Supporting Information for:

Assessment of Commonly Measured Wastewater Parameters to Estimate Sewershed Populations for Use in Wastewater-Based Epidemiology: Insights into Population Dynamics in New York City during the COVID-19 Pandemic

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4. References
1. Background

1.1. New York City sewersheds and boroughs

Figure S1. Map of New York City’s 14 sewersheds and five boroughs. Unique facility IDs of the wastewater resource recovery facilities (WRRFs) that serve each sewershed are indicated. Sewershed boundaries (thin borders) are based on the shapefile available from Open Sewer Atlas NYC. Bold borders indicate boundaries for the five boroughs (shapefile retrieved from NYC OpenData): the Bronx (Bronx County, blue), Queens (Queens County, green), Brooklyn (Kings County, yellow), Staten Island (Richmond County, red), and Manhattan (New York County, purple).

NYC’s 14 WRRFs have a combined design capacity of 1.8 billion gallons daily and treat an average of 1.3 billion gallons of wastewater daily.
2. Methods

2.1. Analysis of routine wastewater monitoring data

Concentrations of ammonia (NH₃), total Kjeldahl nitrogen (TKN), total suspended solids (TSS), and five-day carbonaceous biochemical oxygen demand (CBOD₅) were measured in 24-h flow-weighted composite influent wastewater samples. Influent samples from each facility were composited from eight grab samples collected every three hours over a 24-hour period beginning at 7:00 AM on the sample date and ending at 4:00 AM on the next day; flow rates measured during each 3-hour period were used to determine the volume of each grab sample added to the composite.

Data files provided by NYC DEP contained metadata indicating the weather conditions on each sampling date for each WRRF. Sample dates categorized as having “dry weather conditions” were those without precipitation, designated by the terms “Dry” (“D”), “Clear” (“c”), “sunny”, “N”, “Fair”, “Fine”, and “Cloudy” within the data sets. Sample dates categorized as having “wet weather conditions” were those with precipitation, designated by the terms “Wet” (“W”), “Rain” (“r”), “PRECIP” (“P”), “CLOUDY/RAIN”, “Snow”, and “Snow-melt” within the data set. When considered together, data from both dry and wet weather conditions comprise the “full” data set.

Erroneous data points due to acidification failures during wastewater sample analysis or flow meter malfunctions had been flagged by the New York City (NYC) Department of Environmental Protection (DEP) (NYC DEP) and were removed from the data set for the analysis herein.

2.2. Analysis of the U.S. Census Bureau’s Longitudinal Employer-Household Dynamics Origin-Destination Employment Statistics

The United States Census Bureau’s Longitudinal Employer-Household Dynamics Origin-Destination Employment Statistics (LODES) for 2019 were used to determine typical trends in commuter flows into and out of each sewershed. LODES for 2019 (Version 7), organized by “workplace” and “home” census blocks, were obtained online.⁴ “All Jobs” data from New York State, which summarizes jobs within New York State (inclusive of NYC), were retrieved along with “All Jobs” data from Vermont, Massachusetts, Connecticut, New Jersey, and Pennsylvania.
in order to account for any NYC residents with workplaces in states bordering New York. Census blocks were matched to corresponding zip code tabulation areas (ZCTA) based on geography crosswalk data for New York from the U.S. Census Bureau,\(^4\) which were then matched to modified zip code tabulation areas (MODZCTA), as defined and used by the City of New York.\(^5\) Each MODZCTA was assigned to one sewershed, determined based on sewershed boundary maps provided by the NYC DEP Bureau of Water and Sewer Operations. Any MODZCTA that straddled multiple sewershed areas was assigned to the sewershed in which it had the greatest overlapping land area. The resulting data was used to estimate daily totals for:

1. \(P_{in,A}\), the number of commuters entering each NYC sewershed, \(A\), from residences outside the sewershed (i.e., residents from other NYC sewersheds or from outside of NYC with workplaces in sewershed \(A\)).

2. \(P_{out,A}\), the number of commuters leaving each NYC sewershed, \(A\) (i.e., residents of sewershed \(A\) with workplaces in other NYC sewersheds or outside NYC in the states of New York, Vermont, Massachusetts, Connecticut, New Jersey, or Pennsylvania).

Note that this analysis assumes that employees regularly commute from their residence locations to the workplace locations indicated in the LODES data, which may not always be the case.\(^6\) These estimates also do not reflect time of day or time spent in residences or places of employment. The analysis presented herein is therefore only used for relative comparisons of the effect of commuter populations on each sewershed, for what we assume to be typical workdays.

Using Equation S1, \(P_{in,A}\), and \(P_{out,A}\), we determined \(\Delta_{P,A,\%}\), the percent change in the sewershed population, as compared to the census-based residential population (\(P_A\), as presented in Table 1\(^7\)), due to commuter flows.

\[
\Delta_{P,A,\%} = \frac{P_{in,A} - P_{out,A}}{P_A} \quad \text{Equation S1}
\]

All data analysis was completed using R.\(^8\)
3. Results

3.1. Influent wastewater flow rates

Table S1. Average influent wastewater flow rates at each of NYC’s WRRFs, averaged over 2019 (January 1, 2019 to December 31, 2019). The number of data points used to calculate each average is shown in parentheses.

| Facility ID | Wastewater Resource Recovery Facility (WRRF) | Average Influent Flow Rate (MGD) | Number of data points is in parentheses |
|-------------|------------------------------------------------|----------------------------------|----------------------------------------|
|             |                                                | Full Data Set | Wet Weather | Dry Weather |
| 1           | Rockaway                                       | 22±3 (365)    | 22±4 (96)   | 21±3 (269)  |
| 2           | Red Hook                                       | 29±9 (365)    | 37±12 (123) | 24±1 (242)  |
| 3           | Port Richmond                                  | 31±9 (365)    | 38±12 (127) | 27±4 (238)  |
| 4           | Oakwood Beach                                  | 32±6 (365)    | 38±8 (61)   | 31±5 (304)  |
| 5           | 26th Ward                                      | 47±15 (365)   | 64±19 (91)  | 42±7 (274)  |
| 6           | Tallman Island                                 | 62±13 (365)   | 79±12 (84)  | 57±7 (281)  |
| 7           | North River                                    | 111±22 (365)  | 132±29 (118) | 102±7 (247) |
| 8           | Coney Island                                   | 98±18 (365)   | 116±24 (84) | 93±11 (281) |
| 9           | Jamaica                                        | 84±12 (365)   | 97±15 (97)  | 79±6 (268)  |
| 10          | Hunts Point                                    | 129±32 (365)  | 155±40 (125) | 115±14 (240) |
| 11          | Owl's Head                                     | 92±21 (365)   | 121±22 (98) | 82±4 (267)  |
| 12          | Bowery Bay                                     | 105±31 (365)  | 137±36 (124) | 88±5 (241)  |
| 13          | Newtown Creek                                  | 207±50 (365)  | 258±68 (102) | 187±17 (263) |
| 14          | Wards Island                                   | 190±37 (365)  | 207±43 (121) | 182±30 (244) |
### 3.2. Parameter mass loads

Table S2. Average mass loads of ammonia (NH$_3$) in influent wastewater at each of NYC’s WRRFs, averaged over 2019 (January 1, 2019 to December 31, 2019). The number of data points used to calculate each average is shown in parentheses.

| Facility ID | Wastewater Resource Recovery Facility (WRRF) | Average NH$_3$ Mass Load (10$^6$ g/day) |  |
|-------------|---------------------------------------------|----------------------------------------|--|
|             |                                             | Full Data Set                          | Wet Weather | Dry Weather |
| 1           | Rockaway                                   | 1.1±0.3 (365)                          | 1.1±0.2 (96)  | 1.1±0.3 (269) |
| 2           | Red Hook                                   | 2.1±0.5 (364)                          | 2.2±0.6 (122) | 2.1±0.4 (242) |
| 3           | Port Richmond                              | 1.9±0.4 (52)                           | 2.0±0.4 (20)  | 1.8±0.5 (32)  |
| 4           | Oakwood Beach                              | 4.6±1.3 (52)                           | 4.5±1.0 (8)   | 4.6±1.3 (44)  |
| 5           | 26th Ward                                  | 2.7±0.5 (365)                          | 2.8±0.7 (91)  | 2.7±0.5 (274) |
| 6           | Tallman Island                             | 4.6±0.7 (363)                          | 4.6±1.1 (83)  | 4.6±0.5 (280) |
| 7           | North River                                | 9.8±1.7 (54)                           | 9.9±1.6 (22)  | 9.8±1.7 (32)  |
| 8           | Coney Island                               | 6.2±1.2 (365)                          | 6.5±1.5 (84)  | 6.1±1.0 (281) |
| 9           | Jamaica                                    | 7.6±1.2 (365)                          | 7.8±1.4 (97)  | 7.6±1.1 (268) |
| 10          | Hunts Point                                | 7.4±1.4 (365)                          | 7.5±2.0 (125) | 7.3±1.0 (240) |
| 11          | Owl's Head                                 | 8.6±2.3 (52)                           | 8.9±3.0 (13)  | 8.5±2.0 (39)  |
| 12          | Bowery Bay                                 | 10.4±1.7 (364)                         | 10.4±2.4 (123) | 10.4±1.2 (241) |
| 13          | Newtown Creek                              | 15.7±3.2 (364)                         | 16±3.6 (102)  | 15.5±3.1 (262) |
| 14          | Wards Island                               | 9.6±1.5 (365)                          | 9.4±1.5 (121) | 9.6±1.4 (244) |
Table S3. Average mass loads of total Kjeldahl nitrogen (TKN) in influent wastewater at each of NYC’s WRRFs, averaged over 2019 (January 1, 2019 to December 31, 2019). The number of data points used to calculate each average is shown in parentheses.

| Facility ID | Wastewater Resource Recovery Facility (WRRF) | Average TKN Mass Load (10^6 g/day) | Number of data points is in parentheses |
|-------------|---------------------------------------------|------------------------------------|-----------------------------------------|
|             |                                             | Full Data Set | Wet Weather | Dry Weather |
| 1           | Rockaway                                   | 1.8±0.4 (365) | 1.8±0.3 (96) | 1.7±0.4 (269) |
| 2           | Red Hook                                   | 3.3±0.6 (364) | 3.7±0.8 (122) | 3.1±0.3 (242) |
| 3           | Port Richmond                              | 3.3±0.6 (52)  | 3.7±0.8 (20)  | 3.1±0.4 (32)  |
| 4           | Oakwood Beach                              | 5.9±1.3 (52)  | 6.1±1.2 (8)   | 5.8±1.3 (44)  |
| 5           | 26th Ward                                  | 4.3±0.8 (365) | 4.9±0.9 (91)  | 4.1±0.6 (274) |
| 6           | Tallman Island                             | 6.3±0.8 (364) | 6.9±1.2 (83)  | 6.2±0.5 (281) |
| 7           | North River                                | 13.5±1.9 (54) | 14.3±1.8 (22) | 12.9±1.8 (32) |
| 8           | Coney Island                               | 13.5±3.4 (365) | 14.6±3.4 (84) | 13.1±3.3 (281) |
| 9           | Jamaica                                    | 10.7±1.2 (365) | 11.4±1.4 (97) | 10.5±0.9 (268) |
| 10          | Hunts Point                                | 10.5±1.6 (365) | 11.3±2.3 (125) | 10.1±0.9 (240) |
| 11          | Owl's Head                                 | 11.3±2.0 (52)  | 12.0±3.4 (13)  | 11.1±1.3 (39)  |
| 12          | Bowery Bay                                 | 14.1±2.3 (364) | 15.3±3.0 (123) | 13.4±1.6 (241) |
| 13          | Newtown Creek                              | 24.3±3.8 (364) | 26.6±4.5 (102) | 23.4±3.0 (262) |
| 14          | Wards Island                               | 15.1±1.4 (365) | 15.5±1.5 (121) | 14.9±1.3 (244) |
Table S4. Average mass loads of total suspended solids (TSS) in influent wastewater at each of NYC’s WRRFs, averaged over 2019 (January 1, 2019 to December 31, 2019). The number of data points used to calculate each average is shown in parentheses.

| Facility ID | Wastewater Resource Recovery Facility (WRRF) | Average TSS Mass Load (10^6 g/day) | Full Data Set | Wet Weather | Dry Weather |
|-------------|---------------------------------------------|-----------------------------------|---------------|-------------|-------------|
| 1           | Rockaway                                    | 8.5±3.0 (365)                     | 8.8±2.6 (96)  | 8.3±3.2 (269) |
| 2           | Red Hook                                    | 19.1±11.3 (365)                   | 27.5±14.6 (123) | 14.9±5.6 (242) |
| 3           | Port Richmond                               | 17.3±7.2 (365)                    | 21.8±9.5 (127) | 14.9±3.8 (238) |
| 4           | Oakwood Beach                               | 17.8±9.4 (357)                    | 24.6±12.8 (60) | 16.4±7.9 (297) |
| 5           | 26th Ward                                   | 20.6±11.6 (365)                   | 30.1±15.3 (91) | 17.5±7.8 (274) |
| 6           | Tallman Island                              | 27.7±7.8 (364)                    | 36±9.7 (83)    | 25.3±5.0 (281) |
| 7           | North River                                 | 68.1±21.9 (362)                   | 78.6±25.9 (118) | 63±17.6 (244) |
| 8           | Coney Island                                | 94.2±36.4 (365)                   | 107.3±43.1 (84) | 90.3±33.3 (281) |
| 9           | Jamaica                                     | 47.5±15.5 (365)                   | 58.4±20.6 (97) | 43.6±10.8 (268) |
| 10          | Hunts Point                                 | 50.5±18.9 (365)                   | 63.9±25.8 (125) | 43.6±7.7 (240) |
| 11          | Owl's Head                                  | 52.6±18.4 (365)                   | 70.2±24.7 (98) | 46.1±9.2 (267) |
| 12          | Bowery Bay                                  | 64.5±29.0 (364)                   | 83.5±32.9 (124) | 54.7±20.8 (240) |
| 13          | Newtown Creek                               | 138.8±53.6 (363)                  | 180.2±75.4 (102) | 122.7±29.2 (261) |
| 14          | Wards Island                                | 86.5±23.6 (365)                   | 96.2±28.7 (121) | 81.7±19.0 (244) |
Table S5. Average mass loads of five-day carbonaceous biochemical oxygen demand (CBOD₅) in influent wastewater at each of NYC’s WRFs, averaged over 2019 (January 1, 2019 to December 31, 2019). The number of data points used to calculate each average is shown in parentheses.

| Facility ID | Wastewater Resource Recovery Facility (WRRF) | Average CBOD₅ Mass Load (10⁶ g/day) | Number of data points is in parentheses |
|-------------|---------------------------------------------|--------------------------------------|----------------------------------------|
|             |                                             | Full Data Set                        | Wet Weather                            | Dry Weather                            |
| 1           | Rockaway                                    | 8.5±2.4 (355)                        | 8.8±1.9 (94)                           | 8.4±2.6 (261)                          |
| 2           | Red Hook                                    | 16.3±5.3 (359)                       | 19.6±6.8 (120)                         | 14.6±3.4 (239)                         |
| 3           | Port Richmond                               | 29.4±7.9 (357)                       | 32.7±9.3 (124)                         | 27.6±6.3 (233)                         |
| 4           | Oakwood Beach                               | 15.4±7.0 (360)                       | 18.1±9.6 (60)                          | 14.9±6.2 (300)                         |
| 5           | 26th Ward                                   | 21.4±7.0 (365)                       | 25.9±8.5 (91)                          | 19.9±5.6 (274)                         |
| 6           | Tallman Island                              | 30.6±6.0 (364)                       | 34.4±7.6 (83)                          | 29.5±4.9 (281)                         |
| 7           | North River                                 | 66.7±14.4 (364)                      | 72.5±15.4 (118)                        | 63.9±13.1 (246)                        |
| 8           | Coney Island                                | 57.5±17.3 (357)                      | 65.6±22.2 (81)                         | 55.1±14.8 (276)                        |
| 9           | Jamaica                                     | 47.1±11.6 (363)                      | 50.4±14.7 (96)                         | 45.9±10.0 (267)                        |
| 10          | Hunts Point                                 | 52.9±11.6 (365)                      | 59.8±14.1 (125)                        | 49.2±7.9 (240)                         |
| 11          | Owl's Head                                  | 63.9±19.4 (364)                      | 73.9±23.3 (97)                         | 60.3±16.4 (267)                        |
| 12          | Bowery Bay                                  | 64.2±14.4 (364)                      | 72.0±17.8 (124)                        | 60.2±10.2 (240)                        |
| 13          | Newtown Creek                               | 122.5±31.0 (356)                     | 140.5±49.4 (98)                        | 115.7±22.2 (258)                       |
| 14          | Wards Island                                | 82.2±13.3 (365)                      | 86.6±13.3 (121)                        | 80.1±12.7 (244)                        |
Figure S2. Boxplots of daily ammonia mass loads (10^6 g/day) for each day of the week between January 1, 2019 and December 31, 2019 for NYC’s 14 WRRFs. Boxes summarize the 25th, 50th (median, orange line), and 75th percentiles; whiskers indicate the 5th and 95th percentiles. Average ammonia mass loads for each day of the week using the full data set are shown in bold with the number of data points used to calculate the average in parentheses.

Average ammonia mass loads were lower on weekends for the Newton Creek WRRF (Figure S2), which may reflect the variability in Manhattan’s population due to commuting during weekdays, as discussed in the main manuscript text. It should be noted that NH₃ concentrations were not measured daily at all WRRFs, such as at the North River WRRF.
3.3. Correlations and linear regressions between parameter mass loads and sewershed populations

Table S6 summarizes the Pearson correlation coefficients between the average mass load of each wastewater parameter (2019 data) and sewershed populations estimated from census data (Table 1). Correlations without including data from two WRRFs that serve the borough of Manhattan (Table S6a) were generally stronger than those with data from all 14 WRRFs (Table S6b), with the exception of correlations for TSS.

Table S6. Pearson correlation coefficients (r) between average mass loads of each parameter (NH₃, TKN, TSS, or CBOD₅;  midfield, as defined in the main text) in 2019 and sewershed populations. Correlations are presented (a) without data from the North River and Newtown Creek WRRFs (n=12) and (b) with data from all WRRFs (n=14). Details of this comparison are presented in the main text. Significance values for each correlation are indicated.

(a) Correlations excluding data from the North River and Newtown Creek WRRFs

| Parameter | Pearson correlation coefficient (r) |
|-----------|-----------------------------------|
|           | Full Data Set | Dry weather | Wet Weather |
| NH₃       | 0.96****      | 0.96****    | 0.95****    |
| TKN       | 0.95****      | 0.95****    | 0.94****    |
| TSS       | 0.86***       | 0.84***     | 0.89***     |
| CBOD₅     | 0.98****      | 0.98****    | 0.97****    |

*** p < 0.001, **** p < 0.0001

(b) Correlations with data from all 14 WRRFs

| Parameter | Pearson correlation coefficient (r) |
|-----------|-----------------------------------|
|           | Full Data Set | Dry weather | Wet Weather |
| NH₃       | 0.91****      | 0.91****    | 0.91****    |
| TKN       | 0.91****      | 0.91****    | 0.90****    |
| TSS       | 0.86****      | 0.85***     | 0.85***     |
| CBOD₅     | 0.92****      | 0.93****    | 0.91****    |

*** p < 0.001, **** p < 0.0001
Figure S3. Average mass loads ($M_{iA}$) of (a) NH$_3$, (b) TKN, (c) TSS, and (d) CBOD$_5$ for each WRRF in NYC between January 1, 2019 and December 31, 2019 plotted versus the estimated sewershed population ($P_A$), with all 14 WRRFs included in statistical analyses (in contrast to Figure 1 of the main manuscript which excludes the North River and Newtown Creek WRRFs). Points represent the average mass load calculated using the full data set for each WRRF (i.e., both dry and wet days were included in computed averages), and error bars indicate standard deviation. Numbers adjacent to each point designate the WRRF (codes are presented in Table 1). Lines of best fit for linear regressions including only wet (blue) or dry (red) weather data are shown with 95% confidence intervals shaded (lines of best fit are not shown for regressions based on the full data set). Slopes (equivalent to the per capita mass loads, $M_{i,pc}$) and goodness-of-fit ($R^2$) values are provided for linear regressions using wet weather data (blue text), the full data set (black text), and dry weather data (red text). Average mass loads for all WRRFs were included in linear regressions for comparison to Figure 1.
3.4. Estimates of commuter flows based on 2019 U.S. Census LODES data

Methodology used for analysis summarized in Table S7 is described in section 2.2 of the SI. As described in the main text, typical workday populations of the North River and Newtown Creek WRRFs were 89% and 60% larger than the census-based residential populations for these sewersheds, respectively. Typical workday populations were smaller than census-based residential populations for all other NYC sewersheds due to residents commuting outside their home sewershed for work, with the exception of the sewershed served by the Red Hook WRRF. The Red Hook sewershed had a workday population that was 14% larger than this sewershed’s census-based residential population, an increase notably lower than that estimated for the sewersheds served by the North River and Newtown Creek WRRFs (Table S7).

Table S7. Summary of the effect of commuter flows on the population of each of NYC’s 14 sewersheds.

| Facility ID | Wastewater Resource Recovery Facility (WRRF) | Δ_P, A. %, Percent change in residential sewershed population due to commuting flows (estimated for 2019) |
|-------------|---------------------------------------------|----------------------------------------------------------------------------------------------------------|
| 1           | Rockaway                                    | -25%                                                                                                      |
| 2           | Red Hook                                    | 14%                                                                                                       |
| 3           | Port Richmond                               | -20%                                                                                                      |
| 4           | Oakwood Beach                               | -24%                                                                                                      |
| 5           | 26th Ward                                   | -28%                                                                                                      |
| 6           | Tallman Island                              | -15%                                                                                                      |
| 7           | North River                                 | 89%                                                                                                       |
| 8           | Coney Island                                | -21%                                                                                                      |
| 9           | Jamaica                                     | -29%                                                                                                      |
| 10          | Hunts Point                                 | -25%                                                                                                      |
| 11          | Owl's Head                                  | -14%                                                                                                      |
| 12          | Bowery Bay                                  | -15%                                                                                                      |
| 13          | Newtown Creek                               | 60%                                                                                                       |
| 14          | Wards Island                                | -16%                                                                                                      |
3.5. Time-series analysis

3.5.1. Time-series analysis of dry weather flow rates

Time-series analysis of dry weather flow rates during the pre-PAUSE, PAUSE, and post-PAUSE periods (Figure S5) indicates that flow rates did not exhibit the same trends as those observed in ammonia mass loads for all facilities (compared to Figure 2 in the main text). For those facilities for which trends in flow rates and ammonia loads were similar, the percent changes in flow rates were smaller than those observed for ammonia mass loads (Table S8b compared to Table S8a). Specifically, the percent changes in average flow rates during the PAUSE period for the Rockaway (18%) and North River (-18%) WRRFs were lower than the percent changes in average ammonia mass loads at the same facilities (57% and -53%, respectively). Additionally, no significant change in average flow rates was observed during the PAUSE period at the Port Richmond WRRF, for which there was a significant increase in average ammonia mass loads during the PAUSE period. Changes in average monthly flow rates across years (Table S9b, Figure S6) were also less pronounced than changes in average monthly ammonia mass loads across years (Table S9a, Figure S4). As discussed in the main text, the reduction in monthly average ammonia mass loads at the North River WRRF starting in March 2020 (Figure 3a) was larger than the reduction in average daily flow rates at that time (Figure 3d), and the increase in average ammonia mass loads at the Rockaway WRRF in the spring of 2020 (Figure 3b) was larger than the increase in average flow rates (Figure 3e). Average daily flow rates were therefore less impacted by the population dynamics that resulted from the onset of COVID-19 and the NYS on PAUSE executive order than ammonia mass loads.
3.5.2. Time-series analysis figures and tables

Table S8. Average (a) ammonia mass loads (based on the full data set of wet and dry weather data combined) and (b) dry weather flow rates for the pre-PAUSE (January 1, 2019 - March 22, 2020), PAUSE (March 23, 2020 - June 7, 2020) and post-PAUSE (June 8, 2020 - December 31, 2020) periods. The percent change in the PAUSE and post-PAUSE periods relative to the pre-PAUSE period are shown in parentheses, with significance values between the period averages indicated (Welch’s t test). Blue (positive) indicates an increase; brown (negative) indicates a decrease. The number of data points used to calculate averages for each time period are indicated for ammonia mass loads and flow rates in Figure 2 and Figure S5, respectively.

a. Average ammonia mass loads

| Facility ID | Wastewater Resource Recovery Facility (WRRF) | Average Ammonia Mass Load 10^6 g/day (percent change relative to pre-PAUSE) |
|-------------|---------------------------------------------|--------------------------------------------------------------------------|
|             |                                             | pre-PAUSE | PAUSE | post-PAUSE |
| 1           | Rockaway                                   | 1.1±0.3   | 1.8±0.3 (57%****) | 1.4±0.2 (21%****) |
| 2           | Red Hook                                   | 2.1±0.4   | 1.7±0.2 (-19%*)  | 1.9±0.4 (-9%****) |
| 3           | Port Richmond                              | 1.9±0.4   | 2.6±0.2 (37%*** ) | 2.4±0.3 (26%****) |
| 4           | Oakwood Beach                              | 4.7±1.4   | 4.9±0.7 (4%)     | 4.4±0.7 (-7%)     |
| 5           | 26th Ward                                  | 2.8±0.5   | 2.9±0.4 (3%)     | 3.0±0.5 (6%***)  |
| 6           | Tallman Island                             | 4.6±0.7   | 4.7±0.7 (3%)     | 4.7±0.6 (3%*)    |
| 7           | North River                                | 9.8±1.7   | 4.6±0.6 (-53%****) | 5.7±1.2 (-41%****) |
| 8           | Coney Island                               | 6.2±1.1   | 7.4±1.0 (20%****) | 6.4±1.1 (4%*)    |
| 9           | Jamaica                                    | 7.6±1.2   | 7.3±1.0 (-5%)    | 7.3±1.1 (-5%***) |
| 10          | Hunts Point                                | 7.4±1.3   | 6.9±1.1 (-7%*)   | 7.4±1.1 (0%)     |
| 11          | Owl's Head                                 | 8.8±2.2   | 11.8±6.0 (33%)   | 10.9±2.0 (23%***) |
| 12          | Bowery Bay                                 | 10.4±1.7  | 10.4±1.9 (-1%)   | 9.6±1.3 (-8%****) |
| 13          | Newtown Creek                              | 15.5±3.1  | 10.3±1.2 (-34%**) | 10.8±2 (-30%****) |
| 14          | Wards Island                               | 9.5±1.4   | 8.6±1.0 (-9%****) | 9.2±1.4 (-3%*)   |

*p<0.05, **p<0.01, ***p<0.001, ****p<0.0001
### b. Average dry weather flow rates

| Facility ID | Wastewater Resource Recovery Facility (WRRF) | Average Dry Weather Flow Rate MGD (percent change relative to pre-PAUSE) |
|-------------|---------------------------------------------|-------------------------------------------------------------------|
|             | pre-PAUSE | PAUSE     | post-PAUSE  |
| 1           | Rockaway  | 21±3      | 25±3        | 21±3        | (18%****) | 21±3 | (1%) |
| 2           | Red Hook  | 24±1      | 21±1        | 22±1        | (-11%****) | 22±1 | (-7%****) |
| 3           | Port Richmond | 27±4      | 26±6        | 25±2        | (-2%)    | 25±2 | (-8%****) |
| 4           | Oakwood Beach | 30±4      | 28±3        | 27±4        | (-5%*** )| 27±4 | (-11%****) |
| 5           | 26th Ward | 42±7      | 41±5        | 45±10       | (-2%)    | 45±10 | (7%*** ) |
| 6           | Tallman Island | 57±7      | 57±6        | 55±7        | (0%)     | 55±7 | (-3%*) |
| 7           | North River | 101±7     | 83±5        | 91±10       | (-18%****) | 91±10 | (-10%****) |
| 8           | Coney Island | 92±11     | 87±11       | 83±12       | (-5%** ) | 83±12 | (-10%****) |
| 9           | Jamaica    | 80±6      | 78±2        | 76±5        | (-3%****) | 76±5 | (-5%****) |
| 10          | Hunts Point | 116±13    | 117±6       | 122±8       | (1%)     | 122±8 | (5%****) |
| 11          | Owl's Head | 82±4      | 82±3        | 85±4        | (0%)     | 85±4 | (4%****) |
| 12          | Bowery Bay | 89±5      | 90±4        | 88±4        | (1%)     | 88±4 | (-1%) |
| 13          | Newtown Creek | 185±16    | 159±7       | 179±22      | (-14%****) | 179±22 | (-3%**) |
| 14          | Wards Island | 179±28    | 171±10      | 187±26      | (-5%*** )| 187±26 | (5%**) |

*p<0.05, **p<0.01, ***p<0.001, ****p<0.0001

![Percent Change Diagram]
Figure S4. Monthly averages of ammonia mass loads (based on the full data set) for 2017 (teal triangles), 2018 (teal squares), 2019 (solid black circles), and 2020 (open red circles) relative to January 2019 monthly averages for NYC’s 14 WRRFs. Months in 2020 for which only one ammonia measurement was reported (and no average was calculated) are indicated. Error bars indicate standard deviations of the relative averages, with errors propagated. Panels for the Rockaway, Tallman Island, and North River WRRFs are the same as those presented in Figure 3 of the main text.
Figure S5. Average daily flow rates for NYC’s 14 WRRFs under dry weather conditions between January 1, 2019 and December 31, 2020. Average flow rates for dry weather conditions (black lines) are shown for each of the pre-PAUSE, PAUSE (indicated by vertical dashed lines), and post-PAUSE periods. Note that y-axes scales vary between panels.
Figure S6. Monthly averages of average dry weather flow rates for 2017 (teal triangles), 2018 (teal squares), 2019 (solid black circles), and 2020 (open red circles) relative to January 2019 monthly averages for NYC’s 14 WRRFs. Error bars indicate standard deviations of the relative averages, with errors propagated. Panels for the Rockaway, Tallman Island, and North River WRRFs are the same as those presented in Figure 3 of the main text.
Table S9. Percent change between 2019 and 2020 monthly averages of (a) ammonia mass loads (full data set) and (b) average daily flow rates (dry weather) for NYC’s 14 WRRFs. Blue (positive) indicates an increase in 2020 relative to 2019; brown (negative) indicates a decrease in 2020 relative to 2019. Significance values of the difference between monthly averages are indicated (Welch’s t test).

a. Percent change for ammonia mass loads

| ID | Wastewater Resource Recovery Facility (WRRF) | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|----|---------------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1  | Rockaway                                   | 26* | 27* | 31* | 69* | 61* | 38* | 10* | 6   | 8   | 4   | 7*  | 16* |
| 2  | Red Hook                                    | -4  | 3   | -6  | -19†| -21†| -8† | -20†| -18 | -18*| -20*| -17*| 6   |
| 3  | Port Richmond                               | 21  | 47  | 50* | 64† | 36† | 30† | 61† | 13  | 10  | 9   | 6   | 15  |
| 4  | Oakwood Beach                               | 39  | 15  | 31  | 4   | -15†| 0†  | -6† | 26  | 12  | -6  | -20*| -20 |
| 5  | 26th Ward                                   | 10* | 17* | 10* | -1  | 19* | 9   | 6   | -2  | 7   | 6   | -6  | 2   |
| 6  | Tallman Island                              | 3   | -1  | 3   | 4   | 11* | 3   | -5  | 24* | -4  | -4  | -7* | -2  |
| 7  | North River                                 | -3  | 2   | -25 | -51†| -54†| -51†| -48*| -38*| -44*| -44*| -40*| -2  |
| 8  | Coney Island                                | 2   | 12* | 12* | 26* | 7   | 17* | 6   | 2   | 7   | 13* | -5  | -2  |
| 9  | Jamaica                                     | 4   | 10* | 0   | -4  | -9* | -5  | -8* | -13*| -7  | -2  | -12*| -2  |
| 10 | Hunts Point                                 | 8   | 2   | 7   | 1   | 1   | 3   | 5   | -6  | -6* | -5  | -7  | -3  |
| 11 | Owl’s Head                                  | 0   | 17  | 91  | 72†| 28† | -58†| 65† | 37  | 39* | 10  | -8  | 34* |
| 12 | Bowery Bay                                  | 17* | 12* | 15* | -1  | -11*| -6  | -6  | -3  | -11*| -12*| -13*| -7  |
| 13 | Newtown Creek                               | -2  | 16* | -17*| -42†| -40†| -25†| -25†| -38 | -38*| -47 | -35*| -28*|
| 14 | Wards Island                                | 4   | 7*  | -1  | -16*| -7  | -8* | -8* | -7* | -9* | -9* | -14*| 1   |

*p<0.05; †only one measurement taken in 2020, significance not determined

Percent Change
b. Percent change for average daily flow rates.

| ID  | Wastewater Resource Recovery Facility (WRRF) | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|-----|---------------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1   | Rockaway                                   | 19* | 14* | 21* | 35* | 16* | -3  | 2   | -13*| -9* | -17*| -11*| -6* |
| 2   | Red Hook                                   | -3* | -6* | -6* | -7* | -13*| -14*| -10*| -8* | -13*| -7* | 3   |
| 3   | Port Richmond                              | -16*| -7  | -2  | 6   | -25*| -25*| -10*| -7* | -6* | -2  | 5*  | -1  |
| 4   | Oakwood Beach                              | -20*| -18*| -16*| -5* | -20*| -25*| -13*| -8* | -7* | -3  | 3   | -6  |
| 5   | 26th Ward                                  | -6* | -1  | 4   | -2  | 0   | -9  | 6   | 2   | 14* | 3   | 18* | 21* |
| 6   | Tallman Island                             | -11*| -6  | -2  | 3   | -8* | -14*| -3  | 3   | 4   | -4  | 3   | -4  |
| 7   | North River                                | -2  | -1  | -5* | -12*| -18*| -16*| -11*| -11*| -11*| -12*| -16*| -6* |
| 8   | Coney Island                               | -10*| 2   | 4   | 0   | -15*| -18*| -9  | -14*| -7* | -11*| -6* | -13*|
| 9   | Jamaica                                    | -6* | 0   | -4* | -2  | -7* | -10*| -4* | -3* | -1  | -2  | 6*  | -2  |
| 10  | Hunts Point                                | -1  | -7* | -5  | 0   | 1   | 6*  | 6*  | 10* | 18* | 13* | 15* | 4   |
| 11  | Owl’s Head                                 | -6* | 2   | 1   | 4*  | -3* | -2  | 6*  | 7*  | 5*  | 2*  | 1   | 5*  |
| 12  | Bowery Bay                                 | 1   | 1   | 4*  | 2   | -1  | -6* | -2  | 3*  | 5*  | -2  | -1  | -2  |
| 13  | Newtown Creek                              | 3*  | 2   | -5  | -9* | -19*| -9* | -10*| -6  | -9* | -1  | -8* | 2   |
| 14  | Wards Island                               | -9* | -7  | -19*| -1  | 1   | -6  | -10*| 2   | 10* | 11  | 14* | 2   |

*p<0.05

Percent Change

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3.6. Correlations and linear regressions between flow rates and sewershed populations

Table S10. Pearson correlation coefficients (r) between average daily influent flow rates in 2019 and sewershed populations. Correlations are presented with data from all WRRFs (n=14) and without data from the North River and Newtown Creek WRRFs (n=12). Significance values for each correlation are indicated.

|                           | Full Data Set | Dry Weather | Wet Weather |
|---------------------------|---------------|-------------|-------------|
| All 14 WRRFs             | 0.94****      | 0.93****    | 0.94****    |
| Excluding North River and |               |             |             |
| Newtown Creek WRRFs      | 0.94****      | 0.93****    | 0.96****    |

** p < 0.01, *** p < 0.001, **** p < 0.0001

Figure S7. Average daily flow rates averaged for each WRRF in NYC between January 1, 2019 and December 31, 2019 plotted versus the estimated sewershed population. Points represent the average flow rates based on the full data set (i.e., both dry and wet days were included in computed averages) at each WRRF and error bars indicate standard deviation. Numbers adjacent to each point designate the WRRF (codes are presented in Table 1). Lines of best fit for linear regressions including only wet (blue) or dry (red) weather data are shown with 95% confidence intervals shaded (lines of best fit not shown for regressions based on the full data set). Slopes and goodness-of-fit ($R^2$) values are shown for linear regressions using wet weather data (blue text), the full data set (black text), and dry weather data (red text). Average flow rates for the North River (7) and Newtown Creek (13) WRRFs (gray, open circles) were excluded from linear regressions in the left panel.
4. References

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