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Assessment of the Hydrograv® Adapt Variable Height Secondary Clarifier Inlet at HRSD Nansemond Treatment Plant

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ASSESSMENT OF THE HYDROGRAV® ADAPT VARIABLE HEIGHT SECONDARY CLARIFIER INLET AT HRSD NANSEMOND TREATMENT PLANT

by

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ABSTRACT

Assessment of the Hydrograv® Adapt Variable Height Secondary Clarifier Inlet at HRSD Nansemond Treatment Plant

Matthew Poe

Old Dominion University, 2021

Director: Dr. Gary Schafran

The Hampton Roads Sanitation District (HRSD) recently completed the first North American and center driven installation of the Hydrograv® Adapt Variable Height Secondary Clarifier Inlet (Adapt) at HRSD's Nansemond Treatment Plant. This is a variable height inlet structure designed to decrease clarifier effluent turbidity and maintain low turbidity during high flow events. Low turbidity is achieved by feeding the secondary clarifier influent within the solids blanket during dry weather conditions and lifting the inlet structure during wet weather conditions to avoid disrupting the blanket. The Adapt clarifier was monitored alongside an identical fixed inlet clarifier to assess performance. Both clarifiers were monitored using online and manually sampled measurements of solids blanket thickness and effluent turbidity. Effluent orthophosphate was also monitored to detect and evaluate phosphorus release in both clarifiers. During initial operation, regular orthophosphate spikes were observed in the Adapt clarifier prior to inlet control optimization. Sludge blanket levels in the Adapt clarifier were consistently higher than levels in the fixed inlet clarifier, but this was later discovered to have been caused by dysfunctional manifold seals. Manual sampling completed during normal and stressed conditions indicate that the mean turbidity for the Adapt clarifier was less than that of the fixed inlet clarifier with a 95% level of confidence. The difference in means was only 0.2 to 0.4 NTU and may not result in improved performance when evaluated in the direct filtration pilot. During stress testing the combination of high loading and increased blanket heights from inadequate RAS pumping capabilities led to higher turbidities during the peak evening diurnal. Stress testing should be repeated with mechanical and programming adjustments to allow for additional RAS capacity, and manual turbidity and blanket readings should be collected regularly and over a long duration test period. Depth profiling confirmed a more defined separation of the clear water and sludge blanket in the Adapt compared to the fixed inlet clarifier. Higher nitrate and orthophosphate concentrations observed in the fixed inlet clarifier could have been a result of

orthophosphate release from the settled sludge, unintended mixing, or uneven loading to the clarifiers.

This thesis is dedicated to my wife Arielle, who provided support and encouragement during this endeavor. Through the late nights and early mornings, you were there to pick me up and keep me going.

Also, to my son Aaron and daughter Norah, who were both born while obtaining my MS. Thank you for your understanding during times I was distracted, and I hope this educational experience has shaped me in a way that will help you achieve your life goals.

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1. INTRODUCTION

1.1 BACKGROUND AND LITERATURE REVIEW

Liquid-Solids separation is a vital component of an effective activated sludge process in wastewater treatment. It is commonly achieved using secondary clarifiers which are placed at the end of the activated sludge process. Secondary clarifiers serve two main purposes in the treatment process. The first is to settle the mixed liquor, resulting in a clarifier effluent which is low in total suspended solids (TSS). The second is to thicken activated sludge which is returned to the aeration tank. The returned flow is commonly referred to as return activated sludge (RAS) and is a critical operating parameter in the activated sludge process. RAS flowrate is appropriately selected to ensure sufficient biomass in the aeration tanks and maintain a desired sludge blanket level within the clarifier.

Within the secondary clarifier, there are typically multiple forms of settling occurring. Zone settling occurs at high solids concentrations and is achieved through inter-particle forces causing the particles to settle together while forming a sludge blanket. Discrete settling occurs in the upper portion of the clarifier with low solids concentrations, and compression settling occurs within the sludge blanket in the deeper portion of the clarifier. Flocculation within the inlet zone of the clarifier, particularly within the clarifier feed well, also promotes flocculent settling. Zone settling is the predominate form of settling considered in secondary clarifiers, and the rate of settling is dependent on the characteristics of the flocs formed in the upstream treatment process. The thickening layer of settled mixed liquor in the bottom of the secondary clarifier is commonly referred to as the sludge blanket level, and typically ranges between 1 and 3 feet during normal/appropriate operations. This level is periodically measured by plant operators using a core sampler, however continuous measurements can also be recorded using a permanently mounted sensor.

Two key parameters used in the design and evaluation of secondary clarifiers are surface overflow rate (SOR) and solids loading rate (SLR). The SOR is the ratio of influent flow to clarifier surface area, which is also equal to the critical settling velocity for discrete particle settling. All discretely settling particles with a settling velocity greater than or equal to the

SOR will be captured in the sludge blanket. A clarifier with a low SOR provides more time for biomass floc and particles to settle out to the bottom of the basin. The SLR represents a mass loading per unit area and can be expressed as a function of influent flow rate (Q), return activated sludge flowrate (Q_R), mixed liquor suspended solids concentration (MLSS), and clarifier surface area (A).

$$SLR = \frac{(Q + Q_R)MLSS}{A} \tag{1}$$

Previous research has shown that well designed and operated clarifiers with sufficient basin depth do not show a strong relationship between SOR and clarifier effluent suspended solids (ESS), and that the design should be based on solids flux or state point analysis (Parker et al., 2001). Sludge Volume Index (SVI) is a measure of the settleability of the mixed liquor. SVI is obtained by placing a mixed-liquor sample in a graduated cylinder for 30 minutes, then measuring the height of the settled volume in the cylinder. The corresponding mixed-liquor TSS concentration is measured, and SVI is calculated as the ratio of the settled sludge volume to the TSS concentration. Generally, a lower measured SVI is associated with a better settling sludge which will result in more efficient clarifier performance. It has been shown that plants which incorporate anoxic or anaerobic selectors into the treatment process achieve lower SVI values and subsequently lower effluent suspended solids; further, those that incorporate anaerobic selectors outperform those that utilize anoxic selectors (Parker et al., 2004).

The State Point Analysis (SPA) is a tool commonly used to design and evaluate the performance of secondary clarifiers. SPA provides a means to assess clarifier capacity based on the operating mixed liquor concentration, hydraulic loading rate, RAS flow rate, and whether a specific combination of these parameters results in a limiting condition based on solids-flux theory. The state point resides at the intersection of the overflow and underflow rate lines and is evaluated based on the position of the gravity flux curve. The gravity flux curve is a function of mixed liquor concentration and zone settling velocity, the latter of which is ultimately dependent on SVI specific to a design or current plant configuration.

Common operational problems associated with secondary clarifiers are filamentous and viscous bulking sludge, Nocardia-form foaming, and rising sludge. Filamentous and viscous sludge bulking can occur due to a variety of causes, but both result in a less dense floc that is less likely to settle properly. Nocardia-form foaming is commonly found in systems with fine bubble diffused aeration, anoxic/aerobic BNR processes and has also been associated with fats and oils. If the accumulation of these foam causing organisms is not controlled, it can lead to the problem of Nocardia-form foaming organisms out selecting other activated sludge organisms. Rising sludge is typically associated with denitrification within the sludge blanket. This results in nitrogen gas bubbles which increase the buoyancy of sludge causing it to float to upper regions of the clarifier.

Anaerobic conditions within the sludge blanket can lead to the secondary release of phosphorus in secondary clarifiers. Release has been linked strongly to low redox potential, as well as elevated temperatures and mixing within the clarifier. Laboratory experiments and a study at the City of Baltimore Wastewater Treatment Plant suggested mitigation of release by maintaining high dissolved oxygen during clarification. As part of this study, the use of suction-type mechanisms was recommended which reduce clarifier sludge age when compared with scraper-type mechanisms (Shapiro et al., 1967). In a full-scale study of the Pihlajaniemi Biological Nutrient Removal plant in Savonlinna, Finland, the release of phosphorus was observed with no addition of exogenous chemical oxygen demand (COD). It was suggested that an upper layer of sludge containing nitrate within the blanket may reduce the release of orthophosphate into the clarifier effluent (Mikola et al., 2009).

The proper design of secondary clarifiers is critical to ensure good performance of secondary treatment systems. Surface and solids loading rates, tank types, side water depth, flow distribution, inlet design, weir placement and loading rates, and scum removal should all be carefully considered and assessed during the design process (Metcalf and Eddie, 2014)Secondary clarifier inlets are designed to promote flocculation, dissipate energy, and evenly distribute flow while avoiding interference with the sludge blanket that could produce high ESS. Flow patterns with a parabolic shape centered above the sludge blanket have been a commonly observed phenomenon and are also referred to as density currents. By dye testing multiple clarifiers and frequently measuring concentrations at various distances and depths within the clarifier, Crosby first observed the density current phenomenon. Flow was observed to exit the inlet, then plunge down to the sludge level horizontally until turning up at the peripheral wall (Crosby, 1980). Using numerical and physical modeling, Zhou et al. (1992) predicted and verified the presence of a density waterfall within clarifiers. It was also suggested that, for a given geometry and loading, an optimum densimetric Froude number produced a lower ESS (Zhou et al.,1992). By the reduction of total energy flux associated with kinetic and potential energy due to buoyancy, Bretscher et al., (1992) demonstrated improved settling characteristics by optimizing both inlet aperture and depth, generally suggesting a deeper inlet aperture would inhibit density currents (Bretscher et al., 1992). Following this work, numerical simulations and experiments were carried out using a proposed inlet design consisting of a low inlet height, optimum aperture, inlet volume, and two rows of angle bars (Krebs et al., 1995). A numerical two-dimensional model was later developed and tested against physical experiments to understand the impacts of dynamic loading and included the sludge blanket as a computational domain. The model was able to predict a deterioration of clarifier effluent quality associated with the formation of waves on the sludge blanket surface (Armbruster et al., 2001).

The Hampton Roads Sanitation District (HRSD) recently completed the first North American installation of the Hydrograv® Adapt Variable Height Secondary Clarifier Inlet (Adapt) at HRSD's Nansemond Treatment Plant. The Adapt is a variable height inlet structure that is designed to decrease clarifier effluent turbidity and maintain low turbidity during high flow events. This is achieved by feeding the secondary clarifier influent within the solids blanket during dry weather conditions and lifting the inlet structure during wet weather conditions to avoid disrupting the blanket. An inlet opening that is directed into the sludge blanket prevents the formation of density currents by discharging mixed liquor into a medium of similar density, rather than into the clear water portion of the clarifier where it can undergo turbulent mixing and dispersion. Discharge into the sludge blanket also promotes floc filtration, which requires a small sludge blanket level to function as the filter. The system is also able to decrease the inlet aperture when the inlet is in a low position. In the design and operation of the inlet aperture, care must be taken to avoid excessive velocities which could result in entrainment thus reducing clarifier capacity. The system is equipped with a programmable logic controller (PLC) which controls the height of the inlet based on continuously measured inputs including RAS flow, aeration tank MLTSS, wastewater temperature, clarifier flow, and SVI. The PLC uses an algorithm based on previously completed CFD simulations to estimate the blanket height, then sends the inlet drive a command height; this places the inlet opening just at or below the top of the sludge blanket height. The proposed benefits include reduced effluent suspended solids and allowance of higher loading capacity. Prior to fabrication of the inlet installed at Nansemond Treatment Plant, the Adapt design team completed multiple CFD simulations to optimize design of the inlet configuration.

In a previous study, stress testing of the Adapt was completed at the Moers-Gerdt Wastewater Treatment Plant located near Duisburg, Germany in 2017. Since all clarifiers were already equipped with the Adapt, the inlet on one clarifier was manually positioned to the height of a conventional inlet and compared to the Adapt. The result was a significant improvement in effluent turbidity in the Adapt relative to the conventional inlet position (Benisch et al., 2018). In this study, the Adapt clarifier was monitored alongside an identically sized fixed inlet clarifier at the HRSD Nansemond Treatment Plant to assess performance.

1.2 OBJECTIVES

The objectives of this study were as follows:

- Compare performance of the Adapt inlet and the fixed inlet under the following conditions with a specific goal of keeping secondary clarifier effluent turbidity below 2-3 NTU:
    - Normal operation
    - Wet Weather operation
    - Stress testing
- Determine if phosphorus release occurred in either clarifier’s sludge blanket and if the release increased orthophosphate concentration in secondary clarifier effluent
- Compare performance of the Adapt inlet and fixed inlet using the direct filtration pilot (This will be completed in the future by others).

1.3 STUDY SITE AND PROJECT MOTIVATION

This study was conducted at HRSD's Nansemond Treatment Plant in Suffolk, Virginia, which has a permitted average daily flow of 30 million gallons per day (MGD). As shown in Figure 1, the plant is configured as a 5-stage Bardenhpo process, which facilitates nitrogen, phosphorus and Biological Oxygen Demand (BOD) removal. In 2018, HRSD completed construction of the SWIFT Research Center (SRC) which facilitates pilot scale research to support future full-scale implementation of the Sustainable Water Infrastructure for Tomorrow (SWIFT) initiative.

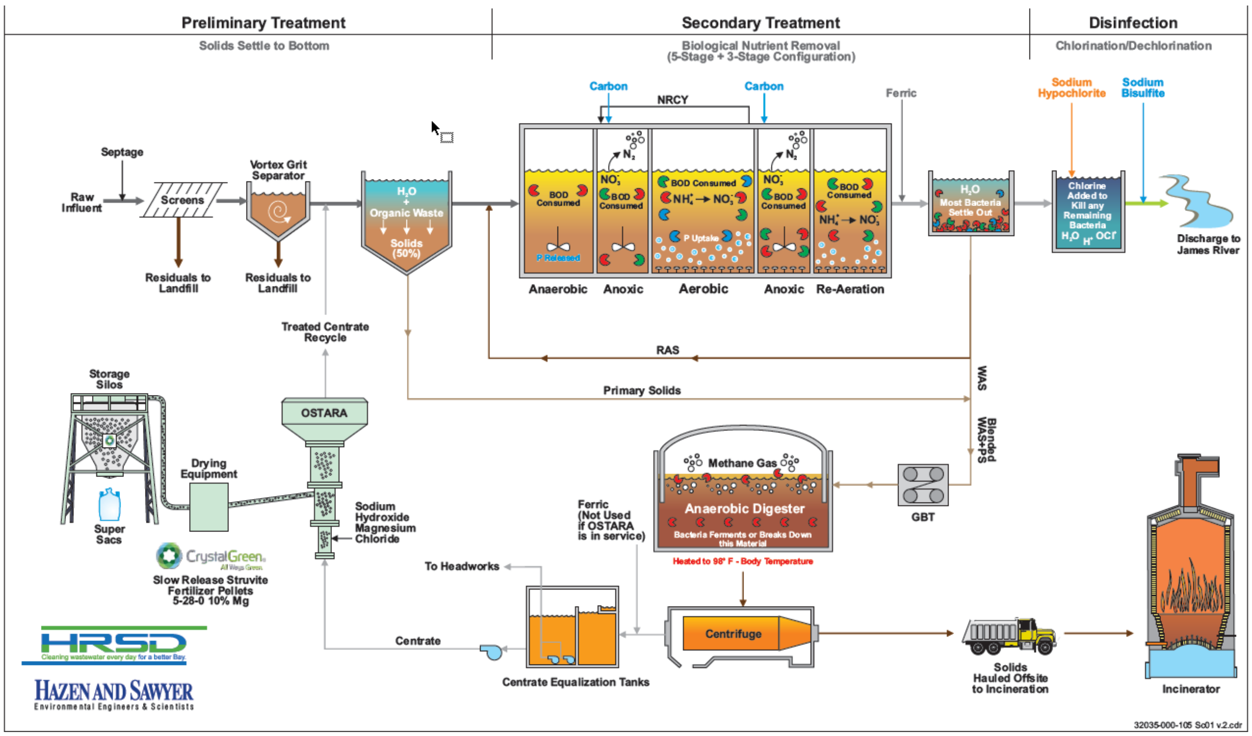


Figure 1 - NTP Process Flow Diagram

As shown in Figure 2, the SRC utilizes vertical turbine pumps to transfer up to 1 MGD of secondary clarifier effluent into the SWIFT treatment process, where it is then treated in an advanced water treatment process consisting of coagulation, flocculation, sedimentation, ozone, filtration, GAC adsorption, UV, and chorine disinfection. The final treated effluent is discharged into the Potomac aquifer through a recharge well. HRSD is currently engaged in pilot scale studies to determine the feasibility of direct filtration for full-scale implementation at select plants, which would eliminate sedimentation from the SWIFT Treatment Process. The implementation of direct filtration for full scale installations would provide a significant savings in future capital, chemical and O&M costs. It would also decrease the footprint required for the new facilities. The use of direct filtration requires a good influent water source characterized by low turbidities, and recent operational experience of the direct filtration pilot suggests optimal performance at turbidities less than 2 to 3 NTU.

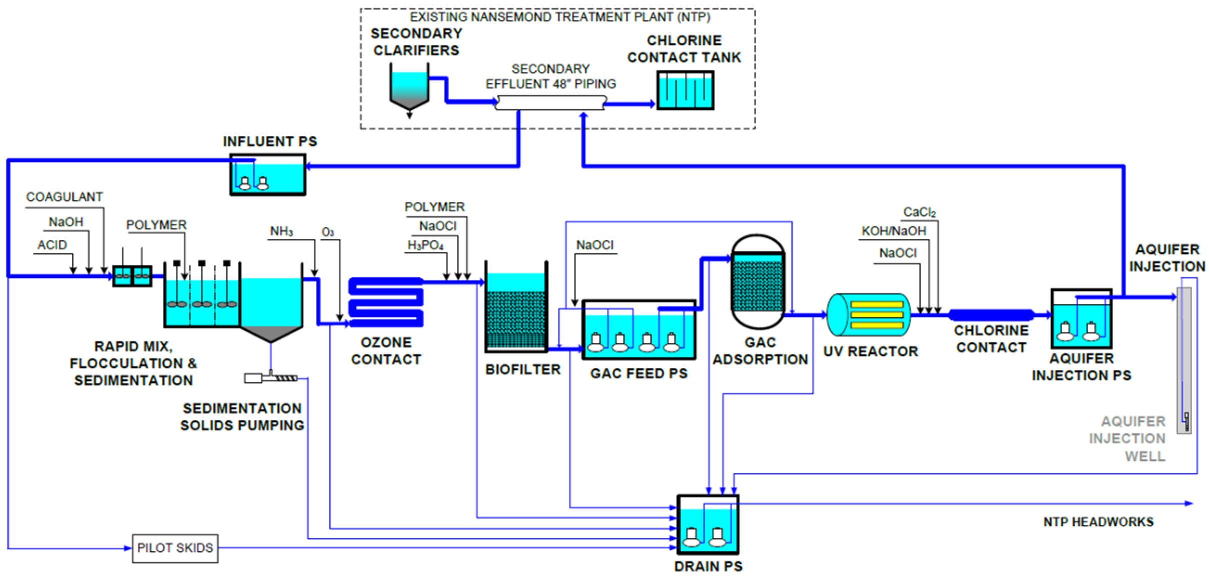


Figure 2 - SWIFT Research Center Process Flow Diagram

The Nansemond Plant produces activated sludge with a low SVI as conveyed by Figure 3. Wastewater plants with SVI below 100 mL/g indicate a sludge that settles well. Based on data obtained between February 2019 and November 2020, the average SVI was 83 mL/g. The consistently low observed SVI typically produces a low effluent turbidity as shown in Figure 4. From May 2020 to May 2021the average turbidity was 2.3 NTU, with a standard deviation of 1.23 and a 90% percentile value of 3.84. During January 2021, there was a sudden increase in turbidity which was then sustained at daily averages of around 3 to 4 NTU. Prior to turbidity increasing, the SVI was very low which has sometimes been shown to produce a weak floc resulting in high secondary clarifier effluent suspended solids (Daigger and Nicholson, 1990). Flows were also elevated during January through March of 2021 because of increased rainfall in the Hampton Roads area, so the exact cause of increased turbidities during this time is unknown. This study attempted to determine if further improvements in secondary clarifier effluent turbidity can be achieved using the

Adapt inlet under various operating conditions, and during times where turbidity is greater than 2 to 3 NTU.

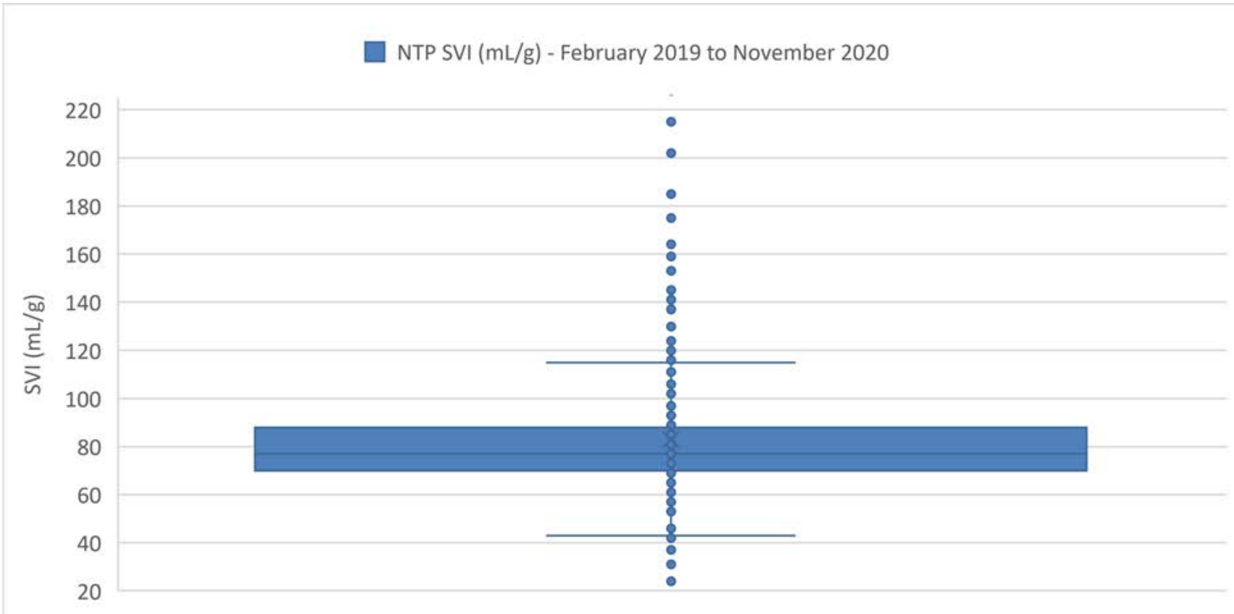


Figure 3 - Nansemond Treatment Plant SVI Values From February 2019 to November 2020

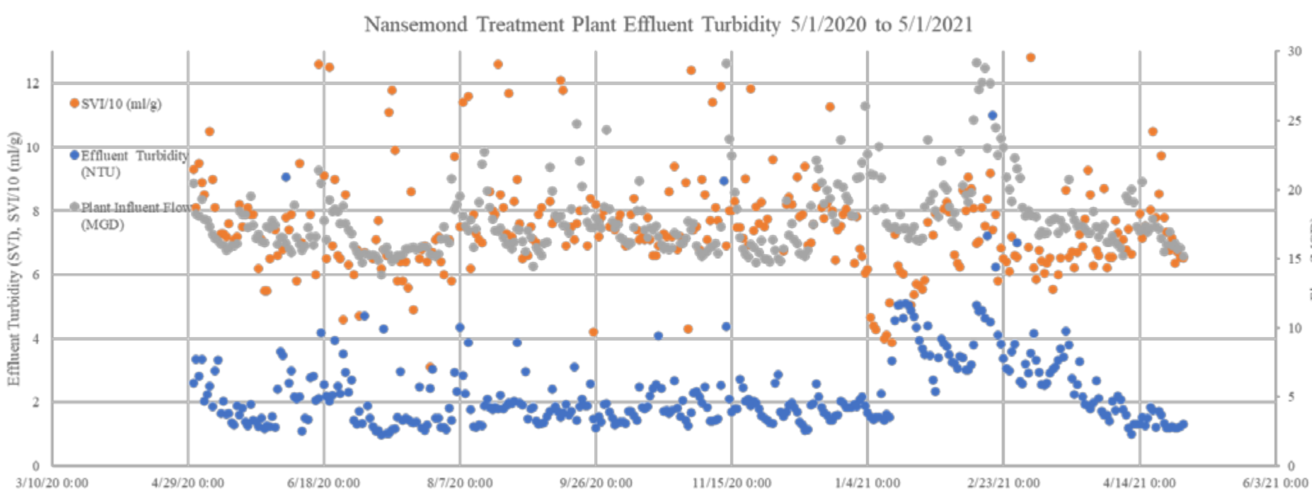


Figure 4 - NTP Effluent Turbidity 5/1/2020 to 5/1/2021

The Nansemond plant has 5 secondary clarifiers, 2 large clarifiers (clarifier 4-5) each with a surface area of 20,100 ft^2 and 3 small clarifiers (clarifiers 1-3) each with a surface area of 5,680 ft^2. Redundancy is provided in the current configuration to allow for maintenance of individual clarifiers. Typical operating scenarios involve either running all 5 clarifiers in parallel, clarifier 4 and 5 only in parallel, or clarifier 4 or 5 in parallel with clarifiers 1-3. For this full-scale pilot, HRSD decided to install the Adapt on clarifier 5, to allow for a side-by-side comparison of clarifiers 4 and 5. The characteristics of clarifiers 4 and 5 are provided in Table 1 These clarifier mechanisms were manufactured by Eimco and are a center feed suction header style design.

Table 1 – Existing Clarifier Characteristics

	Characteristics of Existing Clarifiers (Clarifiers No. 4 and No. 5)
Type of sedimentation tank	Eimco 160’ diam. Center feed circular clarifier (20,100 ft^2)
Side water depth	15’ 2”
Sludge removal	Suction header
Tank inlet design	Center column and 25’ diam cylindrical feed well with EDI consisting of (16) 6”x 0.25” steel baffles around the perimeter of the influent pipe structure. Bottom of feed well 6.6’ from the floor extending 8.5’ to just above the water surface. Stamford baffle on peripheral wall (clarifier 4) Adapt inlet. Stamford baffle on peripheral wall (clarifier 5)
Weir type and launder	V-notch weir and inboard launder with covers
Scum removal	Full radius skimmer and trough scum collector and scum pumps

The RAS pumps are in an adjacent building between both clarifiers and provide suction to the rotating header in the bottom of the clarifier. Small orifices on the front of the header pull sludge from the bottom of the clarifier to a central manifold, then through piping to the RAS pumps and additional piping back to the upstream end of the secondary treatment process. Typical RAS flowrates are between 60-70% of plant flow. Features of the existing clarifier are pictured in Figures 5 and 6.

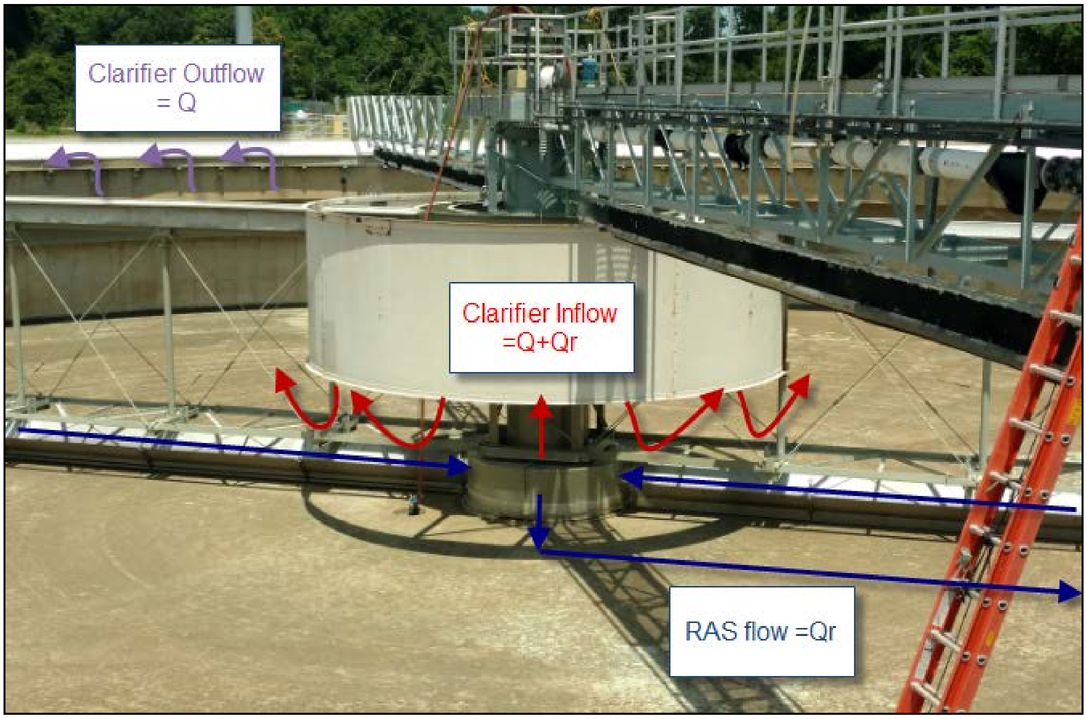


Figure 5 - Existing Clarifier Characteristics

Figure 6 - Additional Existing Clarifier Characteristics

1.4 ADAPT INSTALLATION

Figure 7 depicts the pre and post installation of the Adapt system. Figure 8 displays a cut section of the system which was designed to specifically accommodate the existing rotating structure and suction header at NTP. The construction process involved first the removal of the existing walking bridge. Next, the existing inlet was removed, and modifications were made to the suction header support frame where conflicts near the center column and new structure existed. The inner and lower assembly of the Adapt were then constructed around the existing center column. Following installation of these elements, the stationary outer cylinder was installed; next, the maintenance platform, chain support frame and the clarifier drive which is not pictured in Figure 8. Later, the rotating outer cylinder was installed, followed by reinstallation of the walking bridge, scum pump and other electrical components.

Prior to putting the new system in service, the suction header was rotated without any water in the clarifier to ensure the assembly was balanced and that there were no conflicts with the mechanical equipment. During this testing, it was discovered that the suction header was scraping the clarifier floor and HRSD staff were concerned that continued operation in this state would lead to future mechanical problems. Several attempts were made to alleviate this issue, but ultimately a significant modification was made to the suction header support frame. After the installation was complete, the Adapt was placed into service in September 2020 and was monitored during operational periods until August 2021.

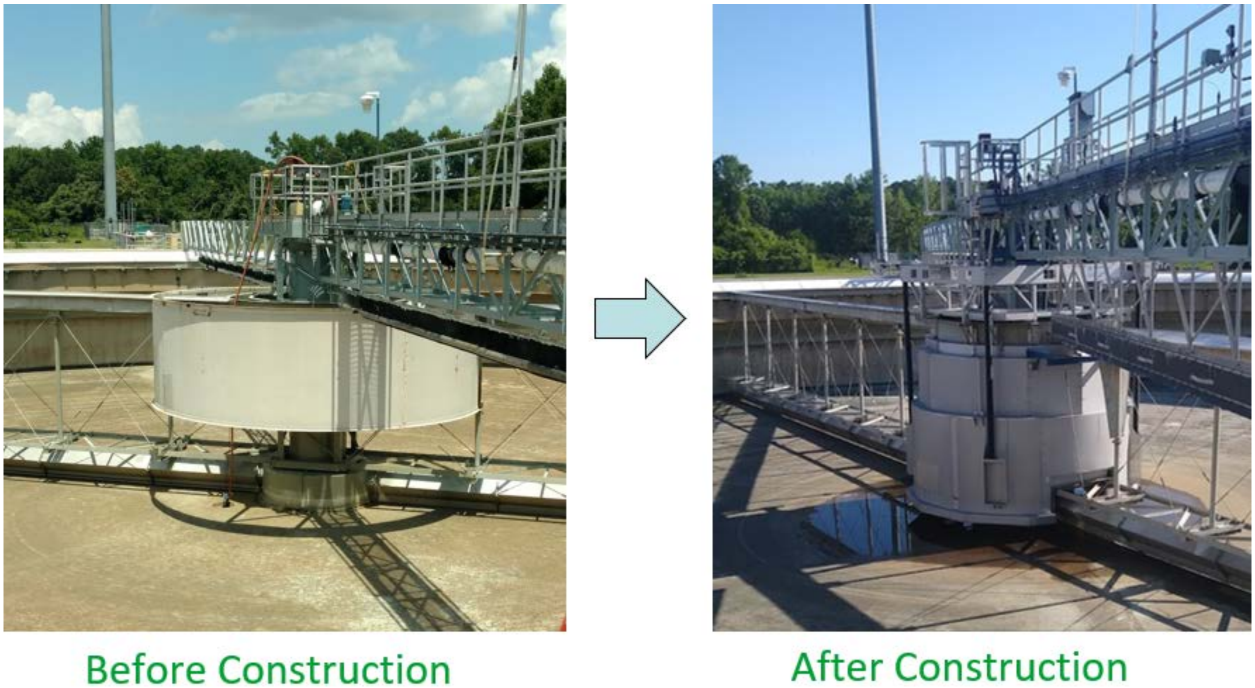


Figure 7 - Pre and Post Adapt Construction

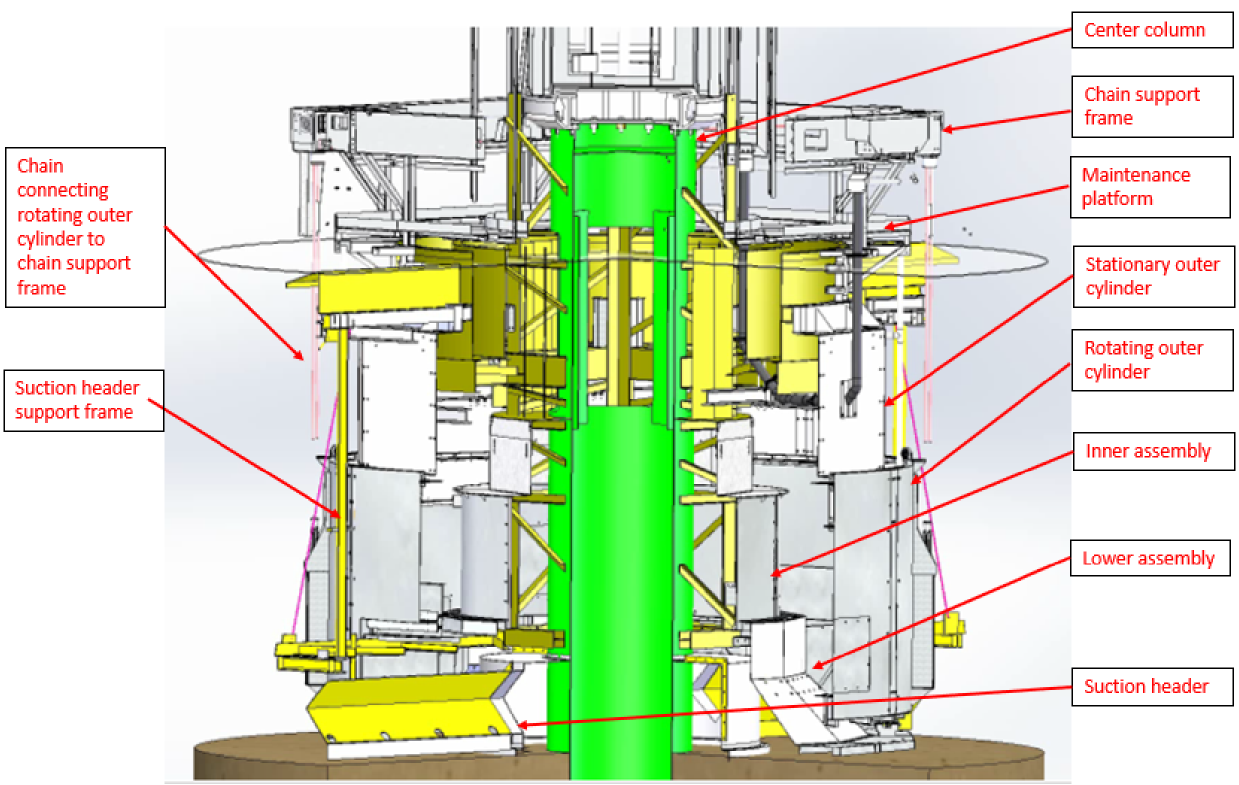


Figure 8 - Adapt System Cut Section

2. METHODOLOGY

2.1 FIXED AND ADAPT INLET ONLINE INSTRUMENTATION

The online instruments used in this study are shown and described in Figure 9 and Table 2. Turbidity and orthophosphate analyzers were installed to measure concentrations from the effluent box of both the fixed and Adapt inlet clarifiers in real time. This was determined to be the most advantageous sample location since it provided a representative aggregate of flow coming from the v-notch weir around the circumference of each clarifier. A steel platform was constructed to the elevation of the top of this box to house the analyzers, pump, and associated electrical equipment. Both analyzers are fed by a peristaltic pump which has suction tubing submerged below the water surface in the effluent box to provide samples at a desired flow rate. It was determined early in the study that the turbidity instruments were prone to fouling, resulting in erratic readings. To reduce the occurrence of fouling, screening material was installed on the open end of the suction tubing to prevent large debris from being introduced to the equipment.

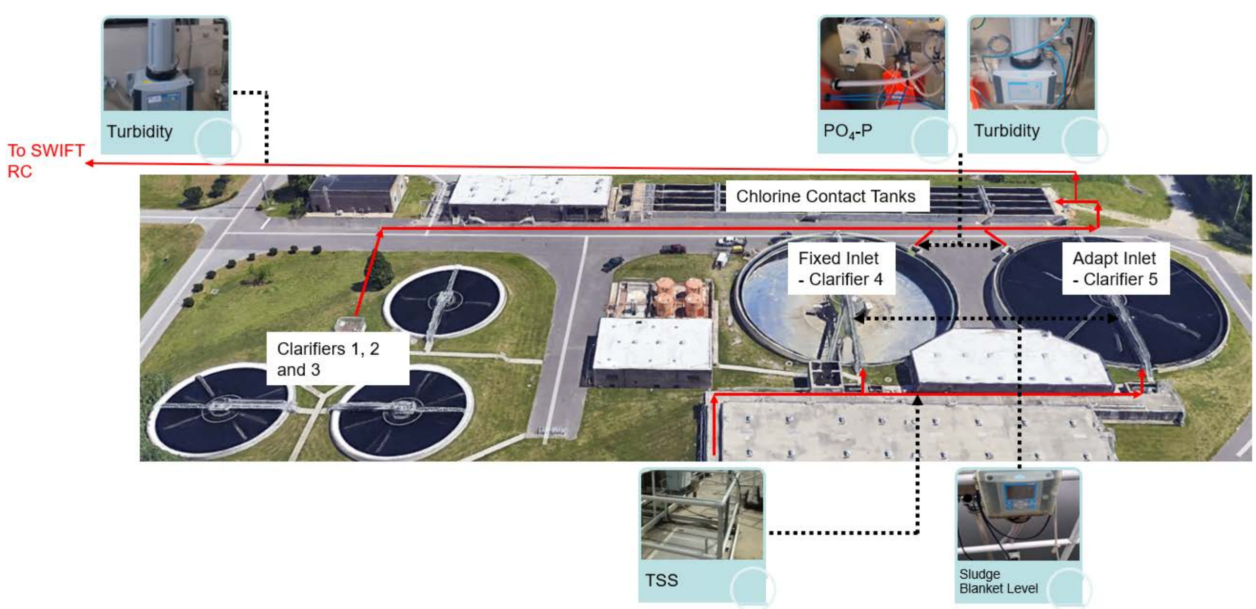


Figure 9 - Online Instrument Schematic

Accumulation of debris on the walls of the tubing was also a common occurrence and regular change out was required. An identical turbidity analyzer installed as part of the SRC construction project was in place to sample the influent of the SRC. This analyzer continuously sampled the combined effluent of all clarifiers in service and was very informative in this study, especially since the instruments sampling directly from the clarifiers were commonly experiencing fouling. This was also useful during stress testing for close monitoring of changes in turbidity. When all flow was directed to the clarifier being stress tested, concentrations measured at the SRC analyzer should have been very close to the same value. Online measurements of orthophosphate were obtained every 20 minutes. This process was automated based on standard method 4500-PE. The intent of measuring orthophosphate in the clarifiers was to determine if phosphorus release would occur in either clarifier and to what extent. Sludge blanket sensors were already installed prior to this study, and were required as a control parameter in the Adapt PLC. These sensors were installed at the midpoint between the center of the clarifier and outer wall. To mitigate conflict with the rotating scum trough, the sensor cable was installed through a conduit that hinges as the scum trough rotates past the sensor. A near infrared technology TSS sensor was installed in the aeration tank effluent channel for this study. Like the sludge blanket sensor, the TSS sensor was a required control parameter for the Adapt PLC. The TSS sensor was also informative in this study as it provided a means to estimate clarifier solids loading rate during testing.

Table 2 - Online Instrumentation Types and Methods

Parameter	Type	Method	Location
Sludge Blanket Depth	Hach Sonotax sc	Ultrasonic	Halfway between center feed well and weir
Turbidity	Hach TU5300 sc	Optical - DIN EN ISO7027	Effluent box of both Fixed inlet clarifier and Adapt inlet clarifier. Also downstream of secondary clarifiers at head of SRC
Orthophosphate	HRSD Design	Colorimetric	Effluent box of both Fixed inlet clarifier and Adapt inlet clarifier
Total Suspended Solids (TSS)	Insite Model 15 Sensor	Near infrared technology	Aeration tank effluent channel

2.2 MANUAL SAMPLING AND MEASUREMENTS

Manual sampling and measurements were conducted for various parts of this study to confirm turbidity, orthophosphate, nitrate, and sludge blanket level values. The specifics of each sampling parameter are shown in Table 3. Manual sludge blanket level measurements were taken with a core sampler at the same location of the installed Hach Sonotax sensor. Generally, the height of the sludge blanket varied depending on the location of the suction header, even with fixed loading conditions. As the suction header rotated past the sensor location, the blanket was often drawn down to a height of only a few inches, then as the suction header got further away from the sensor, the height increased. To provide the most accurate comparison of blanket level between the fixed and Adapt inlet clarifiers, the measurement was typically taken when the suction header was approximately perpendicular to the clarifier bridge. This is also conveyed in an image and plan view of the clarifier in Figure 10.

Table 3 - Manual Sampling Types and Methods

Parameter	Type	Method	Location
Sludge Blanket Depth	Core Sampler (Sludge Judge)	-	Halfway between center feed well and weir
Turbidity	Hach TU5200	Optical - DIN EN ISO7027	Effluent box of both Fixed inlet clarifier and Adapt inlet clarifier. Various depths for depth sampling
Orthophosphate	Hach TNT 843/846	Colormetric	Effluent box of both Fixed inlet clarifier and Adapt inlet clarifier. Various depths for depth sampling
Nitrate	Hach TNT 835	Colormetric	Various depths for depth sampling

Manual samples for turbidity and orthophosphate were collected from the steel platform at the same location of the online analyzer described in section 2.1. As shown in the upper right portion of Figure 11, flow enters the effluent box from the circumferential weir and trough, then is conveyed to the chlorine contact tanks via a 54" gravity pipe exiting the bottom of the box. Samples were obtained by using a sampling pole to retrieve a portion of secondary clarifier effluent from the access platform located on the effluent structure. After samples were retrieved, they were then taken to the SRC laboratory and analyzed using a Hach TU5200 laboratory laser turbidimeter. The same instrument was used for all samples to provide consistency and the samples for both the Fixed and Adapt inlet were generally collected at the same time to capture similar loading conditions.

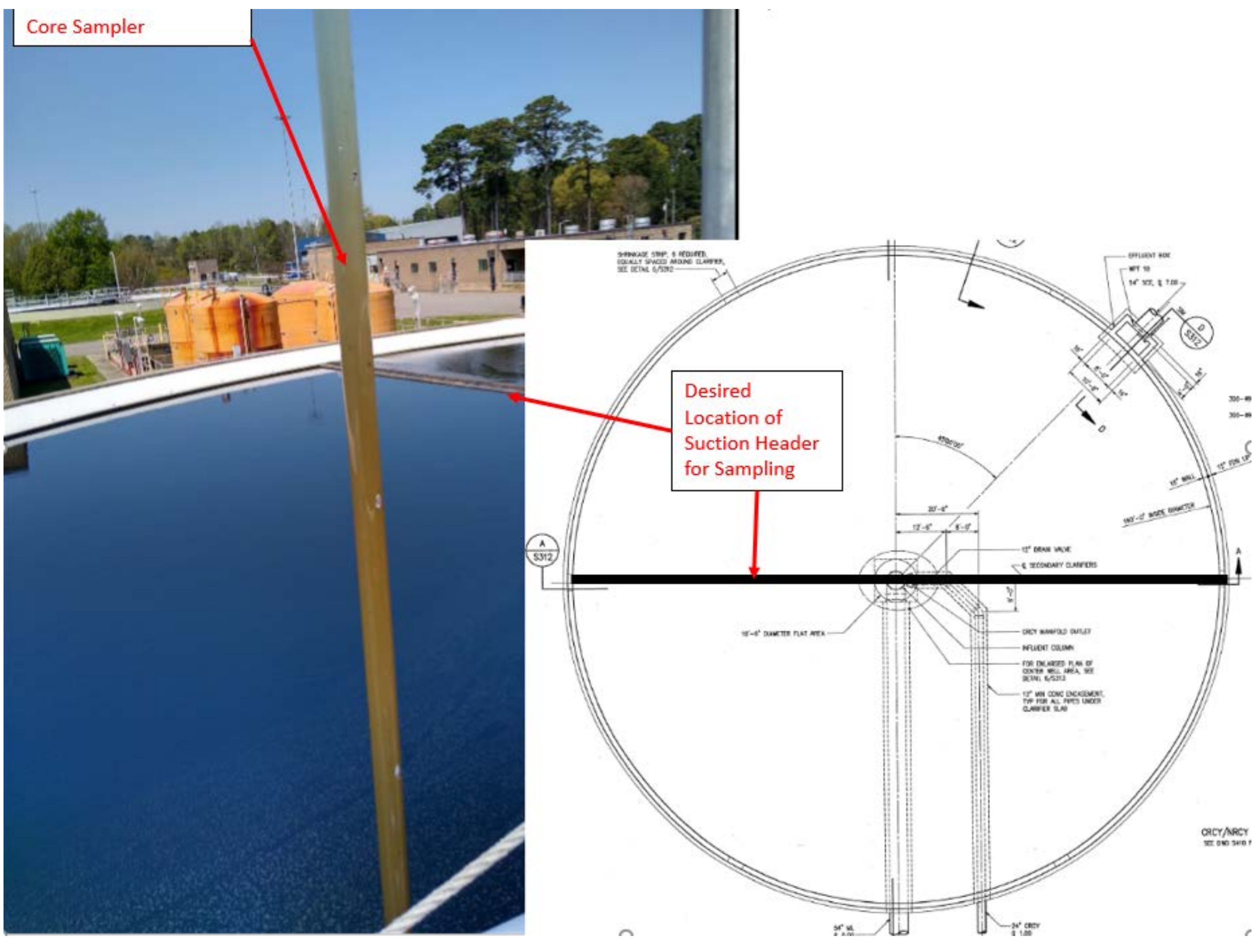


Figure 10 - Core Sampler Measurement

If orthophosphate was being analyzed, the sample was immediately filtered and a Hach TNT 843 or 846 test was conducted depending on expected concentration range. Nitrate was measured during depth sampling using a Hach TNT 835 test, and was also filtered along with the orthophosphate sample.

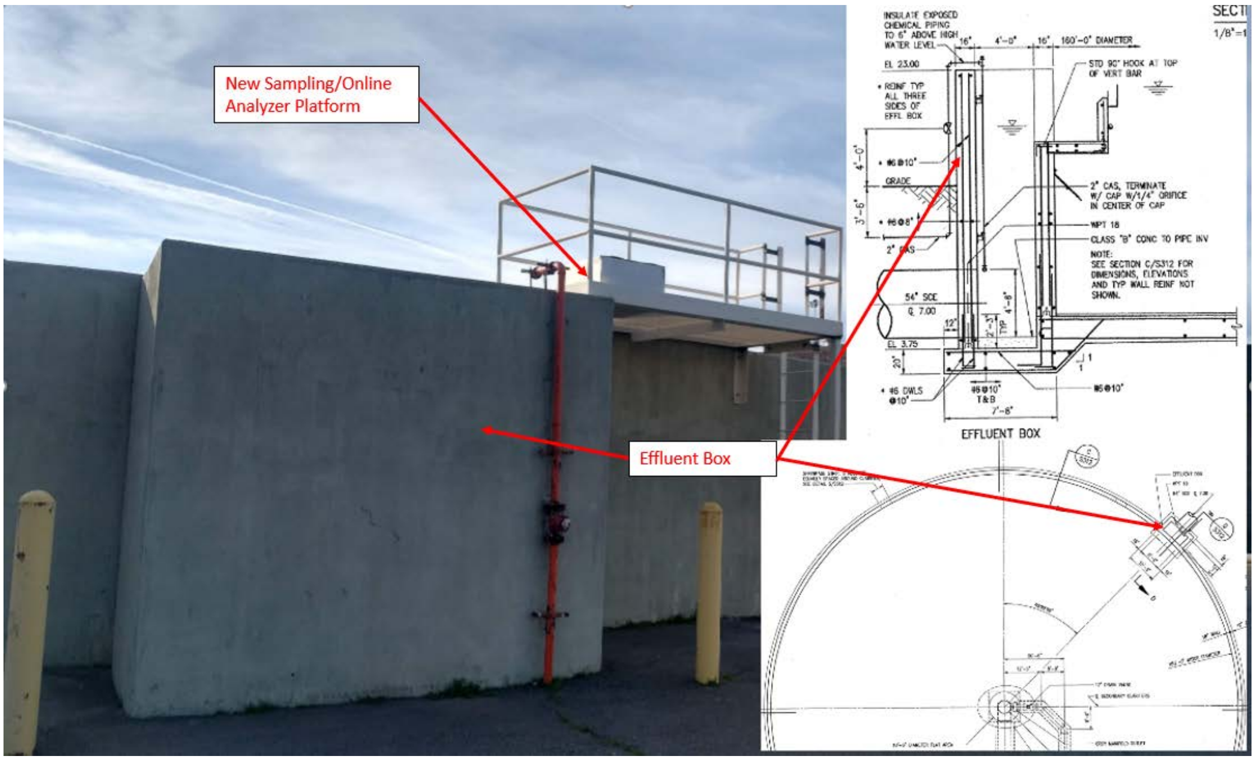


Figure 11 - Effluent Box Sampling and Online Analyzer Platform

2.3 DEPTH PROFILING

To understand if differences in turbidity, orthophosphate, and nitrate were present between the fixed and Adapt inlet clarifiers, a Kemmerer sampler was used to collect samples at a specific depth within the clarifier. The device is show in Figure 12 and consists of the sampler, trigger line, pin, mechanism and sealing balls. The device was armed by pulling up the two sealing balls then inserting the trigger pin before being placed below water. After the device was armed, it was lowered into the water at a desired depth, then the trigger line was pulled which caused the sealing balls to seal and trap the sample. The sample was then drained into a separate container for analysis. Based on a normal blanket depth of 1-2 feet, pre-selected depths of 5, 10, and 13 feet were chosen with the expectation that this would reveal any major differences in characteristics between the fixed and Adapt clarifiers. Three samples (at 5, 10 and 13 feet) were collected at a horizontal distance of 15 feet from the center of the clarifier, and 50' from the center clarifier. These horizontal distances were expected to represent conditions present just outside of the center well (for the fixed inlet clarifier) and Adapt inlet (for the Adapt clarifier), and conditions closer to the walls of the clarifier.

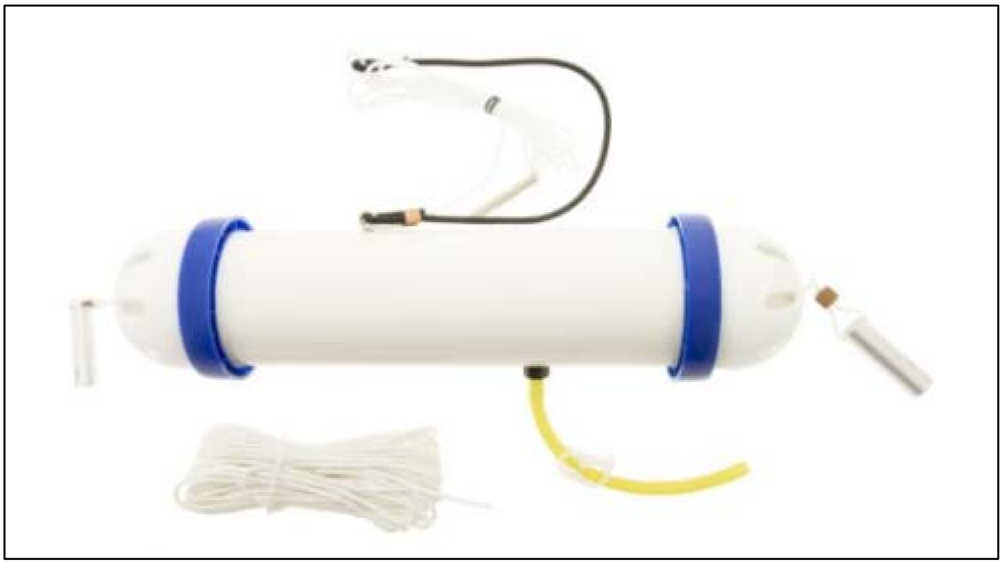


Figure 12 - Depth Sampler Device (Kemmerer Sampler)

2.4 STRESS TESTING

Stress testing of both the fixed and Adapt inlet clarifiers was conducted to evaluate capacity and effluent turbidity under high loading conditions. Figure 13 displays the estimated flow to Clarifier 5 (Adapt clarifier) assuming a flow split based on a ratio of clarifiers in service, assuming a typical diurnal flow pattern. The plant influent flow plot assumes all flow is isolated to the Adapt clarifier, and the Q estimated 4&5 in service assumes half of plant flow is conveyed to each clarifier, since the fixed and Adapt inlet clarifiers are equal in surface area.

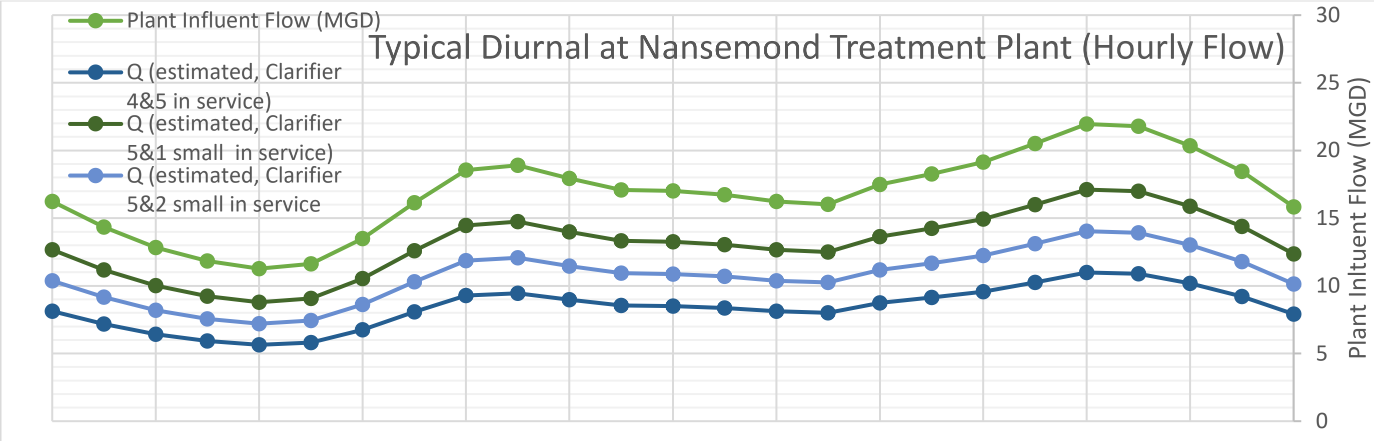


Figure 13 - Typical Diurnal Pattern at NTP

Since HRSD has isolation gates at each clarifier, different combinations of clarifiers in service were achievable to simulate conditions that would cause the Adapt to change position in height based on the parameters within the PLC. Table 4 provides the surface area of each clarifier along with the estimated SOR and SLR for the low (11 MGD) and high (22MGD) diurnal flowrates assuming a mixed liquor TSS concentration of 3000 mg/L and RAS ratio of 0.7. Typical designs target a surface overflow rate of 400 to 600 gpd/ft^2 average and 1000 to 1200 gpd/ft^2 peak, and a solids loading rate of 19-29 lb/d*ft^2 average and 48 lb/d*ft^2 peak (Metcalf and Eddy, 2014). As can be seen in Table 4, when all flow is directed to one of the large clarifiers, the high diurnal flow rate provides loading conditions at the threshold of recommended design conditions.

Table 4- Loading Conditions During Stress Testing

	Diameter (ft)	Surface Area (ft^2)	SOR - Low Diurnal (gpd/ft^2)	SOR - High Diurnal (gpd/ft^2)	SLR -Low Diurnal lb/d*ft^2)	SLR - High Diurnal (lb/d*ft^2)
SC#1	85	5680	0	0	0	0
SC#2	85	5680	0	0	0	0
SC#3	85	5680	0	0	0	0
SC#4	160	20100	0	0	0	0
SC#5	160	20100	550	1090	23	47

3. RESULTS AND DISCUSSION

3.1 INITIAL OPERATION

The Adapt clarifier was placed into service on September 3, 2020. A few days after operation with all five clarifiers in service, HRSD operations staff shifted all flow to clarifiers 4 and 5 (fixed inlet and Adapt, respectively) and one of the small clarifiers. The reason one of the small clarifiers was left in service was to keep minimal flow going through the distribution channel to clarifiers 1-3 to avoid stagnant conditions. HRSD worked with Hydrograv staff to complete the initial optimization of the system, including modifying and correcting PLC logic to accommodate appropriate movement of the inlet position. Figure 14 shows a three-day period when the Adapt clarifier was experiencing orthophosphate spikes during the peak morning hours. As seen in the figure, the inlet was being directed to a low position during late night and early morning hours as plant flow decreased to a minimum. As flows started to increase during the morning the inlet height also increased but with a delay, which seems to have caused an increase in blanket height and subsequent release of orthophosphate. Turbidity will be further discussed in section 3.2, but manual measurements taken during these times did not seem to be affected by the increased blanket heights.

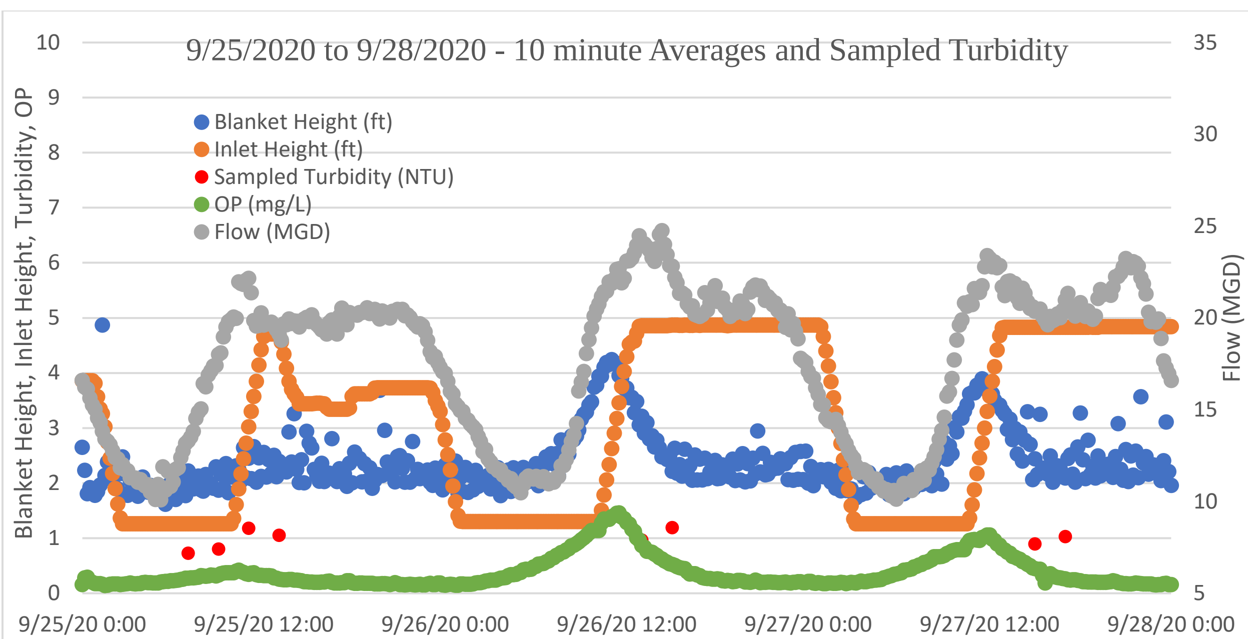


Figure 14 - Blanket Level and Orthophosphate Spikes During Initial Operation

At the beginning of October, the PLC programmer made changes to the logic which were keeping the inlet between the ranges of 2.3 to 2.7 feet in height. These changes were later discovered to be an inadvertent mistake, but as evidenced in Figure 15, the result was a reduction in observed orthophosphate spiking. The spike observed on October 2, 2020 was also observed in the fixed inlet clarifier; accordingly this is not believed to have been a result of an orthophosphate release within the clarifier. Regular blanket and orthophosphate spikes were not observed in the fixed inlet clarifier during this period. Figure 16 contains manual sampling data for the period of 9/23/2020 to 10/11/2020. Thirty-six pairs of samples were collected for the Adapt and the fixed inlet each at the same time. The Adapt had an average effluent orthophosphate concentration of 0.54 mg/l and the fixed inlet clarifier had an average concentration of 0.19 mg/l. The Adapt clarifier sludge blanket level sensor failed on 10/4/2020, but the data shown in Figure 17 clearly conveys the observation of higher orthophosphate concentrations occurring when the inlet was in a very low position and as flows started to increase during the morning hours.

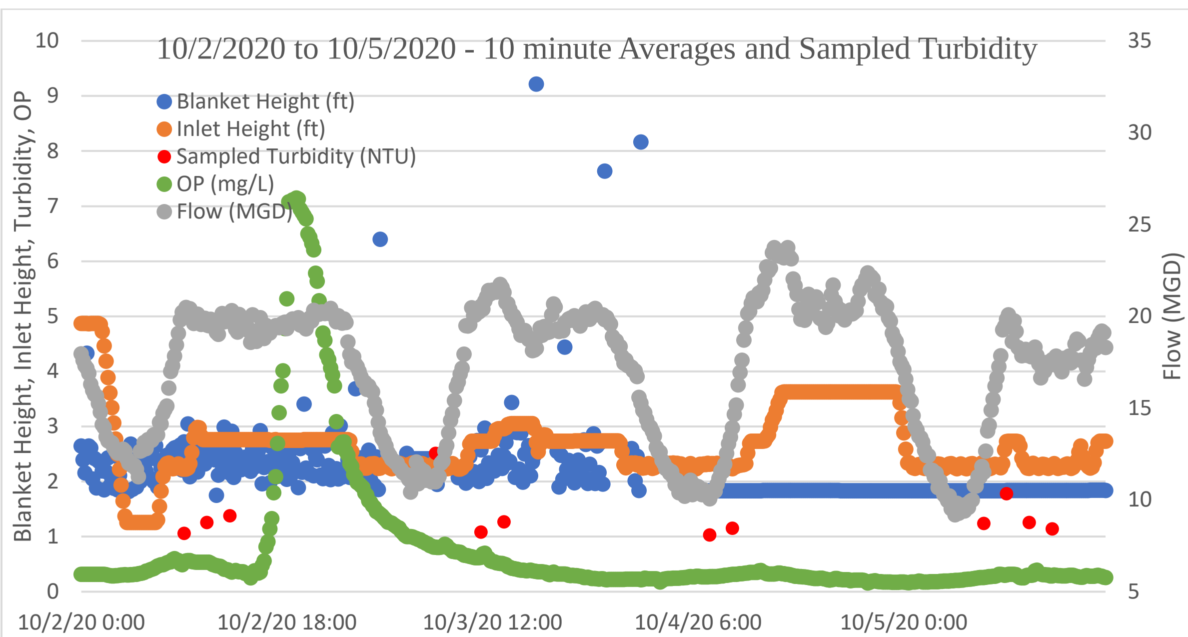


Figure 15 - Higher Inlet Operating Height and Orthophosphate Reduction

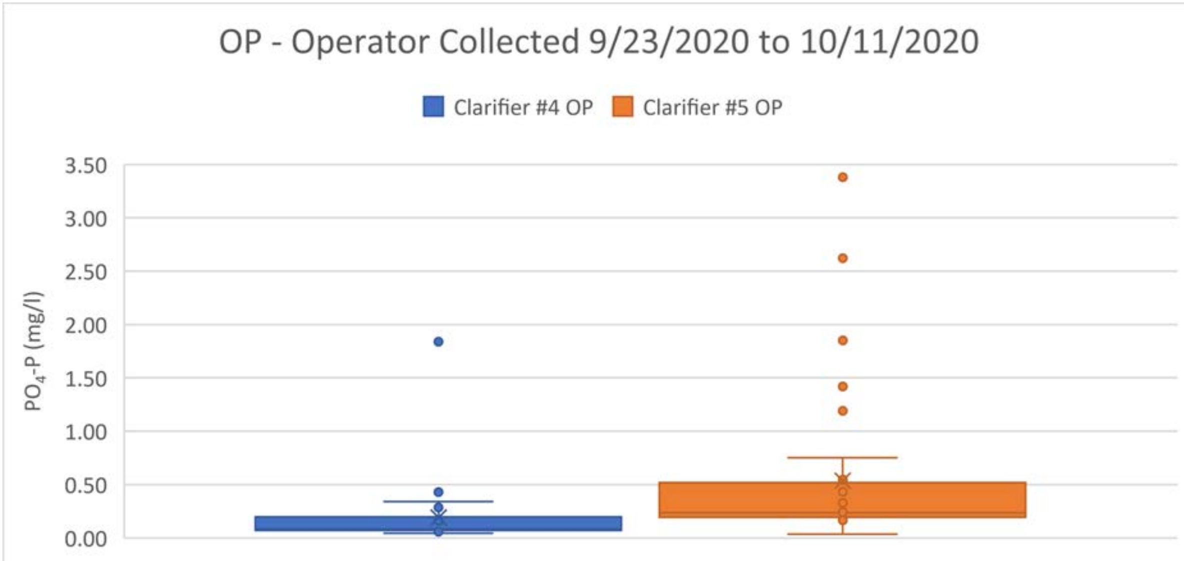


Figure 16 - Manual Orthophosphate Sampling 9/23/2020 to 10/11/2020

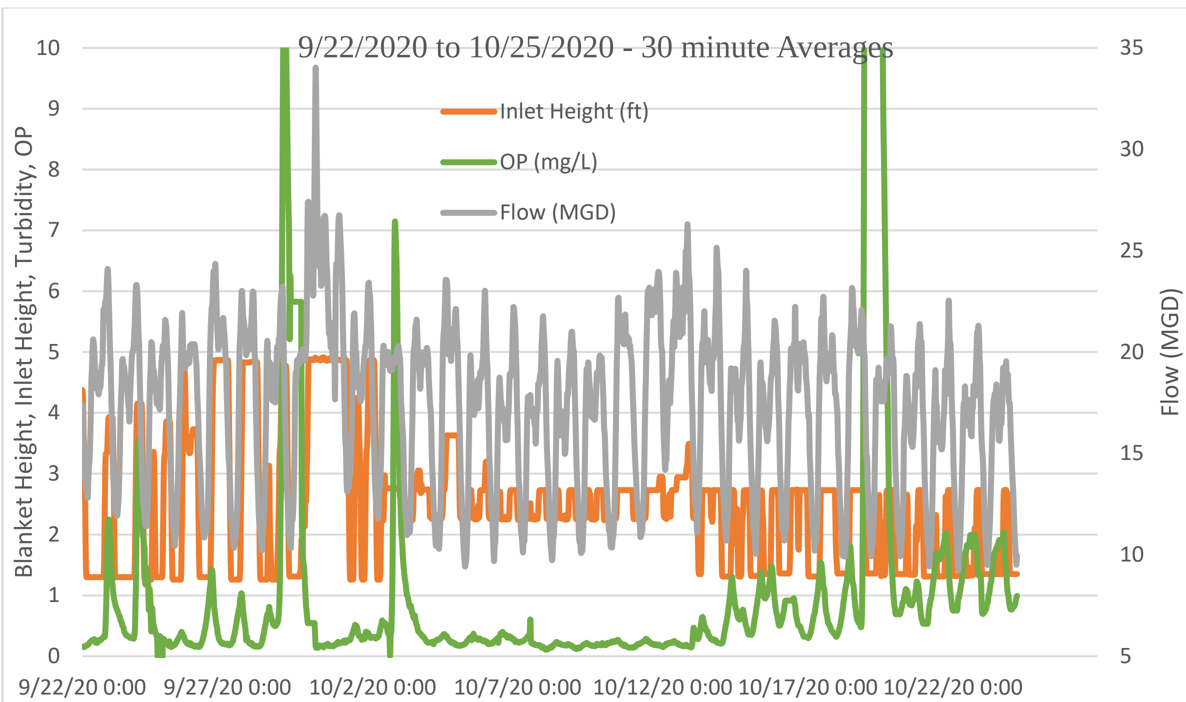


Figure 17 - September and October 2020 Orthophosphate and Inlet Height

HRSD conveyed this information to the Hydrograv team, suggesting the possibility of the inlet not reacting fast enough or being directed into a position that was too low. HRSD staff also began a manual sampling regime for each clarifier which will be further discussed in section 3.2. Manual sampling along with the online sludge blanket level sensors confirmed that the blanket level in the Adapt clarifier was consistently higher than in the fixed inlet clarifier. After review of the data, the Hydrograv team conveyed that the CFD model results did not indicate blanket levels consistent with what was being observed in the September and October 2020 data.

Based on the CFD model results provided by Hydrograv, HRSD began to investigate possibilities for the cause of higher blankets in the Adapt clarifier than in the fixed inlet clarifier. Flow is not measured at the influent of each individual clarifier, so the first check was to ensure an equal flow split between the fixed inlet and Adapt clarifier. Flow enters each clarifier by passing over a rectangular sharp crested weir just downstream of the secondary clarifier distribution channel. Weir calculations indicated that if these two weirs were different in elevation by only several inches, there could be a significant difference in flow and loading rate to each clarifier. Laser level measurements were taken at the locations marked by arrows in Figure 18, where points on the weir could be physically reached with a telehandler or by hand. The results indicated that the two weirs varied only by one one-hundredth of a foot in elevation, so the possibility of an unequal flow split was ruled out. TSS concentrations just upstream of each clarifier in the secondary distribution channel were also measured with a handheld probe to rule out the possibility of a higher concentration entering clarifier 5. Concentrations were very close to one another which indicated similar TSS loading entering each clarifier.

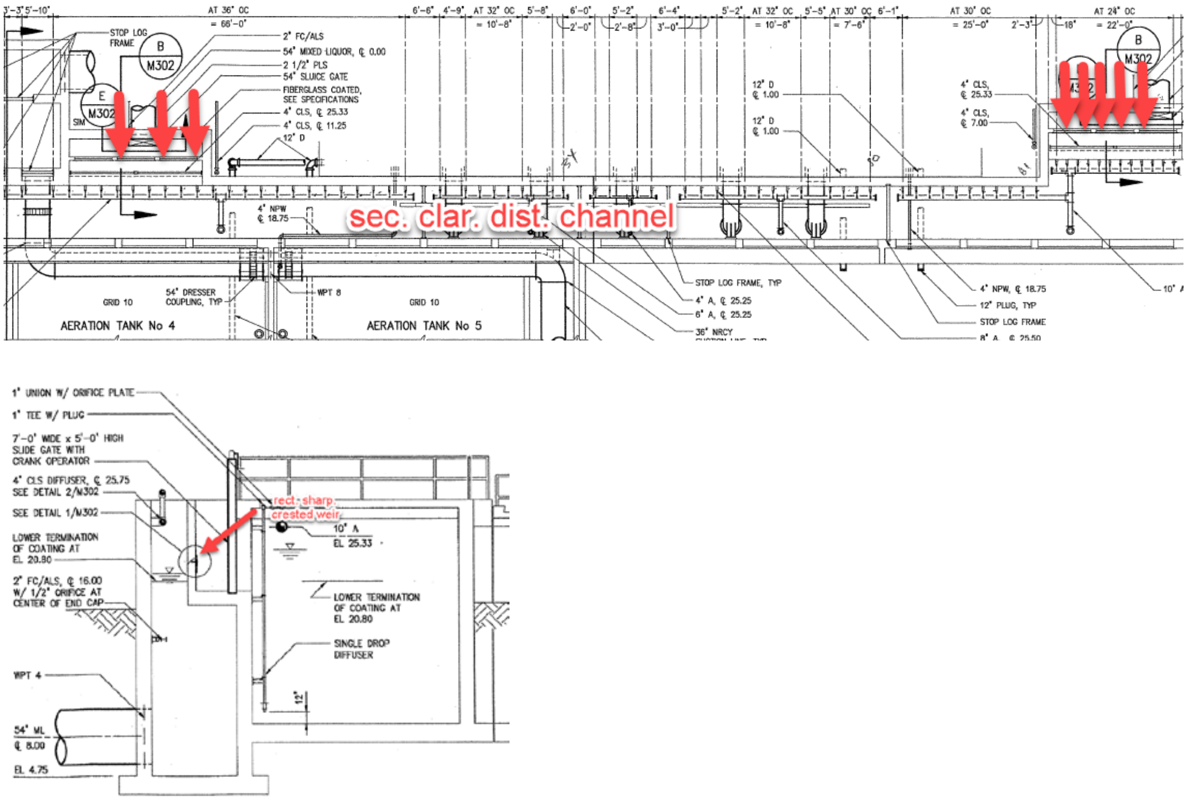


Figure 18 - Clarifier 4 and 5 Weir Locations

The project team also suspected the possibility of an issue with the suction header, causing inadequate removal of sludge within the Adapt clarifier. A first step was to measure RAS concentrations from both clarifiers, which was completed using a blowoff valve on the discharge side of each clarifier’s dedicated RAS pump. The RAS MLTSS concentration within each clarifier did vary, but no clear pattern was observed. Initial investigations indicated a consistently lower (around 2,000 mg/l) RAS concentration in the Adapt clarifier; with additional testing, the fixed inlet clarifier varied in concentration from 6,100 to 7,500 mg/l, whereas the Adapt varied from 5,900 to 9,600 mg/l. During some of the measuring periods, concentrations were higher in the Adapt clarifier and the opposite was true for other measuring periods. Ultimately, it was decided that the most direct way to make an accurate comparison of clarifier performance, especially with respect to sludge blanket height, was to stress test each clarifier independently under similar loading conditions. This testing was completed in late October and will be further described in section 3.3. Leading up to the stress testing of clarifier 5, the sludge height indicating sensor for the Adapt inlet failed. The PLC/HMI did not properly indicate the sensor failure, and while HRSD staff were attempting to adjust the inlet height manually during the stress test, the Adapt experienced a failure of the inlet motor gear. The Hydrograv team agreed to repair the Adapt but due to travel restrictions and the time required to complete the failure investigation, the repair was not complete until 1/22/2021.

During the time the Adapt clarifier was out of service, HRSD staff also inspected the suction header manifold seals illustrated in Figure 19, and both seals were found to be folded in and in poor condition. After the Hydrograv team replaced the motor assembly and shaft, HRSD staff replaced both manifold seals and the Adapt was placed back into service on 3/9/2021. Along with the repair, the Hydrograv team also provided a secondary sensor to avoid future damage to the gear in an event of another failure of the inlet height sensor.

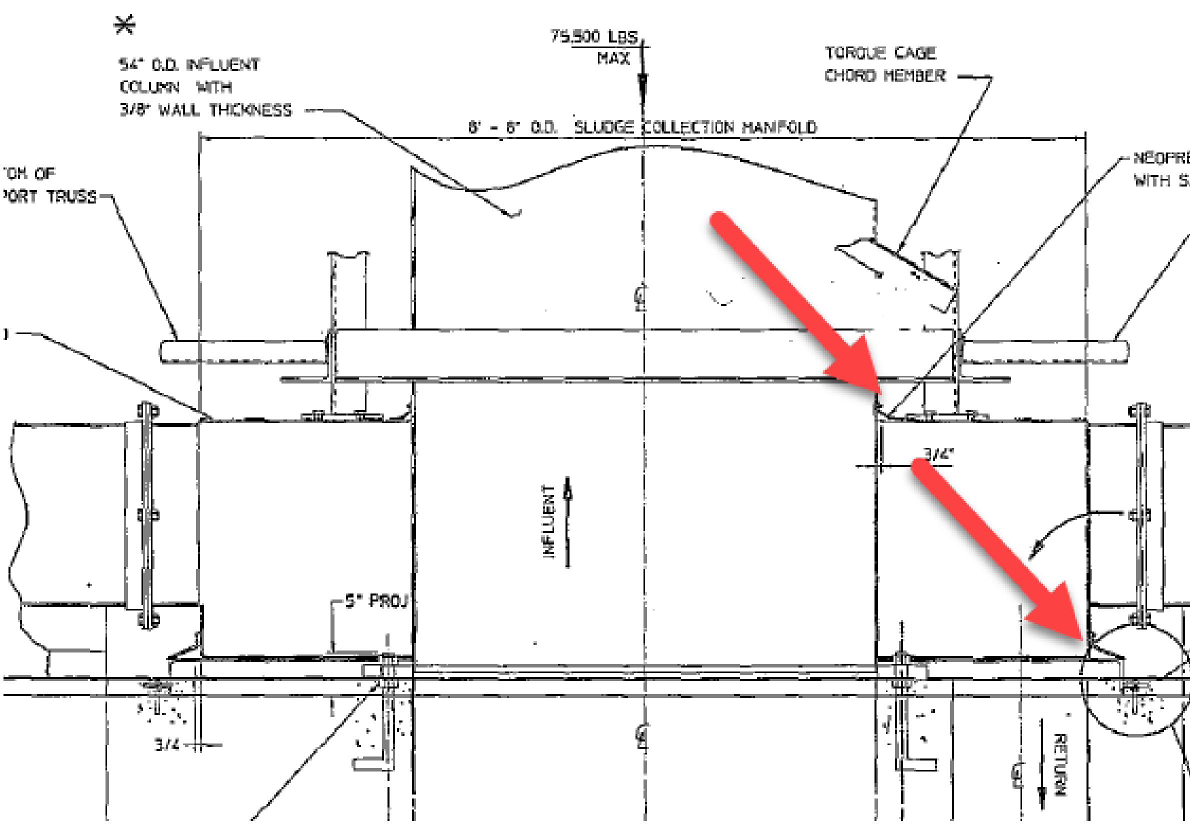
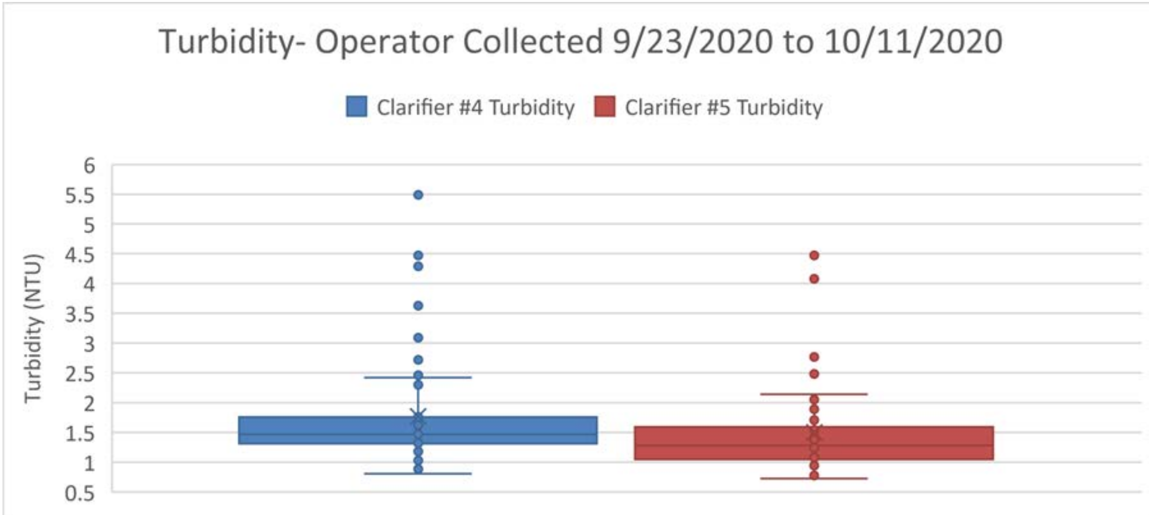


Figure 19 - Suction Header Manifold Seals

3.2 MANUAL SAMPLING COMPARISON

Grab samples were collected from each clarifier effluent box at the same time for the data presented in this section. Box and whisker plot results for the period of 9/23/2020 to 10/11/2020 are displayed in Figure 20. During this period, clarifiers 4 and 5 were in service along with one of the three small clarifiers. The sample mean for clarifier 5 (Adapt inlet) was 1.50 NTU and that of clarifier 4 (fixed inlet) was 1.77 NTU. The standard deviation for clarifier 5 was slightly lower than clarifier 4 with values of 0.78 and 0.89 NTU respectively. To understand the statistical significance of this observed difference in sample means, a two-sample t-test assuming unequal variances was conducted for both blanket and turbidity observations and results are provided in Table 5. The one tail p value of 0.036 indicates that the Adapt clarifier provided a mean turbidity value less than for clarifier 4 at a 95% level of confidence. During this period, blanket levels in clarifier 5 were consistently higher than in clarifier 4, which as discussed in Section 3.1, was later determined to likely be caused by faulty suction manifold seals. A similar issue was also reported regarding secondary clarification issues at the City of Atlanta Water Reclamation Center, where leaking TowBro™ type seals were discovered after observation and investigation of high sludge blanket levels (Parker et al., 2000).



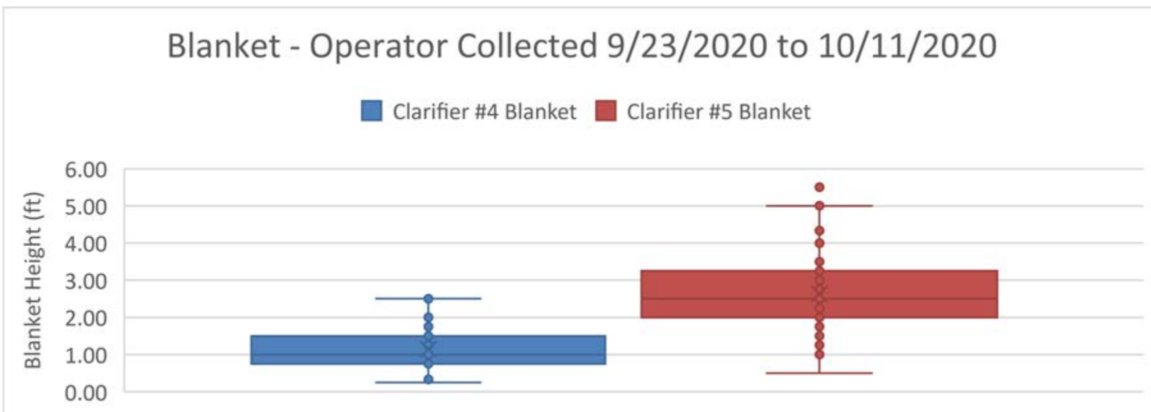


Figure 20 - Turbidity and Blanket Data 9/23/2020 to 10/11/2020 for Variable (Clarifier #5 and Fixed-Inlet (Clarifier #4) Clarifiers

Table 5 - Two-Sample t-Test Assuming Unequal Variances for 9/23/2020 to 10/11/2020 for Variable (Clarifier #5) and Fixed-Inlet (Clarifier #4) Clarifiers

	#5 Turbidity (NTU)	*#4 Turbidity (NTU)*		*#5 Blanket (ft)*	*#4 Blanket (ft)*
Mean	1.502	1.772	Mean	2.632	1.141
Variance	0.6092	0.7991	Variance	1.111	0.3319
Observations	63	63	Observations	63	63
Hypothesized Mean Difference	0		Hypothesized Mean Difference	0	
df	122		df	96	
t Stat	-1.810		t Stat	9.849	
P(T<=t) one-tail	0.0363		P(T<=t) one-tail	1.568E-16	
t Critical one-tail	1.657		t Critical one-tail	1.661	

Box and whisker plot results for the period of 3/23/2021 to 4/5/5021 are displayed in Figure 21. The sample mean for clarifier 5 was 1.71 (standard deviation 0.36) NTU and that of clarifier 4 was 1.99 (standard deviation 0.78) NTU. A t-test assuming unequal variances was again conducted for both blanket and turbidity observations and results are provided in Table 6. The one tail p value of 0.0038 suggests that the Adapt clarifier provided a mean turbidity value less than the fixed inlet clarifier at a 95% level of confidence. All 5 clarifiers were in service from 3/23/2021 to 3/29/2021 and the inlet stayed in the lowest position for almost the entire duration. Only clarifiers 4 and 5 were in service from 3/29/2021 to 4/5/2021, and the inlet height moved between the lowest position and approximately 3 feet most of the time, occasionally moving up to 4 feet during higher flows. As observed in Table 6, there was no evidence of a statistically significant difference in sludge blanket level for this period, indicating manifold seal replacements on the Adapt clarifier improved the effectiveness of sludge removal.

Figure 22 includes a plot of turbidity measurements during this period with a vertical line indicating when flow was transitioned from all five to two clarifiers. The Adapt clarifier had a lower effluent turbidity than the fixed inlet clarifier for most the observations. When the measured value was higher for clarifier 5, the differences in the measurements are very close to 0 NTU. On the contrary, six observations where values were higher for clarifier 4 had a difference of greater than 1 NTU.

During the September and October 2020 manual sampling period, online data were plotted with manual samples to compare measurements at the same time periods. Generally, manual and online data matched very well for orthophosphate and blanket measurements. Manually sampled turbidity measurements tended to measure lower than online measurements, likely due to accumulation of debris as mentioned in section 2.1. The online and manually sampled turbidity data seemed to oscillate up and down together, but even when recently cleaned, the online instruments regularly read up to 0.5 NTU higher than the manually sampled data.

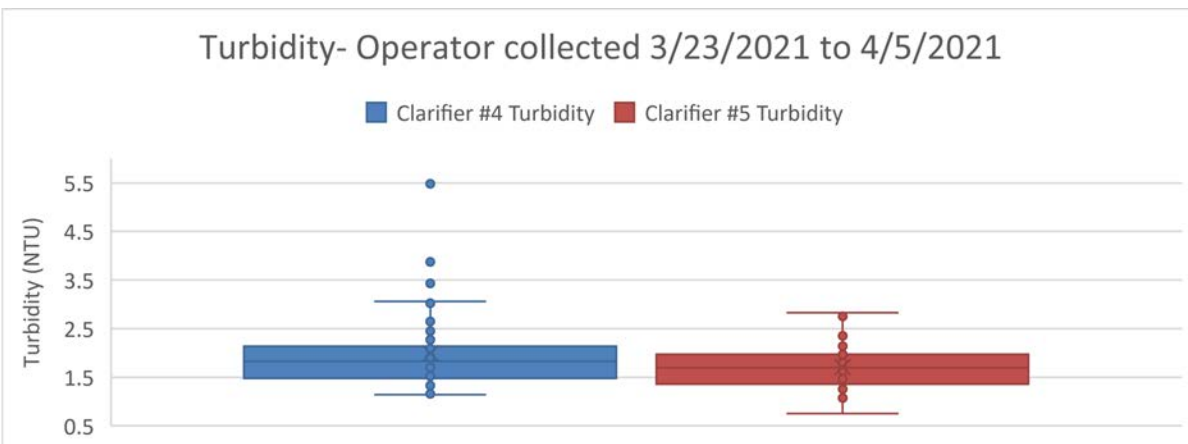


Figure 21 - Turbidity and Blanket Data 3/23/2021 to 4/5/2021

Table 6 - Two-Sample t-Test Assuming Unequal Variances for 3/23/2021 to 4/5/2021 for Variable (Clarifier #5) and Fixed-Inlet (Clarifier #4) Clarifiers

	#5 Turbidity (NTU)	*#4 Turbidity (NTU)*		*#5 Blanket (ft)*	*#4 Blanket (ft)*
Mean	1.708	1.992	Mean	1.364	1.343
Variance	0.1660	0.5714	Variance	0.7729	0.2432
Observations	68	68	Observations	68	68
Hypothesized Mean Difference	0		Hypothesized Mean Difference	0	
df	103		df	105	
t Stat	-2.724		t Stat	0.1696	
P(T<=t) one-tail	0.0038		P(T<=t) one-tail	0.4328	
t Critical one-tail	1.66		t Critical one-tail	1.66	

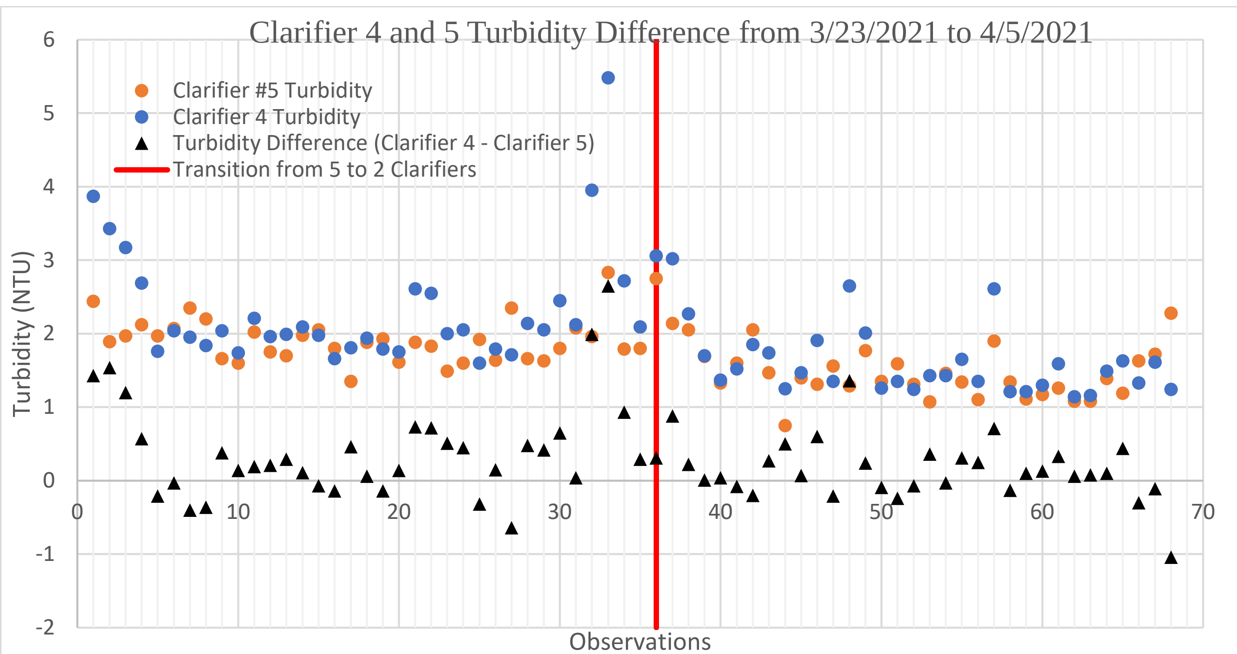


Figure 22 - Clarifier 4 and 5 Effluent Turbidity Values and Differences from 3/23/2021 to 4/5/2021

3.3 STRESS TESTING

The first attempted stress tests occurred in late October 2020, and the main purpose of these tests was to compare the difference in sludge blanket levels under similar loading conditions, as discussed in section 3.1. Clarifier 4 (fixed inlet clarifier) was tested first, and the results are shown in Figure 23. Plant operations staff shifted all flow to clarifier 4 with operations steady by 9:00 AM, and the test was stopped at 1:30 PM. Flow remained very stable during this period, ranging from 16 to 18 MGD. 18 MGD corresponds to a SOR of 895 gpd/ft^2 and maximum SLR during the test was about 33 lb/ft^2*d. Two grab samples were taken for turbidity measurements during the test and measured using the Hach TU5200 instrument. The manual samples were within 0.5 NTU of the online data, and the abrupt increase of turbidity seen by the online measurements in Figure 23 are believed to be a result of temporary instrument fouling. As mentioned in section 2.1, during stress testing when all flow was directed to one clarifier, the measurements from the SRC influent and clarifier effluent should have matched closely. This appeared to be the case for most of the period shown except for what was believed to be spiking resulting from fouling. Since the main purpose of this test was to verify the observed difference in sludge blanket level under similar loading conditions, six blanket level measurements were taken with a core sampler. As can be seen, these measurements corresponded well with the online sensor and remained consistently low for the duration of the test. Figure 24 consists of a state point analysis for the maximum loading conditions during the 10/28/2020 stress test of clarifier 4. SVI on the day of the test was 70 mL/g and aeration tank MLTSS concentration was about 2,800 mg/L. With the state point below the gravity flux curve under these loading conditions, the analysis indicated that the clarifier should have been capable of good performance which was observed during this test.

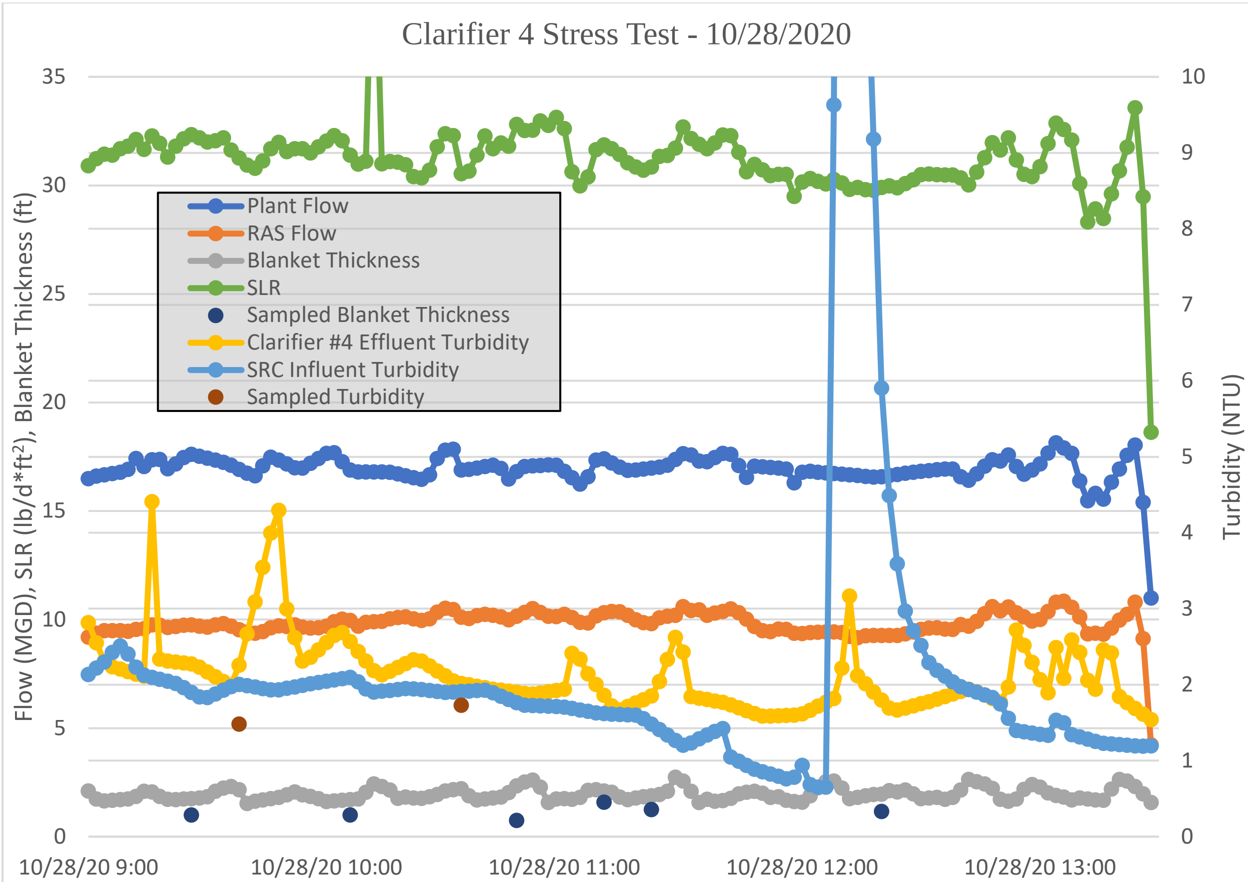


Figure 23 - Clarifier 4 (fixed inlet) Stress Test 10/28/2020

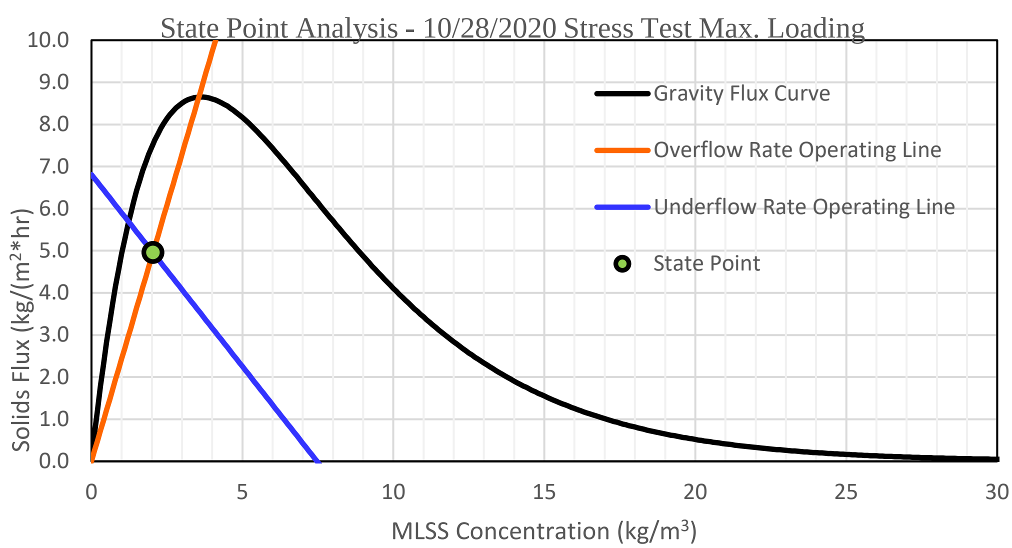


Figure 24 - State Point Analysis for 10/28/2020 Stress Test (Fixed Inlet Clarifier)

On 10/30/2020 a stress on clarifier 5 (Adapt) was attempted, with the intent of duplicating procedures used for the stress test of the fixed inlet clarifier. Early in the test it was discovered that the Adapt inlet position was not changing due to the failure of the height indicating sensor as described in section 3.1. Although incomplete, the results of the test are shown in Figure 25. Flow remained very stable during this period, ranging from 18 to 20 MGD. 20 MGD corresponds to a SOR of 995 gpd/ft^2 and maximum SLR during the test was about 45 lb/ft^2*d. One turbidity sample was taken during the test and measured using the Hach TU5200 instrument. The manual sample corresponded with the SRC online turbidimeter, and like the 10/28/2020 test, abrupt increases of turbidity seen by the online measurements were observed for both instruments. Two blanket level measurements were taken with the core sampler. These measurements corresponded well with the online sensor but contrary to the clarifier 4 test, blankets were slightly higher and climbed steadily for the duration.

Figure 26 includes a state point analysis for the maximum loading conditions during the 10/30/2020 stress test of clarifier 5. SVI on the day of the test was not measured but a value of 70 mL/g was used to develop the gravity flux curve. Aeration tank MLTSS concentration fluctuated between 3000 and 3600 mg/L, which in addition to slightly higher flows, was the cause of the higher solids loading rates for this test. This test was not meaningful in terms of turbidity performance comparison due to the non-functioning inlet, but it did indicate that sludge blankets were likely higher under similar loading conditions. After this test, the Adapt clarifier was taken out of service for repairs and not put back in service until 3/9/2021.

After a period of observation under normal operating conditions, the stress test was repeated for both clarifiers in early April 2021. Early in the morning on 4/6/2021, just prior to the planned stress test of the Adapt clarifier, the sludge blanket sensor caught on the rotating scum trough, ripping the walkway railing off as well as the sensor. Although sensor data would be unavailable, the decision was made to proceed with the test, and the results are shown in Figure 27. A state point analysis for maximum loading conditions is shown in Figure 28. Manual samples of sludge blanket and turbidity were collected from about 10:00 AM to 2:00 PM. The manual turbidity measurements were slightly lower than the measurements from the analyzers. A sharp increase in turbidity was measured by both analyzers around 7:00 PM, trending with the evening peak diurnal flows. Manual blanket measurements ranged from 3 to 5 feet, but readings were not collected during the period of the evening peak diurnal. A manual measurement taken by the night shift operator at 1:00 AM on 4/7/2021 confirms the high turbidity recorded by the online analyzer.

Figures 29 and 30 display results and a state point analysis for the duplicated stress test on the fixed inlet clarifier conducted on 4/7/2021. The observations were very similar to the Adapt clarifier test, where there seemed to be a sharp increase in turbidity occurring during the evening peak diurnal. However, the magnitude of the measurements recorded by the SRC analyzer was much lower than that of the clarifier analyzer. Manual blanket measurements ranged from 4 to 7 feet, but readings were again not collected during the period of the evening peak diurnal. For both early April stress tests, there was found to be a limitation in RAS pumping capacity during testing, which is a likely explanation for the increased blanket and turbidity values observed during peak diurnal flows. It is likely that during both tests, the blanket thickness steadily increased through the duration of the day, then the combination of elevated blanket level, increased flow during evening peak diurnal, and limited RAS pumping resulted in high effluent turbidities in the range of 4 to 8 NTU.

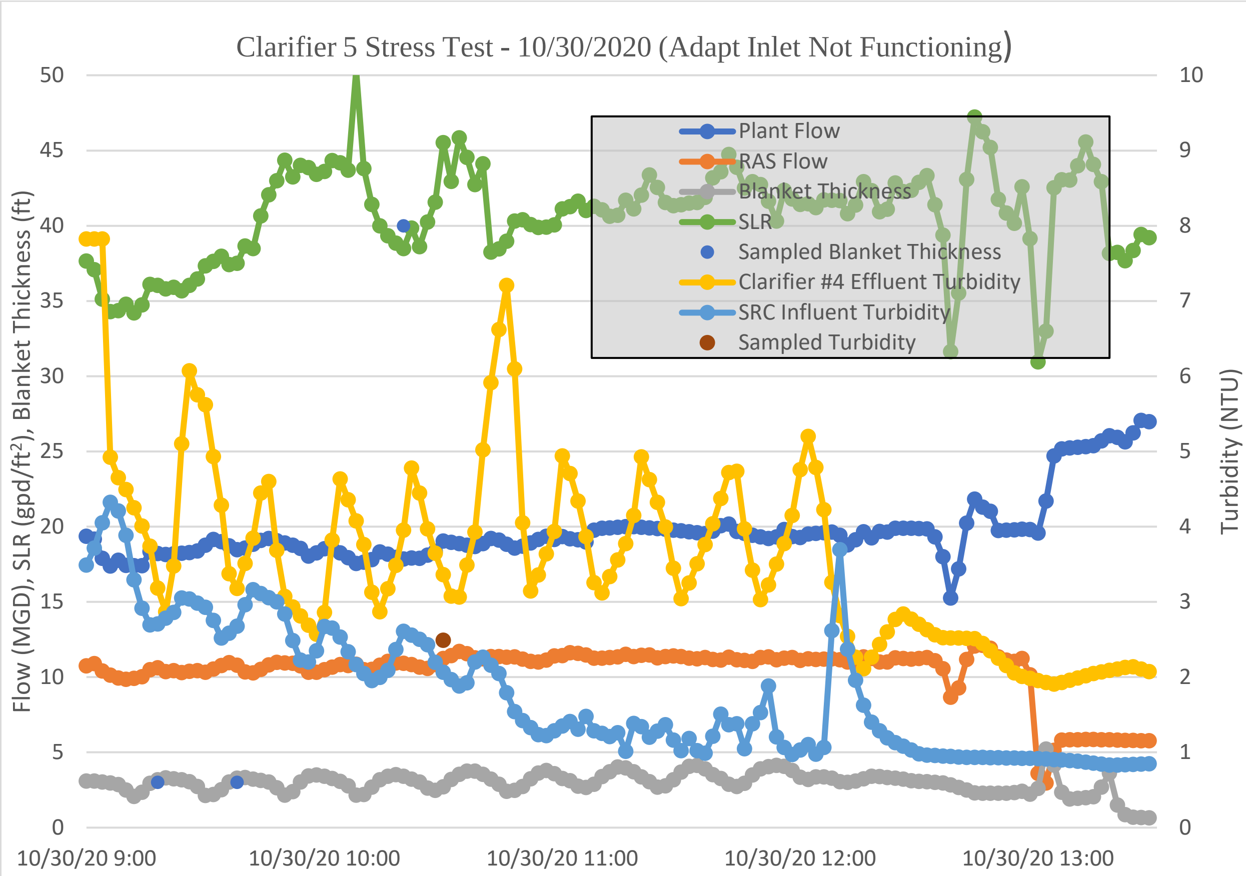


Figure 25 - Clarifier 5 (Adapt inlet) Stress Test 10/30/2020

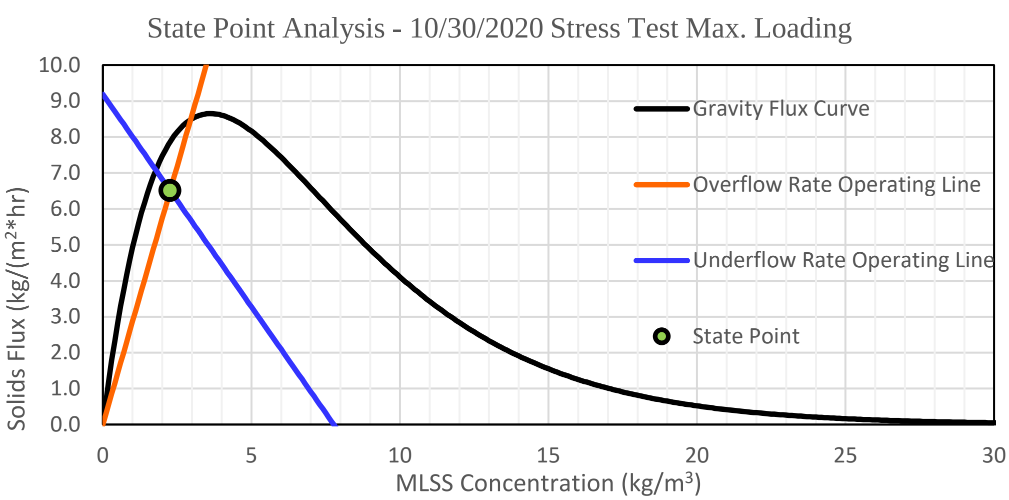


Figure 26 - State Point Analysis for 10/28/2020 Stress Test (Adapt Clarifier)

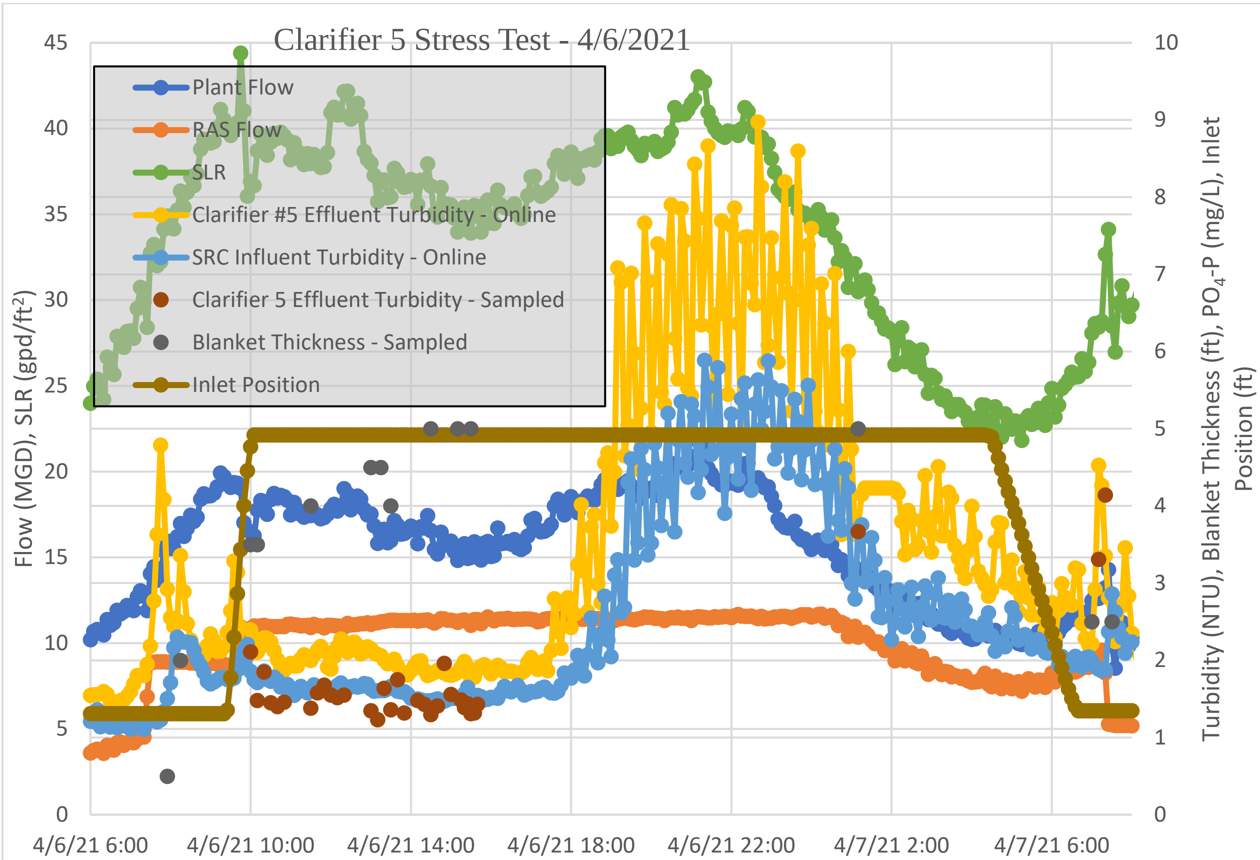


Figure 27 - Clarifier 5 (Adapt inlet) Stress Test 4/6/2020

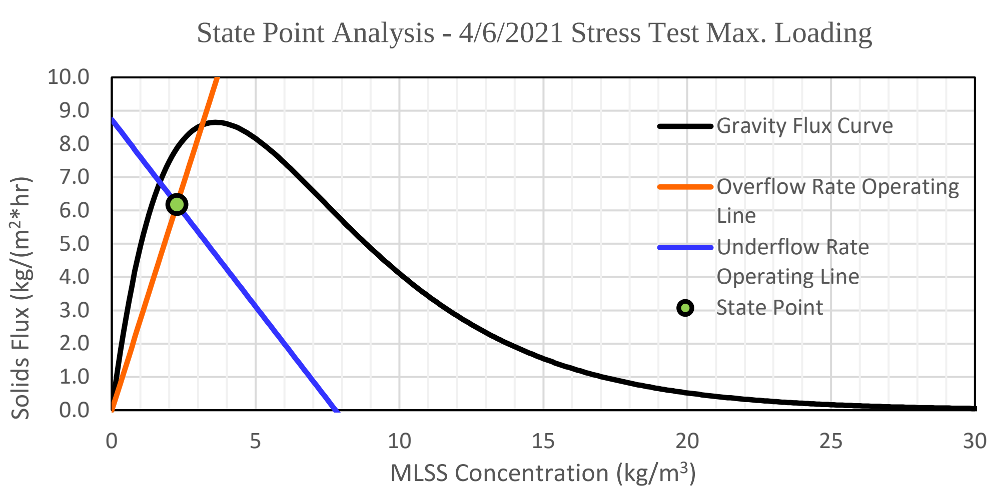


Figure 28 - State Point Analysis for 10/28/2020 Stress Test (Adapt Clarifier)

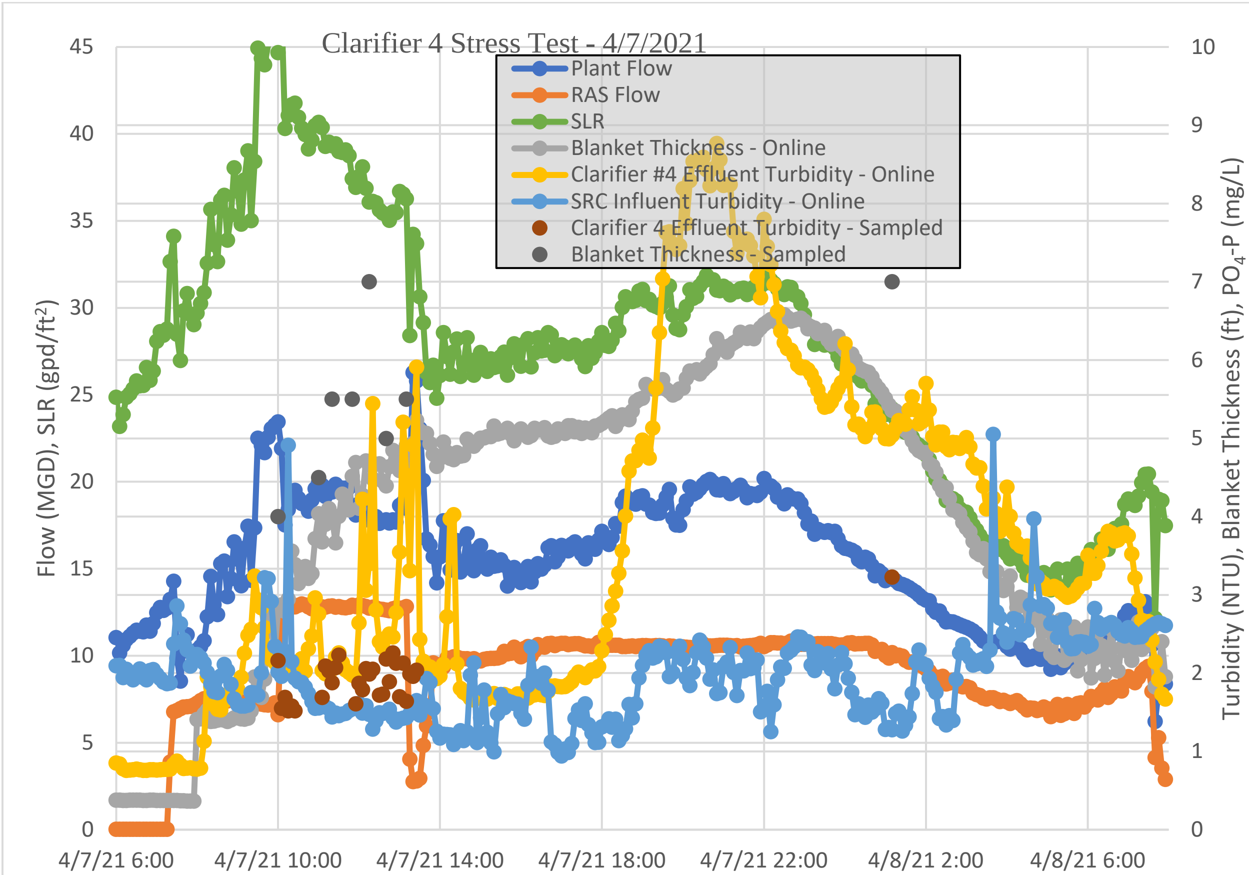


Figure 29 - Clarifier 4 (Fixed Inlet) Stress Test for 4/7/2021 for Clarifier 4 (Fixed Inlet)

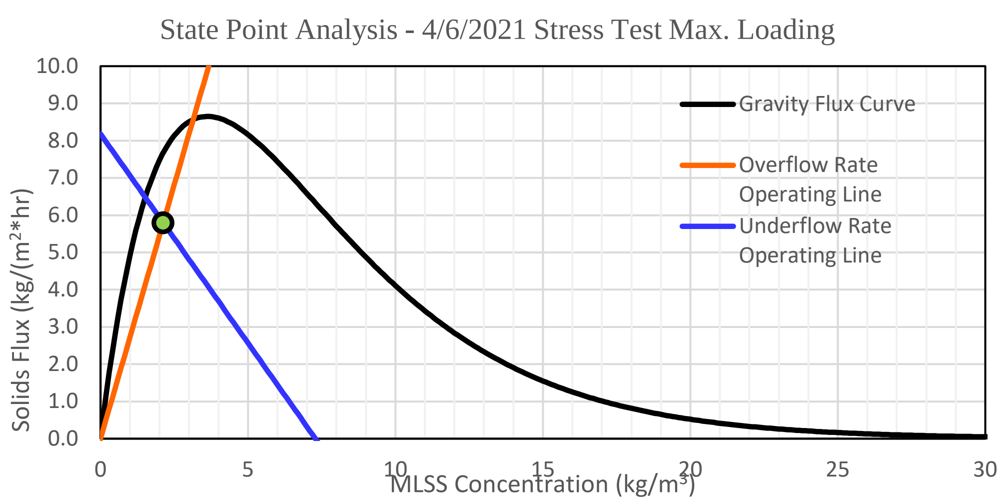


Figure 30 - State Point Analysis for 4/7/2021 Stress Test for Clarifier 4 (Fixed Inlet)

The measured MLTSS data from 4/6/2021 to 4/8/2021 also supports this understanding in terms of a mass balance around the secondary clarifier. The plot shown in Figure 31 shows the measured aeration tank MLTSS over the testing period, along with turbidities and plant flow. Since wasting flow rate was not altered during this period, the drop in MLTSS concentration over time can be explained by the storage of settled mixed liquor within the secondary clarifier sludge blanket. Since the lack of adequate RAS pumping capability was the likely cause of increased turbidity during the evening, stress testing should be repeated, and changes should be made to allow for increased pumping capabilities during testing. This is possible with simple valving and programming logic updates to the existing system.

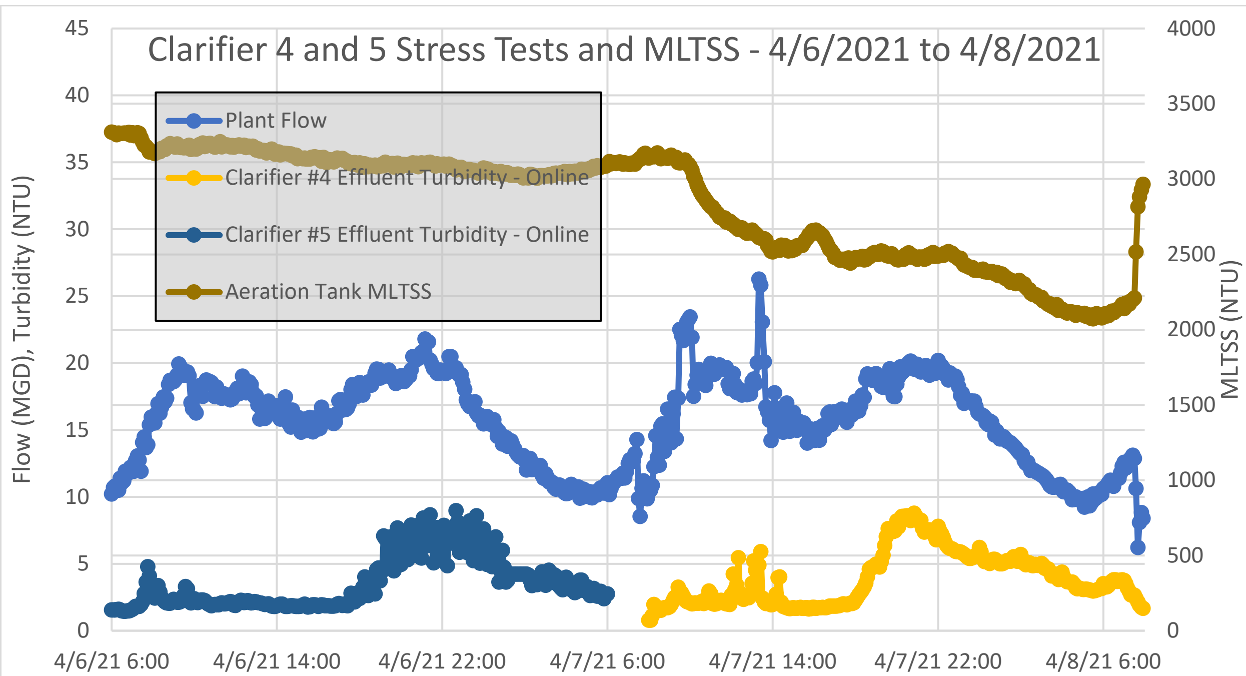


Figure 31 - Early April Clarifier 4 and 5 Stress Tests and MLTSS

Box and whisker result plots for the 4/6/2021 and 4/7/2021 stress tests are shown in Figure 32. The sample mean for clarifier 5 was 1.51 NTU and that of clarifier 4 was 1.89 NTU. The standard deviation for clarifier 5 and clarifier 4 were 0.20 NTU and 0.23 NTU respectively. A t-test assuming unequal variances was repeated for turbidity observations and results are provided in Table 7. The low one tail p value suggests that the Adapt clarifier will provide a mean turbidity value less than clarifier 4 at a 95% level of confidence during stressed conditions.

Figure 32 - Manual Turbidity Measurements for Early April Stress Tests

As previously discussed, the blanket level data was not available for the clarifier 5 stress test, but measurements taken with the core sampler for the duration of each test suggested the presence of slightly higher blankets in clarifier 4.

Table 7 - Two-Sample t-Test Assuming Unequal Variances for Early April Stress Tests for Variable (Clarifier #5) and Fixed-Inlet (Clarifier #4) Clarifiers

	#5 turbidity (NTU)	*#4 turbidity (NTU)*
Mean	1.506	1.892
Variance	0.03979	0.05262
Observations	30	30
Hypothesized Mean Difference	0	
df	57	
t Stat	-6.949	
P(T<=t) one-tail	1.936E-09	
t Critical one-tail	1.672	
P(T<=t) two-tail	3.872E-09	
t Critical two-tail	2.002	

3.4 WET WEATHER SAMPLING

Data collected during a rain event on 8/7/2021 is shown in Figure 33. During this event, all clarifiers were in service and, even though plant flow reached 30 MGD, the maximum solids loading rate was only 15 lb/d*ft^2 with a corresponding surface overflow rate of 510 gpd/ft^2. The Adapt inlet completed minor height adjustments operating as intended between 2 and 3 feet from the floor. Online turbidity data ranged between 2-4 NTU, whereas sampled data was between 1-2 NTU. Nearly all the sampled turbidity measurements were slightly lower for the fixed inlet clarifier when compared with the Adapt inlet clarifier, with a sample mean of 1.36 NTU and 1.54 NTU respectively. Although regular blanket measurements were not recorded, it was generally observed that blankets in the fixed inlet clarifier were 0.5 to 1 ft higher than in the Adapt clarifier. During this event, the scum pump was not operational in the Adapt clarifier; as a result, there was a large pile of debris in the trough and the water surface appeared dirty. Due to the low loading rate and dysfunctional scum pump in the Adapt clarifier, this test should be repeated in the future and under higher loader conditions.

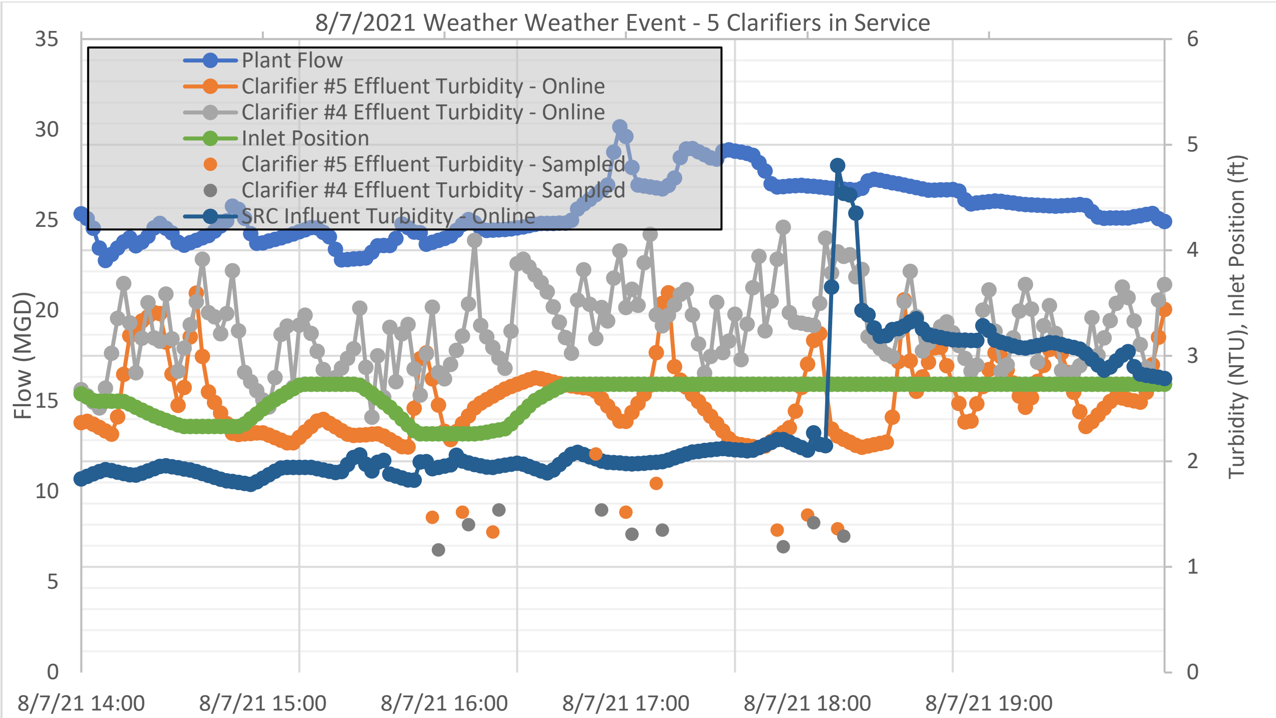
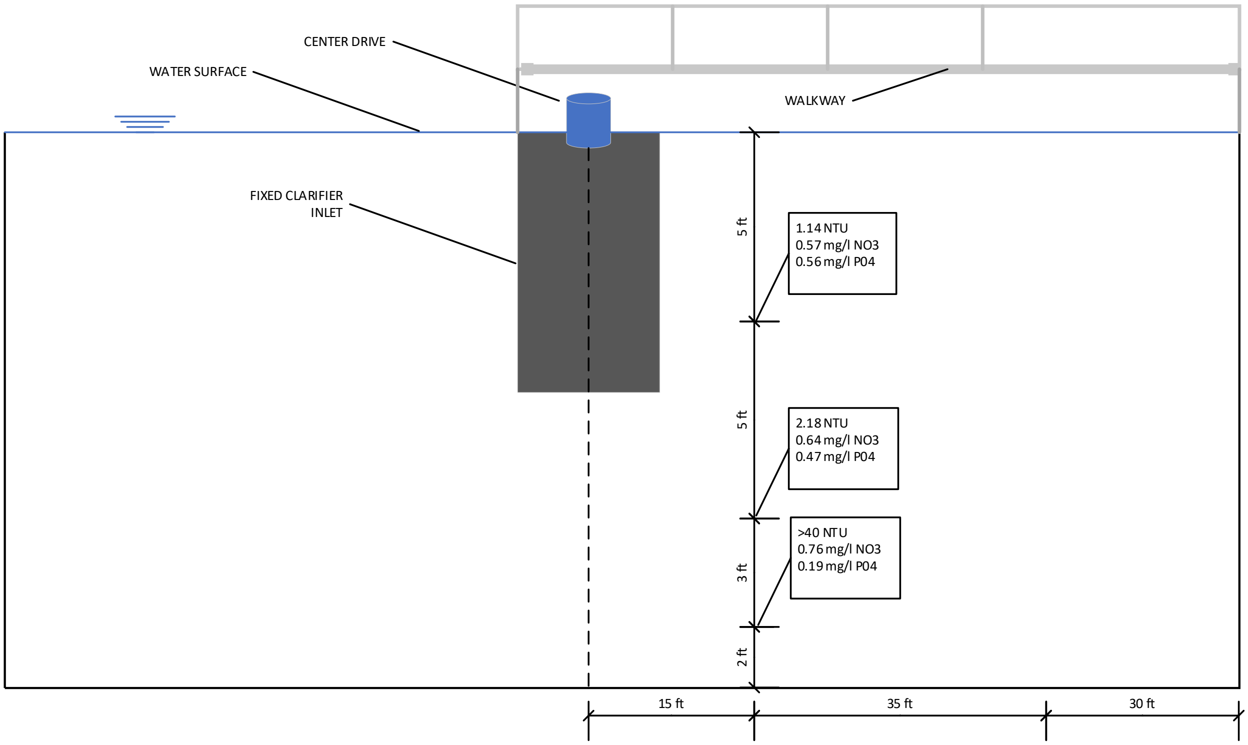


Figure 33 - Wet Weather Event 8/7/2021

3.5 DEPTH PROFILING

Results for depth profiling completed on 8/11/2021 are shown in Figure 34. During the time of sampling, which occurred from 6:00 PM to 8:30 PM, all 5 clarifiers were in service, and the inlet was in the lowest position at 1.35 feet from the floor. Samples were taken 15 feet horizontally from the center drive of each clarifier to provide a consistent means of comparison. Turbidity in the fixed inlet clarifier was above the high range of the instrument (>40 NTU) at a depth of 13 feet, but significantly less at higher depths. Orthophosphate concentrations increased and nitrate decreased from lower to higher elevations. Turbidity in the Adapt inlet clarifier was much lower than the fixed inlet at the 13-foot depth. The 10-foot depth measurement was comparable to the that of the fixed inlet, but the 5- foot depth sample was unexpectedly higher at 5.15 NTU.



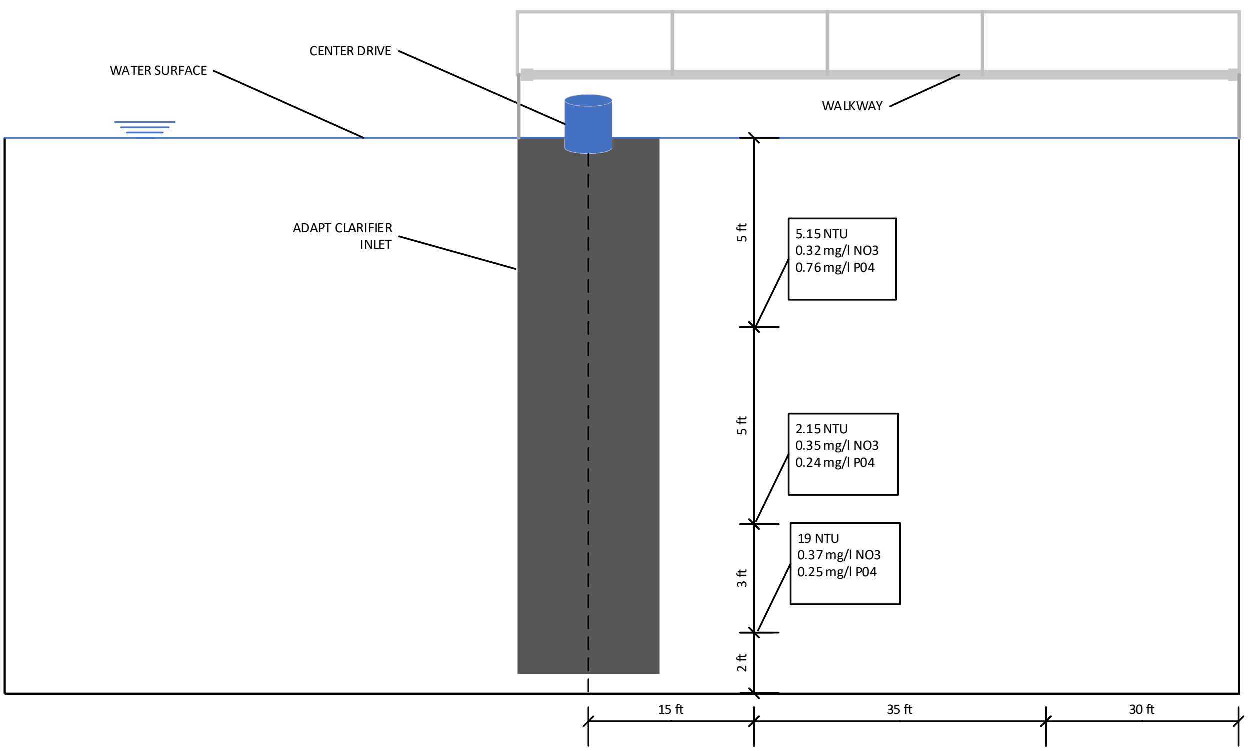


Figure 34 - Fixed and Adapt Inlet Clarifier Depth Profiling 8/11/2021

As with the fixed inlet clarifier, orthophosphate concentrations increased, and nitrate decreased from lower to higher elevations but not as drastically. Since the Adapt inlet was in the lowest position during this testing, all mixed liquor should have been directed very low into the sludge blanket. A possible explanation for higher turbidity at the 5-foot depth during this testing is based on a previous observation of leaking mixed-liquor from an upper section of the inlet. The previous observation was when the inlet was inadvertently in the low position during stress testing when SOR and SLR were high, and mixed liquor was leaking out of a section of the Adapt inlet.

The nitrate profile for both clarifiers was as expected, with higher concentrations close the sludge blanket (biomass), but the orthophosphate profile was not well explained especially in the fixed inlet clarifier. If anaerobic conditions within the sludge blanket leading to orthophosphate release were occurring, the expectation would be a high concentration close to the source of release (the sludge blanket) with concentrations decreasing in the upper portions of the clarifier. A possible explanation for this is that the observed orthophosphate concentration profile is not anaerobically induced but instead present in the incoming mixed liquor. Another explanation is that anaerobically induced release was occurring, but unintended mixing was occurring resulting in higher concentrations of orthophosphate in the upper portions of the clarifier. Orthophosphate concentrations in the fixed inlet effluent, Adapt effluent, and re-aeration channel effluent measured by online analyzers during this time are shown in Figure 35. As seen in the figure, the online analyzers were indicating concentrations close to 0 mg/l in the Adapt clarifier, concentrations around 0.3 mg/l in the fixed inlet clarifier, and concentrations close to 0.2 mg/l in the reaeration channel. Data for the fixed inlet clarifier after 8/13/2021 shows spiking which was likely invalid.

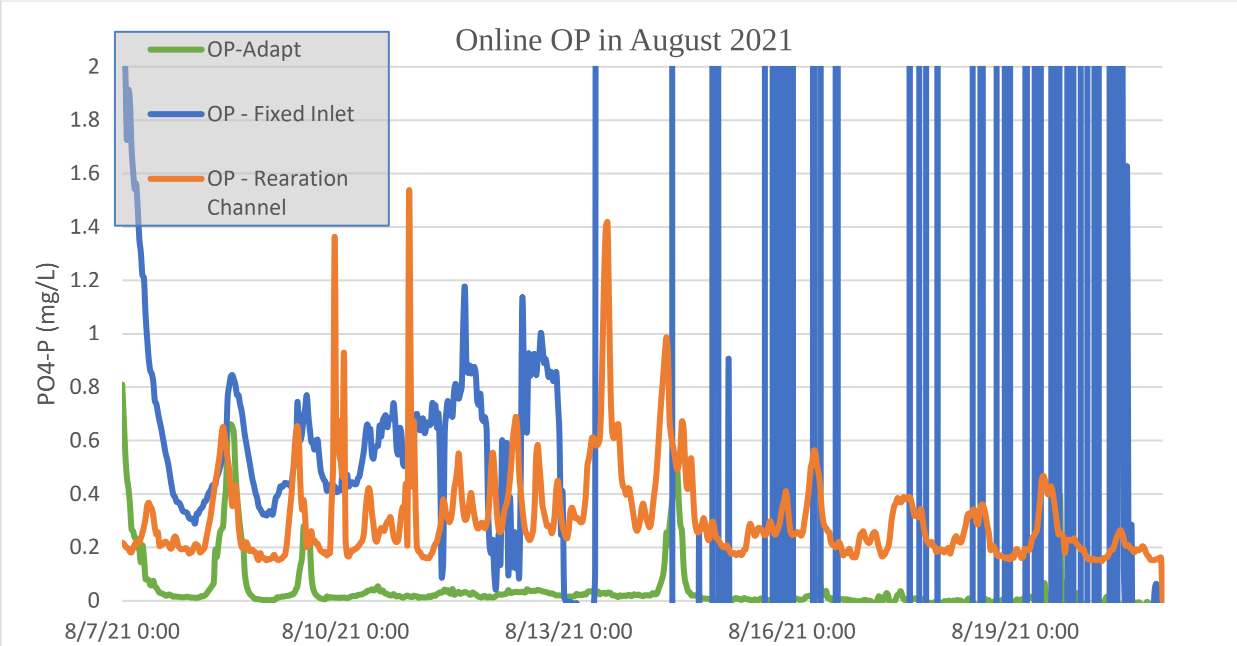


Figure 35 - August 2021 Online Orthophosphate Concentrations

Results for depth profiling completed on 8/17/2021 included measurements at 50 feet from the center drive and are shown in Figure 36. During the time of sampling, which occurred from 6:00 PM to 8:30 PM, all 5 clarifiers were in service, and the inlet was in the lowest position at 1.35 feet from the floor.

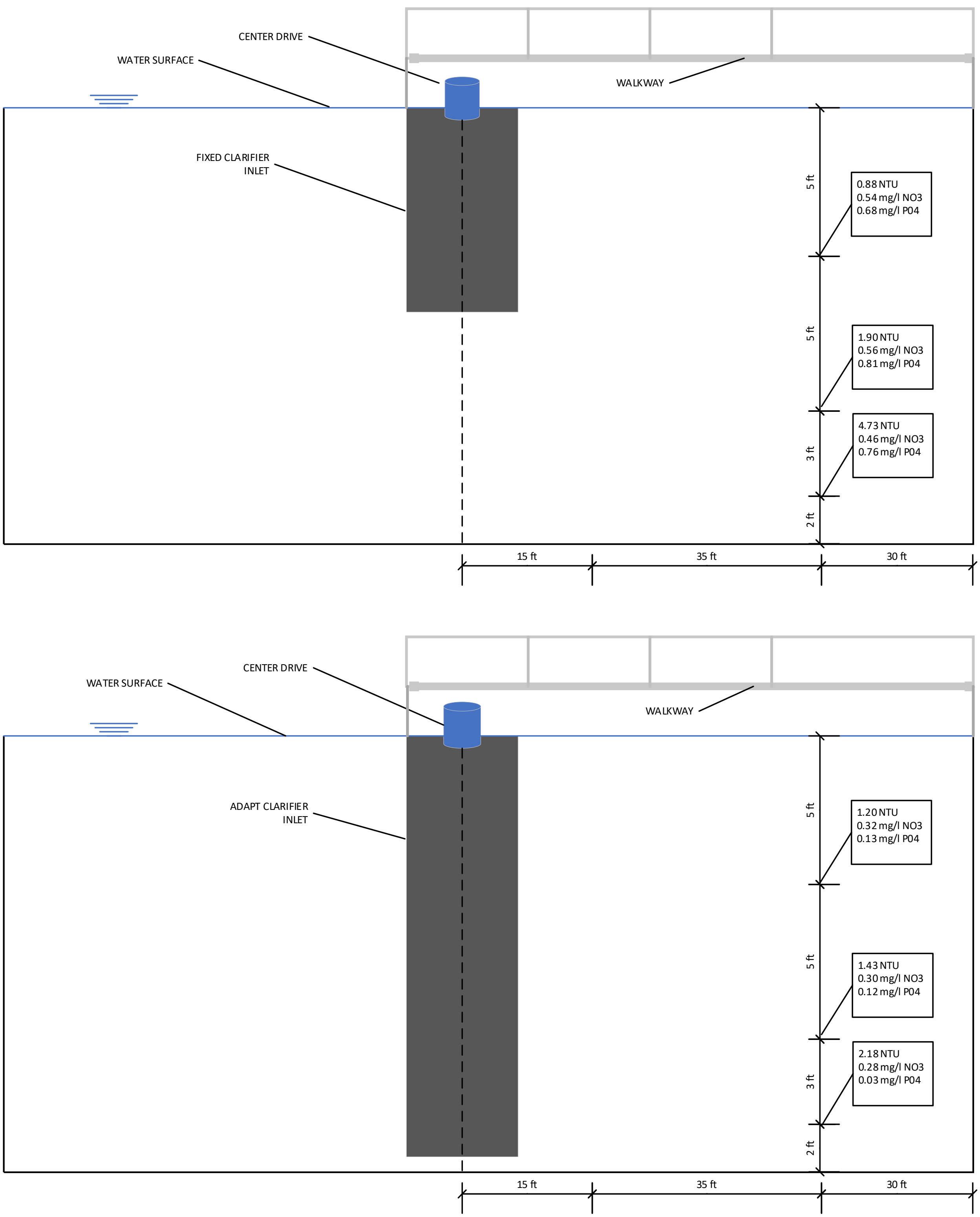


Figure 36 - Fixed and Adapt Inlet Clarifier Depth Profiling 8/17/2021

The fixed inlet clarifier had a very low turbidity at the 5-foot depth, but turbidity at the 10-foot and 13-foot depths were lower in the Adapt inlet clarifier. Generally, both orthophosphate and nitrate increased from lower to higher depths except for the slight decrease at the 5-foot depth in the fixed inlet clarifier. Additionally, both orthophosphate and nitrate concentrations were higher in the fixed inlet clarifier relative to the Adapt clarifier.

On 8/20/2021 depth profiling was completed at both 15 and 50 ft horizontal distances and results are included in Figure 37. Total suspended solids (TSS) measurements were also included in the 8/20/2021 testing. During the time of sampling, which occurred from approximately 8:00 AM to 11:00 AM, all 5 clarifiers were in service, and the inlet was in the lowest position at 1.35 feet from the floor. Turbidity in the fixed inlet clarifier was again very high (>40 NTU) at the 13-foot depth, indicating a lack of solids-liquid separation close to the center of the clarifier, whereas the sludge and clear water in the Adapt clarifier appear to separate very close to the center. However, turbidity measurements at the 50-foot horizontal distance for both clarifiers had very similar values, indicating that the mixed-liquor was settling well and there are little differences in turbidity at higher elevations close to the effluent weirs.

As with the results from 8/17/2021, both orthophosphate and nitrate concentrations were higher in the fixed inlet clarifier relative to the Adapt clarifier. Orthophosphate concentrations in the reaeration channel during the time of testing were approximately 0.2 to 0.3 mg/L, which compared well with concentrations measured at most depths and distances in the Adapt clarifier. Concentrations measured in the fixed inlet clarifier varied considerably more when compared to the Adapt clarifier, suggesting both orthophosphate release from the settled sludge as well as unintended mixing. Another explanation is that loading of nitrate and orthophosphate was not equal to the influent of each clarifier. For example, during testing on 8/20/2021, nitrate concentration at the end of the train 7 second stage anoxic zone was about 1 mg/l, compared to 0.3 mg/l for train 5 and close to 0 mg/l for train 6. There would have been some mixing within the reaeration channel, but it is possible that the combined aeration tank mixed liquor was not completely mixed prior to entering each clarifier. Since train 7 is closer to the Adapt clarifier, it is possible that a higher concentration of nitrate was fed into the sludge blanket due to the low position of the inlet which was inhibiting orthophosphate release. To address this possibility, grab samples of both clarifier influents should be collected as part of any future testing.

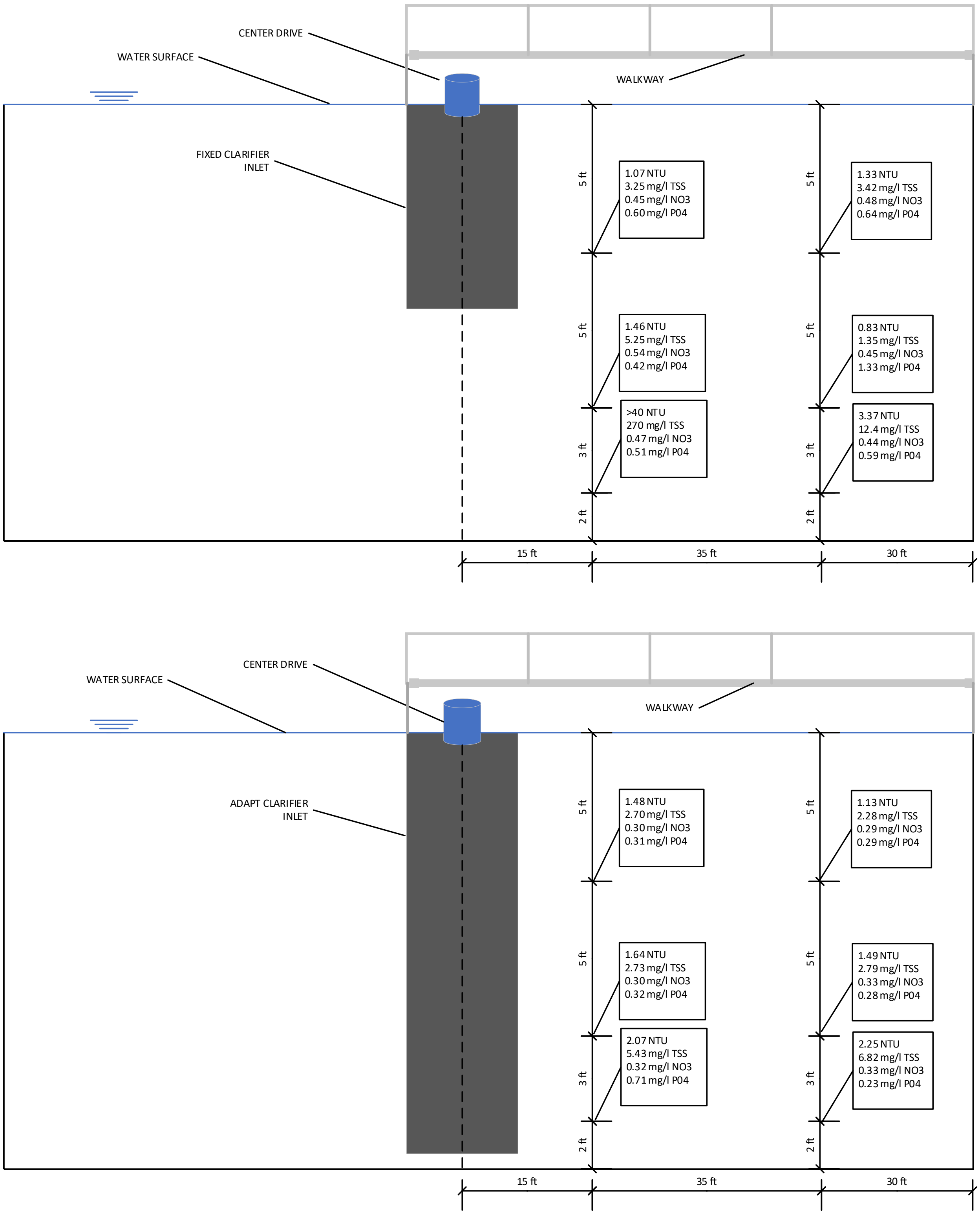


Figure 37 - Fixed and Adapt Inlet Clarifier Depth Profiling 8/20/2021

4. CONCLUSIONS

The objective of this study was to compare the performance of the fixed and Adapt inlet clarifiers at Nansemond Treatment Plant. During initial operation, blanket levels in the Adapt clarifier were consistently higher than in the fixed inlet clarifier. Orthophosphate spikes in the Adapt clarifier effluent were observed during the morning hours when the inlet remained in a low position, and as flows increased, blanket heights also increased. The orthophosphate spikes were reduced when the inlet was operating between the range of 2.3 to 2.7 feet in height. When the Adapt clarifier was taken out of service in late October, it was discovered that both manifold seals were not functional which was likely the cause of the consistently higher blankets in the Adapt clarifier. The higher blankets in the Adapt clarifier did not seem to adversely impact turbidity during dry weather conditions.

During both manual sampling periods, the mean turbidity for the Adapt clarifier was less than that of the fixed inlet clarifier with a 95% level of confidence. However, the difference in means was only 0.2 to 0.4 NTU and may not result in improved performance when evaluated in the direct filtration pilot. Both clarifiers had means less than the secondary clarifier effluent turbidity goal for direct filtration of less than 2-3 NTU. As shown in Figure 38, the operational time for the Adapt has been limited due to mechanical issues requiring the clarifier to be taken out of service. The problem in October 2020 was a result of failure related to the Adapt equipment, but the issues in April and August of 2021 were a result of other matters not related to the Adapt. Unfortunately, the Adapt was out of service in January and February 2021 during a period when secondary clarifier effluent turbidity was consistently measuring between 3 to 4 NTU. There is a possibility that the blanket filtration and solids-liquid separation provided by the Adapt during times of poor settling could result in lower effluent turbidities, when compared to the performance of the fixed inlet. Additional manual sampling should be initiated when the SRF influent turbidity is experiencing a prolonged period of values greater than 3 NTU.

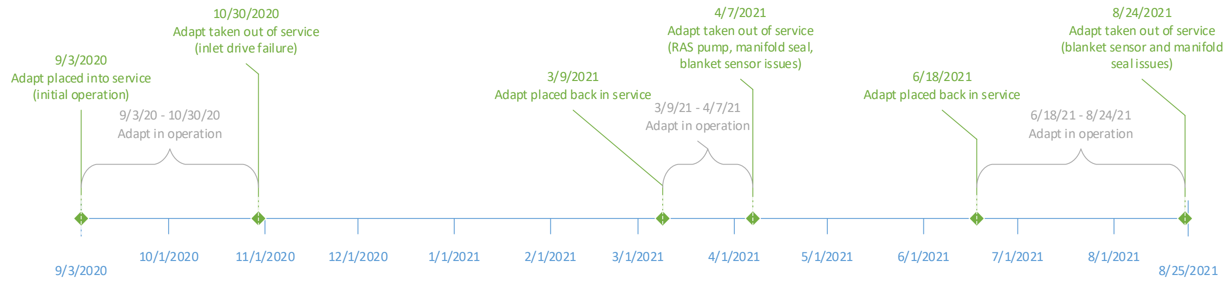


Figure 38 - Timeline of Adapt Operation

Manual sampling during the April 2021 stress tests also indicated slightly lower mean effluent turbidities in the Adapt clarifier compared to the fixed inlet clarifier. The combination of high loading and increased blanket heights from inadequate RAS pumping capabilities led to higher turbidities during the peak evening diurnal. Stress testing should be repeated with mechanical and programming adjustments to allow for additional RAS capacity, and manual turbidity and blanket readings should be collected regularly and over a long duration (24-hour stress test and sampling).

Depth profiling confirmed a more defined solids-liquid separation of the clear water and sludge blanket in the Adapt compared to the fixed inlet clarifier. Turbidities at higher elevations close to the effluent weirs were similar indicating that the mixed liquor was settling well. When the Adapt is back in operation, additional investigation should be completed to determine if mixed liquor is leaking from the inlet while in the low position. Nitrate and orthophosphate concentrations were generally higher in the fixed inlet clarifier than in the Adapt clarifier. This could have been a result of orthophosphate release from the settled sludge, unintended mixing, or uneven loading to the clarifiers. When this testing is repeated, individual samples at the influent of each clarifier should be collected to eliminate the uncertainty of uneven loading of nitrate or orthophosphate.

REFERENCES

Armbruster, M., Krebs, P., & Rodi, W. (2001). Numerical Modelling of Dynamic Sludge Blanket Behaviour in secondary clarifiers. *Water Science and Technology, 43(11), 173-180.*

Benisch, M., Neethling, J. B., Hammer, G., & Armbruster, M. (2018). Stress Testing of a Secondary Clarifier with an Adaptive Inlet Structure. Proceedings of the Water Environment Federation, 2018(7), 5133-5147.

Bretscher, U., Krebs, P., & Hager, W. H. (1992). Improvement of flow in final settling tanks. *Journal of Environmental Engineering, 118(3), 307-321.*

Crosby, R. M., & Bender, J. H. (1980). Hydraulic considerations that affect secondary clarifier performance. Center for Environmental Research Information.

Daigger, G. T., & Nicholson, G. A. (1990). Performance of four full-scale nitrifying wastewater treatment plants incorporating selectors. *Research Journal of the Water Pollution Control Federation, 676-683.*

Krebs, P., Vischer, D., & Gujer, W. (1995). Inlet-structure design for final clarifiers. *Journal of Environmental Engineering, 121(8), 558-564.*

Metcalf & Eddy, Abu-Orf, M., Bowden, G., Burton, F. L., Pfrang, W., Stensel, H. D., ... & AECOM (Firm). (2014). Wastewater engineering: Treatment and resource recovery. McGraw Hill Education.

Mikola, A., Rautiainen, J., & Vahala, R. (2009). Secondary clarifier conditions conducting to secondary phosphorus release in a BNR plant. *Water Science and Technology, 60(9), 2413-2418.*

Parker, D., Appleton, R., Bratby, J., & Melcer, H. (2004). North American performance experience with anoxic and anaerobic selectors for activated sludge bulking control. *Water Science and Technology, 50(7), 221-228.*

Parker, D. S., Kinnear, D. J., & Wahlberg, E. J. (2001). Review of folklore in design and operation of secondary clarifiers. *Journal of Environmental Engineering, 127(6), 476-484.*

Parker, D. S., Wahlberg, E. J., & Gerges, H. Z. (2000). Improving secondary clarifier performance and capacity using a structured diagnostic approach. *Water Science and Technology, 41(9), 201-208.*

Shapiro, J., & Levin, G. V. (1967). Anoxically induced release of phosphate in wastewater treatment. *Journal of Water Pollution Control Federation, 1810-1818.*

Zhou, S., McCorquodale, J. A., & Vitasovic, Z. (1992). Influences of density on circular clarifiers with baffles. *Journal of Environmental Engineering, 118(6), 829-847.*

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VWLA, 2020

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