Technical Review of Cape Fear River PFAS Loading Reduction Plan for Cape Fear Public Utility Authority (CFPUA)

September 27, 2019

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1.0 BACKGROUND

Chemours Company issued the Cape Fear River PFAS Loading Reduction Plan (Geosyntec, 2019) to the North Carolina Department of Environmental Quality (NCDEQ) and Cape Fear River Watch (CFRW) on August 26, 2016 in response to the Consent Order (CO) entered by the Bladen County Superior Court (paragraphs 12 and 11.1) on February 25, 2019. The CO was issued regarding emissions and discharges of per- and polyfluoroalkyl substances (PFAS), including hexafluoropropylene oxide dimer acid (HFPO-DA; 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propanoic acid) and the ammonium salt of HFPO-DA, which has the trade name of GenX®, from the Fayetteville Works facility. GenX is used to manufacture high performance fluoropolymers. GenX replaces the ammonium salt of perfluorooctanoic acid (PFOA), which was phased out of production in 2009 because PFOA is persistent in the environment, bioaccumulates, and is toxic. At that time the Fayetteville Works facility was owned and operated by E.I. du Pont de Nemours and Company (DuPont). The Chemours Company was founded in July 2015 as a spin-off from DuPont.

In 2009 EPA authorized the manufacture of GenX; however, EPA also issued an order that required DuPont to capture, at an overall efficiency of 99%, new chemical substances from wastewater effluent and air emissions (premanufacture notice numbers P-08-508 and P-08-509). News broke regarding high levels of GenX and PFAS in the Cape Fear River and downstream potable waters in 2017 – spurring further environmental investigations and facility inspections. Shortly thereafter NCDEQ filed a Complaint alleging violations of the premanufacture order due to evidence in downstream waters of PFAS discharges by Chemours and DuPont, ultimately leading to the August 26, 2016 CO.

The Fayetteville Works facility is located in Bladen County, NC on the west side of the Cape Fear River just upstream of the William O, Huske Lock and Dam (Lock and Dam #3). The facility includes two Chemours manufacturing areas, the Monomers IXM area and the Polymer Processing Aid Area (PPA area), as well as an onsite process Wastewater Treatment Plant (WWTP) and Power Area (Geosyntec, 2019). In addition, manufacturing areas on the facility grounds are leased to Kuraray America Inc. for Butacite® and SentryGlas® production and to DuPont for polyvinyl fluoride (PVF) resin manufacturing.

The Chemours Fayetteville Works facility is located about 55 miles upstream of the Kings Bluff water intake on the Cape Fear River where the Cape Fear Public Utility Authority (CFPUA) withdraws water for treatment and potable use distribution. Elevated levels of PFAS have been observed in both the raw source water from the Cape Fear River and finished water at the CFPUA's Water Treatment Plants (WTPs). Traditional water treatment processes do not successfully remove GenX and other PFAS (Hopkins et al., 2018). The effectiveness of currently implemented and proposed PFAS pollution control strategies adopted by Chemours directly affect the quality of CFPUA's intake water and community exposure to these substances.

In light of these concerns, CFPUA engaged Tetra Tech to conduct a technical review of the PFAS Loading Reduction Plan and associated environmental assessments. Specifically, CFPUA requested input on the technical soundness of the surface and groundwater modeling, reasonableness of the assumptions applied in the analyses, reasonableness of the seven proposed strategies for reducing PFAS loads, identification of critical gaps in the analyses, and recommendations for additional studies related to reducing PFAS loads.

The Cape Fear River PFAS Loading Reduction Plan itself consists of 33 pages plus a cover letter, but is supported by five technical appendices: 1) PFAS Mass Loading Model, 2) Seeps and Creeks

Investigation Report, 3) Outfall 002 Assessment, 4) Terracotta Pipe Grouting Report, and 5) HFPO-DA Loading Reduction Estimates, all of which were completed by Chemours' consultant, Geosyntec Consultants of NC, P.C. The PFAS Loading Reduction Plan includes seven proposed actions aimed to reduce PFAS loading to the Cape Fear River. Findings from the review of the plan and supporting technical reports are discussed in this memorandum.

To better understand the relationship between river flow rate at the Kings Bluff intake and PFAS concentrations, CFPUA has developed a correlation analysis between the variables. CFPUA requested a technical review of the correlation analysis, which is also discussed in this memorandum as are implications related to the loading reduction plan.

2.0 TECHNICAL REVIEW

The PFAS loading reduction plan is informed by the PFAS Mass Loading Model (MLM), which evaluates contributions of PFAS to the Cape Fear River from nine pathways (Figure 1):

- Upstream river water and groundwater
- Willis Creek (north of the facility)
- Direct atmospheric deposition on the river in the vicinity of the facility
- Outfall 002
- Onsite upwelling groundwater
- Four identified onsite channelized seeps
- Old Outfall 002
- Offsite groundwater
- Georgia Branch Creek (south of the facility)

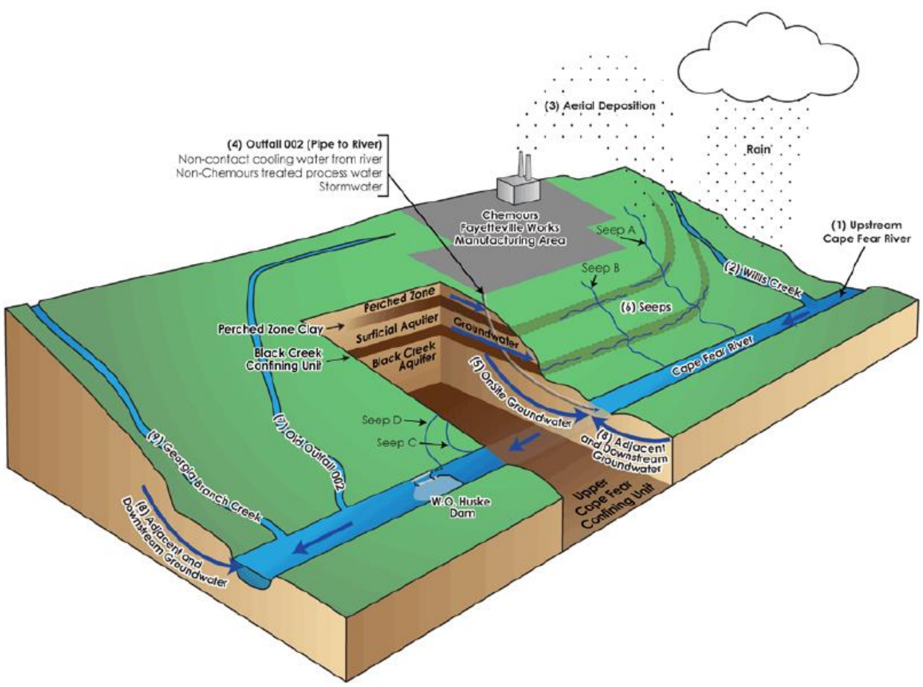

Figure 1. PFAS Transport Pathways (Geosyntec, 2019; Figure 5)

The MLM incorporates analyses and findings from the other appendices, such as the Seeps and Creeks Investigation Report that is used for characterizing groundwater conditions and contributions. Comments on the technical soundness, reasonableness of the assumptions applied, and critical gaps are discussed in the sections below. Key comments are summarized in Table 1.

Table 1. Key Comments from the Technical Review

Brief Description of Comment	Section (Comment Number)
Lack of adequate groundwater monitoring data and application of post-Hurricane Florence data.	2.1 (#1) and 2.2 (#1 and #5)
The modeling applied insufficient extents for resurfacing groundwater, resulting in potentially underestimated loads to the river.	2.2 (#2 and #3)
Limited scope of atmospheric deposition modeling (e.g., only HFPO-DA; seemingly conservative application of October 2018 conditions; limited spatial extent)	2.1 (#4)
Lack of information about the extent, magnitude, and impacts of offsite PFAS groundwater and soil contamination that may continue to contribute PFAS to the river.	2.2 (#4) and 2.3 (#7)
Lack of information to characterize PFAS contamination of sediment in the Cape Fear River bed and riparian wetlands.	2.2 (#6) and 2.3 (#7)
Implementation timing and ongoing risks for untreated sources.	2.3 (#1 and #2)
Lack of information regarding the effectiveness of treatment technologies.	2.3 (#3)
Need for notification requirements regarding spills or other releases since no production related changes have been required to date.	2.3 (#5)
Concerns regarding discharges of Kuraray process wastewater shown to contain elevated PFAS concentrations.	2.3 (#6)

2.1 TECHNICAL SOUNDNESS

This section summarizes our concerns regarding the technical soundness of data that has been assembled and cited to support conclusions in Cape Fear River PFAS Loading Reduction Plan and supporting appendices.

1. Onsite groundwater sampling data used to estimate mass loading to the river is based on a single round of samples collected primarily post Hurricane Florence – four of the five well samples in Appendix A are from late October – early November 2018, while the hurricane occurred in September 2018 with over 12 inches of rain recorded in nearby Fayetteville during the hurricane. This rainfall (and associated infiltration) may have significantly impacted short-term groundwater

sampling data, thus the representativeness of the data used is in question, especially since no other sampling data for the wells were provided for comparison purposes.

2. Onsite and offsite groundwater (transport pathways 5 and 8) PFAS concentrations used for the mass loading model are not provided in Table 3 of the MLM report. Is there a reason why these were specifically excluded while all other transport pathways had concentrations provided? What are the concentrations that were used?
3. It is unclear how groundwater south of the plant between Old Outfall 2 and Georgia Bank Creek was handled. Was groundwater in this area included in the onsite or offsite groundwater mass loading calculations? What parameters were used in the evaluation of contributions to the river from this area?
4. Previously reported deposition contours for air emissions from the Fayetteville Works facility were used to quantify the atmospheric deposition load in the MLM (ERM, 2018). Estimated deposition rates were combined with the average Cape Fear River surface area and estimated residence time to estimate a mass loading from aerial deposition to the river. The deposition load to the river surface was only evaluated for a ~3.5 km segment of the river near the facility. Key concerns regarding the modeling analysis follow, and critical gaps in the overall study related to atmospheric deposition are discussed in the next subsection. Note that some information discussed here is presented in the atmospheric deposition modeling report (ERM, 2018).
    a. The atmospheric deposition modeling focuses solely on HFPO-DA (ERM, 2018). To estimate the atmospheric deposition load of other PFAS compounds (non-HFPO-DA) for the MLM, concentration ratios derived from well monitoring samples are applied. The report, however, lacks proof that ratios from well measurements are directly applicable to air concentrations. Indeed, the ratios are likely to be different as PFAS compounds volatility, airborne transport, and subsurface soil sorption characteristics are not linearly related (ITRC, 2018). Therefore, this is not a reasonable assumption given the lack of evidence. The report also does not describe how the air transport and deposition of other PFAS compounds (non-HFPO-DA) differs from that of HFPO-DA.
    b. The MLM applies expected not actual emissions from the facility for October 2018. The MLM does not thoroughly discuss how factors that influence variability in air transport and deposition (e.g., fluctuations due to weather) are addressed. It is unclear if the results applied represent a single month (i.e., October 2018) extrapolated to represent annual deposition or if annual deposition is characterized by modeling emissions, transport, and deposition over a multi-year period. If it is the former, the application of October 2018 seems to be conservative; simulations of PFAS deposition for May 2018 are more widespread compared to October 2018. According to Table C-1 the same emission rates are applied for both (May and October 2018) scenarios, which means the differences in the extent of deposition are due to atmospheric conditions. Application of conditions for a single month is not reasonable for evaluating the annual load and the MLM should account for variability in conditions that impact the load. If in fact the atmospheric deposition modeling used to inform the MLM simulated a multi-year period, the report should clarify the methods. In addition, it is important that the impacts of intra- and inter-annual variability are discussed, including fluctuating emissions from the facility (i.e., due to operations cycling) and weather (e.g., wind direction and speed).
    c. Dilution factors are applied to estimate resulting concentrations in groundwater wells surrounding the property for various atmospheric deposition scenarios, however, the approach assumes zero concentration in existing aquifer water. Thus, the resulting

groundwater concentrations presented are biased low. [Note this information does not seem to be applied in the MLM.]

5. It is noted in Section 2.1.5. of the “Seeps and Creeks” appendix that samples were collected to avoid inclusion of suspended solids. In the final bullet of Section 3.4 of the Outfall 002 Assessment report it is stated that no relationship between TSS and total or dissolved PFAS was found (although details of the analysis are not provided). However, this conflicts with the fact that elevated PFAS concentrations at Location 22 are attributed to sediment clogging the autosampler (Outfall 002 Assessment report). Sorption of PFAS compounds is complex because the compounds have a lipophilic head and a hydrophobic tail. Thus, a clear relationship to TSS is not expected. A relationship to organic carbon on a PFAS species-by-species basis is likely yet was not examined.
6. The MLM approximates loading rates for each pathway based on PFAS concentration and flow data. The validity of the results for certain pathways is impacted by sparse monitoring records. For example, only a single sample was applied to characterize the upstream load (Section 4.1), even though elevated PFAS levels have been observed in upstream waters such as the Haw River (Barnes, 2019). Using a single sample to estimate the long-term load is not sufficient and additional monitoring should be conducted to characterize the upstream load across various seasons and flow regimes. It is stated in Section 4.5 that all EPA 537 PFAS compounds did not originate from the site as these were present in intake water. Therefore, EPA 537 PFAS compounds were assigned a zero concentration for the MLM. It can be deferred (although it is not explicitly stated) that this finding is based on the single upstream sample. Additional sampling is needed to evaluate the potential contribution of EPA 537 PFAS from the site.
7. No explanation is provided as to why some EPA 537 PFAS sampling method substances are reported as “NS” – defined as compound was not analyzed for in collected sample(s) or sample was not collected. Due to the lack of monitoring for these compounds, the total PFAS concentrations and loads reported in the study may be an underestimate of actual total PFAS concentrations and loads.
8. The DVM Narrative Reports show that many of the collected samples applied in the MLM did not meet sampling protocols (e.g., due to exceeded hold time). In addition, there are several cases where the dissolved concentration exceeds that of the total concentration for a PFAS substance (Table 10 Analytical Results – Stormwater Sampling). These data quality concerns contribute uncertainty to the monitoring and modeling results.
9. Results from TestAmerica were pending from the Outfall 002 monitoring at the time the report was issued. Results presented are from the onsite Chemours lab. The report does not specify if the Chemours lab is approved through the Resource Conservation and Recovery Act (RCRA). The report and modeling should be updated to incorporate the TestAmerica records.
10. HFPO-DA reductions from 2017 and 2019 in the load to the Cape Fear River are presented in the HFPO-DA Loading Reduction Estimates report. For both 2017 and 2019 monitoring from a single day was applied to estimate a typical daily load, which was directly extrapolated to generate an annual load (by multiplying by the number of days per year). The river flow applied to compute the annual load estimate for 2019 was less than one-third of the river flow applied to compute the annual load estimate for 2017, which falsely skews (overestimates) the reported percent reductions in loading to the Cape Fear River. It is not reasonable to assume that monitoring from a single day can be used to compute an accurate annual load. Recent load estimates computed by CFPUA based on more frequent monitoring at Lock and Dam #1 are higher. The analysis

should be redone and samples from multiple monitoring events spanning various seasons and flows should be applied for characterizing baseline and current loads and associated reductions.

2.2 CRITICAL GAPS

1. Overall, there is a significant lack of site-specific data regarding groundwater conditions at the facility. The report indicates that a total of five monitoring wells were available and used in the mass loading evaluation, which is not nearly adequate for delineating site geologic/hydrogeologic conditions and groundwater impacts considering the three groundwater flow systems involved. The report also indicates that additional groundwater characterization work is planned/underway for the site, which should provide data to more accurately portray onsite groundwater impacts to the river and improve the representativeness of the loading model. Hydrogeologic characteristics were in many cases estimated based on literature values and/or empirical evidence – generic ranges for hydraulic conductivity were used from general hydrogeology references, and groundwater flow gradients were estimated from water levels in riverside wells and a river gauging level remote from the site. It is important to collect adequate site-specific data to use in developing a technically sound detailed hydrogeologic conceptual site model that encompasses all three groundwater flow zones identified at the site (perched zone, surficial aquifer, and Black Creek aquifer) for quantifying groundwater flow rates and volumetric discharges/mass loading to the river.
2. Using observed mass loading at Bladen Bluffs, the MLM was calibrated through the adjustment of the following parameters: hydrologic conductivity for the Upper and Lower portions of the Black Creek Aquifer, groundwater discharge length (i.e., area contributing resurfacing groundwater to the river), and an offsite gradient adjustment factor. The rationale for modifying the discharge area for groundwater during model calibration iterations (only 40% to 75% of the total area was used) is unclear – all groundwater in the three flow zones identified (perched zone, surficial aquifer, Black Creek aquifer) should eventually discharge to the Cape Fear River either via direct discharge (Black Creek aquifer) or via seeps and surface water. Clearly the onsite groundwater discharge area length is significantly under-represented as described in Table D-2 of the onsite groundwater flow estimate (2,900 feet), which results in an under-estimation of onsite groundwater discharge from the Chemours site to the river. The calibration process was used as the rationale for this reduced length, however, the calibration process should be constrained to accurately reflect site conditions. Assuming 100% discharge of the Black Creek aquifer to the river would increase discharge/mass loading to the river significantly.
3. Similar to the previous comment, groundwater upwelling to the river is assumed to be less than 100%. Based on a USGS report regarding groundwater flow in the Coastal Plain Aquifer System of North Carolina, some shallow groundwater in the area may resurface as baseflow to the Cape Fear River while some may resurface further downstream (Giese et. al., 1991); however, additional field information is needed to support this parameterization. The assumed aquifer thickness for offsite groundwater discharge to the river is not provided – what was assumed and what is the basis for the assumption? Finally, a hydraulic conductivity value of 2.55 x 10-4 m/s was used for calculating offsite groundwater discharge to the river; however much lower K values were assumed for onsite groundwater (Black Creek aquifer). It is reasonable to assume that offsite shallow groundwater across the river is from the same formation; why the difference in K values? This would underestimate the relative mass loading via onsite groundwater versus

offsite groundwater. In addition, the Black Creek aquifer is likely to be slightly thicker on the other side of the River as it is generally down-dip; was this taken into account?

4. The loading analysis excludes deposition to surrounding land (wet or dry) that is stored in offsite soils, transported to streams via erosion, and leached into groundwater. These mechanisms and associated loadings have yet to be properly quantified. An investigation for the DuPont Washington Works plant near the Ohio-West Virginia border found contamination from atmospheric deposition up to 20 miles from the plant (Zevitas and Zemba, 2018). It is plausible that air emissions at the Fayetteville Works facility were/are transported further than assumed in the loading analysis, deposited, stored in soils, and leached into groundwater that resurfaces as baseflow to the river. Wells exhibiting high levels of PFAS contamination opposite of observed groundwater pathways (e.g., wells on the east side of the river) support this concept (ERM, 2018). This also could explain why concentrations and loads of some PFAS compounds are higher at the Kings Bluff intake compared to Bladen Bluffs, specifically during June 2019 (Table 7-A and Table 7-B), but the MLM was only calibrated at the Bladen Bluffs intake located about five miles downstream of the facility. CFPUA analyzed the relationship between raw water total PFAS and river flow rate using 2019 monitoring records (Figure 2). Elevated PFAS concentrations occur during periods of low flow. Given the halting of the release of process wastewater by Chemours, the elevated concentrations are likely attributable to onsite and offsite groundwater, releases from sediment bed stores, and/or currently unidentified other point sources. Therefore, a critical gap in the current analysis framework is that the extent, magnitude, and impacts of offsite PFAS groundwater and soil contamination has not been evaluated. Releases of contaminated groundwater, diffusion from contaminated sediment, and erosion of contaminated soils may contribute PFAS to the CFPUA's intake water following the implementation of the proposed control strategies (Section 2.3). Additional offsite monitoring and modeling is needed to understand the long-term implications on downstream water quality.

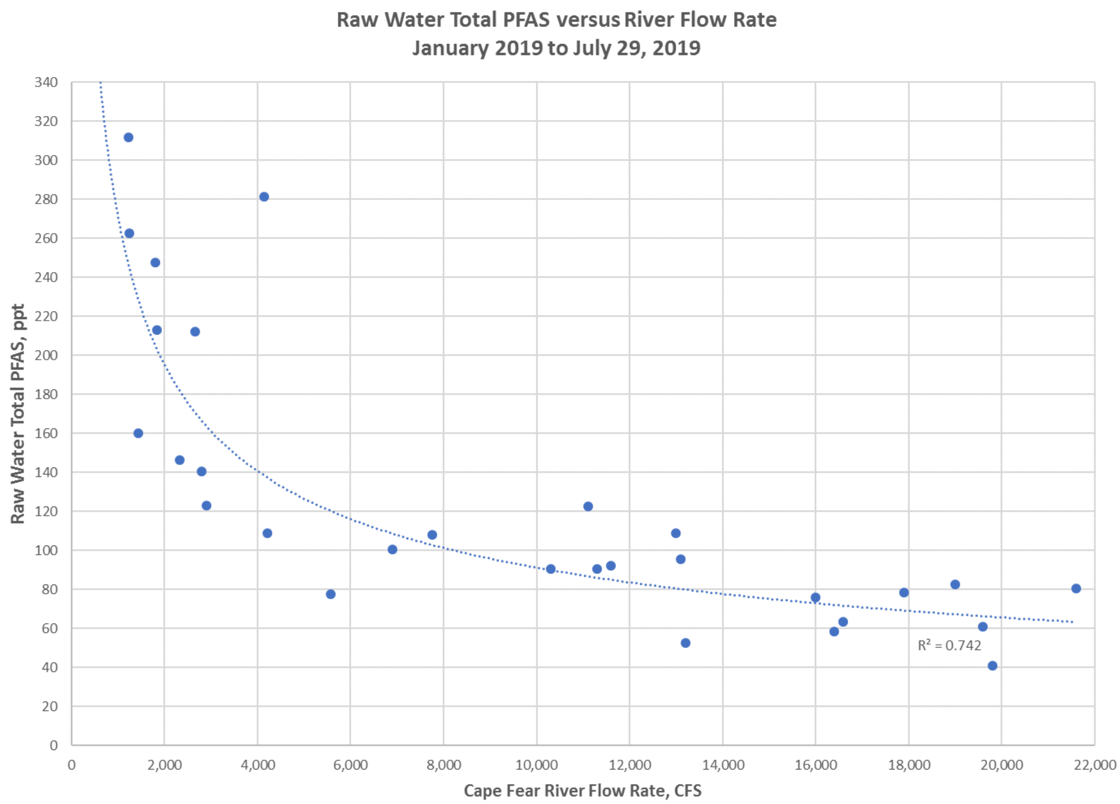

Figure 2. PFAS Concentrations and Cape Fear River Flow (provided by CFPUA)

5. For offsite groundwater where airborne deposition is considered to be the mechanism for PFAS transport to groundwater, prevailing wind directions should be utilized to estimate groundwater concentrations and mass loading to the river through offsite groundwater discharge to the river (see supplemental wind rose). For example, the predominant wind directions measured at nearby Fayetteville are from the southwest and from the northeast, which generally correlates with Figure E-2. For the area east and southeast of the site, however, there is very little data (few residential wells) and a review of Figure E-2 suggests that PFAS loading to groundwater in this area may be underestimated. The sampling data for wells west and northwest of the site (a much larger data set) could, however, be used to project/estimate groundwater concentrations/mass loading due to airborne deposition in the east-southeast area as the proportion of west and northwest winds (from west to east) is similar to/slightly higher than east/southeast winds (1998 – 2019 data). As currently configured, it appears that offsite groundwater mass loading to the river from east/southeast of the site may be underestimated.
6. A critical gap in the technical framework is that no sampling has been reported to characterize PFAS contamination of sediment in the Cape Fear River bed or riparian wetlands. It is anticipated that historic emissions and discharges from the facility have accumulated and caused long-term residual contamination of the river and riparian wetlands. Diffusion from such contaminant stores could provide a long-term source of PFAS contamination to the river. Scouring of contaminated sediment from the river bed or banks during high flow events could also elevate PFAS concentrations in downstream intake water. Sediment sampling along the mainstem should be conducted to characterize the extent and magnitude of sediment bed and riparian wetland contamination and the potential associated risks. Areas prone to excess build-

up of organic matter, such as sluggish riverine swamps and pools behind the locks and dams, face a higher risk of exhibiting elevated sediment PFAS concentrations. A comprehensive study is needed to characterize sediment PFAS contamination in the Cape Fear River bed that includes assessment of potential contamination hot-spots, such as the Kings Bluff intake canal situated near the Cape Fear River Lock and Dam #1. In addition, onsite sediment sampling has been sparse and should be extended to all concentrated surface flow pathways (e.g., open channel to Outfall 002).

7. A flow-based PFAS loading curve prepared by CFPUA for 2019 is shown in Figure 3. Higher PFAS loads are associated with higher flows, which indicates that stormwater and/or sediment bed erosion (as described in the previous comment) contributes PFAS to the river. Yet, these sources are poorly quantified, including both onsite and offsite stormwater contributions.

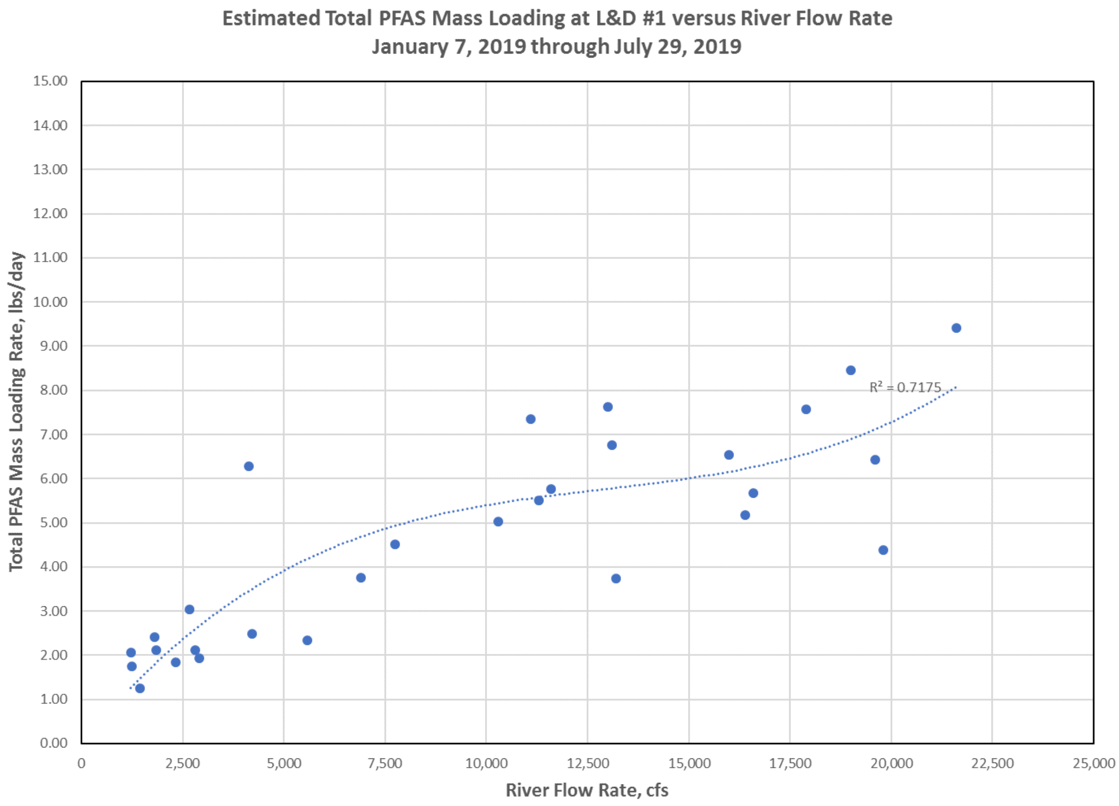

Figure 3. Flow-based PFAS Loading Rate (provided by CFPUA)

8. A mass balance evaluation of flow from the facility to the river is not provided in the Geosyntec (2019) report and is needed to verify the overall annual flow balance applied in the MLM. Such an evaluation should incorporate flow sources, storages, and discharges surface and subsurface discharges from the facility study area.
9. The possibility of additional diffuse discharges from the perched zone/shallow aquifer in other areas along the river should be investigated.

2.3 LOADING REDUCTION PLAN AND STRATEGIES

Chemours has previously implemented PFAS loading control measures: 1) eliminating process wastewater discharges (excluding those from site tenants Kuraray and DuPont), 2) air emission controls, 3) lining the facility's cooling water channel and sediment ponds, and 4) extraction of groundwater discarded offsite.

Seven new control strategies are proposed for the Chemours Fayetteville Works facility in the current plan (Geosyntec, 2019): 1) capture and treat Old Outfall 002 water (within two years), 2) capture and treat groundwater from seeps (within five years), 3) targeted sediment removal from conveyance network (within one year), 4) develop a stormwater pollution prevention plan (within one year), 5) targeted stormwater source control and/or treatment (within four years), 6) decommission and replacement of remaining terracotta piping (that carried industrial process wastewater; within two years), and 7) assessment of potential groundwater intrusion into the conveyance network (within five years). All proposed actions are to be implemented within five years and are onsite controls (on the Fayetteville Works property). Key comments regarding the plan and strategies follow.

1. It is stated on page v. regarding the control strategies that "Four of these actions would be implemented within two years of Consent Order Amendment and three of the actions would be implemented within five years of Consent Order Amendment (assuming all necessary permits and authorizations are provided in a timely manner)." Control actions may not be implemented on schedule due to the ambiguity of this statement, which poses a risk to downstream users.
2. The actions related to groundwater (#2 and #7) are set to take the longest time to implement yet are the top loading sources according to the MLM. Plans to evaluate and address groundwater and stormwater are still being developed, thus, loadings from these sources remain a vulnerability to downstream water supplies.
3. No specific treatment option is listed for captured onsite surface and groundwater, nor is the effectiveness of the proposed treatment methods demonstrated. Without these specifications it is uncertain if the loading reduction plan will effectively mitigate PFAS pollution. An onsite study evaluating the proposed treatment technologies and observed effectiveness (i.e., percent removal, treated concentrations and loads) should be required.
4. The onsite perched zone pumping described in the report (Section 3; Completed Reduction Actions) amounts to <0.1 gpm. Has there been any evaluation to determine whether the pumping rate can be increased via more aggressive pumping or additional groundwater extraction points to enhance capture of this highly impacted groundwater?
5. No manufacturing process changes have been required to date. Spills or unknown leaks or emissions at the facility remain a risk to CFPUA's source water. In paragraph 15 of the CO, Chemours is to provide notification to downstream water utilities in the event of elevated PFAS releases through Outfall 002. However, CFPUA should consider requesting spill (or other contaminant release) notification requirements that are more comprehensive.
6. Discharge of Chemours' process wastewater has been halted and the waste is injected into subsurface storage out-of-state. However, elevated HFPO-DA and PFMOAA concentrations were also observed in Kuraray process wastewater, which continues to be discharged from the onsite WWTP (page 18 of the Outfall 002 Assessment) via Outfall 002. Sources causing contamination of Kuraray process wastewater have not been identified and quantified. Furthermore, control strategies have not been required or proposed for the Kuraray process wastewater.

7. No PFAS loading control strategies are recommended for contaminated offsite soils, offsite groundwater, or river sediment due to the lack of evaluation of these sources (see Section 2.2). Additional strategies may be needed following the evaluation of these sources to ensure protection of downstream water quality.

All monitoring applied in the assessment appears to have been conducted by Geosyntec and contracted labs for Chemours. DEQ can require split sampling (samples provided to DEQ for parallel testing) per the Consent Order. Split sampling would be beneficial from the perspective of CFPUA for quality assurance and control checking, therefore, CFPUA should inquire about completed split sampling and the findings, or the rationale for why split sampling has not occurred to date.

3.0 REFERENCES

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