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Is bigger better? Driving factors of POTW performance in New York

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ABSTRACT

Like many regions around the world, New York State, USA, faces challenges in meeting wastewater treatment quality standards because of aging infrastructure, limited funding, shifting demographics and increasingly stringent environmental regulations. In recent decades construction of new wastewater treatment and distribution infrastructure in NY has most often occurred in exurban communities and suburban developments that are less dense than traditional urban cores. Here, we examine the role of size and capacity utilization on wastewater treatment effectiveness with respect to critical effluent parameters, and additionally explore which common facility engineering controls influence water quality treatment using a unique dataset of descriptive information. Our results challenge conventional wisdom, suggesting that the largest facilities (>30,000 m^3/d), not the smallest (<300 m^3/d), discharge TSS, BOD, and coliform at significantly higher relative effluent concentrations (i.e., the ratio of discharged concentrations to allowable limits). Capacity utilization was also positively correlated to higher concentrations of TSS, BOD, and coliform effluent concentrations in larger facilities, though those concentrations were often within regulated limits. This implies that smaller-sized facilities may perform better in terms of environmental quality, but that the largest facilities demonstrate efficiency in the sense that they are not "over-treating" wastewater while avoiding violations. Results from NY suggest that medium sized facilities (300–30,000 m^3/d) are sophisticated enough to incorporate appropriate unit processes, and employ operators with sufficient training and oversight, to reach treatment outcomes that are both reliable and of high quality.

1. Introduction

Environmental and public health each rely on appropriate and effective water resources infrastructure. Wastewater treatment facilities are critical components in the infrastructure landscape that must treat sewage and stormwater-derived organic material, nutrients, and pathogens to sufficient standards so as to protect receiving waters. Constructing and maintaining such facilities requires significant financial investment. Globally, needed upgrades to aging and inadequate water infrastructure, combined with construction associated with new infrastructure, are projected to cost trillions of dollars (Deloitte, 2012). It is incumbent upon engineers, regulators, and scientists, among others, to ensure that such investments are being made in an environmentally responsible manner.

In the United States (US), despite passage of the Federal Water Pollution Control Act amendments to the Clean Water Act in 1972, surface water quality is still at risk of impairment from inadequate municipal sewage and stormwater treatment (Maupin and Ivahnenko, 2011; Moore et al., 2011; United States Environmental Protection Agency (USEPA), 2009). At the same time, funding needs associated with wastewater and stormwater collection and treatment infrastructure are calculated to be on the order of hundreds of billions of dollars over the next twenty years (USEPA, 2016). In many places, critical infrastructure was initially built in the 1970's during a time when higher levels of federal funding were available. Now, those systems are due for replacement, repair, and upgrade, and paying for such improvements has increasingly fallen to local municipalities (Vedachalam et al., 2014). Older cities, particularly in the Northeast and Midwest US, are additionally challenged with issues associated with declining or stagnant

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population, and the migration of industry out of urban centers and/or the region. In New York State (NY), for example, the combination of need, lack of funding, and pressure related to increasingly stringent water quality regulations has been described by state agencies as a "gathering storm" that threatens both surface water quality and the financial stability of NY's communities (NYSDEC, 2008). In 2014, the Office of the NY State Comptroller released a report describing the difficulty local governments face in addressing infrastructure investment needs (New York State Office of the Comptroller (NYSOC), 2014). The NY State Environmental Facilities Corporation, tasked with oversight of the state's Clean Water State Revolving Fund, reported in 2017 that it was "able to provide zero-percent interest rate or low-cost financing for approximately $830 million of projects costs, which comprises approximately 25% of the identified demand (NYSDEC & EFC, 2017)."

In recent decades, within the context of the funding constraints described above, construction of new wastewater treatment and distribution infrastructure in NY has most often occurred in exurban communities and suburban developments that are relatively small and less dense than traditional urban cores (Rahm et al., 2013). Thus, newly constructed facilities have likewise been smaller than the large facilities built in major cities in the past. It is important to question whether this movement toward smaller, more distributed wastewater treatment makes sense.

From a financial perspective, conventional wisdom suggests that economies of scale exist when systems are larger, thus making it more efficient per capita to maintain assets and fund needed construction. How true is this for POTWs? For both water supply and wastewater infrastructure, research has suggested that costs are largely associated with distribution systems rather than treatment facilities themselves, and that expansion of services in sparsely populated areas, or in urban areas with low housing density, does not achieve the economies of scale that many associate with expansion or consolidation (Boisvert and Schmit, 1997; Carruthers and Ulfarsson, 2008). For drinking water supply and delivery in the US, utilities exhibit economies of scale, but outside of major cities, increased population density does not result in cost savings (Aniket et al., 2017). Given the limited evidence it appears that financial economies of scale are by no means assured, but rather conditional on the specific characteristics of any given system. Thus, even without considering environmental quality implications, there is an ongoing challenge to determine the optimum size of centralized wastewater treatment facilities, and planning appropriate transitions from older systems to newer ones.

With respect to water quality, there is reason for concern as the size of publicly owned wastewater treatment works (POTW) decrease to the point of complete decentralization. On-site wastewater treatment systems have been criticized for their potential to fail (Ahmed et al., 2005), their inability to reliably treat nutrients and emerging contaminants (Subedi et al., 2015; Oakley et al., 2010) as well as challenges associated with regulation and maintenance (Withers et al., 2014; Mohamed, 2009), all of which potentially threaten nearby ground and surface waters. Promises to transition small communities from onsite to centralized treatment systems rarely materialize due to concerns about costs and land development; but, when those transitions do happen, the result is often a relatively small facility (Vedachalam et al., 2015). In some cases, small and/or suburban communities must decide between constructing a new, small POTW, or connecting to an existing, larger POTW in a nearby urban area. The question then arises, as a community chooses between smaller or larger facilities, are there inherent water quality tradeoffs that ought to be explicitly considered? It is this question of water quality tradeoffs that we focus on here.

From a water quality perspective, recent studies have sought to develop insight into POTW treatment performance and its relationship to facility characteristics such as size and capacity utilization. Using a national-scale sample of POTWs, Weirich et al. (2011) used a generalized linear model approach to predict effluent concentrations of four commonly regulated water quality parameters: total suspended solids (TSS), biochemical oxygen demand (BOD), fecal coliform (COLI), and ammonia (NH3) (Weirich et al., 2011). They determined that small ($<40\ m^3/d$) wastewater treatment facilities were 10 times more likely to violate their discharge permits than the largest ($<400{,}000\ m^3/d$) facilities for TSS, BOD, and NH3, thus suggesting that small facilities potentially put receiving waters at greater risk of contamination. Meanwhile, the largest facilities ($>40{,}000\ m^3/d$) were predicted to discharge effluent concentrations close to their permitted limits, but at reduced violation rates. For facilities below $40{,}000\ m^3/d$, they also observed that as facility size increased, effluent concentrations of TSS, BOD, and NH3 decreased. Subsequent research added spatial variables to this modeling approach based on the hypothesis that geographic factors such as temperature and precipitation may affect POTW performance on a local scale (Suchetana et al., 2016). Results suggested that treatment of TSS and BOD was susceptible to seasonal variability, highlighting the possibility that conclusions regarding the drivers of effluent outcomes may be region-specific. Other research has suggested that urban/rural character, and process parameters such as hydraulic retention time are important indicators of overall POTW performance (Oliveira et al., 2008). Together, these studies highlight the need to examine driving factors of POTW treatment performance across size groups and within the context of regional demographic and financial challenges.

Using data from POTWs in NY, this study re-examined the role of size and capacity utilization on POTW effectiveness with respect to critical effluent parameters. Additionally, we explored how common facility engineering controls influenced water quality treatment using a unique dataset of descriptive information gathered by the state environmental regulatory agency. A goal of this work was to test conventional wisdom and the hypothesis that larger facilities have better water quality treatment outcomes due to their economies of scale. An additional hypothesis was that facility operational and engineering processes would be important drivers of effluent water quality.

2. Methods

2.1. Data

Data on water quality parameters, flow, regulatory constraints, and facility identity were gathered on POTWs in the state of New York from facility discharge monitoring reports (DMR) compiled by the US Environmental Protection Agency (USEPA) and made available via the DMR Pollutant Loading Tool (USEPA, 2015). Yearly datasets were acquired through the Advanced Search feature. Supplemental Table S1 details the selection criteria used for querying the DMR database, while Supplemental Table S2 delineates the output fields specified. Raw data was compiled and subject to cleaning and verification.

Observations within the dataset were removed whenever they lacked data on facility flow rate, or in cases where regulatory flow and effluent limits were not specified. Observations from facilities that split effluent flow between multiple outfalls were also removed from further analysis. Observations were included only from facilities that reported data on a monthly basis, and for which there were at least one year of consecutive observations. For water quality parameters, observations below detection limits (BDL) were replaced with a numerical value equal to one-half of the detection limit value. To check the sensitivity of this assumption, preliminary