

Geosyntec Response to NCDAQ Comments

May 18, 2018

This document has been prepared to provide responses to comments provided by North Carolina Department of Air Quality (“NCDAQ”) on May 11, 2018 to a letter submitted by Chemours Company’s legal representatives on April 27, 2018 (the “April 27 Response”) for the Chemours Fayetteville Works site (“the Site”). The April 27 Response provided information requested by the NCDAQ in their April 6, 2018 letter *60-Day Notice of Intent to Modify Air Quality Permit No. 03735T43* (the “April 6 Letter”) regarding GenX compounds (referred to in this document as “HFPO-DA” – i.e., hexafluoropropylene oxide dimer acid). Exhibit 10 *Assessment of Impact of Current and Anticipated Reduced Air Emissions on Groundwater Concentrations of HFPO Dimer Acid in the Vicinity of the Chemours Fayetteville Works* (“the Assessment”) of the April 27 Response was prepared by Geosyntec Consultants of NC, P.C. (Geosyntec). Responses to NC DAQ’s comments to the Assessment are provided below, and an updated version of the Assessment is attached herein.

NCDAQ Comment 1: There is no mention of the process to verify the steady state or impact model. Typically, a model will predict results in the future. Model verification occurs by taking samples in the future, comparing the sample results to the predicted results and then, if necessary, revising the model. Please submit the process to verify the steady state or impact model.

Geosyntec Response to Comment 1: Chemours will monitor residential wells to evaluate concentration changes over time. Complete details about program will be communicated in a Residential Indicator Well Evaluation Outline (“Evaluation Outline”) that will be submitted to NCDAQ separately. This work will consider data from the granular activated carbon (GAC) treatment of residential well water program and the quarterly monitoring of wells with HFPO-DA concentrations between 100 and 140-nanograms per liter (ng/L). The Evaluation Outline will identify at least 20 key indicator locations to be evaluated over a period of at least 5 years. The key indicator locations will be selected to evaluate general trends within the area surrounding the Site and will be selected to represent a range of conditions that may influence concentration trends, including distances from the Site and well screen intervals. More specifically, this will include locations both proximal and more distant from the Site, and locations with shallow (i.e., <30 feet below ground surface [ft bgs]) and deep (i.e., >80-ft bgs). As necessary, additional locations may be included beyond those evaluated as part of the existing residential well programs, such that this range of conditions can be evaluated. The attached updated version of the Assessment also indicates Chemours will be submitting an Evaluation Outline describing how changes in groundwater conditions following the Air Emission Reductions will be evaluated.

NCDAQ Comment 2: Table 1 seems to indicate that once Phase 3 of the Air Emission reduction is completed that there will be 0 locations that exceed 140 ng/L and 18 locations that exceed 10 ng/L. However, these drinking water reductions will take many years to achieve. Please address the timeline required to meet the reductions as described.

Geosyntec Response to Comment 2: The analysis developed within the period allocated by NCDAQ did not include an evaluation of timeframes to reduce groundwater concentrations of historically deposited HFPO-DA to below 140-ng/L or 10-ng/L. The analysis tools employed in the Assessment do not have the capability to estimate timeframes. However, the groundwater infiltration and residence times presented in the Assessment can be used to provide some general guidelines as to the potential range for timeframes. For example, it is anticipated that concentration reductions may be observed within a few years of reduced air deposition from the Phase 3 conditions, in areas where the groundwater table is shallow and where wells are also installed close to the water table. Concentration reductions in areas where the groundwater table is deeper (i.e. thicker unsaturated zone) and/or the wells are deeper will take a longer period of time. Geosyntec understands that Chemours, recognizing the longer timeframes for groundwater to reach targets, is actively working with NCDEQ and residents to ensure impacted residents have access long-term clean and reliable drinking water supplies. The attached updated version of the Assessment notes that the analytical tools employed are not able to estimate timeframes for groundwater to reach 140-ng/L or 10-ng/L.

NCDAQ Comment 3: The model assumes homogeneous soils and groundwater flow throughout the contaminated area. Please address this comment and the impacts on the model.

Geosyntec Response to Comment 3: The Assessment was prepared as a representative examination of anticipated concentration trends in the contaminated area. The Assessment used representative empirical data available and performed some sensitivity analyses of key parameters. We acknowledge that heterogeneities will exist leading to some areas achieving concentration reductions faster, and some achieving concentration reductions slower. The sensitivity of calculated results to varying multiple parameters was evaluated. A single value for hydraulic conductivity was applied. The hydraulic conductivity data (72.3-feet per day [ft/d]) came from a surficial aquifer pump test, which samples the larger scale hydraulic conductivity of the system, and the Assessment was concerned with the larger scale transport of HFPO-DA. The selected hydraulic conductivity value is further discussed below in Response to Comment 7. Below is a list of sensitivities examined in the Assessment:

- The sensitivity of infiltration times to unsaturated zones ranging between 10 to 100-feet (ft) thick was evaluated;
- The sensitivity of infiltration times to vertical hydraulic conductivity being a factor of 10X less than horizontal hydraulic conductivity (7.23-ft/d vs 72.3-ft/d) was evaluated;

- The sensitivity of infiltration times to varying organic carbon content from 0.1% to 1% was evaluated;
- The shallowest (i.e. most conservative) groundwater gradients between monitoring wells measured in the Surficial Aquifer at the Site were used to estimate groundwater velocities (280 to 830-ft per year); and
- The sensitivity of groundwater travel times to different potential discharge points (creeks vs. Cape Fear River) was evaluated.

The sensitivity analysis is already discussed in the Assessment; however, we have added a note to the Assessment to more specifically reference why the sensitivity analysis was performed.

NCDAQ Comment 4: The model assumes that all of the exceedances occur in the Surficial Aquifer. Please discuss the impacts to the model with exceedances in the other aquifers.

Geosyntec Response to Comment 4: The Assessment did not ascribe aquifers to residential groundwater exceedances since geological logs for residential wells were unavailable. HFPO-DA infiltration time through the unsaturated zone to the Surficial Aquifer was estimated since the geological column is fully saturated beneath the Surficial Aquifer. Residential wells will serve to mix water in the aquifers since they are pumping wells drawing water towards them. For wells that are located deeper, the timeframes for achieving concentration reductions will be longer. Consistent with Response to Comment 2, references to this range of conditions have been added to the Assessment.

NCDAQ Comment 5: The text indicates that the creeks are discharge points, however other Chemours reports indicate that the creeks are both losing and gaining creeks. Please clarify the current text compared to other Chemours reports.

Geosyntec Response to Comment 5: The Assessment text evaluates potential HFPO-DA groundwater residence times from infiltration through migration to possible discharge points. This evaluation considered both discharge to the Cape Fear River as well as discharge to nearby creeks (Willis Creek, Georgia Branch Creek, etc.). A range of possible discharge points was considered as a sensitivity analysis to understand the possible range in transport times. While local creeks originate in the local catchment and will be predominantly gaining streams, we agree that in localized areas the creeks may have the potential to be losing creeks. The text of the attached updated version of the Assessment has been clarified to recognize the nature of the creeks and the intent of the sensitivity analysis.

NCDAQ Comment 6: Well depths used in the model are from resident's wells, however the data to confirm the depth of the well, the water bearing zone of the well, and screen interval was not included. Please update the submittal to include this information.

Geosyntec Response to Comment 6: Well depths data have been provided to NCDEQ by Chemours when analytical data are available from sampled residential wells. All well depth data are reported by residents. Water bearing zone intervals and screen intervals for the residential wells were neither reported nor recorded and are therefore not provided in the Assessment. Well depths are provided as part of the updated Assessment attached to this response.

NCDAQ Comment 7: Groundwater flow data used in the model is from an on-site pump test based on only one pumping well and one observation well. The test was conducted in the Surficial Aquifer only. Please respond to this comment and how it impacts the model.

Geosyntec Response to Comment 7: The Assessment used data from the pump test at Site since it provided representative empirical Site-specific information relevant to the Assessment. The pump test samples the larger scale hydraulic conductivity of the local area, and the Assessment was concerned with the larger scale hydraulic conductivity. We do acknowledge that the pump test did not assess Black Creek Aquifer hydraulic conductivity. The hydraulic conductivity value of 72.3-ft/d obtained from the pump test at Site is consistent with that typically expected for the geologic media observed in the Surficial and Black Creek Aquifers, both of which have been described in borehole logs to be comprised of fine, medium and coarse-grained sands on-Site (Additional Investigation Report; Parsons, 2018). Fine and medium grained sands typically have hydraulic conductivities within a range of 0.06 to 57-ft/d and 0.3 to 140-ft/d, respectively (Domenico and Schwartz, 1998). The Site-specific hydraulic conductivity used in the Assessment falls within the middle of these ranges.

Heterogeneities and resultant variations in hydraulic conductivity will result in faster or slower groundwater velocities and consequently faster or slower concentration reductions. The Assessment has been updated to further discuss the hydraulic conductivity data used in the analysis.

NCDAQ Comment 8: The concentrations of GenX in the soils off-site is assumed since there has been no offsite soil sampling. It is unknown how a change in the soil concentrations will affect the drinking water. Please respond to these comments and how they impact the conclusions of the report.

Geosyntec Response to Comment 8: The Assessment did not include assumptions about HFPO-DA (GenX) concentrations in soil. Instead, the assessment was based on the aerial mass

deposition rate during each emissions reduction phase assessed and then calculated vertical transport rates to the water table. During the calculation setup phase of the assessment a sensitivity assessment was performed to evaluate if vertical migration times through the unsaturated zone as estimated by SESOIL would be affected by different mass loading rates. The sensitivity analysis showed infiltration times were insensitive to the mass loading rate of HFPO-DA. The Assessment has been updated to discuss this sensitivity analysis.

References

Domenico, P.A. and Schwartz, F.W., 1998. *Physical and chemical hydrogeology* (Vol. 506). New York: Wiley.

Parsons, 2018. Additional Site Investigation Report, Chemours Fayetteville Works Site. RCRA Permit No. NCD047368642-R1.

Updated Assessment of Impact of Current and Anticipated Reduced Air Emissions on Groundwater Concentrations of HFPO Dimer Acid in the Vicinity of the Chemours Fayetteville Works.

May 18, 2018

EXECUTIVE SUMMARY

Chemours requested Geosyntec Consultants of NC, P.C. (Geosyntec), a consulting and engineering firm with over 1,200 scientists and with a specialization in environmental and natural resources matters, to perform an evaluation of the impact of air emissions of GenX compounds (referred to in this report as “HFPO-DA” – i.e., hexafluoropropylene oxide dimer acid) from the Fayetteville Works site (“the Site”) on groundwater concentrations in the surrounding areas. Geosyntec has performed prior work for Chemours with respect to the Site and HFPO-DA, including assisting with the development of the conceptual site model that underlies the current groundwater remediation efforts there.

Chemours requested that Geosyntec perform this evaluation in response to an April 6, 2018, Notice of Intent issued by the North Carolina Department of Environmental Quality, Division of Air Quality (“NCDAQ”), and that Geosyntec complete its assessment and prepare this report in advance of the April 27, 2018 response deadline set by NCDAQ. In doing so, Geosyntec has utilized expertise through its organization, and this report was prepared by the following engineers and scientists:

Matt Vanderkooy, M.Sc. – Mr. Vanderkooy is a scientist with over 8 years of experience assessing and remediation contaminated Sites. A large part of his practice is focused on developing integrated conceptual site models that link geology, hydrogeology, contaminant chemistry, diffuse and point sources, groundwater-surface water interactions along with other factors together to best understand and then address environmental contamination. Mr. Vanderkooy’s practice specialties have included assessing and preparing remedies for Sites where contaminants are being transported by groundwater to surface water receptors, and field and laboratory assessments of

treatment alternatives for recalcitrant contaminants in sediments and treatment of discharging groundwater with elevated pH.

Chris Robinson, Ph.D. - Dr. Robinson is a Principal with MMI Engineering, a division of Geosyntec, with over 20 years of experience, with his practice focused in fluid dynamics consultancy: internal and external flows, flows with heat transfer, fires, atmospheric dispersion, non-Newtonian flow, fluid systems analysis and forensic investigation. Dr. Robinson provides support to clients in the oil and gas, defense, renewables, power, aerospace, environmental and water industries. He has provided technical expert services in evaluating atmospheric dispersion for multiple sites over his career at MMI.

James Rayner, M.Sc. - Mr. Rayner is a scientist with over 16 years of experience in the assessment, management and remediation of contaminated land in the UK, Europe, North America and South America. He specializes in the evaluation of multi-phase flow and transport in porous and fractured media with particular expertise in understanding groundwater-surface water interactions and assessing the natural attenuation of point and diffuse sources of chemical releases at local, site and catchment scales. The application of quantitative analysis to integrate data, validate understanding and forecast outcomes is at the forefront of Mr. Rayner's capabilities and approach to evaluating to complex sites.

Leah MacKinnon, M.A.Sc. - Ms. MacKinnon is a Principal with over 20 years of experience in the United States, Canada, and Europe focusing on investigation and remediation of groundwater containing recalcitrant compounds using innovative in situ technologies. Her technical experience involves evaluating fate and transport, conceptual site model development and the design, implementation and interpretation of remediation technologies for treatment of a broad suite of contaminants including chlorinated solvents, pharmaceuticals, energetics, pesticides, perfluorinated compounds and metals.

Geosyntec has evaluated existing groundwater data, existing air emissions data, and expected air emissions reduction data to evaluate the current state of groundwater concentrations of HFPO-DA and the anticipated reductions in groundwater concentrations over time. Based on our analysis of this data, we have reached the following conclusions:

First, HFPO-DA concentrations in groundwater in the area of the Site, which has been impacted by decades of HFPO-DA air emissions, are likely at steady state. Under such steady state conditions, if the operating conditions at the Site remained the same, the concentrations of HFPO-DA in groundwater caused by air emissions would also be expected to remain constant. In other words, current operating conditions would be expected to lead to neither an increase nor a decrease in present HFPO-DA groundwater concentrations that have arisen over time.

Second, reducing air emissions of HFPO-DA from the Site will likely lead to corresponding reductions in groundwater concentrations over time. Geosyntec understands that planned emissions reductions at the Site will be achieved over three phases (Phases 1, 2, and 3) leading to estimated overall reductions of 40% by the end of May 2018, 72% by October 2018, and 99% by April 2020.¹ These reductions in air emissions will lead to reductions of HFPO-DA at the 781 sampled locations where 1,128 residential drinking water samples have been collected and analyzed to date. Of these 781 locations 558 locations had at least one sample exceeding 10-nanograms per liter (ng/L) and 167 locations had at least one sample exceeding 140-ng/L. Over time under Phase 3 conditions (i.e., an overall 99% reduction in emissions) HFPO-DA concentrations will decrease. Estimates suggest 18 locations will exceed 10-ng/L and no locations will exceed 140-ng/L. The analysis tools employed to respond to NCDQAQ's request over the period allocated by NCDQAQ do not have the capability to estimate timeframes. However, the groundwater infiltration and residence times presented herein can be used to provide some general guidelines as to the potential range for timeframes. For example, it is anticipated that concentration reductions may be observed within a few years of reduced air deposition from the Phase 3 conditions, in areas where the groundwater table is shallow and where wells are also installed close to the water table. Concentration reductions in areas where the groundwater table is deeper (i.e. thicker unsaturated zone) and/or the wells are deeper will take a longer period of time.

Third, under present conditions the median detected concentration is 65-ng/L for the all detected data. The future Phase 3 estimated median concentration for these presently detected samples is 3.25-ng/L. The estimated new median concentrations for each emissions reductions phase is summarized below in Table 1 along with the number of locations

¹ Chemours has detailed the technical bases for these estimated reductions in other materials that will accompany this report, and we have relied on the information provided to us by Chemours.

estimated to have HFPO-DA concentrations above of 10 and 140-ng/L for each emissions reduction phase. Table 2 presents the calculated future concentrations for the 18 locations where HFPO-DA concentrations are estimated to remain above 10-ng/L under Phase 3 conditions. These estimates are based on the present maximum reported concentrations at these locations. This assessment is consistent with the planned emission reductions, dynamics of aerial transport and deposition, and local groundwater dynamics. Content presented in the following pages details and supports this assessment.

Table 1: Summary of estimated groundwater concentration reductions in sampled residential wells over time

	Median Detected Concentration (ng/L)	Locations Exceeding 10 ng/L	Locations Exceeding 140 ng/L
Present Conditions	65.0	558 of 781 = 71.4%	167 of 781 = 21.4%
Phase 1 40% Reduction	39.3	500 of 781 = 64%	118 of 781 = 15.1%
Phase 2 72% Reduction	18.0	370 of 781 = 47.4%	46 of 781 = 5.9%
Phase 3 99% Reduction	0.76	18 of 781 = 2.3%	0 of 781 = 0%

Notes

– Median data are calculated using detected data in the present conditions scenario their calculated reduced concentrations for Phases 1, 2 and 3.

Table 2: Summary of expected groundwater concentration reductions for the 18 locations estimated to have future groundwater concentrations remaining above 10-ng/L under steady state Phase 3 conditions.

Concentration Rank	Locations	Sample Date	HFPO-DA Concentrations (ng/L) per Emission Conditions			
			Present Conditions	Phase 1, 40% Reduction	Phase 2, 72% Reduction	Phase 3, 99% Reduction
1	A	12/13/2017	4,000	2,418	1,109	46.8
2	B	11/30/2017	1,600	967	444	18.7
3	C	11/29/2017	1,400	846	388	16.4
4	D	09/14/2017	1,300	786	360	15.2
5	E	12/13/2017	1,300	786	360	15.2
6	F	10/24/2017	1,300	786	360	15.2
7	G	10/18/2017	1,200	725	333	14.0
8	H	11/14/2017	1,100	665	305	12.9
9	I	10/13/2017	1,100	665	305	12.9
10	J	10/19/2017	1,100	665	305	12.9
11	K	09/25/2017	1,000	604	277	11.7
12	L	10/24/2017	960	580	266	11.2
13	M	10/24/2017	960	580	266	11.2
14	N	09/25/2017	940	568	261	11.0
15	O	09/28/2017	930	562	258	10.9
16	P	10/18/2017	920	556	255	10.8
17	Q	09/06/2017	910	550	252	10.6
18	R	11/07/2017	890	538	247	10.4

Notes

- Location addresses were anonymized and are listed as letters A through R herein.

To evaluate the effectiveness of the planned emission reductions, Chemours will monitor residential wells to evaluate concentration changes over time. Complete details about program will be communicated in a Residential Indicator Well Evaluation Outline (“Evaluation Outline”) that will be submitted to NCDAQ separately. This work will consider data from the granular activated carbon (GAC) treatment of residential well water program and the quarterly monitoring

of wells with HFPO-DA concentrations between 100 and 140- ng/L. The Evaluation Outline will identify at least 20 key indicator locations to be evaluated over a period of at least 5 years. The key indicator locations will be selected as to evaluate general trends within the area surrounding the Site and will be selected to represent a range of conditions that may influence concentration trends, including distances from the Site and well screen intervals. More specifically, this will include locations both proximal and more distant from the Site, and locations with shallow (i.e., <30 feet below ground surface [ft bgs]) and deep (i.e., >80-ft bgs). As necessary, additional locations may be included beyond those evaluated as part of the existing residential well programs, such that this range of conditions can be evaluated.

BASIS OF ASSESSMENT

This assessment has been developed from the following bases, which are supported, expanded upon and further detailed in the remainder of this document. Changes in HFPO-DA aerial deposition, in general, will scale linearly, at a 1:1 ratio, with changes in HFPO-DA emissions from the emission sources. In other words, a 95% reduction in emission rates leads to a corresponding 95% decrease in deposition rates. Using a mass balance approach, a 95% reduction in deposition rates will also lead to a 95% decrease in groundwater concentrations over time since HFPO-DA groundwater concentrations are likely at local steady state conditions based on analyses presented below. These dynamics can then be applied to estimate future groundwater concentrations. For example, a location with a present local steady state HFPO-DA concentration of 100-ng/L will over time reach a concentration of 5-ng/L.

HFPO-DA GROUNDWATER CONCENTRATION REDUCTIONS SCALE LINEARLY WITH DEPOSITION REDUCTIONS

Based on mass balance principles reducing HFPO-DA deposition and infiltration will lead to a proportionate (i.e. linear) reduction in groundwater concentrations over time. In other words, a 95% reduction in deposited HFPO-DA means that groundwater concentrations will also decline by 95%, as 95% less mass is being added to the subsurface. Therefore, future groundwater concentrations at residential sampling locations can be estimated using a linear approach where the emission reduction factors are applied to present residential groundwater concentrations.

This linear approach for estimating groundwater concentration requires the relationship between deposited HFPO-DA and groundwater concentrations be at steady state. If concentrations are at steady state, then observed concentrations are not expected to change unless the mass loading to the system changes. For steady state conditions to be established the following conditions must be met:

1. HFPO-DA infiltration through the unsaturated zone must be relatively rapid compared to the length of time over which deposition has occurred; and
2. Residence times of infiltrated HFPO-DA migrating toward the Cape Fear River (the river) must be similar to or shorter than the length of time over which deposition has occurred.

These conditions are evaluated in the following subsections.

HFPO-DA Infiltration Time

HFPO-DA is a very soluble and will be minimally retarded in groundwater infiltration. Infiltration times were modeled using SESOIL to model infiltration of both water and HFPO-DA through the unsaturated zone to groundwater based on site-specific conditions. SESOIL (Bonzountas and Wagner, 1984) is an industry standard, a one-dimensional vertical transport model for the unsaturated zone. SESOIL uses Site specific climate data, Fayetteville, North Carolina, to provide rainfall frequency, duration and volume data when assessing infiltration transport. The following inputs were used in performing the modeled simulations:

- Unsaturated zone thicknesses ranging from 10 to 100-feet (ft) thick. This range of values was selected based on reported well depths data recorded by Parsons during residential sampling. Of all wells reported, 96% were installed between 10 and 100-ft bgs. Median well installation depth was 32-ft bgs.
- Modeled simulations used a conservative hydraulic conductivity value of 7.23-feet per day (ft/d). This chosen hydraulic conductivity value is 10% the measured horizontal hydraulic conductivity, 72.3-ft/d, measured during the drawdown phase of the Additional Investigation Program aquifer test in the Surficial Aquifer (Parsons, 2018). The horizontal conductivity value is further discussed on Page 9 of this assessment. A conservative value of 10% of the horizontal hydraulic conductivity was chosen since infiltration is a vertical process and vertical hydraulic conductivities through horizontally layered soils, such as

those around the Site. Vertical hydraulic conductivities through these types of alluvial soils are typically 10% to 50% the value of horizontal hydraulic conductivities (Todd, 1980).

- HFPO-DA infiltration times were calculated using a laboratory measured organic carbon partition coefficient (K_{oc}) value of 12 (DuPont, 2008).
- The sensitivity of HFPO-DA infiltration times to fraction organic carbon (f_{oc}) content was evaluated using f_{oc} values ranging between 0.1% and 1%, consistent with the range documented for North Carolina alluvial sands from a coastal plains site (Deiss et al., 2017a; Deiss et al., 2017b).
- The sensitivity of HFPO-DA infiltration times through the unsaturated zone to different mass loading rates was also evaluated by considering a range of $2.77 \cdot 10^{-5}$ micrograms per centimeter squared per month ($\mu\text{g}/\text{cm}^2/\text{mth}$) to $1\text{-}\mu\text{g}/\text{cm}^2/\text{mth}$. The sensitivity analysis showed infiltration times were insensitive to the concentration of HFPO-DA.

As described above, a range of values was used for several input parameters to evaluate the potential range of estimates based on differences in conditions within the evaluated area. Part of the sensitivity assessment included evaluating how different unsaturated zone thicknesses effected infiltration times. While no off-Site geology logs were available, so the specific aquifers in which wells were installed could not be assessed, some residents did report well depths. Attached to this assessment as Table A1 is an anonymized table of well depths, and below in Table 3 is a summary of the distribution of well depths.

Table 3: Summary of 223 Reported Residential Well Depths

Percentile	Well Depth (ft bgs)
Minimum	10
5th	17
10th	18
25th	25
50th	32
75th	60
90th	84
95th	100
Maximum	250

The well depth data, along with several other parameters were used to perform infiltration time sensitivity assessments. Below are representative infiltration time estimates based on the modeling simulations performed using varying parameter values:

- Modeled water infiltration times through unsaturated zones between 20 to 100-ft thick ranged between 0.42 to 1.58-years.
- Modeled water infiltration times through a 30-ft thick zone required 0.55-years for infiltration to occur. A 30-ft thick zone was used to represent the infiltration depth to the median groundwater well.
- Modeled HFPO-DA infiltration times through a 30-ft thick unsaturated zone with foc values ranging from 0.1% and 1% ranged from 0.75 to 2.25 years.
- Modeled HFPO-DA infiltration times through a 100-ft thick unsaturated zone with an foc values of 0.5% was 4.5 years.

On net infiltration times were estimated to be between 0.4 and 4.5 years. These infiltration time estimates, are 9 to 100 times lower than the length of time HFPO-DA deposition has been occurring, 40-years. Because infiltration times are relatively rapid compared the deposition time period it is expected that current HFPO-DA concentrations will be at steady state.

Groundwater Velocities and Residence Times

Estimating HFPO-DA residence times in groundwater from infiltration to discharge helps assess if HFPO-DA concentrations in groundwater may be approaching steady state. Residence times were evaluated by calculating groundwater velocities using on-Site data and then applying these velocities to distances from locations where residential HFPO-DA samples have been collected in conjunction with the calculated retardation coefficient for HFPO-DA.

Velocity estimates were calculated using hydraulic gradient data collected during the Additional Investigation Program (Parsons, 2018) from on-Site groundwater wells screened in the Surficial Aquifer. This is the same unit as that for residential wells with the highest HFPO-DA concentrations.

The estimates used the representative hydraulic conductivity value of 72.3-ft/d from the drawdown phase of Additional Investigation Program aquifer test. The pump test sampled the larger scale hydraulic conductivity of the local area, which is relevant to this assessment. It is acknowledged that the pump test did not assess Black Creek Aquifer hydraulic conductivity. The hydraulic conductivity value of 72.3-ft/d obtained from the pump test at Site is consistent with that typically expected for the geologic media observed in the Surficial and Black Creek Aquifers, both of which have been described in borehole logs to be comprised of fine, medium and coarse-grained sands on-Site (Additional Investigation Report; Parsons, 2018). Fine and medium grained sands typically have hydraulic conductivities within a range of 0.06 to 57-ft/d and 0.3 to 140-ft/d, respectively (Domenico and Schwartz, 1998). The Site-specific hydraulic conductivity used falls within the middle of these ranges.

Gradients used in this calculation were from surficial wells furthest upgradient from the river adjacent to the Site (MW-13D, MW-14D, MW-15DR, MW-16D, MW-17D, MW-21D, MW-22D). These locations had some of the lowest surficial aquifer groundwater gradients which will result in slower groundwater flow. As example the groundwater velocity between MW-17D and MW-21D was calculated to be 830-ft/yr based on a distance of 1,140-ft between the wells, a hydraulic head difference of 10.83-ft and an assumed effective porosity of 0.3. The range of estimated groundwater velocities in the Surficial Aquifer residential sampling area was estimated to range between 280 and 830-ft/yr.

A retardation coefficient was calculated for HFPO-DA using the equation below:

$$R = 1 + \frac{f_{oc}K_{oc}\rho_b}{n}$$

Where R is the retardation coefficient, f_{oc} is the fraction of organic carbon assumed to be 0.5%, K_{oc} is the organic carbon partition coefficient measured to be 12 (Dupont, 2008), ρ_b is the bulk density of sand assumed to be 1.8 kg/L, and n is the effective porosity assumed to be 0.3. The resultant retardation coefficient is calculated to be 1.36. Effective HFPO-DA groundwater velocities are then calculated by dividing groundwater velocities by the retardation coefficient. This retardation coefficient yields estimated effective HFPO-DA transport velocities of 206 and 610-ft/yr.

The range of HFPO-DA groundwater residence times from infiltration through migration to possible groundwater discharge points at the river were calculated for residential sampling locations which had HFPO-DA groundwater concentrations greater than 500-ng/L. Distances from these locations to a nearby creek (e.g. Willis Creek, Georgia Branch Creek, etc.,) and the river were calculated. Both the creeks and the river were used in the evaluation to consider the potential range in residence times. Nearby creeks represent the closest possible groundwater discharge points in the system. This assessment recognizes that these nearby creeks originate in the local catchment will be predominantly gaining streams, but that in localized areas they may have the potential to be losing creeks. The river represents the furthest groundwater discharge point in the system. The calculated distances to these potential discharge points were:

- Nearest Discharge Point (Nearby Creek or Cape Fear River): 0.046 to 0.86-miles, or 244 to 4,522-ft.
- Cape Fear River: 0.1 to 2.7-miles, or 530 to 14,250-ft.

Applying effective HFPO-DA groundwater velocities of 206 and 610-ft/yr to these distances yields an estimated range groundwater residence times spanning 0.4 to 21.95 years for the closest creek or river and 1.2 to 71 years for discharge to the river. For potential discharge to the nearest discharge points (i.e., closest creeks), all calculated residence times were less than 40 years. For potential discharge to the Cape Fear River 90% of calculated residence times were less than 40 years.

Table 4: Distribution of estimated groundwater residence times for locations with concentrations above 500-ng/L.

Percentile	Locations Above 500-ng/L Estimated Groundwater Residence Time (Years) To:	
	Nearest Discharge Point Closest Creek or Cape Fear River	Cape Fear River
0	0.4	1.2
1	0.5	1.2
5	0.8	1.7
10	1.2	2.7
25	1.7	4.9
50	3.4	11
75	5.3	21
90	9.7	38
95	13	57
99	16	62
100	22	71

Based on a 40-year deposition period, most sample locations will likely have experienced at least one residence time, and many sampling locations will have experienced multiple cycles of infiltration, migration and discharge. Since these cycles work to establish steady state conditions within a groundwater plume, HFPO-DA concentrations at most locations sampled in the residential sampling program are likely approaching steady state.

Groundwater Concentrations Linear Scaling Conclusions

HFPO-DA groundwater concentrations at residential sampling locations are expected decrease linearly with reductions in HFPO-DA deposition based on a mass balance assessment. This assessment requires present measured groundwater concentrations to be at steady state. In other words, concentrations are not expected to change unless the HFPO-DA mass loading rates change. When mass loading rates change under steady state conditions then groundwater

concentrations will also change. For example, if mass loading decreases by 95% then since 95% less HFPO-DA mass is entering the system and over time groundwater concentrations will also decrease by 95%. Data regarding residential well sampling locations were assessed and suggested steady state conditions were likely for both HFPO-DA infiltration dynamics and HFPO-DA transport through groundwater towards the discharge point.

Infiltration modeling using SESOIL suggested all residential sampling locations are at steady state with respect to HFPO-DA infiltration from surface, through the unsaturated zone to groundwater. The estimated range of infiltration times ranges from 0.4 to 4.5 year; much less than the 40-year time period that HFPO-DA deposition has been occurring over. Additionally, groundwater flow data adjusted for HFPO-DA retardation suggest most residential sampling locations have experienced at least one to multiple cycles of infiltration, migration and discharge which further helps establish steady state conditions.

HFPO-DA DEPOSITION REDUCTIONS SCALE LINEARLY WITH EMISSIONS REDUCTIONS

Reductions in HFPO-DA deposition will, in general, scale linearly with reductions in emissions based on the dynamics of aerial deposition and consistent with how aerial deposition is modeled in AERMOD, the atmospheric dispersion model used by the NCDAQ and developed by the United States Environmental Protection Agency (USEPA). The remainder of this section provides supporting detail for this approach, including descriptions of the overall modeling technique, individual model units for key physical processes and underlying equations.

Modeling Technique

Atmospheric dispersion modeling using AERMOD is a suitable approach for dispersion modeling in systems where long-term average dispersion characteristics are required (typically annual averages); and where plume interactions with complex geometry (buildings, facilities, rugged terrain, etc.) is minimal. The assumption for a linear relationship between emission and deposition rate is based on the underlying models and associated equations used in AERMOD.

Basis of Assessment

The following assumptions are made in this analysis:

- AERMOD is an appropriate tool for atmospheric dispersion modeling of the Dimer Acid releases at Chemours' Fayetteville Chemical Works Site. AERMOD will continue to be used by NCDQA for the assessment of atmospheric dispersion of stack and fugitive emissions at this site. NCDQA are applying AERMOD modeling techniques correctly.
- There will be no change in meteorological conditions or the meteorological data set used in the atmospheric dispersion modeling for this site or for future modeling analysis within this program of work.
- There will be no change to the location of height of stacks, or location of fugitive emissions, or the layout of building on and around the site which would change the boundary conditions for the analysis.
- There will be no change to the terrain (large earthworks, etc.) which would affect the elevation of receptor points.
- This analysis can accommodate changes to the emissions rates at the different stacks and fugitive sources; and changes to the concentration of HFPO-DA within these emissions.
- The concentration of plumes in air are represented in the following analysis by both C and χ . These represent the same variable and can be used interchangeably. Both have been used here to maintain consistency with the different source documents, which use these two variable names for concentration.

Underlying Equations

AERMOD models dispersion of plumes within the Planetary Boundary Layer (PBL). The PBL may form in two different conditions – either a Stable Boundary Layer (SBL) in which vertical motion is suppressed, or Convective Boundary Layer (CBL) in which vertical motion of air is generated by differences in vertical temperature gradients.

AERMOD uses Probability Density Functions (PDFs) to calculate plume concentration downwind of a source. These are different for SCL and CBL conditions:

- SBL – horizontal and vertical PDFs are both Gaussian
- CBL – horizontal PDF is Gaussian; vertical PDF is non-Gaussian.

The Gaussian profile for the SBL is provided in EPA, 2004a, Equation 67 as:

$$C_s \{x_r, y_r, z\} = \frac{Q}{\sqrt{2\pi\tilde{u}\sigma_{zz}}} \cdot F_y \cdot \sum_{m=-\infty}^{\infty} \left[\exp\left(-\frac{(z - h_{es} - 2mz_{i\text{eff}})^2}{2\sigma_{zz}^2}\right) + \exp\left(-\frac{(z + h_{es} + 2mz_{i\text{eff}})^2}{2\sigma_{zz}^2}\right) \right]$$

The key variables of interest to this discussion are: C_s – the plume concentration at location x_r downstream of the source, y_r lateral displacement from the plume centerline, and z , height; and Q the emission rate of the plume from the source. This may be a point source, such as a stack, or an area or volume source.

As shown in the equation above, the relationship between plume concentration and emission rate is linear. Any changes to emission rates with no changes to the meteorological conditions will result in changes by the same factor to the downstream concentration of the plume.

In the CBL the horizontal dispersion is also Gaussian and has the form shown above. The formulation for the vertical PDF is more complex and uses contribution from “direct”, “indirect” and “penetrated” sources to determine the overall dispersion in the vertical direction. These are described in USEPA, 2004a equations 59, 65 and 66. Inspection of those equations demonstrates that the relationship between plume concentration and emission rate remains linear.

Particle Model

AERMOD is a steady state model which calculates dispersion quantities over fixed averaging periods – typically one hour. This assumes that particles are sufficiently small and light for gravitational and body forces (which would create differential movement) to be significantly smaller than convective forces in the wind and buoyancy forces acting on the plume. NCDQAQ performed modeling based on data collected from the Site and assumed a particle size of PM2.5 micrometers (i.e. microns or μm) or smaller (Barton et al., 2006). Based on this particle size there should be no differential movement of Dimer Acid particles in the plume and hence the relationship between emission rate and downstream concentration will remain linear.

Terrain Following

AERMOD includes a terrain following model; the total concentration of the plume (or particles) at a location downwind of the source is a combination of a contribution from the horizontal plume and a plume following the terrain. This is provided in USEPA (2004a) equation 48 as:

$$C_T \{x_r, y_r, z_r\} = f \cdot C_{c,s} \{x_r, y_r, z_r\} + (1 - f) C_{c,s} \{x_r, y_r, z_p\}$$

A weighting function f is used to provide the relative contributions from the horizontal dispersion $C_{s,c}\{x_r, y_r, z_r\}$ and terrain following dispersion $C_{s,c}\{x_r, y_r, z_p\}$. The principal difference between these is the height of the receptor z_r or z_p .

Since no changes will occur to surrounding terrain or yearly meteorological conditions neither the weighting function, f , or the relative contributions from terrain following and horizontal dispersion will change due to a change in the emissions rate at the source. Hence, the relationship between emission rate and downstream concentration will remain linear.

Downwash

AERMOD uses a separate model formulation to calculate downwash in the wakes of buildings etc; this is known as the PRIME model, Schulman et al., 2000. The AERMOD description of model formulation document, (USEPA, 2004a) equation 89 shows the interface between the AERMOD dispersion and PRIME downwash models for concentration, χ and weighting function γ :

$$\chi_{TOTAL} = \gamma \chi_{PRIME} + (1 - \gamma) \chi_{AERMOD}$$

The weighting function γ is equal to 1.0 in the wake region of the building etc, and beyond the wake region is calculated by the AERMOD formulation document equation 90:

$$\gamma = \exp\left(\frac{-(x - \sigma_{xg})^2}{2\sigma_{xg}^2}\right) \exp\left(\frac{-(y - \sigma_{yg})^2}{2\sigma_{yg}^2}\right) \exp\left(\frac{-(z - \sigma_{zg})^2}{2\sigma_{zg}^2}\right)$$

Where x , y , and z are distances from the source and the σ values are various dispersion coefficients. None of these are dependent on the plume emission rate. The PRIME model is described in full in Shulman et al., 2000; this shows that the linear relationship between emissions rate and concentration of the plume (particles) is linear in the wake region. Hence, the relationship between emission rate and downstream concentration will remain linear.

Deposition Model

AERMOD calculates the dry deposition flux as stated in AERMOD Deposition Algorithms – Science Document (USEPA, 2004b) equation 1, which is:

$$F_d = \chi_d \cdot V_d$$

Where χ_d is the local concentration at height z_r , and V_d is the deposition velocity. The description following this equation in USEPA, 2004b for the derivation of V_d does not include plume (particle) concentration. Hence, the relationship between emission rate and downstream concentration will remain linear.

Source Contribution Analysis for Multiple Sources

The plume dispersion PDFs in AERMOD are formulated for single plumes from point, area or volume sources. Where multiple sources are included in a model, the contributions from each are summed.

If the emission from each source is changed by the same factor, then downstream concentrations will also be changed by that same factor. However, where emission sources are changed by different factors the downstream concentration will be changed by the mass-weighted average effect of the sources.

Emissions and Deposition Linear Scaling Conclusions

The above descriptions demonstrate that the main models used within AERMOD have a linear relationship between the emissions rate at a source (point, area, volume) and the deposition of particles to the ground. Where a number of sources are present, any changes to downstream

deposition rates due to changes in emissions at the sources, can be assessed by the mass-weighted sum of the individual sources. Specifically, for the Site there are multiple stacks emitting HFPO-DA. These stacks are relatively close to each other, especially compared to distances to residential well receptors, and each stack at the end of emissions reduction Phase 3 will have the same type of emissions reduction technology applied. Therefore, the effect of multiple stacks at the Site is not expected to result in substantial changes from HFPO-DA deposition linearity for the purposes of the analyses presented herein.

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TABLE A1
RESIDENT REPORTED RESIDENTIAL WELL DEPTHS
 Chemours Fayetteville Works, North Carolina

Table A1 Entry Number	Most Recent Sample Date	Total Well Depth (ft bgs)	Table A1 Entry Number	Most Recent Sample Date	Total Well Depth (ft bgs)
1	29-Nov-17	10	41	14-Dec-17	20
2	1-Feb-18	13	42	31-Jan-18	20
3	23-Jan-18	14	43	29-Nov-17	20
4	5-Oct-17	14	44	31-Jan-18	20
5	6-Feb-18	14	45	31-Jan-18	20
6	2-Feb-18	14	46	31-Jan-18	20
7	6-Feb-18	15	47	20-Oct-17	20
8	6-Feb-18	15	48	14-Dec-17	20
9	12-Dec-17	16	49	1-Feb-18	22
10	17-Oct-17	17	50	7-Feb-18	23
11	7-Dec-17	17	51	21-Nov-17	23
12	1-Feb-18	17	52	1-Feb-18	23
13	1-Feb-18	17	53	12-Dec-17	23
14	23-Oct-17	18	54	6-Feb-18	24
15	5-Dec-17	18	55	30-Nov-17	25
16	31-Jan-18	18	56	19-Oct-17	25
17	31-Jan-18	18	57	7-Feb-18	25
18	31-Jan-18	18	58	31-Jan-18	25
19	31-Jan-18	18	59	30-Jan-18	25
20	30-Jan-18	18	60	30-Jan-18	25
21	30-Jan-18	18	61	30-Jan-18	25
22	24-Jan-18	18	62	31-Jan-18	25
23	14-Dec-17	18	63	30-Nov-17	25
24	2-Feb-18	18	64	5-Feb-18	25
25	7-Feb-18	18	65	5-Feb-18	25
26	29-Nov-17	19	66	30-Jan-18	25
27	29-Nov-17	19	67	30-Jan-18	25
28	17-Oct-17	19	68	30-Jan-18	25
29	18-Oct-17	19	69	30-Jan-18	25
30	7-Dec-17	19	70	24-Jan-18	25
31	17-Oct-17	20	71	24-Jan-18	25
32	1-Feb-18	20	72	24-Jan-18	25
33	7-Nov-17	20	73	2-Feb-18	25
34	20-Nov-17	20	74	1-Feb-18	25
35	24-Jan-18	20	75	25-Jan-18	25
36	18-Oct-17	20	76	1-Feb-18	25
37	29-Nov-17	20	77	3-Jan-18	25
38	31-Jan-18	20	78	4-Dec-17	25
39	26-Jan-18	20	79	7-Feb-18	25
40	25-Jan-18	20	80	5-Dec-17	25

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 Chemours Fayetteville Works, North Carolina

Table A1 Entry Number	Most Recent Sample Date	Total Well Depth (ft bgs)	Table A1 Entry Number	Most Recent Sample Date	Total Well Depth (ft bgs)
81	1-Dec-17	26	121	18-Oct-17	35
82	7-Dec-17	26	122	1-Feb-18	35
83	24-Jan-18	27	123	5-Dec-17	35
84	18-Dec-17	27	124	19-Oct-17	35
85	6-Nov-17	27	125	18-Oct-17	35
86	20-Oct-17	28	126	18-Oct-17	36
87	16-Oct-17	28	127	5-Feb-18	37
88	5-Dec-17	28	128	29-Sep-17	38
89	5-Dec-17	28	129	20-Oct-17	39
90	18-Dec-17	28	130	24-Oct-17	40
91	26-Jan-18	30	131	19-Sep-17	40
92	23-Jan-18	30	132	1-Feb-18	40
93	29-Jan-18	30	133	28-Nov-17	40
94	5-Feb-18	30	134	4-Dec-17	40
95	16-Oct-17	30	135	19-Oct-17	40
96	15-Nov-17	30	136	18-Oct-17	42
97	13-Dec-17	30	137	6-Feb-18	42
98	7-Nov-17	30	138	24-Jan-18	42
99	1-Feb-18	30	139	5-Dec-17	42
100	1-Feb-18	30	140	12-Dec-17	45
101	6-Feb-18	30	141	29-Sep-17	45
102	28-Nov-17	30	142	5-Dec-17	45
103	7-Feb-18	30	143	17-Oct-17	46
104	30-Jan-18	30	144	20-Oct-17	47
105	25-Jan-18	30	145	13-Feb-18	47
106	18-Dec-17	30	146	19-Oct-17	49
107	9-Nov-17	30	147	20-Sep-17	50
108	30-Nov-17	30	148	20-Dec-17	50
109	25-Jan-18	32	149	1-Dec-17	50
110	16-Oct-17	32	150	18-Oct-17	50
111	26-Jan-18	32	151	22-Nov-17	50
112	4-Dec-17	32	152	18-Oct-17	50
113	12-Jan-18	32	153	27-Oct-17	50
114	19-Oct-17	32	154	22-Jan-18	50
115	19-Oct-17	35	155	6-Feb-18	52
116	5-Oct-17	35	156	12-Dec-17	54
117	10-Jan-18	35	157	8-Dec-17	55
118	27-Nov-17	35	158	18-Oct-17	55
119	2-Feb-18	35	159	22-Jan-18	55
120	16-Oct-17	35	160	24-Jan-18	55

TABLE A1
RESIDENT REPORTED RESIDENTIAL WELL DEPTHS
 Chemours Fayetteville Works, North Carolina

Table A1 Entry Number	Most Recent Sample Date	Total Well Depth (ft bgs)	Table A1 Entry Number	Most Recent Sample Date	Total Well Depth (ft bgs)
161	5-Feb-18	58	193	23-Jan-18	78
162	28-Dec-17	60	194	20-Oct-17	80
163	20-Sep-17	60	195	5-Feb-18	80
164	30-Jan-18	60	196	30-Jan-18	80
165	31-Jan-18	60	197	15-Dec-17	80
166	15-Sep-17	60	198	30-Nov-17	80
167	17-Oct-17	60	199	25-Sep-17	80
168	26-Jan-18	60	200	30-Jan-18	84
169	17-Oct-17	60	201	30-Jan-18	84
170	13-Dec-17	60	202	14-Dec-17	85
171	24-Jan-18	60	203	6-Feb-18	85
172	7-Nov-17	60	204	31-Jan-18	85
173	18-Oct-17	62	205	13-Feb-18	88
174	4-Dec-17	62	206	30-Jan-18	89
175	16-Oct-17	65	207	30-Jan-18	90
176	29-Nov-17	65	208	17-Oct-17	90
177	16-Oct-17	65	209	31-Jan-18	90
178	7-Nov-17	70	210	30-Jan-18	96
179	16-Oct-17	70	211	15-Sep-17	98
180	20-Sep-17	70	212	16-Oct-17	100
181	28-Nov-17	70	213	31-Jan-18	100
182	19-Dec-17	70	214	30-Nov-17	100
183	1-Feb-18	70	215	1-Feb-18	100
184	19-Oct-17	70	216	18-Oct-17	100
185	20-Oct-17	70	217	1-Feb-18	100
186	31-Jan-18	72	218	31-Jan-18	150
187	20-Oct-17	72	219	4-Dec-17	150
188	18-Oct-17	72	220	17-Oct-17	153
189	19-Oct-17	73	221	30-Jan-18	200
190	29-Nov-17	75	222	6-Feb-18	249
191	25-Jan-18	75	223	1-Feb-18	250
192	13-Dec-17	75			

Note

Well depths data where available were reported by residents.

Acronyms

ft bgs - feet below ground surface