Chesapeake Bay Watershed Significant Wastewater Treatment Plant Growth Methodology

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NEW YORK CHEMUNG AND SUSQUEHANNA RIVER BASIN

New York State Department of Environmental Conservation

Kathy Hochul, Governor | Basil Seggos, Commissioner

Background

The Chesapeake Bay watershed in New York consists of the Chemung and Upper Susquehanna River basins (Figure 1). In May 2021, the New York Department of Environmental Conservation (DEC) published a Final Amended Phase III Watershed Implementation Plan (Phase III WIP), which details the actions New York will take to meet required nutrient reduction targets established under the Chesapeake Bay Total Maximum Daily Load (TMDL) by 2025.[1]

In New York's Phase III WIP, 32 wastewater treatment plant (WWTP) facilities were identified as Significant facilities in the Chemung and Upper Susquehanna River basins, consisting of six industrial and 26 municipal facilities of varying sizes (Table 1, Figure 1). As part of the Final Amended Phase III WIP, New York updated its projection of wastewater sector loads expected in 2025 from these facilities. This new projection is based on a three-year average flow and (Table 1) and corresponding nutrient loads, rather than loads based on full permitted design flows[2]. Since these facilities rarely discharge close to their full design flow, the updated projection provides a more accurate representation of expected wastewater sector loads.

It is not expected that a significant increase in flow due to growth will occur prior to 2025. According to census projections within the Chemung and Upper Susquehanna River basins, there will be little to no population growth in the region. This indicates that flow demand at existing wastewater treatment plants in the region will likely remain unchanged, if not decrease through 2025. If new industries are attracted to the region, then flow demand may increase at existing facilities. Wastewater treatment flow may also be impacted by wet weather, as a result of Inflow and Infiltration (I&I) of excess groundwater and stormwater into sewer collection systems.

As part of the US Environmental Protection Agency (EPA) review of New York's Final Amended Phase III WIP, DEC agreed to develop a growth tracking methodology for the 32 Significant wastewater facilities. This methodology will be utilized every two years as part of New York's Milestone reporting to EPA. This methodology utilizes a set of statistical analyses to monitor flow changes to wastewater facilities. This methodology is meant to determine if changes in flow are due to measurable growth or due to wet weather and impacts of I&I. If flow changes are due to growth, New York will implement actions to offset the load associated with growth. Flow increases due to wet weather as a result of excessive I&I will be addressed through I&I studies and remediation.

The analyses aimed to achieve three objectives: 1) determine the presence of linear trend for the wastewater treatment plant facility outflow measurements in each facility, 2) determine the direction of any significant trend for the facility outflow measurements, and 3) determine the correlation of the facility outflow measurements with the streamflow measurements. This series of analyses helps identify facilities experiencing increased wastewater treatment loads independent of flow fluctuations in the watershed and can be used as a growth tracking threshold.

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[1]Division of Water, Bureau of Watershed Resource Management. Final Amended Phase III Watershed Implementation Plan: New York Chemung and Susquehanna River Basins. (2021).

[2] The average flow (MGD) was based on DMR data from the 2017-2019 reporting period (July 2016-June 19).

Table 1: Average flow value (MGD) for 32 Significant facilities from Phase III WIP.

Facility Name	Facility Type	SPDES	Monthly Flow Monitoring Start Year	Phase III WIP Average Flow (MGD)[3]
Addison (V)[4]	Municipal	NY0020320	2001	0.25
Alfred (V)	Municipal	NY0022357	1998	0.44
Amphenol Corp Aerospace Operations	Industrial	NY0003824	2014	0.14
Bath (V) WWTP	Municipal	NY0021431	1997	0.59
Binghamton Johnson City Joint STP	Municipal	NY0024414	2000	18.00
Canisteo (V) STP	Municipal	NY0023248	2000	0.32
Chemung Co. SD #1 (Lake Street) STP	Municipal	NY0036986	1998	8.46
Chenango Northgate WWTP	Municipal	NY0213781	1998	0.53
Chobani	Industrial	NY0004189	2014	0.55
Cooperstown	Municipal	NY0023591	2000	0.43
Corning (C) WWTP	Municipal	NY0025721	1999	1.39
Elmira/Chemung Co. SD#2	Municipal	NY0035742	1998	5.76
Endicott (V)	Municipal	NY0027669	2000	10.12
Endicott Interconnect Technologies Inc.[5]	Industrial	NY0003808	2017	0.71
Erwin (T)	Municipal	NY0023906	2001	0.23
Greene (V) WWTP	Municipal	NY0021407	1997	0.60
Hamilton (V)	Municipal	NY0020672	2004	2.37
Hornell (C)	Municipal	NY0023647	1997	1.01
Kerry Bio-Science	Industrial	NY0004243	2000	0.39
Leprino Foods	Industrial	NY0157295	2014	0.27

[3] The average flow (MGD) was based on DMR data from the 2017-2019 reporting period (July 2016-June 19).
[4] Facility has completed consolidation with Erwin (T) in 2021. Permit will be terminated.
[5] Facility shut down operations in 2020.

Le Roy R. Summerson WWTF (Cortland)	Municipal	NY0027561	1999	5.96
Norwich	Municipal	NY0021423	2000	2.08
Oneonta (C)	Municipal	NY0031151	2000	2.12
Owego #2	Municipal	NY0025798	2001	1.20
Owego (T) #1	Municipal	NY0022730	2000	0.47
Owego (V)	Municipal	NY0029262	2000	0.61
Painted Post (V)	Municipal	NY0025712	2009	0.18
Richfield Springs (V)	Municipal	NY0031411	2000	0.22
Sherburne (V) WWTP	Municipal	NY0021466	2004	0.33
Sidney (V)	Municipal	NY0029271	2001	0.64
Upstate Cheese Farms LLC	Industrial	NY0004308	1998	0.91
Waverly (V)	Municipal	NY0031089	2001	0.58

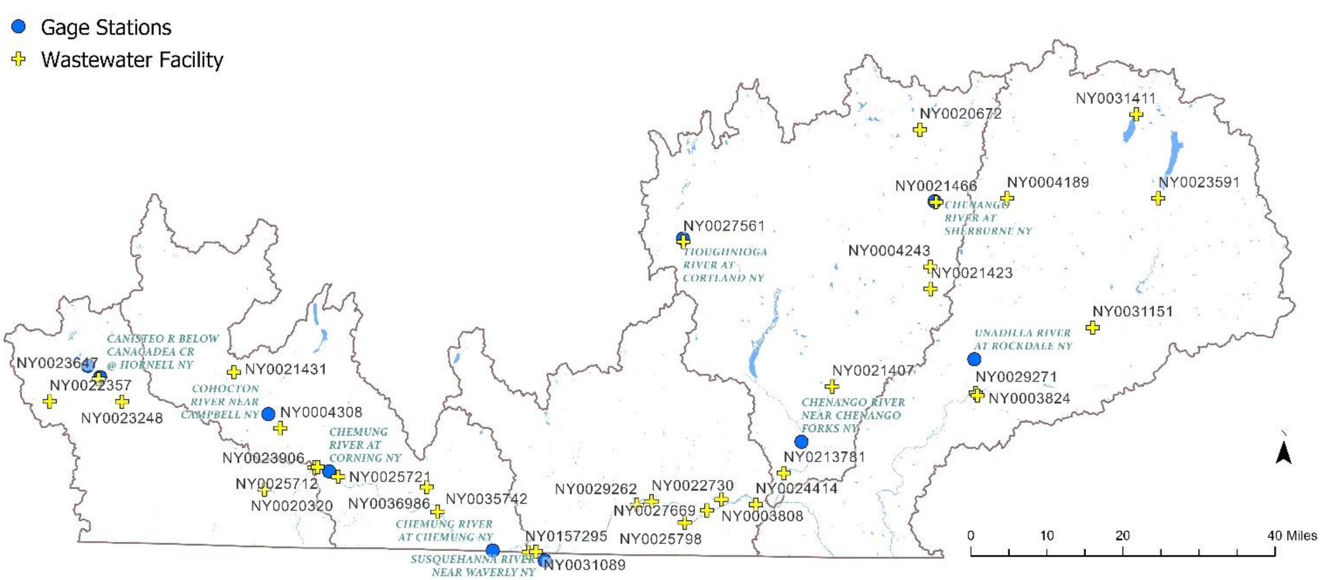

Figure 1: Map of 32 primary wastewater treatment plant facilities and 10 USGS gage stations in the Chemung and Upper Susquehanna River basin of New York state.

Analysis of Trends

Datasets

USGS Chemung and Susquehanna River basin flow data

Streamflow data was obtained from the United States Geological Survey (https://waterdata.usgs.gov/nwis). Annual flow (discharge, cubic feet per second) was obtained for 10 locations across the Chemung and Upper Susquehanna River basins (Table 2).

Table 2: Ten USGS gage stations used for flow analysis with their respective earliest recorded measurement. All stations are still in service and have had continuous annual measurements since its start year.

Station ID	Station name	Basin	Start year
01502500	Unadilla River at Rockdale, NY	Susquehanna	1930
01509000	Tioughnioga River at Cortland, NY	Susquehanna	1939
01515000	Susquehanna River near Waverly, NY	Susquehanna	1938
01529500	Cohocton River near Campbell, NY	Chemung	1919
01505000	Chenango River at Sherburne, NY	Susquehanna	1939
01529950	Chemung River at Corning, NY	Chemung	1980
01531000	Chemung River at Chemung, NY	Chemung	1907
01524500	Canisteo River below Canacadea Creek at Hornell, NY	Chemung	1949
01523500	Canacadea Creek Near Hornell, NY	Chemung	1949
01512500	Chenango River near Chenango Forks, NY	Susquehanna	1913

Wastewater treatment plant facility outflow data

Flow data, with the exception of Upstate Farms Cheese LLC (NY0004308), were measured and recorded as monthly averages by each facility. Upstate Farms Cheese LLC (NY0004308) outflow measurements were recorded as a daily average flow reported only once a month. Additionally, only data after 2014 were included for three industrial facilities, i.e., Amphenol Corp Aerospace Operations (NY0003824), Chobani (NY0004189), and Leprino Foods (NY0157295), as they only started reporting monthly average flow measurements after 2014. Similarly, only data after 2017 were included for Endicott Interconnect Technologies Inc. (NY0003808) for the same reason. All outflow discharges were standardized to million gallons per day (MGD).

Statistical Approach – Municipal Facilities

There are many statistical methods to estimate trends in flow datasets. However, there are limitations to every statistic based on its assumptions and data requirements that can cause variation in answers depending upon which methods are used. For this reason, a weight of evidence approach using two different statistics that made up for the limitations of the other was used to determine trends in growth at the 26 significant municipal facilities. The first statistic used was a Mann-Kendall Test. This test has very few assumptions, so it is more reliable at detecting trends, however it is unable to differentiate between trends caused by growth in the facility or growth due to I&I. The second statistic is a linear regression model. The linear regression is able to differentiate between growth in the facility and growth in I&I, however it can be less reliable because it has certain assumptions about the data that can incorrectly bias the model if they are not met. In some cases, the data in the study slightly violates those assumptions about the data, so the combined approach of both statistics are necessary. All analyses were conducted using R 4.1.1[6] with packages tidyverse[7], lubridate[8], Kendall[9], and trend.[10]

Mann-Kendall Test

A Mann-Kendall trend test was conducted to detect monotonic linear trends in facility outflows with Sen's slope (β) as a post hoc confirmation of the trend direction.[11] The Mann-Kendall test conducts a test of significance for the Kendall's r correlation value, which relates the variable Y (i.e., outflow) and the time variable (i.e., year). The Mann-Kendall's test was selected due to the ease of use with no assumptions of normality required and ease of interpretation, where the null hypothesis (H_0) is rejected if Kendall's S differs significantly from 0. The Theil-Sen estimator (Sen's Slope) was calculated for any significant trends as a post hoc confirmation to determine the direction of the trend. A negative Sen's slope indicates a negative trend while a positive Sen's slope indicates a positive trend. The same test was conducted on the stream flow measurements to determine the significance of the trends. An α of 0.1 ($p < 0.1$) was used for the Mann-Kendall test to provide a more conservative identification of potentially changing discharges from wastewater facilities, i.e., more inclusive of facilities with potentially significant outflow trends.

Linear Regression Model

A linear modeling approach was used as a supporting analysis to determine the correlation between facility outflow and streamflow, which may indicate how streamflow and precipitation affects the outflow of the facility and provide a better understanding of their effects on any observed trends. Linear regression models were fitted for each facility in the river basin, with year and streamflow measurements as the fixed variables. Facility outflow measurements and streamflow were natural log-transformed to mitigate the right-skewness and better meet the assumption of the linear regression.

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[6]R Core Team. R: a language and environment for statistical computing. (2021)
[7]Wickham, H. et al. Welcome to the tidyverse. Journal of Open Source Software 4, 1686 (2019).
[8]Grolemund, G. & Wickham, H. Dates and times made easy with lubridate. Journal of Statistical Software 40, 1–25 (2011).
[9]McLeod, A. I. Kendall: Kendall rank correlation and mann-kendall trend test. (2011).
[10]Pohlert, T. Trend: Non-parametric trend tests and change-point detection. (2020).
[11]Helsel, D. R., Hirsch, R. M., Ryberg, K. R., Archfield, S. A. & Gilroy, E. J. Statistical methods in water resources: U.S. Geological Survey Techniques and Methods. vol. 4 1–484 (U.S. Geological Survey, 2020).

$$log\ (Outflow)_i = \beta_0 + \beta_1\ (Year)_i + \beta_2\ log(Streamflow)_i$$

Corrected Akaike Information Criterion (AICc), calculated during the model selection process, showed that a simpler model with only year and streamflow had the best fit for the dataset. In addition, previous studies on streamflow trends in this region have had varying results, depending on the spatial or temporal scope[12]. In this context, no interaction terms were included in this supplementary linear model analysis. ANOVA test of significance was used to evaluate the significance of “year” and “streamflow” in relation to facility outflow at an α of 0.05 ($p < 0.05$).

Pearson's r was calculated for facilities that showed a significant relationship between facility outflows and streamflow to clarify the direction and strength of the linear correlation[13].

Statistical Approach – Industrial Facilities

The six industrial facilities in the watershed were reviewed for growth using a similar method to the municipal facilities. Increased flow at industrial facilities is assumed to be due to increased production, and is not influenced by external factors, such as I&I. The Mann-Kendall test facilities was used for industrial facilities to determine if the facilities were showing a significant trend in growth and if the trend was increasing or decreasing. The linear regression model was used to evaluate the significance of “year” in relation to facility outflow, but not the significance of “streamflow” since it does not apply to industrial facilities.

[12]Glas, R., Burns, D., & Lautz, L. Historical changes in New York State streamflow: Attribution of temporal shifts and spatial patterns from 1961 to 2016. Journal of Hydrology 574, 308-323. (2019).
[13] Helsel, D. R., Hirsch, R. M., Ryberg, K. R., Archfield, S. A. & Gilroy, E. J. Statistical methods in water resources: U.S. Geological Survey Techniques and Methods. vol. 4 1–484 (U.S. Geological Survey, 2020).

Summary of Results

Municipal Facilities

Municipal Facilities that do not have significant Mann-Kendall test results suggest that they have not experienced any significant growth (row 7 in Table 3) while facilities with a significant Mann-Kendall test result but a negative Sen's slope indicates outflow from these facilities have a decreasing trend. In both of these cases, no action would be taken. Conversely, facilities with a significant Mann-Kendall test result and positive Sen's slope indicates outflows from these facilities are increasing. Linear regression results would be used to support the Mann-Kendall test results.

Linear regression with a significant correlation with year also indicates a significant trend and a significant correlation with streamflow indicates potential inflow and infiltration (I&I) at the WWTP (e.g., rows 2, 5, and 6 in Table 3). Specifically, facility outflows that have a significantly positive correlation with streamflow would suggest that changes in the streamflow of the region also contributed to potential I&I in these facilities and may have influenced the outflow trends for the WWTP. However, due to the non-normal error distribution and presence of outliers in this dataset, results from the linear regression are less reliable compared to the nonparametric trend test results from the Mann-Kendall test. Facilities with potential I&I issues will be addressed through I&I studies and remediation.

Facilities which show a significant positive trend with or without a significant correlation with streamflow would be reviewed for potential growth if they are above the average outflow value allowed in the Phase III WIP (row 3 and 5 in Table 3). If these outflow changes are attributed to growth for two consecutive two-year milestone periods, a total of four years, New York will implement actions to offset the associated loads.

Table 3: Example of the results table for the municipal wastewater treatment plant (WWTP) outflow growth analysis. Significance of the Mann-Kendall test and the linear regression will be reported as a logical: "Y" indicates "Yes" (result significant) and "N" indicates "No" (result not significant). Sen's slope estimate and the Pearson's r correlation value for WWTP outflow with streamflow would also be reported.

SPDES	Mann-Kendall Test			Linear Regression			Action Taken
	p-value	Significance	Sen's Slope	Year	Streamflow	Streamflow r	
1	p < 0.1	Y	-	N	N	0 to 1	No action
2	p < 0.1	Y	+	N	Y	0 to 1	Address I&I at facility
3	p < 0.1	Y	+	Y	N	0 to 1	Review for potential growth if above WIP III outflow average (Table 1)
4	p < 0.1	Y	-	Y	N	0 to 1	No action
5	p < 0.1	Y	+	Y	Y	0 to 1	Address I&I at facility and review for potential growth if above WIP III outflow average (Table 1)
6	p < 0.1	Y	-	Y	Y	0 to 1	Address I&I at facility
7	p > 0.1	N	+ / -	-	-	0 to 1	No action

Industrial Facilities

Industrial Facilities that do not have significant Mann-Kendall test results suggest that they have not experienced any significant growth (row 5 in Table 4) while facilities with a significant Mann-Kendall test result but a negative Sen's slope indicates outflow from these facilities have a decreasing trend. In both of these cases, no action would be taken. Conversely, facilities with a significant Mann-Kendall test result and positive Sen's slope indicates outflows from these facilities are increasing. Linear regression results for significant correlation with year would be used to support the Mann-Kendall test results.

Facilities which show a significant positive trend with a significant correlation with year would be reviewed for potential growth if they are above the average outflow value allowed in the Phase III WIP (row 3 in Table 3). If these outflow changes are attributed to growth for two consecutive two-year milestone periods, a total of four years, New York will implement actions to offset the associated loads.

Table 4: Example of the results table for the industrial wastewater treatment plant (WWTP) outflow growth analysis. Significance of the Mann-Kendall test and the linear regression will be reported as a logical: "Y" indicates "Yes" (result significant) and "N" indicates "No" (result not significant). Sen's slope estimate for WWTP outflow with year would also be reported.

SPDES	Mann-Kendall Test			Linear Regression	Action Taken
	p-value	Significance	Sen's Slope	Year	
1	$p < 0.1$	Y	+	N	No action
2	$p < 0.1$	Y	-	N	No action
3	$p < 0.1$	Y	+	Y	Review for potential growth if above WIP III outflow average (Table 1)
4	$p < 0.1$	Y	-	Y	No action
5	$p > 0.1$	N	+ / -	-	No action