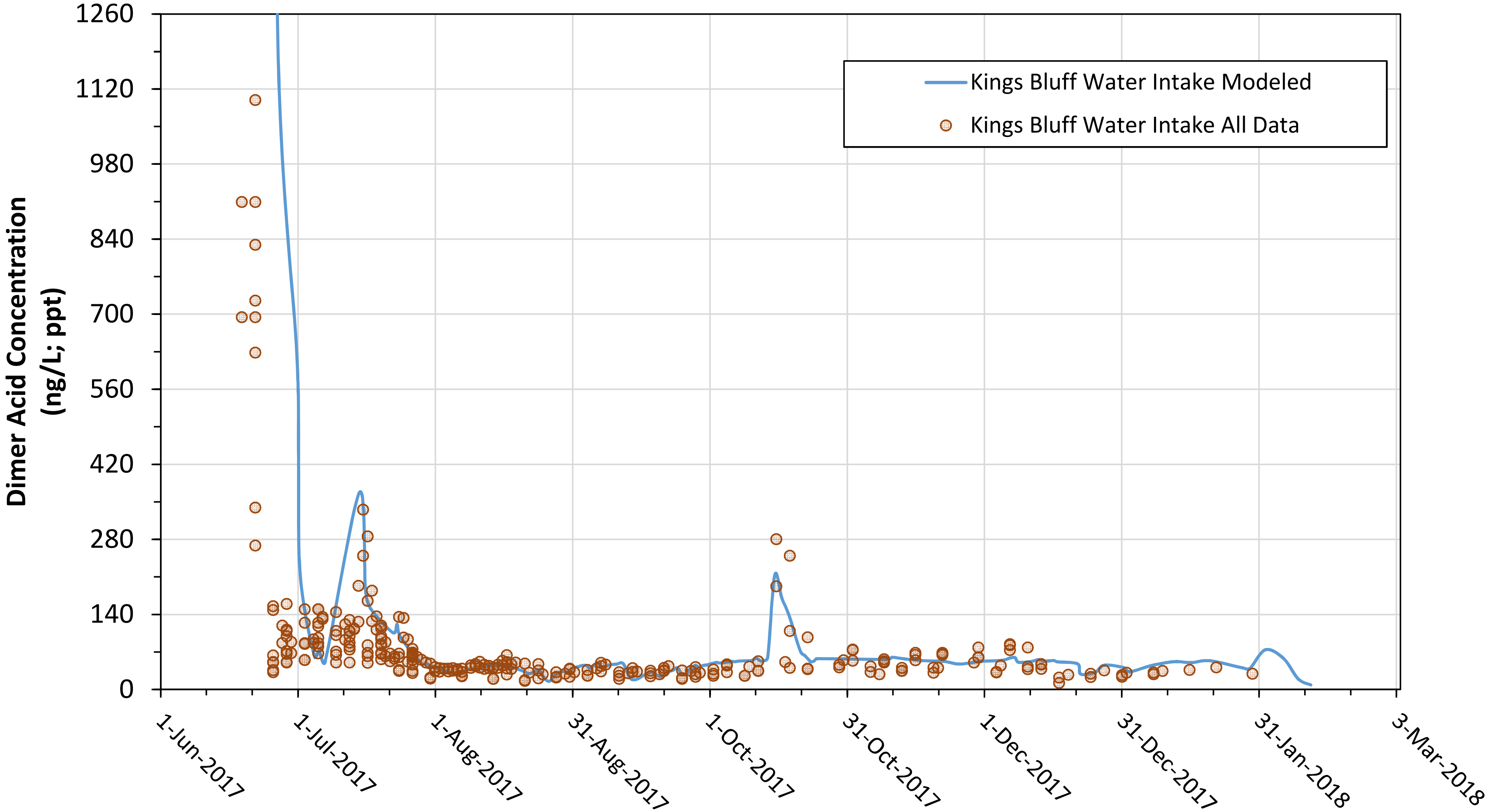

Notes:
ng/L - nanograms per liter
ppt - parts per trillion

River Mass Flux Model Estimates at Kings Bluff Intake Canal
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Figure 3

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