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# Evaluation of grit properties at a medium-capacity wastewater treatment plant: A case study

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ABSTRACT

The optimized, tailored approaches in the design of wastewater treatment plants (WWTPs) minimize expenditure of the resources, increase treatment effectiveness, and prolong useful life of the infrastructure. In this study, wastewater grit characteristics were evaluated over the course of one year at the headworks and collection network of the Atlantic County Utilities Authority (ACUA) WWTP, located in New Jersey, USA. The mixed grit at the ACUA WWTP can be characterized as particles prevalently in the fine sand size range with high content of organic matter, low fraction of fats, oils, and grease (FOG), and very low settling velocity. A significant seasonal variability was observed in the measured parameters. These results will be utilized in the design of the most effective, fiscally responsible, and sustainable method of grit removal at the study site and may serve to promote utilization of WWTP-specific design at other facilities.

## 1. Introduction

Clean water is one of the most valuable resources on Earth. Fortune Business Insights projects the global water and wastewater treatment market to grow from USD 283.48 billion in 2021 to USD 465.23 billion in 2028, in order to satisfy the expanding municipal, agricultural, and industrial needs (Fortune Business Insights, 2021). In the United States alone, approximately 34 billion gallons of wastewater are being processed by wastewater treatment plants (WWTPs) every day (USEPA, 2003). WWTPs utilize a series of physical, biological, and chemical processes to separate the unwanted constituents (e.g., large particles, suspended solids, pathogens, synthetic organic chemicals, and nutrients) from the wastewater before discharging the treated water back into the environment. Grit removal process is a step in preliminary wastewater treatment with the main goal to remove a wide variety of particles suspended in influent, including gravel, sand, eggshells, bone chips, and seeds, which range from 75 to 300 micrometers (Herrick et al., 2015). Although grit consists of relatively small particles, its potential for damage is great. If not removed, it can accumulate and, thus, reduce the capacity of the downstream treatment units, including aeration tanks and bioreactors (Mansour-Geoffrion et al., 2010; Sandell, 2017) or block transfer lines and pipes. Additionally, abrasion is a common result of poor grit removal operations, which results in damages to mechanical equipment, i.e., pumps and centrifuges (Gang et al., 2010). It has been shown that without the removal of grit, pump impellers can lose up to 30% of their life cycle due to abrasion (Kiepper and Ritz, 2017). In some instances, machinery becomes completely non-functional. Removal of grit is important not only due to the various damages from the abrasion and clogging of systems, but also due to the increased costs of maintenance after grit enters the downstream processes throughout the plant. On average, annual maintenance costs can account for up to 15% to 25% of total WWTP operational costs, with mechanical equipment accounting for up to 6% of those maintenance costs (Sandell, 2017).

Traditional grit removal tank design is relatively simple and is based on the particle settling velocity, which depends on the specific gravity of the particle. The ideal target grit particle for grit removal system design is spherical, homogeneous, 200 micrometers in size, with a specific gravity of 2.65 (Finger and Parrick, 1980; Tchobanoglous et al., 2014). The typical specific gravity of soil ranges from 2.64 to 2.72, yet it has been reported that the overall specific gravity of wastewater particles is lowered due to layers of organic material that typically coat the particles and lies between 1.1 and 2.65 (Plana et al., 2019; WEF, 2016). In the real world, however, the ideal conditions are rarely satisfied, as grit may be introduced from a wide variety of sources, depending on the location of the WWTP and the composition of its influent. Aerated and vortex grit tanks can be designed for a specific target particle as their different flow

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regimes allow for more efficient separation of smaller grit and organic coatings. However, the knowledge of the grit composition and properties is crucial for design of these systems as modifications can be costly. Therefore, it is currently becoming more evident that it is best for facilities to choose grit removal options based on the specific needs of the facility and at a cost the facility can afford (USEPA, 2003) and a new way to characterize grit, using actual measurements of particle size and settling velocity, was proposed by some authors (Reddy and Pagilla, 2009; Herrick et al., 2015). This revised approach promotes the development of WWTP-specific grit removal solutions, based on the unique characteristics of the grit received by the facility, and thus, eliminates uncertainties associated with a design based on the broad definition of grit. A wider acceptance of this tailored approach can change the traditional way of the wastewater infrastructure design and allow to create facilities capable of delivering supreme performance without inflating the design, construction, and operation budget.

This is a case study developed for the Atlantic County Utilities Authority (ACUA) WWTP – a medium-capacity secondary treatment facility built in the 1970′s, located on the Atlantic Ocean coast in the USA, and currently utilizing primary treatment as the main means of grit removal.

The overall goal of this study was to fill the research gaps in the growing body of work which promotes the departure of WWTP design from the traditional practices and the associated uncertainties through application of the actual site-specific data, ultimately leading to the development of the most appropriate, fiscally responsible, and sustainable method of grit removal at a study site. This study has four major aims: (1) to characterize physical attributes of grit entering ACUA's WWTP as a case study; (2) to assess potential seasonal variability in grit composition and properties; (3) to evaluate the effect of changes in grit composition on its settling; and (4) to investigate potential source areas of enhanced grit input. The results of this research are instrumental in serving as the basis for promotion of wider acceptance of the development of site-specific infrastructure development approaches with the ultimate goals to preserve the resources and to be the best stewards for the environment.

## 2. Materials and methods

### 2.1. Study site

The subject site of this study is the Atlantic County Regional WWTP located on the Absecon Island, an 8.1-mile-long barrier island in the Atlantic Ocean, off the coast of New Jersey, USA. The WWTP has been operational since 1978. The WWTP was originally designed to serve only a few neighboring communities, however; due to the rise of tourism along the New Jersey coast and the establishment of Stockton University, ACUA began to serve a wider area. ACUA currently treats wastewater from 14 different participating communities with approximately 225,000 full-time residents. ACUA receives an influent of 40 million gallons per day (MGD), which is below the plant's design capacity of 60 MGD. ACUA WWTP houses primary and secondary treatment and its upgrade to a tertiary treatment unit is not anticipated in the near future.

The ACUA wastewater treatment process begins with bar screens, where large debris are removed from the influent. The wastewater then enters the primary clarifiers where solids settle out to the bottom and are collected. Overflow from the primary clarifiers enters the aeration basins where dissolved solids and organic matter are digested. All wastewater then enters the secondary clarifiers from which 85% to 95% of the pollutants have been removed. The treated effluent is then disinfected with chlorine. Once the wastewater treatment process is finished, the treated water is discharged into the Atlantic Ocean off the New Jersey coast. To minimize any negative impact on the environment, the resulting sludge from the process is incinerated on site, and the residue is placed into a landfill and compacted in accordance with the design specifications.

ACUA WWTP currently has no system in place to remove grit entering the WWTP headworks. With 40 MGD of wastewater entering the facility, it is reasonable to assume that a relatively significant quantity of grit may be a component of the influent. Stormwater runoff is routed separately from municipal wastewater in the service area and is normally not a part of the ACUA influent. However, during heavy rainfall events, stormwater can enter the municipal sewage system via flooded manholes. Considering the proximity of the facility to the Atlantic Coast, sand could be a major component of the stormwater grit makeup. The influent levels at ACUA rise during storm surges, giving reason to believe that quantities of grit increase as well. During these storm surges, the plant can receive its full designed capacity of 60 MGD, which is a 50% increase over its regular load. Although stormwater and wastewater may seem similar, they have notable differences. Stormwater is much harder to predict; peak flow, volume, quality, composition, and pollutant levels are all factors that are difficult to foresee (Reese, 2012). Having the potential for an excess number of unknown substances introduced into the treatment system via stormwater intrusion in addition to the more predictable average daily loads supports the reasoning for the design of a custom, facility-specific grit removal system at the ACUA WWTP.

### 2.2. Sample collection and preservation

Liquid grab samples were collected once a month over a period of one calendar year between September 2020 and August 2021 from plant's headworks and three main wastewater pumping stations which route wastewater to the plant from the collection network. One of the pumping stations is located on mainland, inland from the WWTP (Inland Station) and two of the stations are located on the Absecon Island, one on the north end of the island (Coastal Station N) and one on the south end of the island (Coastal Station S). A total of 24 L of each plant influent and pumping station samples were collected using the facility's existing sampling pumps and ports. For the plant influent, a peristaltic pump with intake located in the middle of the post-screen effluent outflow at the headworks facility was used for sample collection. At the pumping stations, sampling ports located on the outflow lines were used for sampling. All samples were placed on ice and transported to the laboratory for analyses.

In recent years representativeness of single point sampling has been questioned in literature, with vertical profile sampling (e.g., vertical slotted sampler and a multi-point manifold sampler) considered to be superior to the single point devices due to their ability to capture partially settled particles within the flow (Reddy and Pagilla, 2009). Additionally, composite samples consisting of increments collected overtime can be argued to be preferable due to the non-steady nature of wastewater flow. However, the sampling approach employed in this study was limited by the following:

- Site conditions, i.e., underground conveyance of screened influent to the primary treatment, which made utilization of vertical profile sampling devices technically infeasible;
- Transport and analysis limitations, i.e., the samples had to be transported off-site for analyses at a state university laboratory, which had imposed strict limits on the wastewater volumes due to its potential to contain COVID-19 virus; and
- Lack of onsite cooling capacity to prevent biological degradation of organic matter in the event composite samples were to be collected.

### 2.3. Settling velocity

Multiple settling column designs exist for grit particles settling evaluation, including the CERGRENE protocol (Chebbo, 1992), the Aston column (Tyack et al., 1993), the UFT column (Michelbach and Wöhrle, 1993), the U.S. EPA column (O'Connor et al., 2002), the ViCAs protocol (Chebbo and Gromaire, 2009), and the upwards velocity column (Osei et al., 2012). Most of these columns are designed to show the particle settling velocity distribution, i.e., either numerous sampling ports are utilized along the column's height to collect various sample fractions at the same time or a single port at the bottom is used to evacuate settled particles at prescribed time intervals. None of these columns were readily available at the time of this project and construction of one was made impossible by the nationwide shortage of special-order acrylic products due to the COVID-19 pandemic. Thus, a simplified protocol was developed for this study in order to facilitate observation of settling particles and measurement of their terminal velocities. Fig. 1 shows a schematic diagram of the rectangular open-top tank made of acrylic plastic for optical transparency. The tank dimensions were 12 inches wide by 30 inches high by 4 inches deep. The dimensions were calculated to minimize the wall effect and drag on the particles, which requires a minimum container thickness of 4 inches (Van Loosdrecht, 2016). A 1-inch by 1-inch square grid was etched on the outside of one panel to be used as a frame of reference for estimating a particle travel path. A softbox light source utilizing a cool white (6500 K) light bulb with the light output of 4250 lm was placed behind the tank to improve visibility of discrete particles.

Plant influent was the only sample type analyzed for settling velocity. For each experiment, the tank was filled with 23 L of plant influent and particles were allowed to settle undisturbed for 2 h. A time lapse video of settling progress was recorded with a digital camera at a rate of one frame per second. The images were processed in Adobe Photoshop and Premiere software. Ten randomly selected non-aggregated particles were traced through the water column, and settling velocity was calculated for each particle using the total path traveled in the recorded time interval.

### 2.4. *Particle size distribution*

Plant influent and pumping stations samples were separated on wet sieves to evaluate particle size distribution. The experimental procedure was modified from the ASTM Standard D6913/D6913M (ASTM, 2017), which describes the method of particle size distribution for soil using sieve analysis. All samples were wet sieved over a stack of six Gilson Company Inc. ASTM E11 Specification USA Standard Test Sieves (sieve

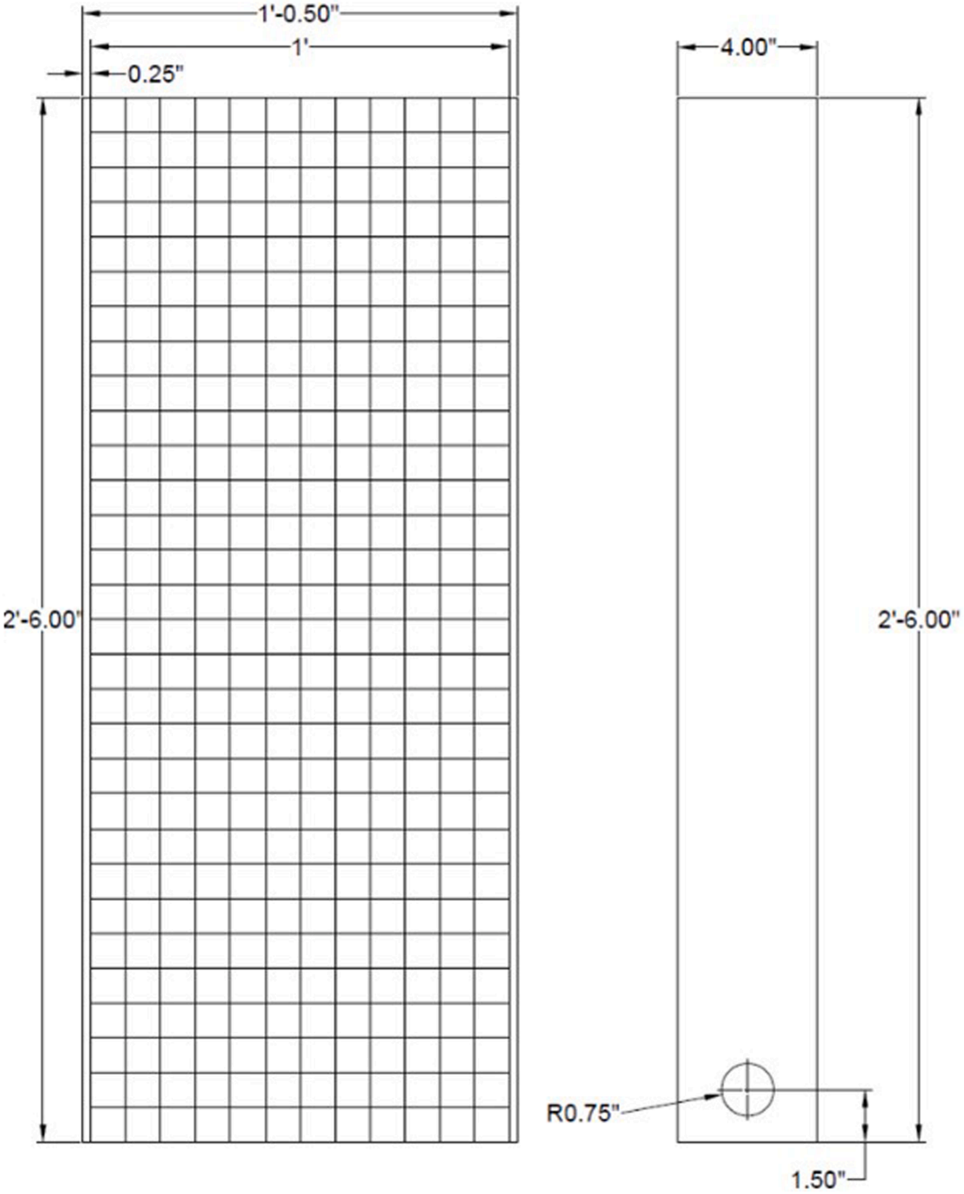

**Fig. 1.** Schematic of settling velocity tank design including dimensions for experimentally measuring settling velocity of particles suspended in plant influent over sampling period.

1 = 2.36 mm [No. 8], sieve 2 = 1.18 mm [No. 16], sieve 3 = 0.6 mm [No. 30], sieve 4 = 0.3 mm [No. 50], sieve 5 = 0.15 mm [No. 100], sieve 6 = 0.075 mm [No. 200]; opening dimensions). Particles passing the finest sieve were discarded. All sieves were massed clean and empty using an Ohaus Ranger 7000 Digital Scale prior to analysis. For each sample, 23 L of wastewater were poured over a dedicated sieve stack. The sample container was triple rinsed and the rinsate loaded onto the sieves to ensure complete transfer of solids. The loaded sieve stacks were manually agitated under the stream of clean water with a throughput of 2 L/min to facilitate solids distribution. The loaded sieves were dried in a VWR Gravity Convection Oven at 103 °C for 24 h and massed again after cooling to room temperature using the same scale to determine the mass of solids retained. The results were expressed as the fraction of solids mass retained on each sieve relative to the total mass of solids retained on all sieves.

### *2.5. Total suspended solids*

All samples were analyzed for the total suspended solids (TSS) content using the United States Environmental Protection Agency (USEPA) Method 160.2 (USEPA, 1999) with minor modifications to account for differences in equipment and supplies available. Each sample was agitated, then a 50 mL volume of subsample was poured from the sample bottle into a graduated cylinder and immediately filtered under vacuum, using a standard Pall Corporation filtering manifold, equipped with pre-weighed 4.7 cm in diameter Whatman Glass Microfiber Filters ([GF/F] 0.7 μm pore size). A total of six subsamples were loaded onto individual GF/Fs, with three filters used as true replicates in TSS analysis and the remaining three GF/Fs stored at −20 °C for further organic analyses. Sample volume was established experimentally at the beginning of the sampling period by passing sufficient volumes of sample through the filter to achieve clogging, in order to allow for maximum solids load. The loaded filters were dried to a constant mass in a VWR Gravity Convection Oven at 103 °C for 24 h and weighed again after cooling to room temperature in a desiccator on a Denver Instruments A-200DS Analytical Balance. The results were expressed as mass of solids retained on the filter per unit volume of sample filtered.

### *2.6. Volatile suspended solids*

The filtered residue material used in the TSS analysis was also utilized to approximate the organic matter content as the volatile fraction of the suspended solids (VSS) via Loss on Ignition (LOI) test following the modified USEPA Method 160.4 (USEPA, 1971). The standard method temperature was modified from 550 °C to 400 °C due to the decomposition of aluminum foil used to wrap individual filters at higher temperatures. Additionally, ashing of soil samples at temperatures below 550 °C has been recommended in literature in order to avoid losses of $CO_2$ from carbonates, structural water from minerals, and decomposition of hydrated salts (Combs and Nathan, 1998), all of which are listed as sources of error in the standard USEPA Method 160.4. The highest feasible temperature was determined through a series of experiments with blank filter packets and was established at 400 °C. The combustion time was increased from 1.5 to 8 h in order to promote complete oxidation/volatilization of organic and volatile matter.

After weighing for TSS analysis, the individually wrapped, loaded, dried GF/F filters were combusted at 400 °C for 8 h in the Thermo Scientific Lindberg/Blue M Muffle Furnace, then cooled to room temperature in a desiccator and weighed on the Denver Instruments A-200DS Analytical Balance. The mass lost on ignition (i.e., the difference in mass before and after combustion of the sample) was assumed to be representative of the VSS available for combustion. The VSS results were expressed as a fraction of the TSS content of the samples.

### *2.7. Extraction of total fats, oil, and grease*

All samples were analyzed for the total fats, oil, and grease (FOG) content. The method used was adapted and modified from Mclachlan et al., 2020 and the USEPA Method 1664B (USEPA, 2010). The filters reserved from the TSS analysis were placed into 20 mL test tubes with 10 mL n-hexane, vortexed for 10 s, then left undisturbed in the dark for 1 hour. The extracts were then transferred into tared 4 mL vials and dried in a 65 °C water bath under a gentle stream of nitrogen. After drying, the vials with FOG residue were weighed on the on a Denver Instruments A-200DS Analytical Balance. The resulting total FOG values were expressed as percent of TSS.

## 3. Results and discussion

Grit composition is inherently heterogeneous and varies with time. Long-term evaluation of this heterogeneity allows to capture the range of grit characteristics and aids in the determination of the most appropriate method of grit removal at the study site. In this study, seasonal changes were observed in particle size distribution, TSS loads, and VSS fraction of TSS.

### *3.1. Size gradation*

Table 1 shows the results of the particle size distribution evaluation of the plant influent and wastewater collected from the three main pumping stations. The results are expressed as mean values for each sieve mesh aperture at each sampling location averaged over the entire data set with one standard deviation. The high standard deviation values indicate a significant amount of data spread observed at each sampling location over the course of a calendar year. Particles retained on the coarsest sieve were confirmed to be organic in nature (e.g., seeds, pieces of wood, etc.) and no fine gravel was observed in any of the samples. Most of the particles were in the sand size range, with fine sand (particles with diameters in the range of 75 – 200 μm) fraction being slightly more prevalent overall. Presence of a relatively high fraction of fine sand (near 35% in plant influent) carries an important implication for the grit removal system implementation, as most conventional grit removal systems are designed for ideal target spherical particles with 200 μm mean diameter (Barter and Sherony, 2018).

Relative differences between sampling locations on each sampling date were evaluated using the particle size distribution curves presented in Fig. 2. Notable differences were identified between the locations as summarized below: (1) Coastal Station N contained more coarse fraction particles in the period between November 2020 and April 2021; (2)

**Table 1**
Mean particle size distributions at all sampling locations collected monthly over a period of 12 months ($n = 12$). Mean value of the three replicates ± 1 standard deviation.

| Sieve Aperture, μm | Unit | Sampling Location<br>Plant Influent ($n = 12$) | Inland Station ($n = 12$) | Coastal Station N ($n = 12$) | Coastal Station S ($n = 12$) |
|---|---|---|---|---|---|
| 2360 | % Retained | 4.30 ± 4.16 | 9.74 ± 6.64 | 12.09 ± 10.44 | 9.01 ± 8.51 |
| 1180 | % Retained | 6.09 ± 6.79 | 7.05 ± 5.68 | 6.53 ± 6.16 | 4.19 ± 3.92 |
| 600 | % Retained | 22.98 ± 9.36 | 18.92 ± 10.95 | 18.48 ± 12.59 | 15.30 ± 7.71 |
| 300 | % Retained | 31.90 ± 10.28 | 26.63 ± 9.24 | 27.49 ± 14.62 | 26.76 ± 8.95 |
| 150 | % Retained | 17.19 ± 8.66 | 20.42 ± 9.53 | 24.29 ± 16.35 | 27.87 ± 7.73 |
| 75 | % Retained | 17.55 ± 8.83 | 17.25 ± 8.42 | 11.12 ± 9.45 | 16.87 ± 11.20 |

n, number of samples.

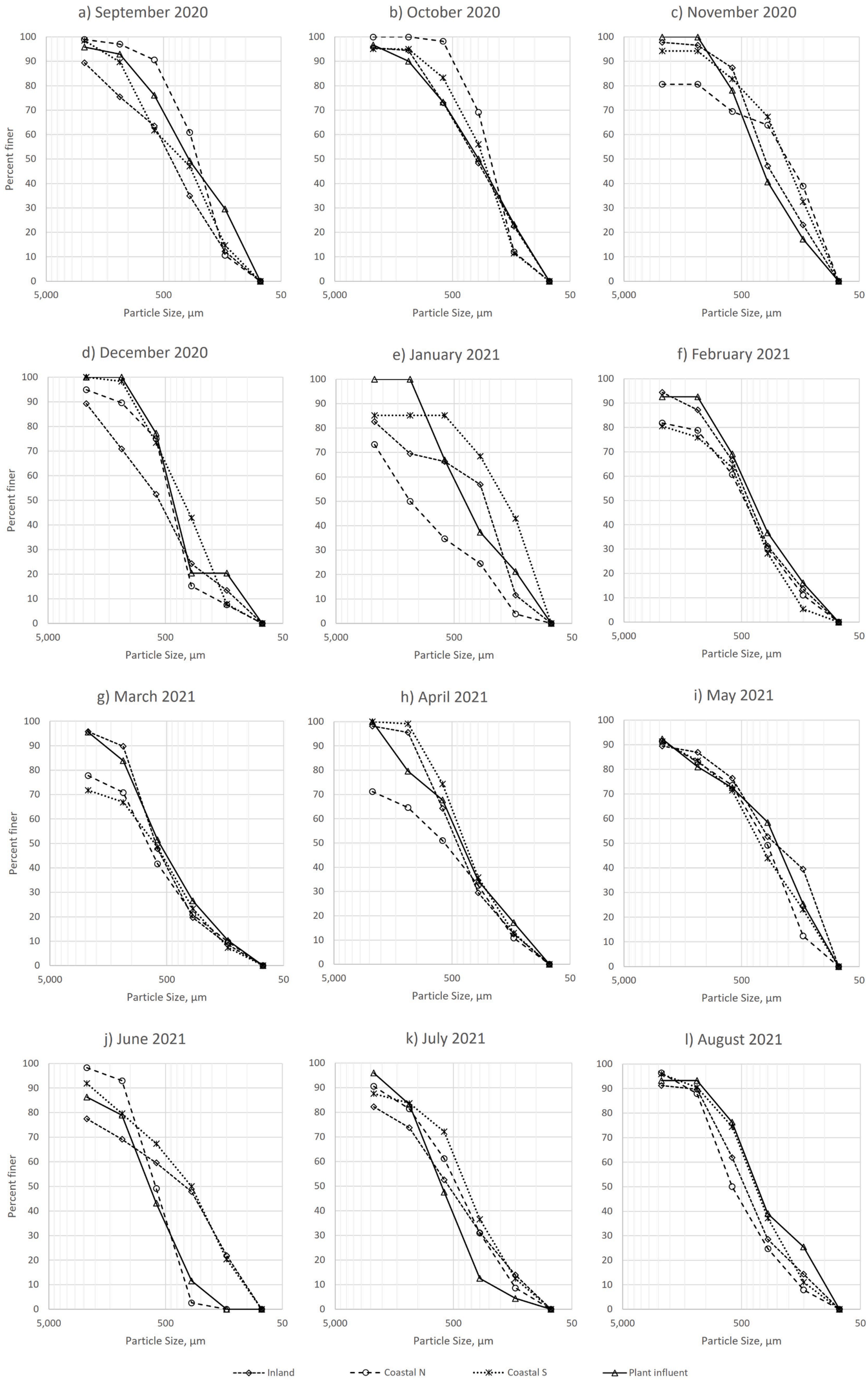

**Fig. 2.** Evaluation of seasonal changes in particle size distribution at all sampling locations in the following periods: autumn months (September through November, Row 1, panels a through c), winter months (December through February, Row 2, panels d through f), spring months (March through May, Row 3, panels g through i), and summer months (June through August, Row 4, panels j through l).

Coastal Station S particle size distribution was significantly different from the Coastal Station N, which suggests different input sources despite the near proximity geographically; (3) results of analyses of samples collected in January 2021 were not in agreement with the rest of the data, indicating that some of the material in the coarse sand fraction has potentially settled in the plant collection pipes prior to reaching the plant.

Panels in rows are arranged as calendar seasons in the following order: panels a-c represent autumn months (September through November), panels d-f represent winter months (December through February), panels g-i represent spring months (March through May), and panels j-l represent summer months (June through August).

Particle size distribution in panels a-c demonstrates a shift from finer to coarser particles in the plant influent from September (29.58% finer than 150 μm) to November (17.19% finer than 150 μm). This shift is not reflected in particle size distributions recorded at the pumping stations, all of which showed an increase in the finer than 150 μm size fraction from September to November (10.57% to 38.89% at Coastal Station N, 14.71% to 32.69% at Coastal Station S, and 12.23% to 22.99% at Inland Station [values are given for September and November at each sampling location]). Since both coastal pumping stations are located in the areas with a significant number of summertime residents, it is reasonable to anticipate a decrease in the volumes of wastewater generated in the off-season months. A decrease in flow through the collection network can lead to sedimentation of the heaviest particles, which require a flow velocity of above 1.07 m/s to remain in suspension. The particles, which settle out within the collection pipes, will remain in place or travel along the sedimentation bed if the flow velocity is above 0.52 m/s (Rippon et al., 2010). The increase of the coarser fraction in the plant influent can potentially be attributed to the grit input with the stormwater runoff infiltrating through the flooded manholes and damaged collection pipes.

The opposite trend was observed in the winter months in the pumping stations samples, where the finer than 150 μm size fraction constituted less than 10% of the total solids at coastal stations (with the exception of January sample collected at Coastal Station S) and less than 14% at Inland Station, while plant influent contained 16.18 – 21.19% of the particles smaller than 150 μm. The relative increase of coarser particle fraction in the pumping stations can be attributed to deicing events, which can influence the grit input, especially if damages in the collection network pipes can be suspected (Plana et al., 2017).

All samples had a relative increase in the finer than 150 μm size fraction between March and May (9.72% to 12.35% increase at Coastal Station N, 7.36% to 23.08% increase at Coastal Station S, 8.55% to 39.47% increase at Inland Station, and 10.29% to 25.35% increase observed in plant influent sample).

In the summer months, overall particle size distribution shifted from finer to coarser particles, especially evident in the Coastal Station N samples, where the finer than 150 μm size fraction has decreased from 12.35% in May to 0% in June, followed by a slight rebound to 8.68% in July and 7.89% in August. Plant influent particle size distribution also displayed a significant decrease in the finer than 150 μm fraction in June and July (from 25.35% in May to 0% in June and 4.43% in July); however, it rebounded to 25.42% in August, nearing the results recorded in September sample. The increase in the coarser fraction, especially at the coastal stations, can be attributed to the proximity of the serviced communities to the Atlantic Ocean coast and the significant number of vacationers occupying the area in the warmer months, indicating the potential enhanced input of beach sand.

For the plant influent, particle size distribution in August 2021 and September 2020 were very similar, confirming that a single 12-month evaluation of changes is adequate to capture potential seasonal trends. Particle size distributions in plant influent samples show changes which can be aligned with the seasons. The WWTP receives a significant amount of fine sized particles (under 150 μm) in autumn, and it gradually decreases through the winter and spring months to near zero in the summer. The relative increase in the coarse fraction in the summer months could potentially be attributed to the increased input of sand in the coastal stations samples, which is confirmed by the low organic matter (VSS) content, discussed in the following subsection.

The particular focus placed on the finer than 150 μm fraction is necessary because, while the ideal grit particle for grit removal system design is about 200 μm in diameter (Barter and Sherony, 2018), membrane bioreactors effectiveness can be reduced by particles as small as 75–106 μm (Andoh and Neumayer, 2009). ACUA WWTP does not currently have a membrane bioreactor in place and potentially could introduce biotechnology to its secondary treatment units as an upgrade in the future, thus necessitating a decrease in the cut point particle size for the grit removal system design in order to avoid potential challenges in the future, i.e., when small particles pass through the treatment stages and affect performance of upgraded secondary or tertiary units (Gravette et al., 2000). Additional potential sand loads during storm events should also be included in the grit removal design specifications.

### *3.2. Total suspended solids and volatile suspended solids*

Results of the TSS and VSS evaluation are summarized in Table 2 and presented graphically in Fig. 3. TSS concentrations were highest in the summer months (June through August) at all locations. Additionally, anomalous high TSS concentrations were recorded at Coastal Station N in September (293 ± 37 mg/L), at the Inland Station in December (237 ± 36 mg/L), and at both Coastal Station S and plant influent in January (321 ± 74 mg/L and 259 ± 34 mg/L, respectively). Overall, TSS concentrations ranged between 50 ± 5 and 341 ± 41 mg/L, similar to the values reported in other studies (e.g., Sari et al., 2014; Verma et al., 2013), and tended to be higher in the warmer months. VSS fraction of the TSS tended to be lower in the warmer months with the lowest values ranging between 48% and 64% of the respective TSS measurements recorded in October at all sampling locations. A rapid increase in VSS fraction of TSS in November has been recorded at all locations, with values ranging between 89% and 97% of the TSS. While the TSS values displayed temporal and spatial variability in the sampling period between the months of November and April, the VSS fraction remained relatively stable at levels near 90% of the TSS. VSS fraction has decreased rapidly in August, most notably at both coastal stations, where TSS concentrations remained high, potentially indicating an increased influx of sand material. Review of the particle size distribution for August (Fig. 2h) does not provide sufficient evidence to support this claim. However, the data for September and October (Fig. 2a and Fig. 2b, respectively) indicate larger fraction of coarser material, particularly at Coastal Station N. This relative increase in coarse material fraction, combined with high TSS and low VSS values, suggest that increased input of sand is likely in the coastal areas.

### *3.3. Fats, oils, and grease*

Traditional grit removal technology relies on settling due to gravity, and grit composition is one of the most important factors influencing the settling process of a particle. Settling is affected by particle material, size, and shape (Boyrs et al., 2002), which determine the inherent density and the amount of drag. Density can further be affected by various coatings on the surface of the particles, especially those with low specific gravity (Osei et al., 2012), i.e., fats, oils, and greases, collectively referred to as FOG. In this study, the total FOG concentrations, as part of the VSS, were evaluated to investigate the potential effect of FOG on the measured settling velocity. The results of the FOG analysis are presented graphically in Fig. 4. Overall, FOG concentrations measured in crude sewage collected from the three pumping stations and in the plant influent were relatively low (most samples below 10 mg/L), with the highest concentration of 38 ± 10 mg/L measured at Coastal Station S in August. These values were significantly lower than some of the concentrations reported in literature (e.g., 57 ± 11 mg/L in Collin et al., 2020, and 50 – 150 mg/L in Laak, 1986). In general, FOG fraction of VSS

**Table 2**
Results of TSS concentration evaluation and its constituent VSS fraction at the three main pumping stations and in the plant influent over the period of 12 months. Mean value of the three replicates ± 1 standard deviation.

| | | Sampling Period | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sampling Location | Parameter, Unit | Sep.*n* = 3 | Oct.*n* = 3 | Nov.*n* = 3 | Dec.*n* = 3 | Jan.*n* = 3 | Feb.*n* = 3 | Mar.*n* = 3 | Apr.*n* = 3 | May.*n* = 3 | Jun.*n* = 3 | Jul.*n* = 3 | Aug.*n* = 3 |
| Coastal N | TSS, mg/L | 293 ± 37 | 114 ± 9 | 90 ± 2 | 155 ± 27 | 88 ± 11 | 96 ± 11 | 130 ± 61 | 107 ± 15 | 91 ± 2 | 160 ± 8 | 187 ± 16 | 221 ± 4 |
| | VSS,%TSS | 72 ± 4 | 53 ± 7 | 93 ± 7 | 87 ± 1 | 80 ± 2 | 86 ± 8 | 94 ± 6 | 81 ± 5 | 89 ± 9 | 88 ± 2 | 80 ± 2 | 76 ± 2 |
| Coastal S | TSS, mg/L | 106 ± 5 | 50 ± 5 | 99 ± 10 | 170 ± 4 | 321 ± 74 | 89 ± 10 | 114 ± 5 | 147 ± 21 | 189 ± 13 | 211 ± 16 | 103 ± 8 | 273 ± 7 |
| | VSS,%TSS | 76 ± 6 | 50 ± 5 | 97 ± 4 | 90 ± 2 | 84 ± 0 | 89 ± 1 | 88 ± 2 | 83 ± 3 | 84 ± 3 | 89 ± 1 | 77 ± 2 | 77 ± 1 |
| Inland | TSS, mg/L | 121 ± 10 | 135 ± 5 | 75 ± 4 | 237 ± 36 | 106 ± 2 | 137 ± 13 | 179 ± 51 | 166 ± 3 | 169 ± 4 | 165 ± 6 | 341 ± 41 | 159 ± 6 |
| | VSS,%TSS | 78 ± 4 | 64 ± 3 | 93 ± 1 | 92 ± 2 | 89 ± 2 | 94 ± 2 | 90 ± 3 | 84 ± 2 | 81 ± 4 | 89 ± 3 | 63 ± 4 | 69 ± 3 |
| Influent | TSS, mg/L | 135 ± 1 | 81 ± 6 | 103 ± 3 | 134 ± 6 | 259 ± 34 | 126 ± 11 | 69 ± 6 | 141 ± 16 | 189 ± 8 | 157 ± 6 | 249 ± 36 | 127 ± 3 |
| | VSS,%TSS | 58 ± 2 | 48 ± 5 | 89 ± 3 | 94 ± 4 | 85 ± 1 | 91 ± 2 | 75 ± 8 | 83 ± 3 | 89 ± 3 | 87 ± 1 | 85 ± 2 | 60 ± 1 |

n, number of samples.

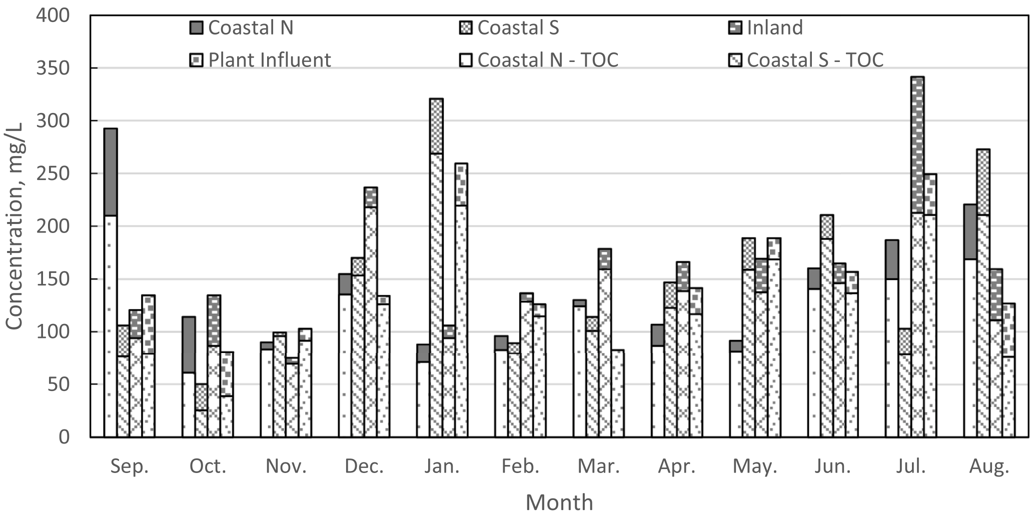

**Fig. 3.** TSS concentrations with VSS fraction at the three main pumping stations and in the plant influent over the period of 12 months. The height of each bar represents the total TSS concentration in each sample; the division line represents inorganic fraction (top) and volatile organic fraction (VSS, bottom). 3.3 Fats, Oils, and Grease.

was higher in the warmer months (March through August), which could be attributed to the enhanced mobility of FOG at elevated temperatures; however, results from September were some of the lowest; and, therefore, it is unlikely that changes in the FOG mobility influenced the spring and summer samples. This temporal variability could be attributed to the presence of organic matter naturally rich in lipids, such as animals (e.g., invertebrates) and plant debris, which would be expected to be more abundant in the warmer seasons.

### 3.4. *Settling velocity*

Settling velocity was evaluated for the six monthly plant influent samples collected in the sampling period between March and August 2021. Measurements fell in the range between 1.49 mm/s and 3.72 mm/s. Based on previous literature, the average settling velocity for mixed grit sourced from various sites ranges from 1.4 to 14 mm/s (Aidun, 2013; Flanagan, 2014; Judd et al., 2017). Based on the observed particle size distributions, settling velocities were expected to be in the middle of the reported range for mixed grit; however, all measurements fell withing the lower third of the expected range, which could potentially be attributed to non-FOG organic coatings, i.e., bacterial biofilms and exopolymer strands. Further evaluation of the classes of organic compounds which comprise the VSS could provide additional information about the factors influencing buoyancy of the particles, e.g., bacterial exopolymer strands or other voluminous growths could increase surface area to volume ratio of the individual particles, thus increasing their drag. Other factors which could reduce settling velocity, include particle makeup and viscosity of the influent.

## 4. Conclusions

Overall, the main goal of this study was to contribute to the expanding collection of physical measurements gathered from various WWTPs all over the globe and to verify whether the traditional design approaches, which rely on broad assumptions, are still able to result in an effective grit removal system at the study site. This research will not only provide the study site with the tools necessary for the development of a tailored grit removal solution but will also add to the collection of available measured results which could be used for a broader evaluation of the validity of the traditional design approaches.

The results reported in this paper indicate that implementation of facility-specific grit removal solutions is feasible and necessary to ensure effective operation, which preserves existing and future resources by reducing costs associated with repairs of damages caused by grit and by eliminating risk to the modern technologies which require improved preliminary and primary treatments.

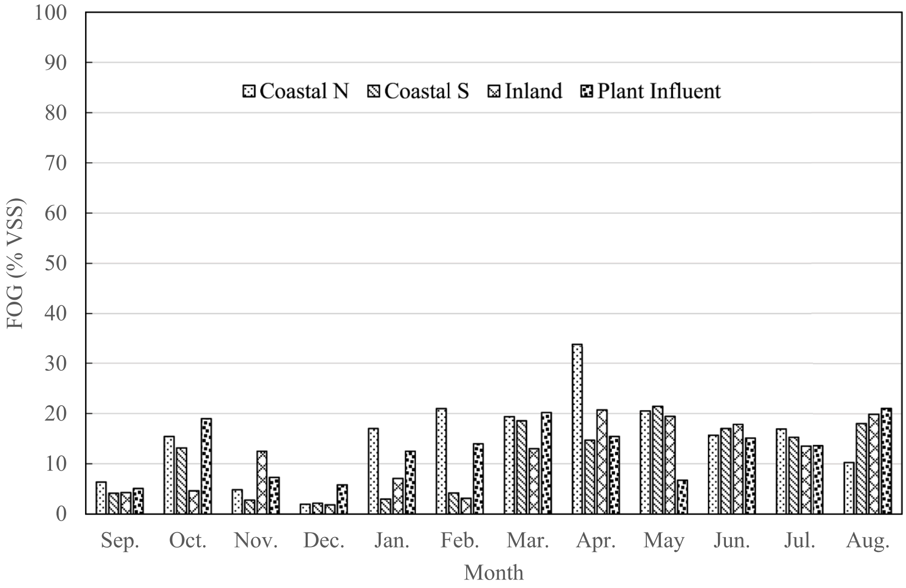

**Fig. 4.** FOG concentrations as fraction of VSS at the three main pumping stations and in the plant influent over the period of 12 months. The height of each bar represents the FOG fraction of the VSS in each sample.

The results of this study confirm that the traditional definition of grit as a clean inorganic sphere with a diameter larger than 0.21 mm is not applicable to grit entering the ACUA WWTP. The majority of particles evaluated were finer and contained a significant fraction of organic matter, which resulted in very low measured settling velocities. Without the particle size distribution and settling velocity data, solids at the ACUA WWTP appear to be fairly average in terms of concentration and composition, which shows the importance of evaluating the exact parameters that influence solids removal. Additionally, a significant seasonal variability was observed in grit composition throughout the sampling period. Considering the fact that the ACUA WWTP receives the influent from both coastal and inland communities, it is reasonable to anticipate an increase in grit loads during the summer months; however, these anticipations are difficult to estimate. The results of this case study provide numerical evidence that during the summer months, more grit in general, and more coarse grit (i.e., sand) specifically, is present in the ACUA WWTP plant influent. These results confirm that coastal areas can be viewed as sources of enhanced grit input in the summer months and can be applied as assumptions to wastewater treatment facilities located in similar areas.

These results serve as a testament that grit removal solutions design should not rely on the outdated design criteria and that facility-specific conditions can and should be incorporated in order to develop the most effective and financially viable system. While these results cannot be directly applied to other facilities, the major conclusions can be approximated for the similar WWTPs located in coastal areas either in the United States or abroad. Additionally, the simplified methods for grit characterization developed for this project from the standard and commonly used methods, can be utilized at virtually any laboratory situated within a wastewater facility, eliminating the need for consulting or research fees associated with the contracting of a third party to perform grit characterization.

## Credit author statement

**Kolosovska, T.**: original draft manuscript, revisions draft, methodology, sampling and analyses. **Bauer, S.**: project inception and development, research supervision and guidance, manuscript draft and revisions oversight.

## Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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